Ensuring Sustainable Agriculture in the Face of a Changing Climate

A Handbook of Resources Summer 2015





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July 15, 2015

Dear Colleague:

The challenges of ensuring sustainable agriculture in the face of a changing climate are significant. By working together, researchers, educators, and producers can learn about and overcome these challenges. To help us move forward in that direction, we have complied resources about climate change and sustainable agriculture. Our hope is that you can use these resources to better communicate climate change with producers and other clientele. With support from a North Central Region – Sustainable Agricultural Research and Education (SARE) professional development grant, we have created the following resources:

- A Resource Handbook with materials that cover topics ranging from climate basics to communicating about climate change. The Handbook includes science-based information on climate change relevant to sustainable agriculture with an emphasis on field crop agriculture.
- 2. A Curriculum on sustainable field crop agriculture and climate change that can be used with clientele, such as producers groups. This curriculum is a PowerPoint presentation and may be adapted to suit your needs. It contains a written script in the notes section. To help you evaluate the effectiveness of this Curriculum with your clientele, we have included an evaluation form that you can distribute after your presentation.

Both of these resources are available for download at http://lter.kbs.msu.edu/get-involved/educational-resources/

We hope these resources are useful for you. Please feel free to contact us with questions or comments.

Founded 1855

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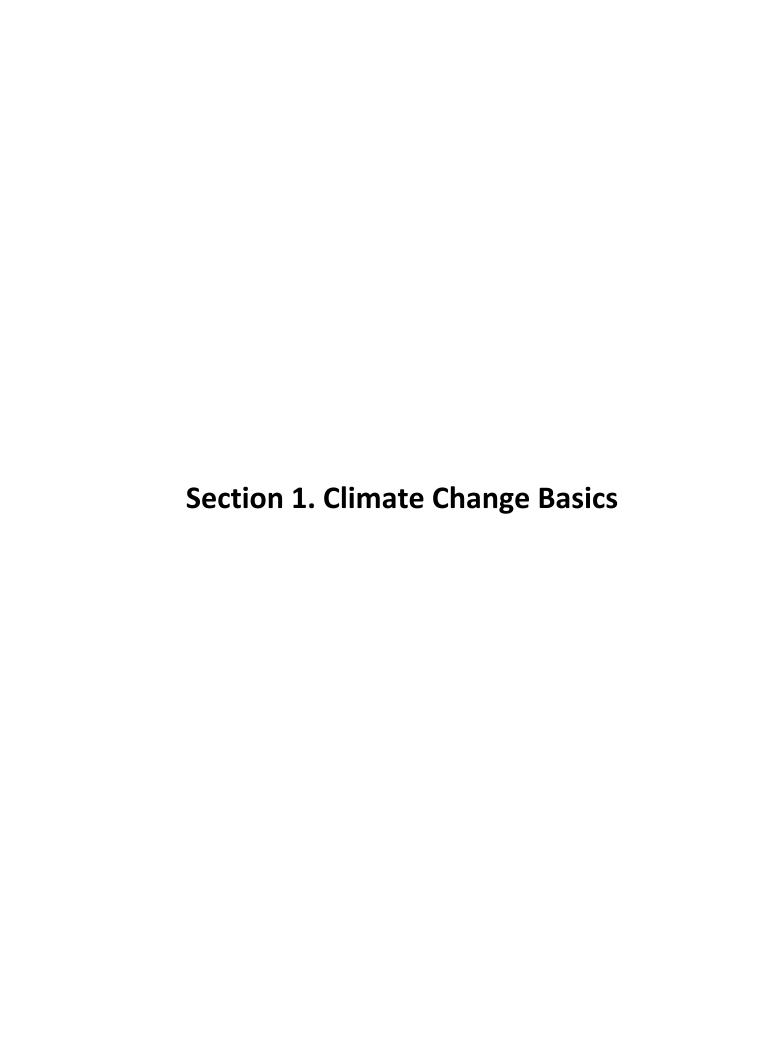
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CLIMATE BASICS

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The Earth's climate is a complex system and is influenced by many factors, including human activities. It has changed greatly in the past and will continue to change in the future.

Depending on whether future greenhouse gas emissions stabilize or increase, we can expect warming of the planet similar to or greater than recent years.

What drives Earth's climate system?

Mark Twain once said, "Climate is what we expect, weather is what we get." The terms "weather" and "climate" are closely related but have subtly different meanings. Both refer to changes in atmospheric variables — such as air temperature, humidity, wind and clouds — but over different periods of time. On the basis of an international agreement of climatologists, a period of three consecutive decades, or 30 years, is commonly used to describe climate at a given location!. Weather, on the other hand, refers to the same variables but over much shorter periods of time — hours or days.

The Earth's climate and weather systems are powered by radiant energy from the sun. Of the solar energy intercepted by the Earth and its atmosphere, about 30 percent is reflected back out to space, 20 percent is absorbed by the atmosphere and 50 percent is absorbed by the Earth's surface. Because of the Earth's 23.5-degree tilt on its axis of rotation and its annual orbit around the sun, some areas of the world receive more energy, and some less. An illustration of the net energy at the Earth's surface during June (Northern Hemisphere summer) is given in Figure 1. At that time of the year, the greatest energy surpluses are found in the low to middle latitudes of the Northern Hemisphere, where the angle of sunlight is most direct, and the greatest deficits in the 24-day darkness of the polar region of the Southern Hemisphere.

Earth's atmosphere plays a special role in moderating its surface temperature. As solar energy streams through

the atmosphere on its way to the surface, some is absorbed by gases. All solar energy absorbed by the Earth is eventually radiated back toward space as longwave energy. Some of that outgoing energy is reabsorbed by gases in the atmosphere and then re-emitted back toward the Earth's surface. This temporarily traps extra energy in the Earth's atmosphere and increases the Earth's surface temperature. The importance of this so-called "greenhouse effect" cannot be overstated. Without an atmosphere that acts as a blanket to absorb heat, the Earth would be almost 60 degrees Fahrenheit (F) cooler on average than it is now. For example, the moon, our nearest neighbor in the solar system, has surface temperatures ranging from 225 degrees F in the sun to a frigid -240 degrees F in the dark because it lacks an atmosphere.

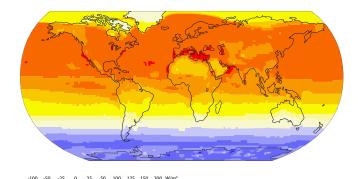


Figure 1: This map shows the global average amounts of net radiative energy (measured in watts per square meter) at the Earth's surface in June (average for years 1959 through 1997). The positive values (yellow, orange and red) represent energy moving toward the surface; the negative values (blue) represent energy moving away from the surface. (Figure adapted from the Climate Lab section of the Environmental Change Research Group, Department of Geography, University of Oregon.)

Several gases in the Earth's atmosphere contribute to the greenhouse effect by reabsorbing outgoing longwave heat energy before it escapes into space. Major greenhouse gases are carbon dioxide, nitrous oxide, methane, water vapor, ozone and halocarbons, all of which are naturally occurring except for halocarbons, which were used as coolants, solvents and refrigerants beginning in the 1930s. Over millennia, the Earth's average surface temperature is correlated with the

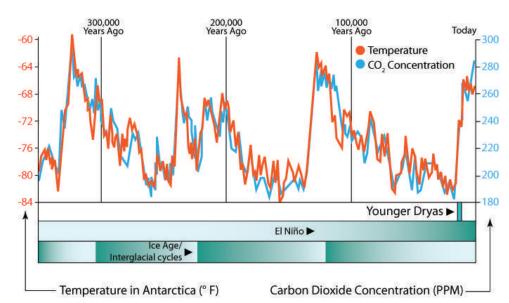


Figure 2: This figure shows the correlation between air temperature and carbon dioxide concentrations at Vostok, Antarctica, from 350,000 years ago through the present. The red line represents temperature in degrees Fahrenheit, and the blue line represents carbon dioxide (CO₂) concentration in parts per million. In recent years, carbon dioxide levels have spiked higher than at any time in the previous 350,000 years of data. (Figure adapted from the Marian Koshland Science Museum of the National Academy of Sciences.)

amount of greenhouse gases in the atmosphere, as shown in Figure 2. Historically, when greenhouse gas concentrations have been relatively high, so have the average surface temperatures. (See MSU Extension Fact Sheet E3148 for more about greenhouse gases.)

What factors affect weather and climate?

The climate of a given location on the Earth's surface is determined by:

- 1) Latitude.
- 2) Proximity to oceans.
- 3) Large-scale atmospheric and ocean circulation patterns.
- 4) Elevation.
- 5) Topographic barriers and features, such as mountains.

The flow of energy from areas of surplus energy (generally close to the equator) to areas of deficit energy (near the poles) drives the Earth's weather and climate systems. This energy imbalance, along with the Earth's daily rotation on its axis, results in the large-scale general circulation of air flow at the Earth's surface. There are three circulation patterns in each hemisphere. These are more commonly known as the Polar Easterlies, the Westerlies and the Trade Winds, which cover polar, midlatitude and tropical zones, respectively. In between these three circulation patterns in each hemisphere is a narrow zone of converging winds in the tropics called the Intertropical Convergence Zone. All of these

circulation features migrate seasonally toward the poles and toward the equator.

What causes the climate to change?

The climate at a given location seems to be relatively stable, but it is ever-changing because of its dynamic nature and many components. For example, Michigan's climate has varied dramatically over time from tropical to glacial conditions. Extensive geological evidence associated with these diverse climates and climatic changes is visible across Michigan's landscape (see Figure 3).

Several processes are linked with major changes in global climate in the past, including:

- 1) Global plate tectonics shifting of continental land masses.
- 2) Sunspots, which are linked with v ariations in solar energy output.
- 3) Variations in Earth's orbit, described by the Milankovitch theory.
- 4) Volcanoes, such as Mt. Pinatubo in 1991.
- 5) Meteor impacts, such as the one that caused a global cooling and extinction event 65 million years ago.
- 6) Periodic changes in the Earth's carbon and nitrogen cycles, including changes in atmospheric greenhouse gas concentrations.



Figure 3: The Petoskey stone is a form of fossilized coral and the state stone of Michigan. The coral dates from the late Devonian Period, approximately 350 million to 400 million years ago. At this time, the Euramerican tectonic plate — containing what is now the Great Lakes region — was located near the equator in a tropical climate and mostly covered by a shallow sea. (Image from Chris Savage.)

All of these processes act to change the amount of energy reaching the Earth's surface. They range from the location of the continents on the Earth (which affects how the planet's surface reflects incoming solar energy) to massive ejections of dust or ash into the atmosphere (which reflects a higher portion of the incoming energy). For example, the eruption of the Mt. Pinatubo volcano in the Philippines during the summer of 1991 led to a global cooling of more than 1 degree F that lasted more than a year. As a result, the average temperature in Michigan during the summer of 1992 dropped more than 4 degrees F below normal. Many crops failed to reach maturity that growing season because of the significantly cooler temperatures.

The Milankovitch theory is based on three types of small, periodic changes in the Earth's orbit: changes in the Earth's 23.5-degree tilt, the shape of its elliptical orbit and the date at which the Earth reaches its closest and furthest points away from the sun. Approximately every 100,000 years, these cycles collectively lead to relative reductions in total incoming solar energy at high latitudes of up to 20 percent. These are thought to be the leading cause of the onset of glacial periods².

Human activity is causing increasing concentrations of greenhouse gases in the atmosphere. Since the beginning of the industrial revolution around 1765, concentrations of carbon dioxide (the main greenhouse gas) and other greenhouse gases in the Earth's

atmosphere have increased from 12 percent to 240 percent. The higher concentration of greenhouse gases has decreased the amount of energy allowed to radiate from Earth back into space by 2 to 3 watts per square meter (W/m², a measure of energy)³.

If current rates of greenhouse gas emissions continue, the Earth could retain between 5 and 10 W/m² more energy (relative to 1765) by the end of the 21st century. Climatologists estimate that this change may ultimately result in a 2- to 7-degree F increase in average

global temperatures by the end of this century⁴.

Compared with the large climatic changes of the geologic past, this type of warming would be very unusual because of the amount of warming that is occurring over a very short time period. Global temperature changes are typically much more gradual, occurring over tens of thousands of years or longer.

It is important to note that humans are not changing the overall amount of carbon, nitrogen or other greenhouse gases in the Earth's global environmental system (with the exception of halocarbons). Human activity is altering the form and location of these elements between Earth's surface and the atmosphere, which in turn drives changes in the climate. For example, fossil fuel combustion coverts carbon that had been stored as a solid or liquid deep in the Earth to carbon dioxide gas that enters the atmosphere, leading to the enhanced greenhouse effect and warming of the Earth. This has strong implications for sustaining our quality of life: although humans already have altered Earth's climate, policies and individual actions can help to mitigate future changes.

How much has the Earth's temperature changed?

Scientific observations of climate have been recorded at locations around the world for about the past 200 years. Even so, the search for climate trends over time is complicated because changes in station location, station environment, observation time, observer and type of

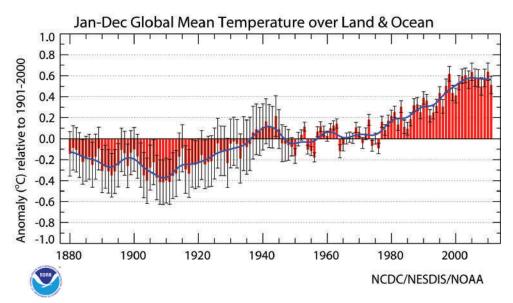


Figure 4: This chart shows the average annual global air temperatures from 1880 to 2010 (in degrees Celsius). The red bars express the yearly difference between the global average and a baseline reference of the 1901-2000 average temperature. For each year, the range of uncertainty is indicated by the gray vertical bars. The thick blue line is a nine-year moving average of the individual years and helps identify longer term trends. (Figure from NOAA National Climatic Data Center following Smith et al., 2008.)

instrument can result in artificial changes in climate. Scientists address these known problems and use only the best quality climate records. These records indicate that the average annual global surface temperature has warmed roughly 1.3 degrees F since the late 1800s (see Figure 4)⁵.

As seen in Figure 4, there are some obvious temperature patterns, including the following fluctuations in the average global temperature:

- A period of decreasing temperatures (about 0.5 degree F) from the late 1800s through about 1910.
- A warming of just less than 1 degree F from 1910 to 1940.
- A slow cooling trend of about 0.1 degree F from 1940 to 1970.
- A warming trend of about 1 degree F from the 1970s to the present.

Overall, Earth is getting warmer. A majority of the warming during the past century (about 0.7 degree F) has occurred since 1979 and over continents rather than oceans. Virtually all recent studies of global temperature trends suggest that the decade between 2001 and 2010 is the warmest in the historical record.

How do we know that recent warming is not just a result of natural variability?

Given the dynamic nature of the Earth's climate system and known changes in Earth's average temperature, the logical question about recent trends is, "How do we know that recent warming is not just a result of natural variability?" Climate scientists address this question using sophisticated computer models of global climate that allow investigation of the relative magnitude of temperature changes associated with various causes. These models also simulate the interactions between the atmosphere and the oceans and biosphere. The Intergovernmental Panel on Climate Change (IPCC) is a group of scientists who issue comprehensive assessments on climate science. In a recent report, they addressed this question of what is causing the recent warming trends. To do this, they tested more than 15 different global climate models at research laboratories around the world with two sets of conditions for the period 1906-2005³:

- 1) Condition A: greenhouse gas concentrations held at a constant level (330 parts per million for carbon dioxide, reflecting only natural influences on the climate).
- 2) Condition B: greenhouse gas concentrations that increase over time (following observed changes, reflecting natural and human influences on the climate).

Scientists ran the climate models with these two sets. of conditions and simulated the corresponding temperatures. These simulated temperatures were then compared to the real, observed temperatures that were recorded from 1906 through 2005. As can be seen in Figure 5, when computer models included natural and human influences (increasing greenhouse gas levels, Condition B), the simulated temperatures were in much better agreement with the observed temperature changes. These results are powerful for two key reasons: first, they increase our confidence that global climate models can accurately simulate the Earth's climate system. Secondly, they suggest that much of the warming of the past two centuries is associated with increasing concentrations of greenhouse gases and not just natural variability. It is important to note that there is widespread scientific consensus on this: 97 percent of climate scientists agree that humans are increasing Earth's temperature^{6,7}.

The IPCC has concluded that "human-induced warming of the climate system is widespread"³, and that "continued greenhouse gas emissions at or above current rates will cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century"⁴.

What does this mean for the future?

Earth's climate is a constantly changing, dynamic process. It has changed greatly in the past and will continue to change in the future. Through increased emissions of greenhouse gases into the atmosphere, human activity has resulted in a warming climate during the past few centuries. Depending on whether future greenhouse gas emissions stabilize or increase, we can expect warming of the planet similar to or greater than what has occurred in recent years. The projected global warming of 2 to 7 degrees F is very large by historical standards and could be the largest observed temperature increase in at least 50 million

years8. Even though that may seem like a small change, history proves that even small changes in the global average temperature can have an enormous impact. For example, the average global temperature at the end of the last glacial epoch (when Michigan was still largely covered by a thick sheet of ice) was only 9 to 11 degrees F cooler than that of today. As a rough analogy, if Michigan's climate warmed 2 to 7 degrees F, it would be somewhat similar to the current and recent past climate across sections of the middle and lower Mississippi Valley (for example, southern Missouri or northern Arkansas).

Changes in climate already have affected us, and uncertainty remains about how we will adapt to future changes.

However, we can stabilize our emissions through political and behavioral choices as well as with new technologies.

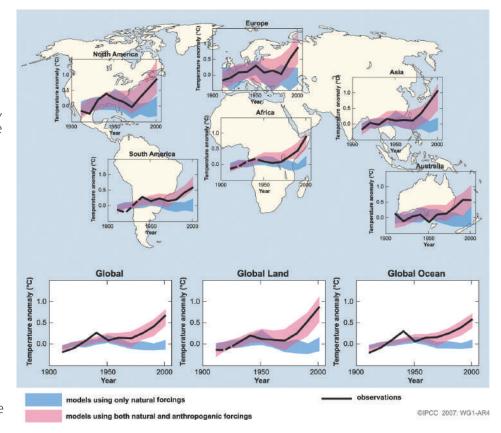


Figure 5: These figures show simulated changes in temperature (in degrees Celsius) during the 1906 through 2005 period relative to the 1901 through 1950 average over the Earth's continents, the entire globe, global land areas and the global ocean. The black lines indicate observed temperatures; the colored bands show the combined range covered by 90 percent of general climate model simulations. The pink areas indicate simulations that include natural and human factors in the climate model (mainly the increasing greenhouse gases); blue indicates simulations that include only natural factors. Dashed black lines indicate decades and continental regions for which there are substantially fewer observations. These results suggest that the models that included human influences were more accurate in describing past observed temperature changes. (Figure from Hegerl et al., 2007³.)

By staying informed and engaging in dialogue about the changes we face, communities can create plans of action to reduce negative impacts, adapt to changes and take advantage of possible positive outcomes. (See MSU Extension Fact Sheet E3150).

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FREQUENTLY ASKED QUESTIONS ABOUT CLIMATE CHANGE

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The Earth's climate is dependent on both human and natural factors, making climate change a complex issue. This Fact Sheet addresses some of the most common questions about climate change. See the other Fact Sheets in this series for more details about climate change, including greenhouse gases, Michigan's changing climate, and agriculture's relationship to climate change.

What's the difference between global warming and climate change?

"Global warming" and "climate change" often are used interchangeably, but they have different meanings. "Global warming" is the current and projected increase in average temperature near the Earth's surface due to increased greenhouse gas levels in the atmosphere (scientists call this the "enhanced greenhouse effect")¹. "Climate change," however, describes shifts in long-term climate patterns, including air temperature, rainfall and snowfall (precipitation), and atmospheric circulation (weather patterns)². Climate change is the more appropriate term for describing the range of past and future climate trends.

Isn't climate change natural?

Yes and no. Climate change is driven by both human and natural causes (see Figures 1 and 2). Humans affect climate change mainly by burning fossil fuels for energy and by converting natural land for human use, both of which emit greenhouse gases². Natural factors, such as continental drift and changes in the Sun, have changed the Earth's climate in the past³. Slight changes in the Earth's orbit and tilting were responsible for past Ice Ages⁴, and volcanoes may have caused short-term climate changes⁵. But since the onset of the Industrial Age, humans have transferred the carbon stored in fossil fuels into the atmosphere as carbon dioxide gas $(CO_2)^2$. This results in CO_2 accumulating in the atmosphere faster than plants or the ocean can remove it⁴.

Carbon dioxide absorbs infrared radiation from the sun, trapping it as heat energy in the atmosphere 4 . Other human activities, such as agriculture, cause the release of other greenhouse gases such as nitrous oxide (N_2 O) and methane (CH_4) 2 . Please see MSU Extension Fact Sheets E3148 and E3149 for more about greenhouse gases and agriculture.

Scientists can measure the amount of $\rm CO_2$ in the atmosphere over time by examining bubbles of air trapped in ice cores that date back 650,000 years. And chemists can determine the source of the $\rm CO_2$ —whether it came from plants or animals through natural processes, or from the burning of fossil fuels. Their analyses show that about a quarter of the carbon dioxide now in the atmosphere is the result of human activity⁶. Natural climate variability alone does not wholly explain recent changes in climate; thus scientists use the term "anthropogenic" to indicate that humans cause climate change⁴.

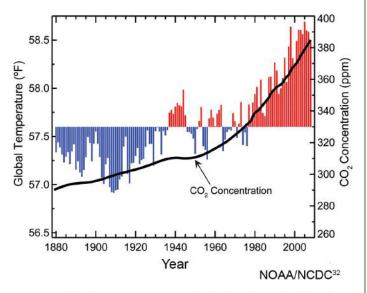


Figure 1: Global average temperature and carbon dioxide (CO₂) levels have been rising since the Industrial Revolution. The red bars represent years when the temperature rose above the average temperature from 1901–2000, the blue bars are below that same average temperature, and the black line is the average CO₂ concentration. This shows a profound increase in both the CO₂ levels and global temperatures. (Figure from NOAA National Climatic Data Center 2010?)

Would a few degrees warmer really make a difference?

Yes. Changes in the global average temperature, even small changes, can result in significant impacts. Over the past century the Earth warmed an average of 1.3 degrees Fahrenheit² (see Figure 1). The consensus of the vast majority of climate scientists is that the Earth will likely continue to warm 2.0 to 11.5 degrees Fahrenheit in the 21st century². While this may not seem like a great concern to our daily lives, regions around the world and within the United States will experience more extreme climate changes than others³. The U.S. Midwest has already seen an increase in temperatures. We can expect to see a decrease in air quality, increase in heat waves, more insect- and water-borne diseases, and heavier precipitation during the winter and spring⁸. Just a few degrees' increase in average temperature can drastically alter the physical and life cycles of the Earth.

If it's hard to predict the week's weather, how can we project climate change?

There is a fundamental difference between *weather predictions* and *climate projections*. "Weather" represents local atmospheric conditions such as humidity, temperature, and precipitation for a short time period. "Climate" explains the atmospheric trends over a much longer period, usually 30 years or more⁹. Short-term predictions of weather are based on current conditions, which are rapidly shifting¹⁰. This is why weather forecasts are more reliable for a few days than a few weeks¹¹. Climate projections, on the other hand, are based on long-term future scenarios, and do not rely on the variability of current weather conditions.

What are global climate models? Are they reliable?

Global climate models are a mathematical representation of past and future climates, based on climate scientists' best knowledge of what factors affect the climate. These computer-based models project the Earth's climate system's response to external factors such as sunspot variability and internal factors such as anthropogenic and natural emissions of greenhouse gases¹². Global climate models are able to reliably simulate past and present climates⁴. Scientists are careful about how they communicate the results of climate models because they cannot yet project small regional changes with accuracy. As scientific knowledge and technologies improve, local projections of climate will also get better.

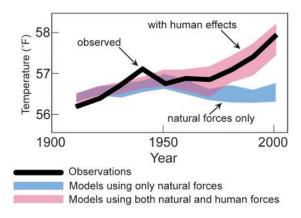


Figure 2: Climate models can help determine the cause of climate change. The black line on this graph represents scientific observations of temperature over the past 100 years. The blue line shows how climate models predict the temperature if only natural climate changes occurred, which is lower than the actual observed temperature. The pink line shows the more accurate prediction of the temperature based on both human and natural causes of climate change. Only when climate models include greenhouse gas increases caused by humans do model results match today's temperatures. (Figure from NOAA National Climatic Data Center 2010⁷.)

Do scientists disagree about climate change?

Nearly all climate scientists agree that the global climate is changing and its cause is human related¹³. Climate science is a long-established scientific field that is based on the basic laws of physics and chemistry¹⁴, and over 95% of Earth scientists (including climate scientists) agree that humans contribute to climate change¹⁵. Most of the debate between scientists occurs over *the extent to which* the climate will change and *the degree to which* humans will have an impact on the future climate.

Can we stop climate change?

Due to the increased levels of carbon dioxide and other greenhouse gases in the atmosphere, some of the impacts of climate change already are in motion. That means that warming of the atmosphere will continue even if we stopped all greenhouse emissions tomorrow. However, it is possible to stabilize our emissions through political and behavioral choices as well as with new technologies. As noted by the National Academy of Sciences, setting lower emissions goals is largely a social choice based on how we judge the risks of climate change¹⁶. Scientists, policy-makers, and stakeholders must work together to determine the risks from different greenhouse gas emissions scenarios, and the costs of implementing change. Our actions now will determine how future generations can respond to the challenge of climate change 17.

How can we act in the face of uncertainty?

Staying informed by seeking out multiple sources of information is key. In addition, we can create plans of action that reduce negative impacts while creating and taking advantage of possible positive outcomes. "No regrets" options are courses of action that can benefit the world ecologically and economically. For example, implementing measures to adapt to climate change also improves resilience to normal climate variability. On a large scale, investments in renewable energy technologies will help reduce greenhouse gas emissions while providing other long-term ecological and financial advantages. Individual actions that reduce greenhouse gas emissions also can be economically and environmentally smart. Uncertainty of the future does not mean we cannot take action. We can act in ways that are good for our world, our health, and our wallets.

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Notas sobre Cambio Climático y Agricultura E3150SP Agosto, 2011

PREGUNTAS FRECUENTES SOBRE CAMBIO CLIMÁTICO

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Traducción al Español: Lea Corkidi. Marzo, 2012

El clima de la Tierra depende tanto de factores naturales como de actividades humanas, lo cual hace del cambio climático un tema complejo. Este artículo se refiere a algunas de las preguntas más comunes sobre este tema. Para obtener mayor información, consultar otras publicaciones de esta serie, incluyendo las referentes a gases de invernadero, el cambio del clima en Michigan y la relación entre la agricultura y el cambio climático.

¿Cuál es la diferencia entre calentamiento global y cambio climático?

Los términos "calentamiento global" y "cambio climático" con frecuencia se usan indistintamente, pero tienen diferentes significados. Se le llama "calentamiento global" al incremento actual y al que se proyecta que ocurrirá en la temperatura media de la superficie de la Tierra, por causa del aumento de los niveles de gases de invernadero en la atmósfera (los científicos le llaman "efecto invernadero ampliado")¹. Sin embargo, el término "cambio climático", se usa para describir cambios a largo plazo en los patrones del clima, incluyendo la temperatura del aire, la lluvia, las nevadas y la circulación atmosférica (fenómenos meteorológicos)². "Cambio climático" es el nombre más apropiado para describir el rango entre las tendencias del clima pasado y futuro.

¿El cambio climático no es un fenómeno natural?

Sí y no. El cambio climático es ocasionado tanto por causas naturales como por actividades humanas (ver Figuras 1 y 2). Los seres humanos intervienen en el cambio del clima principalmente a través de la quema de combustibles fósiles para la obtención de energía, y de la conversión de áreas naturales para uso humano, pues ambas actividades emiten gases de invernadero². Factores naturales, como la deriva continental y cambios en el sol, también han cambiado el clima de la Tierra en el pasado³. Los pequeños cambios en la órbita y la

inclinación de la Tierra fueron responsables de períodos glaciales⁴ anteriores, y la actividad volcánica pudo haber ocasionado cambios climáticos a corto plazo⁵. Sin embargo, desde el inicio de la era industrial, los seres humanos han transferido el carbono almacenado en los combustibles fósiles hacia la atmósfera en forma de dióxido de carbono (CO₂)². Esto ha dado como resultado que la acumulación de CO₂ en la atmósfera, sea más rápida de lo que las plantas o el océano pueden absorberlo⁴.

El dióxido de carbono absorbe la radiación infrarroja del sol, atrapándola como energía térmica en la atmósfera⁴. Otras actividades humanas, como la agricultura, causan la liberación de otros gases de invernadero como son el óxido nitroso (N₂O) y el metano (CH₄)². Para mayor información sobre gases de invernadero y agricultura, consultar las publicaciones E3148SP y E3149.

Los científicos pueden medir la cantidad de CO₂ en la atmósfera examinando las burbujas de aire que han quedado atrapadas en testigos de hielo que datan de hace 650,000 años. A su vez, los químicos pueden determinar el origen del dióxido de carbono, ya sea que provenga de fuentes vegetales o animales a través de procesos naturales, o de la quema de combustibles fósiles. Estos análisis muestran que cerca de la cuarta parte del carbono que está presente actualmente en la atmósfera ha sido resultado de la actividad humana⁶. La variación natural en el clima no explica por completo los cambios recientes en el mismo, por lo tanto, los científicos utilizan el término "antropogénico" para indicar que los humanos ocasionan cambio climático⁴.

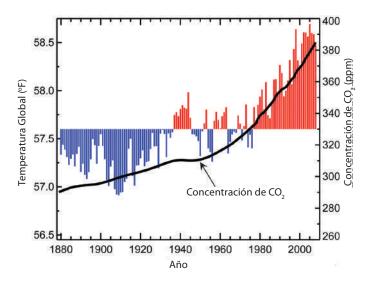


Figura 1: Los niveles de la temperatura media global y del dióxido de carbono se han ido elevando desde la Revolución Industrial. Las barras rojas representan los años en los que la temperatura fue más alta que la temperatura promedio de 1901 a 2000 y las barras azules indican los años en que fue más baja. La línea negra es el promedio de la concentración de CO₂. Esta figura muestra el profundo incremento tanto en los niveles de CO₂ como en la temperatura global (Figura tomada del Centro Nacional de Datos Climáticos de NOAA, 2010²).

¿Realmente hacen diferencia unos cuántos grados más?

Sí. Aún pequeños cambios en la temperatura media global pueden tener un gran impacto. Durante el siglo pasado la temperatura de la Tierra se elevó un promedio de 1.3°F (0.74°C) (ver Figura 1). El consenso de la vasta mayoría de los científicos dedicados al estudio del clima, es que la temperatura de la Tierra seguirá incrementándose de 2.0 a 11.5 °F (1.1 a 6.4 °C) en el siglo XXI². Aunque esto no parezca ser motivo de gran preocupación para nuestra vida cotidiana, ciertas regiones del mundo y de Estados Unidos van a experimentar cambios más radicales en el clima que otras³. En el medio oeste de Estados Unidos ya se ha visto una elevación en la temperatura. Podemos esperar una reducción en la calidad del aire, un incremento en las olas de calor, más enfermedades causadas por insectos y aqua, así como una mayor precipitación durante invierno y primavera8. Incluso unos cuantos grados por arriba del promedio de la temperatura, pueden alterar drásticamente los ciclos físicos y biológicos de la Tierra.

Si ya es difícil predecir el clima de una semana, ¿cómo se puede proyectar el cambio climático?

Existe una diferencia fundamental entre el pronóstico del tiempo y las proyecciones del clima. El "tiempo" representa las condiciones atmosféricas actuales, como son la humedad, temperatura y precipitación en un período corto. El "clima" explica las tendencias atmosféricas en un período mucho más largo, generalmente 30 años o másº. Los pronósticos del tiempo se basan en las condiciones actuales, las cuales cambian rápidamente¹º. Esta es la razón por la cual los pronósticos del tiempo son más confiables por unos cuantos días que por semanas¹¹. Por otra parte, las proyecciones climáticas se basan en eventos futuros a largo plazo y no radican en la variabilidad actual de las condiciones actuales.

¿Qué son los modelos del cambio climático global? ¿Son éstos confiables?

Los modelos del cambio climático global son representaciones matemáticas de climas pasados y futuros, basados en el conocimiento científico de los factores que afectan el clima. Estos modelos hechos por computadoras proyectan la respuesta de los sistemas climáticos de la Tierra a factores externos, como es la variabilidad de la mancha solar, así como a factores internos, como son las emisiones naturales y antropogénicas de gases de invernadero¹². Los modelos del cambio climático global pueden simular confiablemente los climas del pasado y el presente⁴. Los científicos son precavidos al comunicar los resultados de los modelos climáticos, puesto que todavía no es posible proyectar pequeños cambios regionales con precisión. Conforme mejore el conocimiento científico y la tecnología, también mejorarán las proyecciones locales del clima.

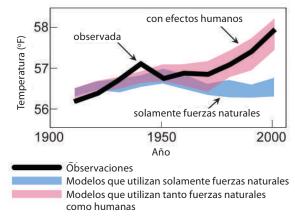


Figura 2: Los modelos climáticos pueden ayudar a determinar la causa del cambio climático. La línea negra de esta gráfica representa las observaciones científicas de la temperatura en los pasados 100 años. La línea azul muestra la manera en que los modelos climáticos predicen la temperatura en caso de que solamente ocurrieran cambios climáticos naturales, la cual es más baja que la temperatura observada actual. La línea rosa muestra la predicción más correcta de la temperatura basada en causas naturales y humanas de cambio climático. Solamente cuando los modelos climáticos incluyen incrementos en los gases de invernadero causados por actividades humanas, los resultados de los modelos coinciden con las temperaturas actuales (Figura tomada del Centro Nacional de Datos Climáticos de NOAA, 2010⁷).

¿Existen desacuerdos entre los científicos sobre el cambio climático?

Casi todos los científicos coinciden en que el clima global está cambiando y que la causa está relacionada con los humanos¹³. La ciencia del clima es una vieja disciplina establecida a lo largo de muchos años que se basa en las leyes de la física y la química¹⁴, de manera que aproximadamente 95% de los científicos (incluyendo los que estudian el clima) concuerdan en que los seres humanos contribuyen al cambio climático¹⁵. La mayor parte del debate entre ellos consiste en el grado en que el clima cambiará y el impacto que la actividad humana tendrá en el clima futuro.

¿Podemos detener el cambio climático?

Debido a los niveles elevados de dióxido de carbono y otros gases de invernadero de la atmósfera, algunos de los impactos del cambio climático ya están en marcha. Esto significa que el calentamiento de la atmósfera continuaría, aún si se detuvieran todas las emisiones de gases de invernadero mañana mismo. De cualquier manera, es posible estabilizar estas emisiones a través de alternativas políticas y de conducta social, así como de nuevas tecnologías. Como lo ha señalado la Academia Nacional de Ciencias, establecer metas para reducir las emisiones es una elección social sustentada en la forma como juzquemos los riesgos del cambio climático¹⁶. Los científicos, políticos y grupos involucrados, deben trabajar conjuntamente para determinar el riesgo de los diversos eventos derivados de emisiones de gases de invernadero y los costos de la implementación de cambios. Nuestras acciones presentes determinarán la manera en que las futuras generaciones responderán al reto del cambio climático¹⁷.

¿Cómo podemos actuar frente a la incertidumbre?

La clave consiste en mantenerse informado a través de diversas fuentes. Adicionalmente, podemos crear planes de acción que reduzcan el impacto negativo mientras se va tomando ventaja de los posibles resultados positivos. Las opciones "sin remordimientos" son formas de acción que pueden beneficiar al mundo tanto ecológica como económicamente. Por ejemplo, la implementación de medidas de adaptación al cambio climático también mejora la capacidad de recuperación frente a la variabilidad normal del clima. A gran escala, las inversiones en tecnología de energía renovable contribuirán a reducir las emisiones de gases de invernadero, además de proporcionar otras ventajas ecológicas y financieras a largo plazo. Las acciones individuales que reduzcan las emisiones de gases de invernadero también pueden ser económica y ambientalmente inteligentes. La incertidumbre del futuro no significa que no podamos actuar en el presente. Podemos actuar de manera positiva para el mundo, nuestra salud y nuestras billeteras.

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Climate Change and Agriculture Fact Sheet Series E3148 April 2011

GREENHOUSE GAS BASICS

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What are greenhouse gases?

Many chemical compounds in the atmosphere act as greenhouse gases. These gases allow sunlight (shortwave radiation) to freely pass through the Earth's atmosphere and heat the land and oceans. The warmed Earth releases this heat in the form of infrared light (longwave radiation), invisible to human eyes¹. Some of the infrared light released by the Earth passes through the atmosphere back into space. However, greenhouse gases will not let all the infrared light pass through the atmosphere¹. They absorb some and radiate it back down to the Earth. This phenomenon, called the greenhouse effect, is naturally occurring and keeps the Earth's surface warm. It is vital to our survival on Earth. Without the greenhouse effect, the Earth's average surface temperature would be about 60° Fahrenheit colder, and our current way of life would be impossible¹.

Greenhouse gases occur naturally and allow us to survive on Earth by warming air near Earth's surface. Human activities are now increasing the amount of greenhouse gases in the atmosphere, which leads to changes in climate. These changes are affecting many human activities, including agriculture.

We know that several gases in the atmosphere can absorb heat. These greenhouse gases are produced both by natural processes and by human activities. The primary ones are:

- Carbon dioxide (CO₂)
- Methane (CH₄)
- Nitrous oxide (N₂O)
- Industrial Gases, including hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride

Water vapor is the most abundant greenhouse gas and plays an important role in regulating the climate. Changes in water vapor from human activities such as irrigation and deforestation can directly affect temperatures at the Earth's surface². However, because human emissions of water vapor do not significantly change water vapor levels in the atmosphere, water vapor is not counted in the United States or international greenhouse gas inventories³.

Why do greenhouse gas levels matter?

Atmospheric concentrations of several important greenhouse gases have increased significantly since large-scale industrialization began around 200 years ago⁴. Fossil fuel combustion converts carbon that had been stored deep in the Earth to carbon dioxide that enters the atmosphere. Clearing land for agriculture converts carbon stored in soils and plants to carbon

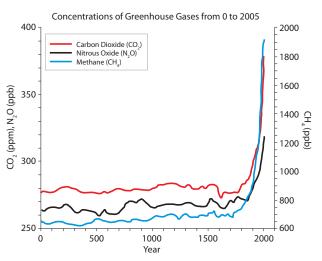


Figure 1: Atmospheric concentrations of the naturally occurring greenhouse gases carbon dioxide, methane, and nitrous oxide over the past 2000 years. Data are from ice core records and contemporary measurements 4.

dioxide. Even though the most important greenhouse gases occur naturally and are important for life on Earth, burning fossil fuels and other human activities have caused a large increase in their concentrations (Figure 1).

This all matters because there is general scientific consensus among climatologists, atmospheric chemists, and other scientists who study Earth's systems that the increase of greenhouse gas concentrations causes a rise in the average global temperature^{5,6}. Assessments by the independent Intergovernmental Panel on Climate Change (IPCC) note that Earth's average global surface temperature has risen between 1.1° and 1.6° Fahrenheit over the past century and that this is very likely caused by human activity⁴. Although this rise in temperature does not seem like much, even small changes in the global temperature can lead to changes we notice at the local level, and

warming in some places – in the Arctic, for example – is much greater than in others. Local changes include shifts in the patterns and severity of rainfall and snowfall, droughts, cloudiness, humidity, and growing season length⁷. These changes have the capacity to greatly affect agriculture (see MSU Extension E3149).

Do all greenhouse gases have the same effect?

Greenhouse gases have different capacities to absorb heat. Scientists use two terms to differentiate the impacts of different greenhouse gases:

Global Warming Potential (GWP)⁴ is an index that represents the global warming impact of a greenhouse gas relative to carbon dioxide. GWP represents the combined effect of how long the gas remains in the atmosphere and its relative effectiveness in absorbing outgoing infrared heat. Table 1 lists the GWP of the three main greenhouse gases (based on a 100-year time horizon). As the table shows, a given molecule of nitrous oxide has over 300 times the impact on global warming as does a molecule of carbon dioxide.

Table 1: Global Warming Potential of greenhouse gases ⁴					
	Atmospheric lifetime (years)	Global Warming Potential (GWP)			
Carbon dioxide (CO ₂)	Variable	1			
Methane (CH ₄)	12	21			
Nitrous oxide (N_2O)	114	310			

Carbon dioxide-equivalents (CO₂-eq)⁴ are units that represent the relative impact of a given gas on atmospheric warming, based on the gas' GWP. For example, a ton of methane can be expressed as 21 tons of CO₂-eq, and a ton of nitrous oxide can be expressed as 310 tons of CO₂-eq. Using a common unit helps when making inventories of greenhouse gases or when comparing strategies to reduce greenhouse gas emissions.

Despite the already changing global climate, we can use a combination of strategies to mitigate climate change both by emitting fewer greenhouse gases and

by removing carbon dioxide from the atmosphere. Decreasing our reliance on fossil fuels and investing in alternative energy sources and more efficient technologies can help to reduce emissions of greenhouse gases. Removing carbon dioxide from the atmosphere and storing it permanently, referred to as carbon sequestration, is another mitigation strategy. This can be accomplished through planting crops or trees that absorb carbon dioxide from the atmosphere via photosynthesis and store it in their ecosystem as roots, wood, or soil organic matter.

See MSU Extension E3149 for a more detailed description of field crop agriculture and climate change.

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Notas sobre Cambio Climático y Agricultura E3148SP Abril, 2011

CONCEPTOS BÁSICOS SOBRE GASES DE INVERNADERO

Julie E. Doll¹ y Marci Baranski ^{1,2} ¹W.K. Kellogg Biological Station, Michigan State University, ²Michigan State University Extension Traducción al Español: Lea Corkidi. Marzo, 2012

¿Qué son los gases de invernadero?

Muchos de los compuestos químicos que se encuentran en la atmósfera funcionan como gases de invernadero. Este tipo de gases permiten que la radiación de onda corta de la luz solar atraviese la atmósfera de nuestro planeta calentando la tierra y los océanos. La Tierra libera calor en forma de luz infrarroja invisible para el ojo humano (radiación de onda larga)¹. Parte de esta luz es reflejada y regresa nuevamente al espacio. Sin embargo, los gases de invernadero impiden que la totalidad de esta radiación infrarroja atraviese la atmósfera¹. Estos gases absorben parte de la luz solar y la irradian hacia la Tierra. Este fenómeno, llamado efecto invernadero, ocurre en forma natural y mantiene cierta temperatura en la superficie de la Tierra que es vital para nuestra sobrevivencia. Sin el efecto invernadero, la temperatura promedio de la Tierra sería aproximadamente 60 °F (33 °C) menor, lo que haría imposible nuestra actual forma de vivir1.

Los gases de invernadero son producidos naturalmente y nos permiten sobrevivir en la Tierra al calentar el aire cercano a su superficie. Sin embargo, las actividades humanas están incrementando la cantidad de gases de invernadero en la atmósfera, ocasionando cambios en el clima. Estos cambios están afectando muchas de nuestras actividades, incluyendo la agricultura.

Sabemos que muchos de los gases que se encuentran en la atmósfera pueden absorber calor. Estos gases de invernadero son producidos, tanto por procesos naturales, como por actividades humanas. Los principales son:

- Dióxido de carbono (CO₂)
- Metano (CH₄)
- Óxido nitroso (N₂O)
- Gases industriales, incluyendo hidrofluorocarbonos, perfluorocarbonos y hexafluoruro de azufre.

El vapor de agua es el gas de invernadero más abundante en la Tierra y juega un papel muy importante en la regulación del clima. Los cambios en la evaporación del agua generados por actividades humanas tales como la irrigación y la deforestación, pueden afectar

directamente las temperaturas de la superficie de la Tierra². Sin embargo, debido a que las emisiones humanas de vapor de agua no han alterado significativamente sus niveles en la atmósfera, éste no está considerado en los inventarios de gases de invernadero de Estados Unidos, como tampoco en los internacionales³.

¿Por qué son importantes los niveles de gases de invernadero?

Las concentraciones atmosféricas de muchos de los gases de invernadero más importantes, se han incrementado significativamente desde que inició la industrialización a gran escala hace alrededor de 200 años⁴. La quema de combustibles fósiles convierte el carbón almacenado en la profundidad de la Tierra en dióxido de carbono y lo libera a la atmósfera. El cambio del uso del suelo hacia la agricultura, también ha convertido el carbono almacenado en el suelo y las plantas, en dióxido de carbono. A pesar de que los gases de invernadero más importantes son producidos naturalmente y son esenciales para la vida, la quema de combustibles fósiles y otras actividades humanas han ocasionado un considerable incremento en sus concentraciones (Figura 1).

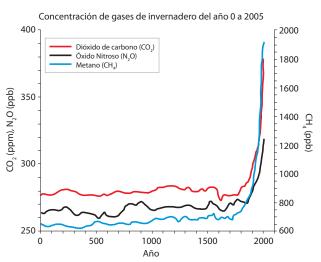


Figura 1: Concentración atmosférica del dióxido de carbono, metano y óxido nitroso durante los pasados 2005 años. Estos son gases de invernadero que ocurren naturalmente. Datos obtenidos en testigos de hielo y mediciones contemporáneas⁴.

Todo esto es importante porque existe consenso general entre los climatólogos, químicos de la atmósfera y otros científicos dedicados al estudio de los sistemas terrestres, en que el incremento de las concentraciones de los gases de invernadero ocasiona una elevación en la temperatura global de la Tierra^{5,6}. Las evaluaciones realizadas por el Panel Intergubernamental Independiente sobre Cambio Climático (IPCC, por sus siglas en inglés), señalan que la temperatura de la superficie terrestre se ha incrementado entre 1.1 a 1.6 °F (0.56 a 0.92 °C) a partir del siglo pasado y que es muy probable que esto haya sido provocado por la actividad humana⁴. A pesar de que este incremento en la temperatura pudiera no parecer significativo, incluso pequeños cambios en la temperatura global pueden ocasionar cambios que son detectados a nivel local, así como que el calentamiento en algunos lugares - por ejemplo en el Ártico - sea mayor que en otros. Los cambios locales incluyen alteraciones en el patrón y la severidad de las lluvias y nevadas, sequías, nubosidad, humedad y longitud de las estaciones de crecimiento⁷. Estos cambios tienen la capacidad de afectar significativamente la agricultura (consultar la publicación E3149 del departamento de Extensión Universitaria de la Universidad del Estado de Michigan).

¿Todos los gases de invernadero tienen el mismo efecto?

No todos los gases de invernadero tienen la misma capacidad para absorber calor. Los científicos usan dos términos para diferenciar el impacto de los gases de invernadero.

El **Potencial de Calentamiento Global**⁴ es un índice que representa el impacto de calentamiento global de un gas de invernadero respecto al del dióxido de carbono. El potencial de calentamiento global indica el efecto combinado del tiempo que el gas permanece en la atmósfera y su efectividad relativa para absorber la radiación infrarroja. La tabla 1 incluye el potencial de calentamiento global de los tres principales gases de invernadero (con base en un horizonte de tiempo de 100 años). Tal como se indica en la tabla, una molécula de óxido nitroso tiene cerca de 300 veces más impacto en el calentamiento global que una molécula de dióxido de carbono.

Tabla 1: Potencial de Calentamiento Global de los gases de invernadero⁴					
	Tiempo de vida en la atmósfera (años)	Potencial de Calentamiento Global			
Dióxido de carbono (CO ₂)	Variable	1			
Metano (CH ₄)	12	21			
Óxido nitroso (N ₂ O)	114	310			

Los equivalentes de dióxido de carbono

(CO₂-eq)⁴ son unidades que representan el impacto relativo de un gas en el calentamiento atmosférico, con base en su potencial de calentamiento global. Por ejemplo, una tonelada de metano puede ser expresada como 21 toneladas equivalentes de CO₂, y una tonelada de óxido nitroso puede ser expresada como 310 toneladas de CO₂-eq. El uso de una unidad común es útil para elaborar inventarios de gases de invernadero o comparar estrategias para la reducción de emisiones de gases.

A pesar de los cambios en el clima ya existentes, se pueden utilizar una combinación de estrategias para mitigar el cambio climático, tanto disminuyendo la cantidad de emisiones de gases, como removiendo dióxido de carbono de la atmósfera. Disminuir nuestra dependencia de los combustibles fósiles mediante la inversión en fuentes alternativas de energía y el desarrollo de tecnologías más eficientes, puede contribuir a la reducción de emisiones de gases de invernadero. Extraer dióxido de carbono de la atmósfera y almacenarlo permanentemente, lo que se conoce como "secuestro de carbono", es otra estrategia para mitigar el cambio climático global. Esto puede llevarse a cabo plantando cultivos o árboles que absorban dióxido de carbono de la atmósfera por medio de la fotosíntesis, almacenándolo en el ecosistema en forma de raíces, madera o materia orgánica del suelo.

Consultar la publicación E3149 para una descripción más detallada sobre agricultura y el cambio climático.

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WHAT WE KNOW:



THE REALITY, RISKS AND RESPONSE TO CLIMATE CHANGE

The AAAS Climate Science Panel



The AAAS Climate Science Panel

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For more information about the panel and the initiative, please visit: whatweknow.aaas.org

The overwhelming evidence of human-caused climate change documents both current impacts with significant costs and extraordinary future risks to society and natural systems. The scientific community has convened conferences, published reports, spoken out at forums and proclaimed, through statements by virtually every national scientific academy and relevant major scientific organization — including the American Association for the Advancement of Science (AAAS) — that climate change puts the well-being of people of all nations at risk.

Surveys show that many Americans think climate change is still a topic of significant scientific disagreement. Thus, it is important and increasingly urgent for the public to know there is now a high degree of agreement among climate scientists that human-caused climate change is real. Moreover, while the public is becoming aware that climate change is increasing the likelihood of certain local disasters, many people do not yet understand that there is a small, but real chance of abrupt, unpredictable and potentially irreversible changes with highly damaging impacts on people in the United States and around the world.

It is not the purpose of this paper to explain why this disconnect between scientific knowledge and public perception has occurred. Nor are we seeking to provide yet another extensive review of the scientific evidence for climate change. Instead, we present key messages for every American about climate change:

1. Climate scientists agree: climate change is happening here and now. Based on well-established evidence, about 97% of climate scientists have concluded that human-caused climate change is happening. This agreement is documented not just by a single study, but by a converging stream of evidence over the past two decades from surveys of scientists, content analyses of peer-reviewed studies, and public statements issued by virtually every membership organization of experts in this field. Average global temperature has increased by about 1.4° F over the last 100 years. Sea level is rising, and some types of extreme events – such as heat waves and heavy precipitation events

- are happening more frequently. Recent scientific findings indicate that climate change is likely responsible for the increase in the intensity of many of these events in recent years.

- 2. We are at risk of pushing our climate system toward abrupt, unpredictable, and potentially irreversible changes with highly damaging impacts. Earth's climate is on a path to warm beyond the range of what has been experienced over the past millions of years. The range of uncertainty for the warming along the current emissions path is wide enough to encompass massively disruptive consequences to societies and ecosystems: as global temperatures rise, there is a real risk, however small, that one or more critical parts of the Earth's climate system will experience abrupt, unpredictable and potentially irreversible changes. Disturbingly, scientists do not know how much warming is required to trigger such changes to the climate system.
- 3. The sooner we act, the lower the risk and cost. And there is much we can do. Waiting to take action will inevitably increase costs, escalate risk, and foreclose options to address the risk. The CO₂ we produce accumulates in Earth's atmosphere for decades, centuries, and longer. It is not like pollution from smog or wastes in our lakes and rivers, where levels respond quickly to the effects of targeted policies. The effects of CO₂ emissions cannot be reversed from one generation to the next until there is a large- scale, cost-effective way to scrub carbon dioxide from the atmosphere.

 Moreover, as emissions continue and warming increases, the risk increases.

By making informed choices now, we can reduce risks for future generations and ourselves, and help communities adapt to climate change. People have responded successfully to other major environmental challenges such as acid rain and the ozone hole with benefits greater than costs, and scientists working with economists believe there are ways to manage the risks of climate change while balancing current and future economic prosperity.

As scientists, it is not our role to tell people what they should do or must believe about the rising threat of climate change. But we consider it to be our responsibility as professionals to ensure, to the best of our ability, that people understand what we know: human-caused climate change is

happening, we face risks of abrupt, unpredictable and potentially irreversible changes, and responding now will lower the risk and cost of taking action.

I. CLIMATE REALITY

A. Climate scientists agree: Humans are driving climate change Many Americans believe scientists disagree. Based on well-established evidence, about 97% of climate scientists have concluded that humans are changing the climate.

In 2013, only 42% of American adults understood that "most scientists think global warming is happening" and 33% said, "... there is a lot of disagreement among scientists about whether or not global warming is happening." Twenty percent said they "don't know enough to say." iv

Even Americans who have come to recognize that climate change is occurring know there are limits to their ability to make this judgment from their own experiences. It might appear as if it's raining more or less often, that it's hotter than usual, or there are more storms than there once were. But is this true climate change, or just natural variation? Does a particularly cold or snowy winter, such as the one the eastern United States experienced in 2013 and 14, or variations in rate of in global surface temperature change, call global warming into question? If the climate is changing, are human activities or natural factors responsible?

Americans look to experts for guidance. If people believe the experts are in doubt about whether global warming is happening, it is no surprise that they will have less confidence in their own beliefs. Perceived expert disagreement has other consequences for the American people.

Research shows that Americans who think the scientific experts disagree about human-caused climate change are less likely to believe that it might have serious consequences. Failure to appreciate the scientific consensus reduces support for a broad societal response to the challenges and risks that climate change presents.

So let us be clear: Based on well-established evidence, about 97% of climate scientists conclude humans are changing the climate.

This widespread agreement is documented not by a single study but by a converging stream of evidence over the past two decades from polls of scientists, iii, iv content analyses of peer-reviewed literature v, vi and from public statements issued by virtually every expert scientific membership organization on this topic. Vii The evidence is overwhelming: levels of greenhouse gases in the atmosphere are rising. Temperatures are going up. Springs are arriving earlier. Ice sheets are melting. Sea level is rising. The patterns of rainfall and drought are changing. Heat waves are getting worse as is extreme precipitation. The oceans are acidifying.

The science linking human activities to climate change is analogous to the science linking smoking to lung and cardiovascular diseases. Physicians, cardiovascular scientists, public health experts and others all agree smoking causes cancer. And this consensus among the health community has convinced most Americans that the health risks from smoking are real. A similar consensus now exists among climate scientists, a consensus that maintains climate change is happening, and human activity is the cause. The National Academy of Sciences, for example, says that "the Earth system is warming and that much of this warming is very likely due to human activities."

B. Climate change is happening now. And it's going to get worse.

Climate Change is already happening. More heat waves, greater sea level rise, and other changes with consequences for human health, natural ecosystems, and agriculture are already occurring in the United States and worldwide. These problems are very likely to become worse over the next 10-20 years and beyond.

No matter where they live, Americans are experiencing the effects of climate change. Of course, extreme weather events of varied intensity have always occurred. Family photo albums, community lore and history books recount the big storms, droughts and floods that communities

have borne. Against this backdrop of natural variation, however, something different is happening. Greenhouse gases from manmade sources such as smokestacks and tailpipes have altered our climate system. Greenhouse gases have supercharged the climate just as steroids supercharged hitting in Major League Baseball. Over the course of a baseball season in the steroid era, we witnessed more – and longer – homers, even though we cannot attribute any specific homer to steroids. Similarly, even though we cannot attribute any particular weather event to climate change, some types of extreme events such as heat waves are now more frequent.

Extreme weather is not just an abstract concept. It is a reality that affects people across the country. In 2013, two out of three Americans said weather in the U.S. has been worse over the past several years, up 12 percentage points since spring 2012. Many (51%) say weather in their local area has been worse over the past several years. Not surprisingly, then, the gap between what we know as scientists (that global warming impacts are here and now) and what Americans perceive is narrowing: about six in 10 Americans already say, "global warming is affecting weather in the U.S." ix

The core science of global warming

After remaining relatively stable at around 280 parts-per-million (ppm) for millennia, carbon dioxide (CO₂) began to rise in the 19th century as people burned fossil fuels in ever-increasing amounts. This upward trend continues today with concentrations breaking the 400 ppm mark just last year. The rate of increase during the last 100 to 150 years has been much more rapid than in other periods of the Earth's history. The warming effect of CO₂ and other heat-trapping gases is well-established and can be demonstrated with simple science experiments and satellite observations. Without the natural "greenhouse" effect from gases in our atmosphere, Earth would be a frozen planet.

In addition to greenhouse gases, there are many other forces that can cause changes in the Earth's climate – including the creation and destruction of the Earth's crust, the planet's wobbly path around (and tilt toward) the sun, variation in the sun's energy output, volcanic eruptions, shifting

ocean currents, and natural changes in CO₂ and other greenhouse gases. These factors have driven the planet through eras of blazing heat and mile-thick ice sheets. But decades of human-generated greenhouse gases are now the major force driving the direction of climate change, currently overwhelming the effects of these other factors. Many studies show that the combined effects of natural drivers of climate cannot explain the temperature increase observed over the past half century.

Since the late 19th century, Earth's global average temperature has risen by about 1.4° F.

Although this may appear to be a small change, the Earth's temperature has remained nearly as stable as that of the human body over the course of Western civilization. Just as a 1.4° F fever would be seen as significant in a child's body, a similar change in our Earth's temperature is also a concern for human society.

The difference was about 9° F between the last Ice Age, when half of North America was covered in a mile-thick ice sheet, and today. However, whereas that warming occurred over thousands of years, today's atmosphere has already warmed by 1.4° F in just over 100 years. The projected rate of temperature change for this century is greater than that of any extended global warming period over the past 65 million years. The Intergovernmental Panel on Climate Change states that continuing on a path of rapid increase in atmospheric CO₂ could cause another 4 to 8° F warming before the year 2100.×

Here's a brief summary of some the impacts of climate change that are already occurring and will increase over the coming years:

Sea Ice

Arctic sea ice has been shrinking dramatically, and the rate of loss is accelerating.xi In September 2012, Arctic summer sea ice fell to a new record low at half the historical average - a loss in area nearly twice the size of Alaska.xii

Ice Sheets and Glaciers

The melting of the Greenland and Antarctica ice sheets has also accelerated notably.^{xiii}

Glaciers continue to melt rapidly, contributing to sea-level rise and also affecting water supplies for as many as a billion people around the world.^{xiv}

Ocean Acidification

The oceans are absorbing much of the CO_2 that smokestacks and tailpipes emit into the atmosphere. As a result, the oceans are rapidly acidifying, with early impacts on shelled organisms such as oysters already documented. The current acidification rate is likely the fastest in 300 million years.^{xv}

Ecological Impacts

As the world has gotten hotter, many of the world's plants and animals, on land and in the oceans, have begun moving toward the poles. Where possible, some terrestrial species are moving up mountainsides, and marine species are moving to deeper depths and higher latitudes. These changes are happening on every continent and in every ocean. XVIXVIIXVIII In some places seasonal behaviors are taking place two or three weeks earlier than they did just a few decades ago. XIX The organisms that cannot adapt to the new climate conditions — because they cannot move fast enough or run out of room — will be worse off.

Extinctions are likely to increase, as climate change combines with other human-related environmental pressures. Moreover, the impacts of climate change on ecosystem processes such as decomposition, plant production and nutrient cycling – processes that determine how much fossil fuel-derived CO_2 the land and ocean will continue to sequester in coming decades – remain largely unknown.

Sea Level Rise

Sea level rise has also accelerated, making storm surges higher and pushing salt water into the aquifers that coastal communities depend on for fresh water, and increasing the extent of coastal flooding. Over the last two decades, sea levels have risen almost twice as fast as the average during the 20th century.^{xx} Salt-water intrusion can be witnessed in southern Florida, where sea level rise is contributing to salt water infiltration of coastal wells.^{xxi}

Floods, Heat Waves and Drought

Global warming has changed the pattern of precipitation worldwide.^{xxii} Flooding in the northern half of the eastern U.S., Great Plains and over much of the Midwest has been increasing, especially over the last several decades. These regional flooding trends in the northeast and upper Midwest are linked to increases in extreme precipitation and are consistent with the global trends driven by climate change.^{xxiii} At the same time, areas such as the U.S. Southwest are witnessing more droughts, and these too are consistent with global climate change patterns projected by climate models as a consequence of rising CO₂ levels.^{xxiiv}

Since 1950, heat waves worldwide have become longer and more frequent.xxv One study indicates that the global area hit by extremely hot summertime temperatures has increased 50-fold,xxvi and the fingerprint of global warming has been firmly identified in these trends.xxvii In the U.S., new record high temperatures now regularly outnumber new record lows by a ratio of 2:1.xxviii

Wildfires

Climate change has amplified the threat of wildfires in many places. In the western U.S., both the area burned by wildfires as well as the length of the fire season have increased substantially in recent decades. Earlier spring snowmelt and higher spring and summer temperatures contribute to this change. Climate change has increased the threat of "mega-fires" – large fires that burn proportionately greater areas. Warming has also led to wildfires present in some regions where they have been absent in recent history.

Effects on Health and Well-being

Climate disruption is already affecting human health and well-being in many ways, and health threats are expected to intensify, xxxiii Some of the well-understood impacts include the direct effects of heat and the effects of other weather conditions such as droughts, floods, and severe storms. Heat waves cause deaths and illness, with urban dwellers, the elderly, the poor, and certain other especially vulnerable groups. XXXXIIII While heat-related deaths and illnesses have diminished in recent decades, thanks to better forecasting, early warning systems, and/or increased air conditioning, factors such as the aging of the population are expected to increase vulnerability. XXXXIII Storms and floods can injure and kill victims in the short term while lingering consequences may range from mold growth in flooded buildings (aggravating asthma) to contaminated drinking water supplies to post-traumatic stress and other mental health disorders. XXXXII Some air pollutants increase with climate change, with the potential to aggravate heart and respiratory diseases. Some plant products such as ragweed pollen reach higher concentrations for longer stretches each year, affecting people with allergies.

Scientists have extensively studied the impact of climate change on the risk of infectious diseases. Climate change affects the life cycle and distribution of disease-carrying "vectors"—mosquitoes, ticks, and rodents, which transmit such diseases as West Nile virus, equine encephalitis, Lyme disease, Rocky Mountain Spotted Fever and Hantavirus. There is uncertainty about how climate change will affect infectious disease risk, since many factors other than climate affect the spread of disease. The role of climate change on the ranges of vector-borne diseases in the U.S., such as Lyme disease, West Nile virus and dengue is an active area of research.

Climate Change and National Security

Recent reports from U.S. Department of Defense (DOD) and National Academy of Science studies have called attention to the implications of current and probable future climate change for U.S. national security.^{xliv} They identify obvious coastal concerns relating to sea level rise, and others

linked to storms, freshwater availability, and agricultural productivity around the globe. For example: "Climate change could have significant geopolitical impacts around the world, contributing to poverty, environmental degradation, and the further weakening of fragile governments. Climate change will contribute to food and water scarcity, will increase the spread of disease, and may spur or exacerbate mass migration." In the context of other global dynamics that give rise to political instability, and societal tensions, changes in climate are considered as potential threat multipliers or instability accelerants according to the CNA Military Advisory Board — a panel of our nation's highest-ranking retired military leaders.* Further, national security assets are often global first respondents to humanitarian needs associated with natural disasters including typhoons, hurricanes, and flooding.

Climate change can influence resource competition and place new burdens on economies, societies, and governance institutions. The reports call attention to the fact that these burdens can trigger violence. There is a growing recognition that the displacement of large numbers of people due to water scarcity and agricultural failure, as in the recent history of Syria, can exacerbate tensions that can lead to civil unrest. Senior officers and officials in the U.S. DOD are now regularly speaking publically about how an unabated rise in greenhouse gas emissions could add additional burdens to the infrastructure and mission capacity of our military forces.

II. CLIMATE RISKS

Given the high stakes, it is valuable to understand not just what **is most likely to**happen, but what **might possibly** happen to our climate. There is a possibility that
temperatures will rise much higher and impacts will be much worse than expected.

Moreover, as global temperature rises, the risk increases that one or more important parts

of the Earth's climate system will experience changes that may be abrupt, unpredictable, and potentially irreversible, causing large damages and high costs. xiviii

We manage risk every day, often without thinking about it. We buckle our seat belts, latch our kids into car seats and buy insurance for a host of unlikely, but serious possibilities such as losing our homes or belongings to theft, fire or flood. We don't think these things will happen, but we cannot be sure they won't. Uncertainty means risk. Much of our day-to-day risk management is to lessen the danger directly. For example, we purchase cars with the latest safety devices and use these. But another form of risk management is to spread the risk, as with insurance. This helps with recovery if the unthinkable happens.

When we take the long view on climate change, we face these same uncertainties and risks. Climate projections for the year 2100 (when many children born this year will still be living) give a range of plausible temperatures. We are uncertain whether we will experience the high or low end of the range, but the risks of bad outcomes increase greatly at the high end of warming scenarios. By analogy, we are acting like people who take risks with their health (e.g., with behaviors like smoking, poor food choices) but still hoping to live long lives free of serious illness.

To make decisions about managing a risk, we consider the likelihood that a particular event will happen, the consequences if it did, and the cost of effective actions to prevent it. These are the same steps that go into making decisions about climate change. The process starts with an understanding of the risks. What is the likelihood that extreme climate changes will occur, and if they do, what consequences will we face? How much will it cost to prevent the risk?

A. High-risk scenarios: the high-side projections

Where there is a range of uncertainty, the high-side projections represent tail risk, a common concept in the world of finance. As most people understand, no investment is a sure thing. There is a range of possibilities about how that investment will fare. You could lose all you invested or make

many times what you paid, but the most likely result is closer to the middle of these extremes.

Although the chance of a very bad outcome — or tail risk — is small, it cannot be ignored. That is why advisors often recommend not investing any more than you can afford to lose.

With our future health and well-being at stake, it is common sense to consider the tail risks of climate change as a part of future plans. Consider the example of a seaside community in Florida. There are three futures to consider. Even under the most optimistic scenario (very aggressive greenhouse gas reductions and minimal melting), sea level is projected to rise about one foot this century. The middle-of-the-road projection for the current pathway is about two feet. This is a fairly likely possibility. The Intergovernmental Panel on Climate Change estimates the probability of a sea level rise of 2 to 3 feet to be more than about 60%. But the tail risk projection as forecast by the U.S. National Climate Assessment sees the community contending with a sea level rise of close to seven feet.

Below are some of the high-side projections and tail risks we incur by following the current path for CO₂ and other greenhouse gas emissions. Most of these projections derive from computer simulations of Earth and its climate system. These models apply the best understanding science has to offer about how our climate works and how it will change in the future. There are many such models and all of them have been validated, to varying degrees, by their ability to replicate past climate changes.

Global Temperature

According to the IPCC, given the current pathway for carbon emissions the high-end of the "likely" range for the expected increase in global temperature is about 8° F by the end of the century. It is similar to the roughly 9° F warming that ended the last ice age. It is important to remember that temperature change due to CO₂ emissions is essentially irreversible for several hundred years since this CO₂ is removed from the atmosphere only very slowly by natural processes. It is important to hundred years since this CO₂ is removed from the atmosphere only very slowly by natural processes.

Floods, Heat Waves, and Drought

Globally, if human society follows the high-end scenario, extreme heat events that currently occur only once every 20 years are projected to occur annually. Global warming will also lead to shifting precipitation patterns and concentration of precipitation into heavier downpours — critical risk factors for flooding and drought.

Sea Level

Sea level rise projections over the next century vary considerably, with the high-end scenarios yielding a rise of up to 6 or 7 feet by 2100. Iv,Ivi About 7 to 8 million people in the U.S. live within 6 feet of the local high tide line, and storm surge can extend flooding far beyond the high tide line, as witnessed in Superstorm Sandy. Ivii Coastal flooding events that currently occur once every 100 years will occur much more frequently, possibly as often as yearly for many locations, rendering many cities and communities uninhabitable as is. Iviii

Current greenhouse gas emissions would have considerable impact on sea level rise beyond the year 2100. In addition to driving sea level rise in the 21st century, current emissions might lead to dramatically higher sea level rise in the distant future, possibly beyond 16 feet, which is higher than the elevation of many major cities around the world. There is a slight risk that such large rise could occur faster than expected (see below).^{lix}

B. Abrupt climate change

Most projections of climate change presume that future changes — greenhouse gas emissions, temperature increases and effects such as sea level rise — will happen incrementally. A given amount of emission will lead to a given amount of temperature increase that will lead to a given amount of smooth incremental sea level rise. However, the geological record for the climate reflects instances where a relatively small change in one element of climate led to abrupt changes in the system as a whole. In other words, pushing global temperatures past certain thresholds could

trigger abrupt, unpredictable and potentially irreversible changes that have massively disruptive and large-scale impacts. At that point, even if we do not add any additional CO₂ to the atmosphere, potentially unstoppable processes are set in motion. We can think of this as sudden climate brake and steering failure where the problem and its consequences are no longer something we can control. In climate terms, abrupt change means change occurring over periods as short as decades or even years.^{|x|}

The risk of abrupt climate change is particularly challenging because, while plausible, we have few historical measurements to guide our judgment of likelihood. The financial meltdown of 2008 was a good example of this kind of risk. We had no history of intertwined real estate and financial markets to draw on, and few experts recognized the risk indicators that led to enormous and rapid economic consequences. It is no surprise that we use a metaphor like bursting bubbles for such highly damaging financial events. We do not recognize we are in one; things seem stable, until suddenly they are not.

If human emissions cause temperatures to increase toward the high end of our projections, we increase the risk that we will push parts of our climate system past certain thresholds that lead to abrupt, unpredictable and potentially irreversible changes to our planet and impacts for Americans and people worldwide.

Some of the planetary climate-related systems — both physical and biological —that could trigger such abrupt changes for the planet, if pushed past their limits, include: large-scale ice sheet collapse, collapse of part of the Gulf Stream, dieback of the Amazon rainforest, and coral reef die-off. Disturbingly, there is low confidence in the estimates of the temperature thresholds that would trigger such changes. While some scenarios – such as the disruption of the Gulf Stream/Atlantic Meridional Overturning Circulation (AMOC) and rapid methane release from the sea floor – based on the latest research are considered very unlikely, this does not mean their likelihood has gone to zero. Livi Given the complexity of these systems and uncertainties in how they will respond to high-end

warming, there may be surprises that we are not yet aware of. As per the National Academy of Sciences Report on Abrupt Impacts of Climate Change: "...'dragons' in the climate system still may exist." |xii

Some potential climate change scenarios include:

Ecosystem Collapse

Climate change threatens the collapse of some ecosystems and amplifies extinction pressures on species, which have already elevated extinction rates well above natural background rates. The rate of climate change now may be as fast as any extended warming period over the past 65 million years, and it is projected to accelerate in the coming decades. When rapid climate change is added to other sources of extinction pressure such as ocean acidification, land use, invasive species, and/or exploitation, the resulting rates of extinction are likely to place our era among a handful of severe biodiversity crises in the Earth's geological record.

Arctic Sea Ice Collapse

Warmer Arctic temperatures have caused Arctic summer sea ice to shrink rapidly over the past decade, with potentially large consequences including shifts in climate and weather around the northern hemisphere. Projections suggest that late summer sea ice may disappear entirely in the coming decades. The loss of Arctic sea ice has serious consequences for the Earth's climate system. Arctic sea ice covers an important portion of the planet's surface and reflects sunlight back into space that would otherwise warm the ocean. The loss of Arctic sea ice creates a feedback loop, as lost ice leads to additional ocean warming. The ice loss has major effects on the Arctic, and may have effects on weather patterns extending into the lower latitudes.

Large-Scale Ice Sheet Collapse

Large-scale melting of both the Greenland and Antarctic Ice Sheets include large-scale losses of ice, potentially leading to tens of feet of sea level rise. While most of these losses are projected as

being unlikely to occur before 2100, we may pass the point where these losses will be set in motion in the coming decades, with at least a slight chance that we have already done so. Ixx

In Antarctica, marine ice/ice sheet instability threatens abrupt and large losses from both the West Antarctic Ice Sheet (WAIS) and portions of the East Antarctic Ice Sheet. Any significant ice loss likely would be irreversible for thousands of years. Simulations of warming and ice loss during earlier warm periods of the last 5 million years indicate these areas can contribute 23 feet of sea level rise.

Some studies indicate that abrupt and irreversible ice loss from WAIS is possible, yet uncertainty regarding the threshold is such that it is not possible to say what temperature rise is necessary to trigger collapse. An abrupt change in the WAIS this century is deemed plausible, with an unknown but probably low probability. Recently an acceleration of ice loss from the WAIS has been observed, and it is not possible to dismiss or confirm that these changes are associated with destabilization of the WAIS.

Destabilizing of Sea Floor Methane

potentially strong feedback loop in a warming climate. Methane is a short-lived but potent greenhouse gas. While the release of these deposits due to global warming is likely to be slow and mitigated by dissolution into the sea, these deposits are large and vulnerable to warming expected on the higher emission pathway. The release of Arctic methane hydrates to the atmosphere would further increase, and perhaps substantially, the rate of global warming.

Permafrost Melt

The release of CO_2 and methane from thawing Arctic permafrost represents another critical feedback loop triggered by global warming.

The amount of carbon stored in the permafrost is the largest reservoir of readily accessible organic carbon on land. However, the positive feedback warming due to the loss of carbon from

frozen soils is generally missing from the major climate change models. Ixxix Not surprisingly, methane and carbon dioxide emissions from thawing permafrost are thus regarded as a key uncertainty in climate change projections.

Disturbingly, there is low confidence in the estimates of expected emissions from thawing permafrost. While an abrupt release on the timescale of a few decades is judged unlikely, this conclusion is based on immature science and sparse monitoring capabilities. The high end of the best estimate range for the total carbon released from thawed permafrost by 2100 is 250 GtC on the higher pathway. Other individual estimates are far higher.

III. CLIMATE RESPONSE

A. The sooner we act, the lower the risk and cost.

The longer we wait to respond, the more the risks of climate change will increase.

Conversely, the sooner we take action, the more options we will have to reduce risk and limit the human and economic cost of climate change.

What steps society takes to meet the challenge of climate change — the questions of when, how and to what extent we respond — is a matter on which all Americans must decide. We urge that these decisions be guided by two inescapable facts: first, the effects of <u>any</u> additional CO₂ emissions will last for centuries; second, there is a risk of abrupt, unpredictable and potentially irreversible changes in the Earth's climate system with massively disruptive impacts.

Emissions of greenhouse gases today commit the planet to unavoidable warming and other impacts in the future. As we continue to increase greenhouse gas emissions, we accelerate and compound the effects and risks of climate change into the future. Conversely, the sooner we make a concerted effort to curtail the burning of fossil fuels as our primary energy source and releasing the CO2 to the air, the lower our risk and cost will be.

B. There is much we can do.

We've successfully faced environmental challenges before. There's much we can do to respond to the challenge and risks of climate change, particularly by tapping America's strength in innovation.

The United States is one of the most resourceful and innovative societies in the world. We are a nation of problem solvers. When scientists identified the grave environmental threats posed by the acid rain and the ozone hole, they worked together with other stakeholders — consumers, industry and government — to develop solutions that would successfully reduce the threat while minimizing short- and long-term economic impacts. As we hope this paper has made clear, however, successfully responding to climate change will test our resolve and ingenuity in ways unlike any other environmental challenge we have faced.

Many of our major cities — New York, Seattle, Boston and Chicago are just a few — have assessed the scientific evidence, and decided to reduce greenhouse gas emissions and prepare for the impacts of climate change.

We believe that our responsibility as scientists is to ensure, to the best of our ability, that people fully understand the climate realities and risks we face. Prior experience shows that we and future generations will be better off when science effectively informs decision-making and action.

Armed with scientific understanding about the gravity of certain environmental problems, our nation has successfully used innovative approaches to address these challenges.

In summary, responding effectively to the challenge of climate change requires a full understanding that there is now a high degree of agreement among climate scientists about the fact that climate change is happening now, because of human activities, and that the risks –including the possibility for abrupt and disruptive changes — will increase the longer greenhouse gas emissions continue.

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Water Resources Sector Midwest Technical Input Report National Climate Assessment

WATER RESOURCES

WHITE PAPER PREPARED FOR THE U.S. GLOBAL CHANGE RESEARCH PROGRAM
NATIONAL CLIMATE ASSESSMENT
MIDWEST TECHNICAL INPUT REPORT

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At the request of the U.S. Global Change Research Program, the Great Lakes Integrated Sciences and Assessments Center (GLISA) and the National Laboratory for Agriculture and the Environment formed a Midwest regional team to provide technical input to the National Climate Assessment (NCA). In March 2012, the team submitted their report to the NCA Development and Advisory Committee. This whitepaper is one chapter from the report, focusing on potential impacts, vulnerabilities, and adaptation options to climate variability and change for the water resources sector.





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Summary

Water resources are important to Midwestern interests, including navigation on the Great Lakes and rivers, agriculture, hydropower, and recreation, and are likely to be subject to impacts from human-caused climate change. While the basic science of climate change is well established, many of the details of impacts on particular sectors at local to regional spatial scales are subject to greater uncertainty. Even though understanding is emerging, some more general patterns are emerging for water resources in the Midwestern US. In general, precipitation has been increasing and this trend is projected to continue. Precipitation increases are particularly pronounced when looking at the winter season and when looking at the few largest rain events of the year, and this is expected to continue. Methods of calculating evapotranspiration (ET) under changed climate are the subject of emerging research, showing that widely-used methods based on temperature as a proxy for potential ET exaggerate projected increases in ET, as demonstrated by severe imbalances in the surface energy budget. When incorporated into further simulations, this leads to excessive reductions in streamflow and lake levels. Simulations using a more energy-based approach to ET give more mixed results in terms of changes in streamflow and lake levels, and often show increases.

Introduction

The water resources of the Midwestern United States, and how they are managed under a future climate, have a significant collective impact on multiple economic sectors in the US, North America, and the world. The North American Laurentian Great Lakes, for example, hold nearly 20% of the earth's accessible surface fresh water supply and have a coastline, and a coastal population, on the same order of magnitude as frequently-studied ocean coasts around the world (Fuller et al. 1995). In light of growing demands for clean water, access to coastal resources, and an improved understanding of climate dynamics in the Midwest region, a significant amount of research has recently been focused on understanding climate impacts on the lakes (both large and small), rivers, and streams in this region.

Various interest groups and socio-economic sectors depend on different aspects of the water cycle, often on different time scales. Rain-fed agriculture does best if soil moisture is replenished at least every 15 days or so. Streamflow, important for flood control, hydropower, navigation, fish migration, and some other ecological factors, has its high extremes controlled by abundant precipitation and snowmelt on short timescales, but its low extremes are controlled primarily by baseflow, which is water that percolates through the soil into ground water, then gradually flows through the ground into streams, wetlands, and lakes. Levels of the Great Lakes are determined by net basin supply, which is the sum of inflow from the land portion of their drainage basin and the precipitation directly over the lake, minus the evaporation from the lake. Because of the large areal extent of the Great Lakes, the effect of short-term variability in net basin supply on lake level is attenuated. Other short-term effects on lake level include wind-driven surges and seiches (waves occurring on the scale of an entire lake).

While not a specific theme of this particular assessment, we find that this region also, through explicit and implicit partnerships with the Canadian government, represents an ideal test bed for establishing effective protocols for collaborative binational water resources and ecosystem services research (Gronewold and Fortin 2012). The value of the water resource management and climate change lessons to be learned from this region, however, depends on an explicit acknowledgement of those water budget components which are uncertain or unobservable (such as overlake evaporation and evapotranspiration), and how projections of regional climate dynamics are downscaled to a suitable local scale, translated into suitable water resource management metrics, and subsequently placed within an appropriate historical context.

Historic variability of hydroclimate

Seasonal to multi-year events

Pan and Pryor (2009) point out that the amount of water vapor in the atmosphere has been increasing at a greater rate in proportion to its historic values than the rate of precipitation. The total water vapor content of the atmosphere has increased in proportion to the Clausius-Clapeyron relation, i.e. it scales as an exponential function of temperature, with absolute humidity or water vapor mixing ratio increasing by about 7% per degree C. However, the mean rate of precipitation has increased by only about 2% per degree C, implying an increasing residence time of water vapor in the atmosphere. Additional theoretical consideration of this phenomenon can be found in Held and Soden (2006).

Pryor et al. (2009) have found statistically significant changes in total precipitation and number of rain days at many stations in the Midwest, mostly increases in both variables, but few stations have statistically significant change in precipitation intensity (precipitation per rain day). They also showed an increase in the amount of precipitation that came on the 10 days of the year with the greatest precipitation. However, this was not evaluated as a proportion of the total precipitation. They also found that there was generally a decrease in the mean number of consecutive days without precipitation.

Observed streamflow has shown an increasing trend since 1940 in the United States in general (Lettenmaier et al. 1994, Lins and Slack 1999, USGS 2005), and particularly in the Midwest region. More specifically, if you rank daily streamflows from least to greatest, the low to medium range values have increased in recent years, while the largest have not (Lins and Slack 1999). Similarly, Hodgkins et al. (2007) show increasing flow at most gauging stations within the Great Lakes basin, both for the period 1935-2004 and 1955-2004. Li et al. (2010) emphasize that outflow from a region of water in streams must be balanced by net inflow of water vapor in the atmosphere, meaning that atmospheric transport is crucial to terrestrial hydrology, including streamflow.

Net basin supply (NBS, which is tributary river inflow plus over-lake precipitation minus over-lake evaporation) is important for the Great Lakes because it sets the level to which the lake must rise or fall so that it is balanced by outflow. Lenters (2004) showed trends of reduced seasonal cycle in NBS and lake levels on Lake Superior. This change includes a reduction between 1948 and 1999 of the NBS during the spring, and an increase of NBS during the autumn. Each of these changes is primarily attributable to changes in runoff and over-lake precipitation, as given in the dataset of Croley and Hunter (1994). During the 1948-99 period, they did not note a strong overall trend in lake level.

A possible non-climatic cause of changes in the lake level regime of the Great Lakes was proposed by Baird and Associates (2005). They proposed that a deepening of the channel of the St. Clair River, which forms part of the connection between Lake Huron and Lake Erie, was responsible for a distinct reduction in the difference in level between these two lakes. With NBS remaining constant, a less impeded flow due to a deeper channel would require that the level of Lakes Huron and Michigan would need to be lower relative to the level of Lake Erie in order to maintain the same volume of flow out of Lake Huron. The International Joint Commission's International Upper Great Lakes Study (IUGLS, (2009) instead found that changes in climate during the period between about 1985 and 2005 was primarily responsible for this change in relative lake levels.

Trends in the entire range of hydrologic variables may depend on the range of dates that are considered in observational analysis. For example, a rapid drop in the level of Lakes Michigan and Huron occurred during the 1990s and 2000s (Baird and Associates, 2005; IUGLS 2009, 2012), so whether or not an analysis extends beyond that date could affect the magnitude of an apparent long-term trend.

Frequency of localized, short-term extremes

As stated above, Pryor et al. (2009) showed an increase in the amount of precipitation that came on the 10 days of the year with the greatest precipitation. That is, more precipitation came during very heavy downpours. However, this was not evaluated as a proportion of the total precipitation. They also found that there was generally a decrease in the mean number of consecutive days without precipitation. This is in basic agreement with the results of the seminal paper of Kunkel et al. (1999).

Changnon (2007) examined the frequency, intensity, and economic impact of severe winter storms in the US between 1949 and 2003. This generally showed an increase in intensity over time, and a decrease in frequency, with these effects most concentrated in the eastern US.

Non-climatic influences

One factor aside from climate that can affect the long-term water budget of the region, as well as the shorter-term temporal characteristics of response of runoff to precipitation events, is land use. Land use in the Midwest has evolved historically from natural forest and grassland to greater agricultural use and increasing urban and suburban development. Andresen et al. (2009) showed that

urban landscapes lower percolation of water into soil and increase surface runoff. Grassland landscapes have the lowest evapotranspiration (ET), while forests have the greatest amount of soil percolation. Cultivated agricultural land has fairly high ET, but also quite high surface runoff. They did not extend their analysis to include how much land was transformed from one of these classes to another. Mishra et al. (2010a) also evaluated the effects of land use on hydrology, showing that conversion of forest to cropland can lead to decreased ET and increased runoff. These effects, when combined with climate change effects, can be additive or compensating. Direct comparison of the results of Andresen et al. (2009) and Mishra et al. (2010a) is difficult because of the differing sets of results that were reported by each and because of the more static land use approach of Andresen et al. (2009) in contrast to the emphasis on land use conversion in Mishra et al. (2010a).

Properties of agricultural landscapes can make them more vulnerable to climate variability and change (Knox 2001). Natural landscapes are better at buffering moisture, making it available to plants for longer periods of time and delaying the eventual runoff of water that does not undergo ET. Thus, even aside from the possibility that precipitation will fall in more concentrated events, cultivated environments, and especially those with tiling to deliver runoff more rapidly, will promote greater extremes in streamflow than forests, grasslands, and other natural land cover types. Similarly, Mao and Cherkauer (2009) used a hydrologic model to demonstrate that land use transformations from pre-settlement times to the present result in decreased ET and increased runoff throughout much of the states of Minnesota, Wisconsin, and Michigan, where the prevailing transformation was from forest to agriculture. Even conversion from evergreen to deciduous forest resulted in decreased ET and increased runoff. A specific difference from the general results of Knox (2001), though, was that conversion from grassland to agriculture, which occurred in much of the southern and western part of the domain, resulted in increased ET and decreased runoff.

Lake water temperature

Austin and Colman (2007) investigated surface temperatures of Lake Superior during the period 1979-2006, and found a positive trend in these temperatures. They found the rate of increase in annual maximum lake surface temperatures to be nearly twice as large as trends in summertime near-surface air temperature over the surrounding land. This was taken as indicating positive feedback mechanisms within the lake, including greater intake of solar radiation due to the reduced duration and extent of ice cover, and the shift in timing of spring overturning of the water column.

Dobiesz and Lester (2009) looked at surface temperatures throughout the Great Lakes, as well as throughout the water

column at one station in western Lake Ontario. They also found a strong trend toward greater water clarity (as measured by Secchi depth) between 1968 and 2002, which is attributable to a combination of abatement of phosphorus loads into the Great Lakes and the invasion of non-native Dreissenid mussels (zebra mussels and quagga mussels). They found positive trends in water temperatures, both at the surface and at depth, and attributed this to a combination of changes in climate and changes in water clarity. Vanderploeg et al. (2012) reinforce this result regarding water clarity and extends this result to Lake Michigan for the difference between the 1994-2003 period (before expansion of quagga mussels to deep water) and 2007-08 (after expansion).

Some of the distinctions between the conclusions of Austin and Colman (2007) and Dobiesz and Lester (2009) illuminate a particular point. It has often been either explicitly or tacitly assumed that changes in temperature occur first in the atmosphere, and then propagate to changes in temperature of the surface (or other effects at the surface). Dobiesz and Lester (2009) hew close to this line of reasoning, implying that surface water temperatures are forced by surface air temperatures, with no notable effect in the opposite direction. Austin and Colman (2007), on the other hand, first present the difference in trends of water surface temperature and air temperature as being counterintuitive, but then offer mechanisms that occur within the water to explain this distinction. This means that the lake water is itself an active player in the climate system; we prefer to view climate and climate change as phenomena of the coupled atmosphere-surface system (including both land and water surfaces).

There was a long-standing gap in measurement of fluxes of water vapor, trace gases, and sensible heat flux from the Great Lakes., for purposes of analysis of moisture and energy budgets of the lakes, and for validation of models. New datastreams (starting in 2008) for in situ measurement of these variables are documented in Blanken et al. (2011) and Spence et al. (2011). These researchers have initiated these measurements at one station each in Lake Superior and Lake Huron.

Paleoclimatic studies

Booth et al. (2006) have characterized persistent anomalies in summer precipitation as being associated with anomalies in zonal surface winds. They show that July precipitation is negatively correlated with zonal wind index (mean sea level pressure gradient between 35° and 55° N across the western hemisphere), with a p<0.05 level of certainty for southern Minnesota, Iowa, and northern Missouri. Note that their zonal wind index quantifies pressure gradients over a range of latitudes farther south than those indicated by the more widely-used North Atlantic Oscillation and Arctic Oscillation (NAO/AO) indices. Their examination of

the possibility of explaining an extended drought in this region between about 1200 and 1400 CE is inconclusive.

Croley and Lewis (2006) examined climatic conditions under which some of the Great Lakes might have been terminal lakes in the past (i.e. lakes with no outflow point because they lose sufficient water to evaporation to offset precipitation and runoff inputs). They arrive at figures of water level as a function of changes in air temperature and precipitation relative to late 20th century climate (their Figures 7 and 8). These figures show a range of climates yielding lake levels above the sill, meaning that there is continuous outflow from the lake. They also show a range with seasonally and interannually intermittent outflow. with the water level always very near to the sill level. Then there is a range with water below the sill level; within this range, the mechanism of balancing the water budget through changes in outflow is removed, and the water level becomes highly sensitive to climate because the water budget must be balanced by changing the evaporation from the lake surface via changing the lake area as a result of changing the lake level until a dynamic equilibrium is reached.

Future projections

Changes in the strength of the global hydrologic cycle provide a backdrop for the regional water budget. As in the historic record, general circulation model (GCM) projections of precipitation rate generally show an increase of about 2% per degree C, while the water vapor content of the atmosphere increases by about 7%, implying longer residence time of water vapor in the atmosphere (Held and Soden 2006, Pan and Pryor 2009). Note also that, in order to maintain an equilibrium value of atmospheric water vapor content, surface ET summed over the globe must equal precipitation summed over the globe, the ET rate also increases by about 2% per degree C.

The magnitude of the most intense precipitation events has been projected to increase throughout the world due to increased greenhouse gases using both theoretical arguments (Trenberth et al. 2003) and analysis of output from global climate models (Sun et al. 2007). It is deemed likely that both floods and droughts will increase in frequency (Wetherald and Manabe 2002, Trenberth et al. 2003, Meehl et al. 2007). However, models remain a problematic tool for evaluating the magnitude and frequency of extremely heavy precipitation events, because in reality the spatial scale of the heaviest precipitation is smaller than the resolved scale of the model. This is true even for regional models with finer resolution than global models.

Trapp et al. (2007) evaluated the number of days that satisfy criteria for severe thunderstorm environmental

conditions under historical greenhouse gas concentrations as compared to late 21st century concentrations. They found that there are more days with severe thunderstorm environment in the future over nearly all of the conterminous United States. Under one of the three GCMs that they showed, this tendency is most concentrated in the Midwest.

Some studies have projected a general increase in runoff for multiple drainage basins throughout the world (Wetherald and Manabe 2002, Manabe et al. 2004, Milly et al. 2005, Kundzewicz et al. 2007). Others have shown increases in the difference between precipitation and ET, which also imply increased outflow, and have extended these results to indicate increased soil moisture (Pan et al. 2004, Liang et al. 2006).

Cherkauer and Sinha (2010) used the Variable Infiltration Capacity (VIC) model to simulate changes in stream flow for six rivers, including four in the Upper Mississippi River basin. They found increased stream flow in these basins associated with warming by anthropogenic greenhouse gases. The anticipated influence of variability, particularly in precipitation, is to both decrease low flows and increase peak flows.

Increased winter precipitation is expected to lead to higher phosphorus loading in streams and draining into lakes (Jeppesen et al. 2009). This can lead to eutrophication, i.e. increased growth of algae and other aquatic plants, without much increase in life at higher levels of the food web. These effects are highly subject to multi-stressor effects, such as interaction with aquatic invasive species (Adrian et al. 2009).

Climate change is expected to warm the near-surface water of lakes more than water at greater depths. This will result in reduced vertical mixing of water, and in turn to reduced dissolved oxygen at depth (Fang et al. 2004). This is a threat to the habitat of fish and other species.

Upper Mississippi/Missouri/Hudson Bay watersheds

Using the Soil and Water Assessment Tool (SWAT), Lu et al. (2010) project that streamflow in the Upper Mississippi River basin will decrease when using climate data derived from GCM simulations in the 2046-65 period as compared to the 1961-2000 period. When averaging over the results using 10 different GCMs, these decreases occur during all seasons except winter. Wu et al. (2011) carried out similar projections for the Upper Mississippi River basin, and found increased water yield during the spring but large decreases in summer. The soil moisture likewise increases in spring and decreases in summer. Accordingly, there is increased risk of both flood and drought, depending on the season.

Ohio River watershed

Mishra et al. (2010b) used VIC driven by general circulation model output to investigate projected trends in drought in parts of Indiana and Illinois within the Ohio River watershed. They found that drought frequency increases during the middle part of the 21st century (2039-2068), while for later in the century, it increased only in the highest emission scenario for greenhouse gases.

Great Lakes watershed

Estimation of the impact of climate change on Great Lakes water budgets and levels began with Croley (1990). The same method has been used multiple times since then, but using results from different GCMs as input (e.g. Lofgren et al. 2002, Angel and Kunkel 2010, Hayhoe et al. 2010). A recent and very comprehensive example of this approach, Angel and Kunkel (2010) assembled results from over 500 GCM simulations from different modeling centers, using various greenhouse gas emission scenarios, and different ensemble members for each model configuration. They found spread among the results of the different model runs, but a general tendency for the lakes' net basin supply and water levels to be reduced, as was generally found in the preceding model studies using the same methods.

Lofgren et al. (2011), however, found fault with this longused methodology, in particular its formulation of ET from land. This formulation relies excessively on using air temperature as a proxy for potential ET, and does not display fidelity to the surface energy budget of the GCMs that are used to drive the offline model of land hydrology. This is also in keeping with the findings of Milly and Dunne (2011). By substituting a simple scheme to drive the hydrologic model using changes in the GCMs' surface energy budget, rather than using the air temperature proxy as previously, Lofgren et al. (2011) projected water levels to drop by a lesser amount, or to actually rise in the future. The differential between water levels projected using the older method and the proposed new method differed by amounts on the order of one meter.

Lorenz et al. (2009) evaluated the water budget for Wisconsin under climate change scenarios based on 15 atmosphere-ocean general circulation models (AOGCMs). They found that there was greater agreement among the various AOGCMs regarding the sensitivity of air temperature to increased greenhouse gases than in the changes in precipitation. They found a negative correlation during July and August between changes in air temperature and ET throughout the central United States, with maximum magnitude over the lower Mississippi River. This was taken to indicate that evaporative cooling was occurring, making both the surface and the lower atmosphere cooler when abundant ET occurred, and cloud formation associated with

higher ET may also enhance this effect. They also found that the amount of precipitation that occurred in the single wettest day of the year increased by an average of 33%, although individual models had increases between 5% and 66%. These results are similar to those of Sun et al. (2007), mentioned above.

Kutzbach et al. (2005) evaluated the Great Lakes basin's future water budget based on the convergence of atmospheric water vapor flux. That is, they inferred how much water is retained at the surface and becomes outflow based on how water was being transported in the atmosphere. Their analysis of AOGCM data indicated that enhanced greenhouse gas concentration will bring greater atmospheric moisture convergence to the Great Lakes basin, i.e. increased outflow, which also directly implies higher levels of the Great Lakes. This is in contrast to the results of Angel and Kunkel (2010) and its predecessor papers.

A newer wave of models will take a more direct approach at estimating hydrologic impacts of climate change in the Great Lakes basin. These involve development of regional climate models that are fully coupled to both the land surface and simplified formulations of the Great Lakes (Lofgren 2004, MacKay et al. 2009, Zhong et al. 2012, IUGLS 2012, M. Notaro and V. Bennington, personal communication). These Great Lakes-specific modeling efforts are complemented by downscaled climate models with a domain covering all of North America, created through the North American Regional Climate Change Assessment Program (NARCCAP, Mearns et al. 2009). Initial findings from these efforts (see, for example, Holman, et al. 2012) suggest that tools such as regional climate models can be used as an aid in estimating the spatial distribution of precipitation and other fields. In this light, there appears to be a need to revisit historical climate and hydrological data sets for the Great Lakes region which, to date, have served as a basis for water budget and water level planning decisions including those impacting hydropower, navigation, and shoreline recreation and infrastructure.

Commonality among many studies

Throughout most of the projections based on general circulation models of future climate noted above, for the Midwest, there is an increase in the annual mean precipitation. And in most of them, increased precipitation happens primarily during the cold season. On the other hand, summer has little projected change or a decrease in precipitation in most models.

Coupled atmospheric-hydrologic phenomenon--Warming hole

Pan et al. (2009) show observational evidence of a summer "warming hole," a region in the contiguous United States in which warming trends are reduced or even reversed for the summer season. Depending on which period is used for calculation of trends, the warming hole is located over the western portion of the Midwestern region and extending further west and south (1976-2000), or primarily to the south of the Midwestern region (1951-75). The proposed mechanism is increased influx of moist air due to the low level jet (LLJ), originating from the Gulf of Mexico. The increased moisture content of the LLJ is a straightforward result of warming of both the atmosphere and the surface, particularly the water surface of the Gulf of Mexico. The resultant increase in rainfall leads to increased evaporative cooling of the surface (the cooling effect is most pronounced for daily maximum temperatures during the summer). As noted, the location of the warming hole has shifted with time, and the mechanisms behind this shift are unclear.

Uncertainty and Probability

Acknowledging and quantifying uncertainty in historical climate data and climate projections, and clearly propagating that uncertainty into policy and management decisions, represent an ongoing challenge to the water resource and climate science community and the general public. Misconceptions about uncertainty, and the confusion associated with knowledge versus ignorance (Curry and Webster, 2011), have important implications for the water resource-climate science nexus, and (following Van de Sluijs, 2005) have led to the term "climate monster", a term intended to reflect that confusion, and represent a source of fear that drives reactions to a future we do not understand and cannot control (Curry and Webster, 2011). Confirming and validating models is, of course, one approach to building confidence in projections about future climate conditions, however there is no clear consensus within the water resources or the climate science community about a metric, or set of metrics, for which the skill of complex (and in some cases, probabilistic) models can be assessed (Guillemot, 2010).

Furthermore, agreement between a model and historical climatic data does not necessarily imply that projections of future climate states will be correct, or even physically reasonable, especially if the model is based more on empirical fitting rather than processes known from first principles. Curry and Webster (2011) say, "Continual ad hoc adjustment of the model (calibration) provides a means for the model to avoid being falsified." A particular example of the problem with empirically-based models being

applied to unprecedented climate regimes is illuminated in Lofgren et al. (2011), in this case leading to demonstrably excessive sensitivity of ET to climate.

The uncertainty in the response of precipitation and ET to enhanced greenhouse gases is greater than the corresponding uncertainty of air temperature, as emphasized by Pan and Pryor (2009) and Lorenz et al. (2009). To compound this issue, the most important quantity in determining streamflow and lake levels is the difference between precipitation and ET. Thus it is the difference between two larger quantities, each having sizable uncertainty, and therefore the uncertainty proportional to this difference is even larger.

Additional insights into management of water resources in the face of uncertainty, as well as reviews of many of the findings mentioned in the current paper, can be found in Brekke et al. (2009).

Conclusions

In general, precipitation has been increasing and this trend is projected to continue. Precipitation increases are particularly pronounced when looking at the winter season and when looking at the few largest rain events of the year, and this is expected to continue. Methods of calculating evapotranspiration (ET) under changed climate are the subject of emerging research, showing that widely-used methods based on temperature as a proxy for potential ET exaggerate projected increases in ET, as demonstrated by severe imbalances in the surface energy budget. When incorporated into further simulations, this leads to excessive reductions in streamflow and lake levels. Simulations using a more energy-based approach to ET give more mixed results in terms of changes in streamflow and lake levels, and often show increases

Impacts on water resources at local to regional scales remain subject to greater uncertainty than projections of basic climate variables such as air temperature and precipitation, especially when these climatic variables are aggregated to the global scale. Relevant policy responses may be to enhance resiliency in the case of occasional low levels on lakes and streams, as well as potentially larger flooding events.

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United States Environmental Protection Agency

Summary of Key Points from Climate Change Indicators in the United States, 2014

EPA's Climate Change Indicators in the United States, 2014, presents compelling evidence that the impacts of climate change are already occurring across the United States. Following is a summary of key points for 30 indicators that track signs of climate change.

U.S. Greenhouse Gas Emissions. In the United States, greenhouse gas emissions caused by human activities increased by 5 percent from 1990 to 2012. However, since 2005, total U.S. greenhouse gas emissions have decreased by 10 percent. Carbon dioxide accounts for most of the nation's emissions and most of the increase since 1990. Electricity generation is the largest source of greenhouse gas emissions in the United States, followed by transportation. Emissions per person have decreased slightly in the last few years.

Global Greenhouse Gas Emissions. Worldwide, net emissions of greenhouse gases from human activities increased by 35 percent from 1990 to 2010. Emissions of carbon dioxide, which account for about three-fourths of total emissions, increased by 42 percent over this period. As with the United States, the majority of the world's emissions result from electricity generation, transportation, and other forms of energy production and use.

U.S. and Global Temperature. Average temperatures have risen across the contiguous 48 states since 1901, with an increased rate of warming over the past 30 years. Seven of the top 10 warmest years on record have occurred since 1998. Average global temperatures show a similar trend, and the top 10 warmest years on record worldwide have all occurred since 1998. Within the United States, temperatures in parts of the North, the West, and Alaska have increased the most.

High and Low Temperatures. Many extreme temperature conditions are becoming more common. Since the 1970s, unusually hot summer temperatures have become more common in the United States, and heat waves have become more frequent—although the most severe heat waves in U.S. history remain those that occurred during the "Dust Bowl" in the 1930s. Record-setting daily high temperatures have become more common than record lows. The decade from 2000 to 2009 had twice as many record highs as record lows.

U.S. and Global Precipitation. Total annual precipitation has increased in the United States and over land areas worldwide. Since 1901, precipitation has increased at an average rate of 0.5 percent per decade in the contiguous 48 states and 0.2 percent per decade over land areas worldwide. However, shifting weather patterns have caused certain areas, such as Hawaii and parts of the Southwest, to experience less precipitation than usual.

Ocean Heat. Three separate analyses show that the amount of heat stored in the ocean has increased substantially since the 1950s. Ocean heat content not only determines sea surface temperature, but also affects sea level and currents.

Sea Surface Temperature. Ocean surface temperatures increased around the world over the 20th century. Even with some year-to-year variation, the overall increase is clear, and sea surface temperatures have been higher during the past three decades than at any other time since reliable observations began in the late 1800s.

Sea Level. When averaged over all the world's oceans, sea level has increased at a rate of roughly six-tenths of an inch per decade since

Atmospheric Concentrations of Greenhouse Gases.

Concentrations of carbon dioxide and other greenhouse gases in the atmosphere have increased since the beginning of the industrial era. Almost all of this increase is attributable to human activities. Historical measurements show that current levels of many greenhouse gases are higher than any levels recorded for hundreds of thousands of years, even after accounting for natural fluctuations.

Climate Forcing. Climate forcing refers to a change in the Earth's energy balance, leading to either a warming or cooling effect. An increase in the atmospheric concentrations of greenhouse gases produces a positive climate forcing, or warming effect. From 1990 to 2013, the total warming effect from greenhouse gases added by humans to the Earth's atmosphere increased by 34 percent. The warming effect associated with carbon dioxide alone increased by 27 percent.

Heavy Precipitation. In recent years, a higher percentage of precipitation in the United States has come in the form of intense singleday events. Nationwide, nine of the top 10 years for extreme one-day precipitation events have occurred since 1990. The occurrence of abnormally high annual precipitation totals (as defined by the National Oceanic and Atmospheric Administration) has also increased.

Drought. Average drought conditions across the nation have varied since records began in 1895. The 1930s and 1950s saw the most widespread droughts, while the last 50 years have generally been wetter than average. However, specific trends vary by region. A more detailed index developed recently shows that between 2000 and 2013, roughly 20 to 70 percent of the United States experienced drought at any given time, but this index has not been in use for long enough to compare with historical drought patterns.

Tropical Cyclone Activity. Tropical storm activity in the Atlantic Ocean, the Caribbean, and the Gulf of Mexico has increased during the past 20 years. Increased storm intensity is closely related to variations in sea surface temperature in the tropical Atlantic. However, changes in observation methods over time make it difficult to know for sure whether a long-term increase in storm activity has occurred. Records collected since the late 1800s suggest that the actual number of hurricanes per year has not increased.

1880. The rate of increase has accelerated in recent years to more than an inch per decade. Changes in sea level relative to the land vary by region. Along the U.S. coastline, sea level has risen the most along the Mid-Atlantic coast and parts of the Gulf coast, where some stations registered increases of more than 8 inches between 1960 and 2013. Sea level has decreased relative to the land in parts of Alaska and the Northwest.

Ocean Acidity. The ocean has become more acidic over the past few centuries because of increased levels of atmospheric carbon dioxide, which dissolves in the water. Higher acidity affects the balance of minerals in the water, which can make it more difficult for certain marine animals to build their skeletons and shells.





Arctic Sea Ice. Part of the Arctic Ocean is covered by ice year-round. The area covered by ice is typically smallest in September, after the summer melting season. The minimum extent of Arctic sea ice has decreased over time, and in September 2012 it was the smallest on record. Arctic ice has also become thinner, which makes it more vulnerable to additional melting.

Glaciers. Glaciers in the United States and around the world have generally shrunk since the 1960s, and the rate at which glaciers are melting has accelerated over the last decade. The loss of ice from glaciers has contributed to the observed rise in sea level.

Lake Ice. Most lakes in the northern United States are freezing later and thawing earlier compared with the 1800s and early 1900s. Freeze dates have shifted later at a rate of roughly half a day to one day per decade, while thaw dates for most of the lakes studied have shifted earlier at a rate of half a day to two days per decade.

Heating and Cooling Degree Days. Heating and cooling degree days measure the difference between outdoor temperatures and the temperatures that people find comfortable indoors. As the U.S. climate has warmed in recent years, heating degree days have decreased and cooling degree days have increased overall, suggesting that Americans need to use less energy for heating and more energy for air conditioning. This pattern stands out the most in the North and West, while much of the Southeast has experienced the opposite results.

Heat-Related Deaths. Over the past three decades, nearly 8,000 Americans were reported to have died as a direct result of heat-related illnesses such as heat stroke. The annual death rate is higher when accounting for other deaths in which heat was reported as a contributing factor. Considerable year-to-year variability in the data and certain limitations of this indicator make it difficult to determine whether the United States has experienced long-term trends in the number of deaths classified as "heat-related."

Lyme Disease. Lyme disease is a bacterial illness spread by ticks that bite humans. Tick habitat and populations are influenced by

Wildfires. Since 1983, the United States has had an average of 72,000 recorded wildfires per year. Of the 10 years with the largest acreage burned, nine have occurred since 2000, with many of the largest increases occurring in western states. The proportion of burned land suffering severe damage each year has ranged from 5 to 22 percent.

Streamflow. Changes in temperature, precipitation, snowpack, and glaciers can affect the rate of streamflow and the timing of peak flow. Over the last 73 years, minimum, maximum, and average flows have changed in many parts of the country—some higher, some lower. Nearly half of the rivers and streams measured show peak winterspring runoff happening at least five days earlier than it did in the mid-20th century.

Great Lakes Water Levels and Temperatures. Water levels in most of the Great Lakes have declined in the last few decades. Water levels in lakes are influenced by water temperature, which affects evaporation rates and ice formation. Since 1995, average surface water temperatures have increased by a few degrees for Lakes Superior, Michigan, Huron, and Ontario. Less of a temperature change has been observed in Lake Erie.

Snowfall. Total snowfall—the amount of snow that falls in a particular location—has decreased in most parts of the country since widespread records began in 1930. One reason for this decline is that more than three-fourths of the locations studied have seen more winter precipitation fall in the form of rain instead of snow.

Snow Cover. Snow cover refers to the area of land that is covered by snow at any given time. Between 1972 and 2013, the average portion of North America covered by snow decreased at a rate of about 3,500 square miles per year, based on weekly measurements taken throughout the year. However, there has been much year-to-year variability.

Snowpack. The depth or thickness of snow on the ground (snowpack) in early spring decreased at about three-fourths of measurement sites in the western United States between 1955 and 2013. However, other locations saw an increase in spring snowpack. The average change across all sites for this time period amounts to about a 14 percent decline.

many factors, including climate. Nationwide, the rate of reported cases of Lyme disease has approximately doubled since 1991. Lyme disease is most common in the Northeast and the upper Midwest, where some states now report 50 to 90 more cases of Lyme disease per 100,000 people than they did in 1991.

Length of Growing Season. The average length of the growing season in the contiguous 48 states has increased by nearly two weeks since the beginning of the 20th century. A particularly large and steady increase has occurred over the last 30 years. The observed changes reflect earlier spring warming as well as later arrival of fall frosts. The length of the growing season has increased more rapidly in the West than in the East.

Ragweed Pollen Season. Warmer temperatures and later fall frosts allow ragweed plants to produce pollen later into the year, potentially prolonging the allergy season for millions of people. The length of ragweed pollen season has increased at 10 out of 11 locations studied in the central United States and Canada since 1995. The change becomes more pronounced from south to north.

Bird Wintering Ranges. Some birds shift their range or alter their migration habits to adapt to changes in temperature or other environmental conditions. Long-term studies have found that bird species in North America have shifted their wintering grounds northward by an average of more than 40 miles since 1966, with several species shifting by hundreds of miles. On average, bird species have also moved their wintering grounds farther from the coast, consistent with inland winter temperatures becoming less severe.

Leaf and Bloom Dates. Leaf growth and flower blooms are examples of natural events whose timing can be influenced by climate change. Observations of lilacs and honeysuckles in the contiguous 48 states suggest that first leaf dates and bloom dates show a great deal of year-to-year variability. Leaf and bloom events are generally happening earlier throughout the North and West but later in much of the South.

For more information, see: www.epa.gov/climatechange/indicators

Climate Change on the Prairie: A Basic Guide to Climate Change in the High Plains Region - UPDATE

Global Climate Change

Why does the climate change?

The Earth's climate has changed throughout history and will continue to change in the future. Global climate change can be attributed to one of two causes, natural or anthropogenic (human-induced), and can occur on different time scales, both short-term and long-term.

A volcanic eruption is an example of natural short-term climate change. When ash is ejected high into the atmosphere, it temporarily blocks the sunlight and subsequently cools the Earth. El Niño is another example of natural short-term change. When the sea surface temperatures in the equatorial Pacific are warmer than normal, global wind patterns can change which affects temperature and precipitation patterns. Long-term climate change, on the order of thousands of years, is due to changes in solar radiation receipt, slight changes in the Earth's orbit, continental drift, formation or loss of ice sheets, and changing ocean currents.

Human activities can also influence climate. The human influence that is most responsible for recent changes in global temperature is the burning of fossil fuels which increases the levels of greenhouse gases in the atmosphere, such as carbon dioxide and methane. Increases in greenhouse gases contribute to a general warming of the Earth because as their concentrations increase so does the temperature.

As the Earth's climate changes, many different sectors will be impacted. The impacts on Earth's ecosystems are already apparent from the tundra to the tropical waters. For example, in the high northern latitudes, permafrost

is thawing which is increasing coastal erosion and damaging infrastructure of the towns which are built upon the permafrost. Rising sea temperatures already threaten the coral reefs of the world which is having an impact on tourism and fisheries.

What are the current trends and projections?

Surface temperature measurements of both the land and the ocean indicate a warming trend since the early 20th century and especially in the last 50 years (Figure 1).

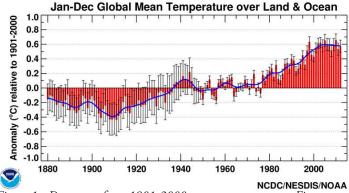


Figure 1: Departure from 1901-2000 average temperature. Figure courtesy National Climatic Data Center.

According to the U.S. Global Change Research Program (USGCRP), models which incorporate different greenhouse gas emission scenarios project global temperatures to increase by 2°F-11.5°F by 2100. If the rate of greenhouse gas emissions is reduced, the temperature increase is projected to be on the lower end of the range and if emission rates continue at or near current rates the temperature increase is projected to be at the higher end of the range.



Climate Change in the United States

Historical trends and projections - temperature

Overall, temperatures across the United States have been warming over the past 100 years and the average temperature has increased by 2°F in the past 50 years (USGCRP). The warming trend is occurring in both the daily maximum and minimum temperatures; however the minimum temperatures are increasing at a faster rate than maximum temperatures. Generally, Alaska, along with western and northern portions of the contiguous 48 states show the greatest warming. Areas of the southeast show a slight cooling over the past century, however, these areas have begun to show a warming trend over the past 30 years.

Climate models are projecting that temperatures will continue to increase now through 2100. Because of the residence time of greenhouse gases in the atmosphere, model projections of near future temperature changes do not vary much. However, by 2100, in the lower emissions scenarios, the increase could range from 4°F-6.5°F and in the higher emissions scenarios the increase could range from 7°F-11°F (USGCRP).

Rate of Temperature Change in the United States, 1901–2011

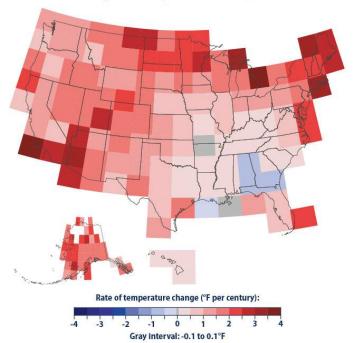


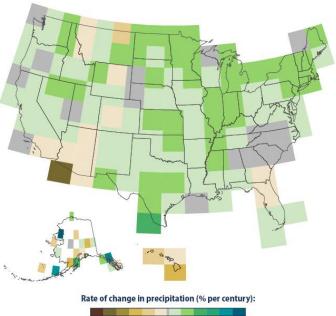
Figure 2: Annual Temperature Trends 1901-2011. Figure courtesy United States Environmental Protection Agency.

Historical trends and projections - precipitation

According to the USGCRP, shifts in global precipitation patterns are already occurring and have resulted in increases in precipitation in some areas and decreases in others. Here in the United States, the total annual precipitation has increased by 5% over the past 50 years (USGCRP). This increase has occurred for the most part due to an increase in the frequency and intensity of heavy downpours. All areas of the United States have shown to have an increase in heavy downpours over the last 50 years, but the areas with the highest increases are the Northeast and the Midwest.

While precipitation changes are much more difficult to predict than temperature changes in the long term, climate models do show indications that northern areas of the United States will become wetter, particularly in the winter and spring, and areas of the south and west will become drier. Models are also projecting an increase in heavy downpours and a decrease in light precipitation over the next 100 years (USGCRP).

Rate of Precipitation Change in the United States, 1901–2011



-60-50-40-30-20-10 0 10 20 30 40 50 60 Gray interval: -2 to 2%

Figure 3: Annual Precipitation Trends 1901-2011. Figure courtesy United States Environmental Protection Agency.



Historical Climate Trends in the High Plains Region

Temperature

Climate records in the High Plains date back well over 100 years, into the 19th century. A look into these historical datasets reveals the variability and trends in climate over time.

The trend in average annual temperature for the six-state region shows a warming trend of 1.9°F over the 118-year period analyzed. Temperatures show cooler than average conditions early in the record, followed by significant warmth during the 1930's dustbowl era, and generally warmer than average conditions since the 1970's, especially since the year 2000. The greatest amount of warming on an annual basis is found in North Dakota (2.9°F), while the least amount of warming is in Kansas and Nebraska (1.3°F). 2012 was the warmest year on record for the Region since records began, with an average temperature of 50.9°F for the High Plains Region.

Regionally, the annual warming trend is greater for nighttime low temperatures than for the daytime high temperatures (2.2°F vs. 1.6°F). This is the case for much of the globe with lows warming more than highs. One reason for this difference is thought to be an increase in the amount of moisture in the air, which affect minimum temperatures much more than maximum temperatures. If average temperature trends

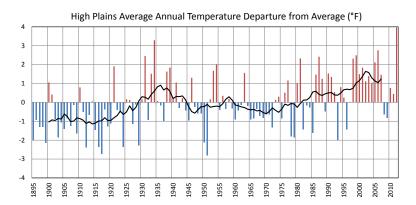


Figure 4: Average Annual Temperature Departure from the 118-Year Long-term Average (°F) in the High Plains Region. Data courtesy National Climatic Data Center.

Climate Change Quick Facts:

According to the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center's 2012 State of the Climate Report:

- Globally, each year since 1976 has been warmer than the long-term average temperature.
- 2012 ranked in the top 10 warmest globally, but was the warmest year on record in the U.S.
- Arctic temperatures are warming about two times faster than the rest of the world.
- CO₂ concentrations topped 400 ppm for the first time in the spring of 2012.

are broken down by season, the warming is strongest in winter (2.9°F) and weakest in autumn (0.7°F) for the Region. This seasonal variability is similar to observed global trends, particularly for land masses in the Northern Hemisphere.

Statewide Average Temperature Change by Season (1895-2012) Temperature in degrees F						
State	Spring	Summer	Autumn	Winter		
North Dakota	2.6	2.0	1.5	5.5		
South Dakota	2.2	1.8	1.1	4.2		
Nebraska	1.8	1.0	0.0	2.0		
Kansas	1.7	1.0	-0.1	2.2		
Wyoming	3.0	2.5	1.0	1.3		
Colorado	2.0	1.1	0.4	1.9		
Average	2.2	1.6	0.7	2.9		

Historical Climate Trends in the High Plains Region

Precipitation

Overall, precipitation trends are weaker than temperature, with only a 1.3% increase in precipitation over the High Plains Region. There is high year-to-year variability throughout the period of record, which is typical for the continental type climate of the Region.

The dry years of the 1930's and 1950's stand out in the record with periods of below average rainfall. The past several decades have been part of a wet period for the Region, though 2012 stands out as one of the driest on record. Wyoming is typically the driest state, while Kansas is the wettest on an annual basis. Aside from Wyoming (with a 13% decrease), annual

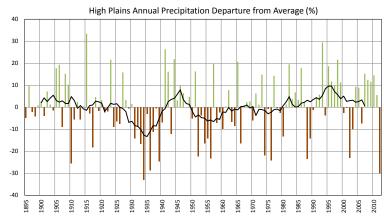


Figure 5: Average Annual Precipitation Departure from the 118-Year Long-term Average (%) in the High Plains Region. Data courtesy National Climatic Data Center.

trends are fairly weak on a state by state basis. There are however, seasonal differences in the precipitation pattern with most states experiencing drier conditions during winter (8% decrease on average) and wetter conditions during autumn (12% increase). The overall trends for spring and summer are on average small.

	nnual Climate Trends (18	895-2012)		
State	grees F, Precipitation in percent	Marrian Town over true	Minimum Tanan anatum	Dunainitation
	Average Temperature	Maximum Temperature	Minimum Temperature	Precipitation
North Dakota	2.9	2.5	3.4	6%
South Dakota	2.4	1.6	3.2	3%
Nebraska	1.3	0.6	1.9	2%
Kansas	1.3	0.9	1.7	5%
Wyoming	2.0	2.7	1.3	-13%
Colorado	1.5	1.5	1.4	-1%
Average	1.9	1.6	2.2	1%

High Plains Region Update: 2010-2012

Three years of extremes

In the three years since the original release of this climate change guide, the High Plains Region has experienced a wide range of extreme conditions. Many of the statistics included in this document have changed quite a bit since the original release simply because the last three years have been so extreme. One of the most interesting examples of the extremes is the major flooding in 2011 followed by drought in 2012.

The winter of 2010-2011 brought record breaking snowfall to areas of Wyoming and Montana. This, coupled with a warm spring and additional heavy precipitation, spurred major flooding on the Missouri River and its tributaries which lasted much of the summer of 2011. Just the following year, the Region experienced its warmest spring on record followed by one of the warmest and driest summers on record. This set the stage for a widespread expansion of drought which caused impacts to many sectors including agriculture (both crops and livestock), water resources, and wildlife.



Notable Events:

- North Dakota had its wettest year on record in 2010.
- A new national hail record for diameter and weight was set on July 23, 2010 in Vivian, South Dakota.
- 2011 was a year of flooding for many of the major rivers including the Missouri, Souris, and Red.
- In 2012, Nebraska and Wyoming had both their warmest and driest year on record.
- Although drought conditions peaked in the summer of 2012, areas near the Colorado/Kansas border have been impacted by drought since 2010.
- The two most destructive fires in Colorado history occurred in 2012 and 2013 (in terms of structures burned: the Waldo Canyon Fire and the Black Forest Fire, respectively).

New Tool: Climate Impact Reporter



http://cir.unl.edu

Interested in looking at climate-related impacts in your local area? Need a place to archive impacts you know about? If so, you should check out HPRCC's new tool: the Climate Impact Reporter.

The Climate Impact Reporter was developed to document climate impacts over a variety of sectors in the High Plains Region. Users can browse for impacts within a specific area (i.e. river basin, state, county) or sector (agriculture, ecosystems, energy, human health, society, transportation, and water resources) using a simple mapping interface. Or, users can log their own impacts. Tutorials for using the Climate Impact Reporter and for logging reports are available on the website.

This tool will hopefully increase the understanding of impacts to extreme events by sector and as a result, will provide critical information for improved decision-making and adaption strategies.

Climate Change Projections and Possible Impacts

Through the use of climate models, scientists have the ability to project future climate based on scenarios of anthropogenic and natural forcings. One of the primary forcings is enhanced greenhouse gas emissions, which alters the amount of radiation we receive and influences temperature. Several research groups across the globe run models using scenarios to simulate future climate, both at the global and regional scale. A composite of the various climate models projects a warming in the High Plains Region of about 4°F by 2050 and 8°F or higher by 2090. The individual models show a range of temperature increases, although they all point to a warming. Model projections of changes in precipitation vary by season, showing a general drying in summer and autumn with wetter conditions in winter. Spring is projected to be wetter in the northern part of the Region and drier in the south. The summer drying trend is compounded by increased evaporation rates due to the projected warming. With approximately 70% of the land in the High Plains Region being used for agricultural or rangeland purposes, this Region is acutely sensitive to these types of changes.



Climate Change Projections and Possible Impacts

Key climate change impacts in this Region include the following:

• Water Resources: An increase in temperature, especially in the summer months, can lead to an increase in evapotranspiration and decrease in soil moisture. This can lead to an increase in irrigation demands, which is heavily relied upon to avoid plant water stress. Increased water use is already putting a strain on water resources in the Region, such as the Ogallala Aquifer.



Fourth Assessment of the Intergovernmental Panel on Climate Change

- Extreme Events: There are expected to be changes in the frequency and severity of extreme events in a warmer climate. This includes more days with heavy precipitation, extreme cold, and growing season frosts. These can affect urban and rural landscapes alike, and often the extreme events have a significant and immediate economic and social impact.
- **Ecosystems:** The likelihood of invasive species and pests is expected to increase in a warmer climate with associated shifts in temperature and precipitation patterns. Productivity and yields of agricultural land will be impacted by such a change. Adding in human-caused stress factors, such as fragmentation of habitat, native species will also become more vulnerable to climate change.



Custer State Park, South Dakota

- **Demographics:** Current population trends in the Region are toward the growth of urban areas and a depopulation of the rural areas. This demographic trend brings a corresponding shift in the needed services and economic base. As such, rural areas are expected to have an increase in vulnerability to climate change. In addition, those living on or near tribal lands are particularly vulnerable to climate change stresses, such as those on water resources, which are expected to increase further in a changing climate.
- * Projections and impacts information courtesy of the U.S. Global Change Research Program

For more information, please contact the High Plains Regional Climate Center:



High Plains Regional Climate Center



Providing Timely Climate Data and Information to the Public for Cost Effective Decision Making

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Climate Change in the **Great Lakes Region**



Average Temperature	Total Precipitation	Heavy Storm Precipitation	Great Lakes Ice Coverage	Frost-free Season
	1	1	1	
2.0°F	11% 1900-2012	37% 1958-2012	71% 1973-2010	9 Days

Temperature

- Since 1900, annual average temperatures have increased by 2.0°F (1.1°C) in the U.S. Great Lakes region.
- By 2050, average air temperatures are projected to increase by 1.8 to 5.4°F (1 to 3°C).
- By 2100, average air temperatures are projected to increase by 3.6 to 11.2°F (2 to 6.2°C).

Precipitation

- Since 1900, total annual precipitation has increased by 10.8% in the U.S. Great Lakes Region, and is expected to continue to increase, though projections of future precipitation vary.
- Precipitation will increase during wet seasons but may remain nearly stable or decrease during the summer.
- Reduced lake ice coverage will result in more exposed water and more opportunity for lake-effect precipitation.

Snow, Ice Cover and Lake Temperature

- Lake temperatures have been increasing faster than surrounding air temperatures.
- From 1973 to 2010, annual average ice coverage on the Great Lakes declined by 71%.
- From 1975 to 2004, the annual number of days with land snow cover decreased by 15 and the average snow depth decreased by 2 inches (5.1 cm).
- Snow and ice levels on the Great Lakes and on land will likely continue to decrease, with little significant ice cover on Lake Superior by mid-century in a typical year.

Extreme Weather

- The frequency and intensity of severe storms has increased. This trend will likely continue as the effects of climate change become more pronounced.
- The amount of precipitation falling in the heaviest 1% of storms increased by 37% in the Midwest and 71% in the Northeast from 1958 through 2012.
- More severe storms may have a negative economic impact due to resulting damages and increased costs of preparation, clean up, and business disruption.

Water Quality and Stormwater Management

- Increased risk of droughts, severe storms, and flooding events may increase the risk of erosion, sewage overflow, lead to more interference with transportation, and more flood damage.
- Future changes in land use could have a far greater impact on water quality than climate change. The coupling of climate change and land use change could therefore result in even stronger effects in some areas.

Lake Levels

- Long-term water levels in the Great Lakes have fallen since reaching record highs in the 1980s.
- While most models project continued, long-term declines in lake levels, shorter-term variations will remain large, and periods of high lake levels are probable.
- Other factors, such as lake regulations, also affect lake levels, though no major management changes have occurred since 2000.





Algal Blooms

- Warmer water surface temperatures increase stratification of the lakes and decrease vertical mixing.
- Stronger storms and the use of impervious surfaces increase runoff and nutrient loading to the Great Lakes.
- Combined sewer overflows and agricultural fertilizers are major contributors to high nutrient loads.
- Stronger storms, warmer temperatures, and nutrient loading are conspiring to produce more hypoxic dead zones and toxic algal blooms.

Fish and Wildlife

- The rate of warming may outpace the rate at which ecosystems are able to migrate and adapt.
- Wildlife populations better adapted to cold temperatures will continue to decline as competing species migrate into the region from the south with rising temperatures.
- Lake stratification and more hypoxic conditions will further stress biomass productivity in lakes and wetlands.
- Increased evaporation rates may decrease wetland area in the region.

Energy and Industry

- Reduced summer water availability may interfere with some industrial operations.
- Warmer temperatures and more frequent heat waves will likely increase electricity demands, particularly in urban areas and during the summer months.

Forests

- As temperatures rise, the distribution and composition of tree species will change and shift northward.
- With warmer temperatures and increasing CO₂, forest productivity will likely increase until other impacts of climate change, such as increased drought, fire, and invasive species present additional stressors to forests.

Water Availability

- Despite increasing precipitation, land surfaces in the Great Lakes region are expected to become drier overall due to increasing temperatures and evaporation rates.
- More frequent summer droughts could affect soil moisture, surface waters, and groundwater supply.
- The seasonal distribution of water availability will likely change. Warmer temperatures may lead to more winter rain and earlier peak streamflows.

Agriculture

- The frost-free season lengthened by 9 days in the
 Midwestern U.S. and 10 days in the Northeast from 1958-2012, and may be up to 1-2 months longer by 2100.
- Through mid-century, a longer growing season and higher CO₂ concentrations will likely have a positive effect on many crop yields.
- By 2100, the negative effects of increasing storm activity, flooding, extreme heat, summer drought risk, and pests may outweigh the benefits of other climate changes.

Transportation

- More extreme heat may increase the risk of heat damage to pavement and rails.
- More extreme precipitation may compromise transportation routes and damage infrastructure.
- Shipping lanes will likely be open earlier and longer due to reduced ice cover on the Great Lakes.
- Lower lake levels lead to decreased depth of navigation channels and a reduction in the maximum loads carried by vessels. For each inch of lost draft, the average 1,000-foot freighter loses \$30,000 per transit.

Public Health

- Increased risk of heat waves and increased humidity may increase the number of heat-related deaths and illnesses.
- More storm activity and flooding will increase the risk of watershed contamination while warmer surface waters amplify the risk of toxic algal blooms and fish contamination.
- Diseases such as West Nile virus and Lyme disease may become more widespread since carrier insects will be more likely to survive milder winters.

Tourism and Recreation

- Winter recreation and tourism are likely to suffer due to reduced snow cover and shorter winters.
- Increased lake contamination and decreasing lake levels may lead to less desirable shorelines, but increasing summer temperatures and a longer summer season, may increase demand for beaches.
- Overall, summer tourism may grow before temperatures rise become unfavorable for many recreational activities.
- Many coldwater species of fish important to recreation are likely to decline while populations of warmwater species grow.





Climate Change Impacts in the United States

CHAPTER 18 MIDWEST

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18 MIDWEST

KEY MESSAGES

- In the next few decades, longer growing seasons and rising carbon dioxide levels will
 increase yields of some crops, though those benefits will be progressively offset by extreme
 weather events. Though adaptation options can reduce some of the detrimental effects, in the
 long term, the combined stresses associated with climate change are expected to decrease
 agricultural productivity.
- 2. The composition of the region's forests is expected to change as rising temperatures drive habitats for many tree species northward. The role of the region's forests as a net absorber of carbon is at risk from disruptions to forest ecosystems, in part due to climate change.
- 3. Increased heat wave intensity and frequency, increased humidity, degraded air quality, and reduced water quality will increase public health risks.
- 4. The Midwest has a highly energy-intensive economy with per capita emissions of greenhouse gases more than 20% higher than the national average. The region also has a large and increasingly utilized potential to reduce emissions that cause climate change.
- 5. Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue, causing erosion, declining water quality, and negative impacts on transportation, agriculture, human health, and infrastructure.
- 6. Climate change will exacerbate a range of risks to the Great Lakes, including changes in the range and distribution of certain fish species, increased invasive species and harmful blooms of algae, and declining beach health. Ice cover declines will lengthen the commercial navigation season.

The Midwest has a population of more than 61 million people (about 20% of the national total) and generates a regional gross domestic product of more than \$2.6 trillion (about 19% of the national total). The Midwest is home to expansive agricultural lands, forests in the north, the Great Lakes, substantial industrial activity, and major urban areas, including eight of the nation's 50 most populous cities. The region has experienced shifts in population, socioeconomic changes, air and water pollution, and landscape changes, and exhibits multiple vulnerabilities to both climate variability and climate change.

In general, climate change will tend to amplify existing climate-related risks from climate to people, ecosystems, and infrastructure in the Midwest (Ch. 10: Energy, Water, and Land). Direct effects of increased heat stress, flooding, drought, and late spring freezes on natural and managed ecosystems may be multiplied by changes in pests and disease prevalence, increased competition from non-native or opportunistic native species, ecosystem disturbances, land-use change, landscape fragmentation, atmospheric pollutants, and economic shocks such as crop failures or reduced yields due to extreme weather

events. These added stresses, when taken collectively, are projected to alter the ecosystem and socioeconomic patterns and processes in ways that most people in the region would consider detrimental. Much of the region's fisheries, recreation, tourism, and commerce depend on the Great Lakes and expansive northern forests, which already face pollution and invasive species pressure that will be exacerbated by climate change.

Most of the region's population lives in cities, which are particularly vulnerable to climate change related flooding and life-threatening heat waves because of aging infrastructure and other factors. Climate change may also augment or intensify other stresses on vegetation encountered in urban environments, including increased atmospheric pollution, heat island effects, a highly variable water cycle, and frequent exposure to new pests and diseases. Some cities in the region are already engaged in the process of capacity building or are actively building resilience to the threats posed by climate change. The region's highly energy-intensive economy emits a disproportionately large amount of the gases responsible for warming

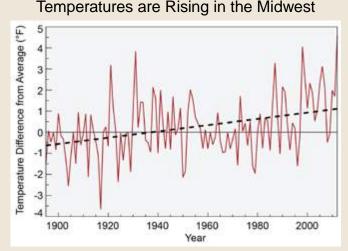


Figure 18.1. Annual average temperatures (red line) across the Midwest show a trend towards increasing temperature. The trend (dashed line) calculated over the period 1895-2012 is equal to an increase of 1.5°F. (Figure source: updated from Kunkel et al. 2013⁴).

the climate (called greenhouse gases or heat-trapping gases). But as discussed below, it also has a large and increasingly realized potential to reduce these emissions.

The rate of warming in the Midwest has markedly accelerated over the past few decades. Between 1900 and 2010, the av-

erage Midwest air temperature increased by more than 1.5°F (Figure 18.1). However, between 1950 and 2010, the average temperature increased twice as quickly, and between 1980 and 2010, it increased three times as quickly as it did from 1900 to 2010. Warming has been more rapid at night and during winter. These trends are consistent with expectations of increased concentrations of heat-trapping gases and observed changes in concentrations of certain particles in the atmosphere. 1,2°

The amount of future warming will depend on changes in the atmospheric concentration of heat-trapping gases. Projections for regionally averaged temperature increases by the middle of the century (2046-2065) relative to 1979-2000 are approximately 3.8°F for a scenario with substantial emissions reductions (B1) and 4.9°F with continued growth in global emissions (A2). The projections for the end of the century (2081-2100) are approximately 5.6°F for the lower emissions scenario and 8.5°F for the higher emissions scenario (see Ch. 2: Our Changing Climate, Key Message 3).³

In 2011, 11 of the 14 U.S. weather-related disasters with damages of more than \$1 billion affected the Midwest. Several types of extreme weather events have already increased in frequency and/or intensity due to climate change, and further increases are projected (Ch. 2: Our Changing Climate, Key Message 7).

Key Message 1: Impacts to Agriculture

In the next few decades, longer growing seasons and rising carbon dioxide levels will increase yields of some crops, though those benefits will be progressively offset by extreme weather events. Though adaptation options can reduce some of the detrimental effects, in the long term, the combined stresses associated with climate change are expected to decrease agricultural productivity.

Agriculture dominates Midwest land use, with more than twothirds of land designated as farmland.³ The region accounts for about 65% of U.S. corn and soybean production,⁷ mostly from non-irrigated lands.¹ Corn and soybeans constitute 85% of Midwest crop receipts, with high-value crops such as fruits and vegetables making up most of the remainder.⁸ Corn and soybean yields increased markedly (by a factor of more than 5) over the last century largely due to technological innovation, but are still vulnerable to year-to-year variations in weather conditions.⁹

The Midwest growing season lengthened by almost two weeks since 1950, due in large part to earlier occurrence of the last spring freeze. This trend is expected to continue, though the potential agricultural consequences are complex and vary by crop. For corn, small long-term average temperature increases will shorten the duration of reproductive development, leading to yield declines, even when offset by carbon dioxide (CO₂) stimulation. For soybeans, yields have a two in

three chance of increasing early in this century due to CO_2 fertilization, but these increases are projected to be offset later in the century by higher temperature stress¹⁴ (see Figure 18.2 for projections of increases in the frost-free season length and the number of summer days with temperatures over 95°F).

Future crop yields will be more strongly influenced by anomalous weather events than by changes in average temperature or annual precipitation (Ch. 6: Agriculture). Cold injury due to a freeze event after plant budding can decimate fruit crop production, as happened in 2002, and again in 2012, to Michigan's \$60 million tart cherry crop. Springtime cold air outbreaks (at least two consecutive days during which the daily average surface air temperature is below 95% of the simulated average wintertime surface air temperature) are projected to continue to occur throughout this century. As a result, increased productivity of some crops due to higher temperatures, longer growing seasons, and elevated CO₂ concentrations could be offset by increased freeze damage. Heat waves during pol-

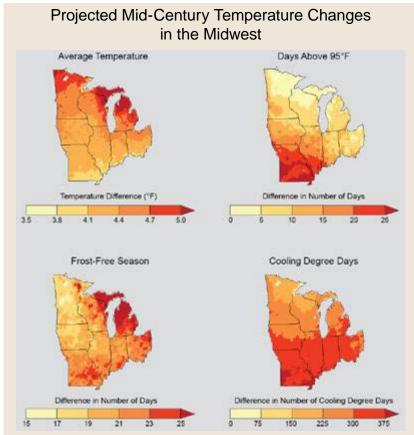


Figure 18.2. Projected increase in annual average temperatures (top left) by mid-century (2041-2070) as compared to the 1971-2000 period tell only part of the climate change story. Maps also show annual projected increases in the number of the hottest days (days over 95°F, top right), longer frost-free seasons (bottom left), and an increase in cooling degree days (bottom right), defined as the number of degrees that a day's average temperature is above 65°F, which generally leads to an increase in energy use for air conditioning. Projections are from global climate models that assume emissions of heat-trapping gases continue to rise (A2 scenario). (Figure source: NOAA NCDC / CICS-NC).

lination of field crops such as corn and soybean also reduce yields (Figure 18.3). Wetter springs may reduce crop yields and profits, sespecially if growers are forced to switch to late-planted, shorter-season varieties. A recent study suggests the volatility of U.S. corn prices is more sensitive to near-term climate change than to energy policy influences or to use of agricultural products for energy production, such as biofuel.

Agriculture is responsible for about 8% of U.S. heattrapping gas emissions, 20 and there is tremendous potential for farming practices to reduce emissions or store more carbon in soil. 21 Although large-scale agriculture in the Midwest historically led to decreased carbon in soils, higher crop residue inputs and adoption of different soil management techniques have reversed this trend. Other techniques, such as planting cover crops and no-till soil management, can further increase CO2 uptake and reduce energy use. 22,23 Use of agricultural best management practices can also improve water quality by reducing the loss of sediments and nutrients from farm fields. Methane released from animals and their wastes can be reduced by altered diets and methane capture systems, and nitrous oxide production can be reduced by judicious fertilizer use²⁴ and improved waste handling. 21 In addition, if biofuel crops are grown sustainably, 25 they offer emissions reduction opportunities by substituting for fossil fuel-based energy (Ch. 10: Energy, Water, and Land).

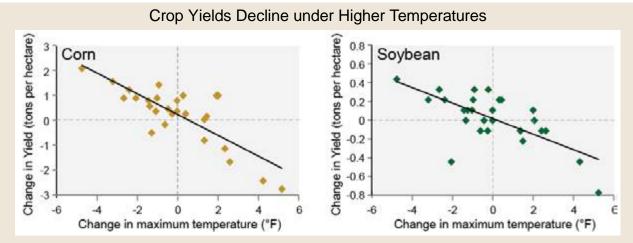


Figure 18.3. Crop yields are very sensitive to temperature and rainfall. They are especially sensitive to high temperatures during the pollination and grain filling period. For example, corn (left) and soybean (right) harvests in Illinois and Indiana, two major producers, were lower in years with average maximum summer (June, July, and August) temperatures higher than the average from 1980 to 2007. Most years with below-average yields are both warmer and drier than normal. There is high correlation between warm and dry conditions during Midwest summers due to similar meteorological conditions and drought-caused changes. (Figure source: Mishra and Cherkauer 2010²⁶).

Key Message 2: Forest Composition

The composition of the region's forests is expected to change as rising temperatures drive habitats for many tree species northward. The role of the region's forests as a net absorber of carbon is at risk from disruptions to forest ecosystems, in part due to climate change.

The Midwest is characterized by a rich diversity of native species juxtaposed on one of the world's most productive agricultural systems.³⁰ The remnants of intact natural ecosystems in the region,³¹ including prairies, forests, streams, and wetlands, are rich with varied species.³² The combined effects of climate change, land-use change, and increasing numbers of invasive species are the primary threats to Midwest natural ecosystems.³³ Species most vulnerable to climate change include those that occur in isolated habitats; live near their physiological tolerance limits; have specific habitat requirements, low reproductive rates, or limited dispersal capability; are dependent on interactions with specific other species; and/or have low genetic variability.³⁴

Among the varied ecosystems of the region, forest systems are particularly vulnerable to multiple stresses. The habitat ranges of many iconic tree species such as paper birch, quaking aspen, balsam fir, and black spruce are projected to decline substantially across the northern Midwest as they shift northward, while species that are common farther south, including several oaks and pines, expand their ranges northward into the region (Figure 18.4). There is considerable variability in the likelihood of a species' habitat changing and the adaptabil-

ity of the species with regard to climate change.³⁷ Migration to accommodate changed habitat is expected to be slow for many Midwest species, due to relatively flat topography, high latitudes, and fragmented habitats including the Great Lakes barrier. To reach areas that are 1.8°F cooler, species in mountainous terrains need to shift 550 feet higher in altitude (which can be achieved in only a few miles), whereas species in flat terrain like the Midwest must move as much as 90 miles north to reach a similarly cooler habitat.³⁸

Although global forests currently capture and store more carbon each year than they emit, ³⁹ the ability of forests to act as large, global carbon absorbers ("sinks") may be reduced by projected increased disturbances from insect outbreaks, ⁴⁰ forest fire, ⁴¹ and drought, ⁴² leading to increases in tree mortality and carbon emissions. Some regions may even shift from being a carbon sink to being an atmospheric carbon dioxide source, ^{43,44} though large uncertainties exist, such as whether projected disturbances to forests will be chronic or episodic. ⁴⁵ Midwest forests are more resilient to forest carbon losses than most western forests because of relatively high moisture availability, greater nitrogen deposition (which tends to act as a fertilizer), and lower wildfire risk. ^{43,46}

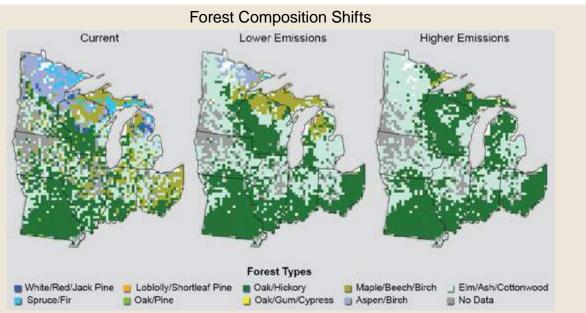


Figure 18.4. As climate changes, species can often adapt by changing their ranges. Maps show current and projected future distribution of habitats for forest types in the Midwest under two emissions scenarios, a lower scenario that assumes reductions in heat-trapping gas emissions (B1), and a very high scenario that assumes continued increases in emissions (A1FI). Habitats for white/red/jack pine, maple/beech/birch, spruce/fir, and aspen/birch forests are projected to greatly decline from the northern forests, especially under higher emissions scenarios, while various oak forest types are projected to expand.³⁷ While some forest types may not remain dominant, they will still be present in reduced quantities. Therefore, it is more appropriate to assess changes on an individual species basis, since all species within a forest type will not exhibit equal responses to climate change. (Figure source: Prasad et al. 2007³⁷).

Key Message 3: Public Health Risks

Increased heat wave intensity and frequency, increased humidity, degraded air quality, and reduced water quality will increase public health risks.

The frequency of major heat waves in the Midwest has increased over the last six decades. 47 For the United States, mortality increases 4% during heat waves compared with non-heat wave days. 48 During July 2011, 132 million people across the U.S. were under a heat alert – and on July 20 of that year, the majority of the Midwest experienced temperatures in excess of 100°F. Heat stress is projected to increase as a result of both increased summer temperatures and humidity. 49,50 One study projected an increase of between 166 and 2,217 excess deaths per year from heat wave-related mortality in Chicago alone by 2081-2100. 51 The lower number assumes a climate scenario with significant reductions in emissions of greenhouse gases (B1), while the upper number assumes a scenario under which emissions continue to increase (A2). These projections are significant when compared to recent Chicago heat waves, where 114 people died from the heat wave of 1999 and about 700 died from the heat wave of 1995.52 Heat response plans and early warning systems save lives, and from 1975 to 2004, mortality rates per heat event declined. 53 However, many municipalities lack such plans. 54

More than 20 million people in the Midwest experience air quality that fails to meet national ambient air quality standards. Degraded air quality due to human-induced emissions and increased pollen season duration are projected to be amplified with higher temperatures, and pollution and pollen exposures, in addition to heat waves, can harm human health (Ch. 9: Human Health). Policy options exist (for example, see "Alternative Transportation Options Create Multiple Benefits") that could reduce emissions of both heat-trapping gases and other air pollutants, yielding benefits for human health and fitness. Increased temperatures and changes in precipitation patterns could also increase the vulnerability of Midwest residents to diseases carried by insects and rodents (Ch. 9: Human Health). Between the second residents in the second residents of the second residen

ALTERNATIVE TRANSPORTATION OPTIONS CREATE MULTIPLE BENEFITS

The transportation sector produces one-third of U.S. greenhouse gas emissions, and automobile exhaust also contains precursors to fine particulate matter ($PM_{2.5}$) and ground-level ozone (O_3), which pose threats to public health. Adopting a low-carbon transportation system with fewer automobiles, therefore, could have immediate health "co-benefits" of both reducing climate change and improving human health via both improved air quality and physical fitness.

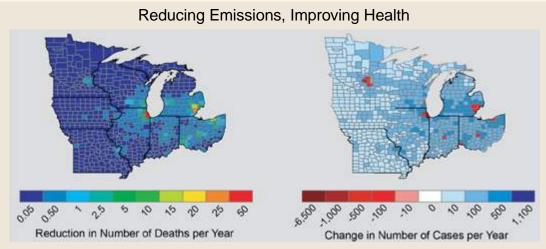


Figure 18.5. Annual reduction in the number of premature deaths (left) and annual change in the number of cases with acute respiratory symptoms (right) due to reductions in particulate matter and ozone caused by reducing automobile exhaust. The maps project health benefits if automobile trips shorter than five miles (round-trip) were eliminated for the 11 largest metropolitan areas in the Midwest. Making 50% of these trips by bicycle just during four summer months would save 1,295 lives and yield savings of more than \$8 billion per year from improved air quality, avoided mortality, and reduced health care costs for the upper Midwest alone. (Figure source: Grabow et al. 2012; reproduced with permission from Environmental Health Perspectives⁵⁹).

Key Message 4: Fossil-Fuel Dependent Electricity System

The Midwest has a highly energy-intensive economy with per capita emissions of greenhouse gases more than 20% higher than the national average. The region also has a large and increasingly utilized potential to reduce emissions that cause climate change.

The Midwest is a major exporter of electricity to other U.S. regions and has a highly energy-intensive economy (Ch. 10: Energy, Water, and Land, Figure 10.4). Energy use per dollar of gross domestic product is approximately 20% above the national average, and per capita greenhouse gas emissions are 22% higher than the national average due, in part, to the reliance on fossil fuels, particularly coal for electricity generation. A large range in seasonal air temperature causes energy demand for both heating and cooling, with the highest demand for winter heating. The demand for heating in major midwestern cities is typically five to seven times that for cooling, although this is expected to shift as a result of longer summers, more frequent heat waves, and higher humidity, leading to an increase in the number of cooling degree days. This increased demand for cooling by the middle of this century is projected to exceed 10 gigawatts (equivalent to at least five large conventional power plants), requiring more than \$6 billion in infrastructure investments. 60 Further, approximately 95% of the electrical generating infrastructure in the Midwest is susceptible to decreased efficiency due to higher temperatures. 60

Climate change presents the Midwest's energy sector with a number of challenges, in part because of its current reliance on coal-based electricity¹ and an aging, less-reliable electric distribution grid⁶¹ that will require significant reinvestment even without additional adaptations to climate change.⁶²

Increased use of natural gas in the Midwest has the potential to reduce emissions of greenhouse gases. The Midwest also has potential to produce energy from zero- and low-carbon sources, given its wind, solar, and biomass resources, and potential for expanded nuclear power. The Midwest does not have the highest solar potential in the country (that is found in the Southwest), but its potential is nonetheless vast, with some parts of the Midwest having as good a solar resource as Florida. 63 More than one-quarter of national installed wind energy capacity, one-third of biodiesel capacity, and more than two-thirds of ethanol production are located in the Midwest (see also Ch. 4: Energy and Ch. 10: Energy, Water, and Land). Progress toward increasing renewable energy is hampered by electricity prices that are distorted through a mix of direct and indirect subsidies and unaccounted-for costs for conventional energy sources.64

Key Message 5: Increased Rainfall and Flooding

Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue, causing erosion, declining water quality, and negative impacts on transportation, agriculture, human health, and infrastructure.

Precipitation in the Midwest is greatest in the east, declining towards the west. Precipitation occurs about once every seven days in the western part of the region and once every three days in the southeastern part.⁶⁵ The 10 rainiest days can contribute as much as 40% of total precipitation in a given year.⁶⁵ Generally, annual precipitation increased during the past century (by up to 20% in some locations), with much of the increase driven by intensification of the heaviest rainfalls.^{65,66} This tendency towards more intense precipitation events is projected to continue in the future.⁶⁷

Model projections for precipitation changes are less certain than those for temperature. ^{3,4} Under a higher emissions scenario (A2), global climate models (GCMs) project average winter and spring precipitation by late this century (2071-2099) to increase 10% to 20% relative to 1971-2000, while changes in summer and fall are not expected to be larger than natural variations. Projected changes in annual precipitation show increases larger than natural variations in the north and smaller in the south (Ch. 2: Our Changing Climate, Key Message 5). ⁴ Regional

climate models (RCMs) using the same emissions scenario also project increased spring precipitation (9% in 2041-2062 relative to 1979-2000) and decreased summer precipitation (by an average of about 8% in 2041-2062 relative to 1979-2000) particularly in the southern portions of the Midwest.³ Increases in the frequency and intensity of extreme precipitation are projected across the entire region in both GCM and RCM simulations (Figure 18.6), and these increases are generally larger than the projected changes in average precipitation.^{3,4}

Flooding can affect the integrity and diversity of aquatic ecosystems. Flooding also causes major human and economic consequences by inundating urban and agricultural land and by disrupting navigation in the region's roads, rivers, and reservoirs (see Ch. 5: Transportation, Ch. 9: Human Health, and Ch. 11: Urban). For example, the 2008 flooding in the Midwest caused 24 deaths, \$15 billion in losses via reduced agricultural yields, and closure of key transportation routes. Water infrastructure for flood control, navigation, and other purposes is susceptible to climate change impacts and other forces because the de-

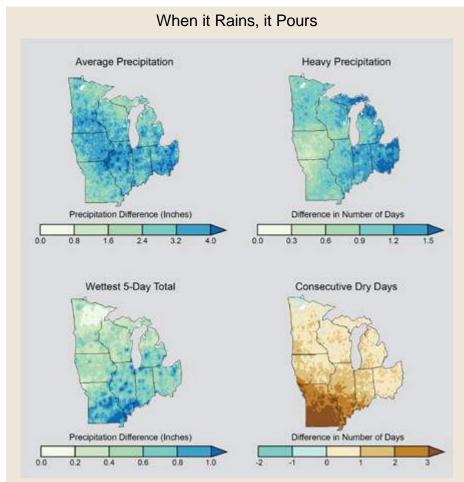


Figure 18.6. Precipitation patterns affect many aspects of life, from agriculture to urban storm drains. These maps show projected changes for the middle of the current century (2041-2070) relative to the end of the last century (1971-2000) across the Midwest under continued emissions (A2 scenario). Top left: the changes in total annual average precipitation. Across the entire Midwest, the total amount of water from rainfall and snowfall is projected to increase. Top right: increase in the number of days with very heavy precipitation (top 2% of all rainfalls each year). Bottom left: increases in the amount of rain falling in the wettest 5-day period over a year. Both (top right and bottom left) indicate that heavy precipitation events will increase in intensity in the future across the Midwest. Bottom right: change in the average maximum number of consecutive days each year with less than 0.01 inches of precipitation. An increase in this variable has been used to indicate an increase in the chance of drought in the future. (Figure source: NOAA NCDC / CICS-NC).

signs are based upon historical patterns of precipitation and streamflow, which are no longer appropriate guides.

Snowfall varies across the region, comprising less than 10% of total precipitation in the south, to more than half in the north, with as much as two inches of water available in the snowpack at the beginning of spring melt in the northern reaches of the river basins. ⁶⁸ When this amount of snowmelt is combined with heavy rainfall, the resulting flooding can be widespread and catastrophic (see "Cedar Rapids: A Tale of Vulnerability and Response"). ⁶⁹ Historical observations indicate declines in the frequency of high magnitude snowfall years over much of the Midwest, ⁷⁰ but an increase in lake effect snowfall. ⁷¹ These divergent trends and their inverse relationships with air tem-

peratures make overall projections of regional impacts of the associated snowmelt extremely difficult. Large-scale flooding can also occur due to extreme precipitation in the absence of snowmelt (for example, Rush Creek and the Root River, Minnesota, in August 2007 and multiple rivers in southern Minnesota in September 2010). These warm-season events are projected to increase in magnitude. Such events tend to be more regional and less likely to cover as large an area as those that occur in spring, in part because soil water storage capacity is typically much greater during the summer.

Changing land use and the expansion of urban areas are reducing water infiltration into the soil and increasing surface runoff. These changes exacerbate impacts caused by increased precipitation intensity. Many major Midwest cities are served by combined storm and sewage drainage systems. As surface area has been increasingly converted to impervious surfaces (such as asphalt) and extreme precipitation events have intensified, combined sewer overflow has degraded water quality, a phenomenon expected to continue to worsen with increased urbanization and climate change.75 The U.S. Environmental Protection Agency (EPA) estimates there are more than 800 billion gallons of untreated combined sewage released into the nation's waters annually. 76 The Great Lakes, which provide drinking water to more than 40 million people and are home to more than 500 beaches,75 have been subject to recent sewage overflows. For example, stormwater across the city of Milwaukee recently showed high human fecal pathogen levels at all 45 outflow

locations, indicating widespread sewage contamination.⁷⁷ One study estimated that increased storm events will lead to an increase of up to 120% in combined sewer overflows into Lake Michigan by 2100 under a very high emissions scenario (A1FI),⁷⁵ leading to additional human health issues and beach closures. Municipalities may be forced to invest in new infrastructure to protect human health and water quality in the Great Lakes, and local communities could face tourism losses from fouled nearshore regions.

Increased precipitation intensity also increases erosion, damaging ecosystems and increasing delivery of sediment and subsequent loss of reservoir storage capacity. Increased storminduced agricultural runoff and rising water temperatures

CEDAR RAPIDS: A TALE OF VULNERABILITY AND RESPONSE

Cedar Rapids, Des Moines, Iowa City, and Ames, Iowa, have all suffered multi-million-dollar losses from floods since 1993. In June 2008, a record flood event exceeded the once-in-500-year flood level by more than 5 feet, causing \$5 to \$6 billion in damages from flooding, or more than \$40,000 per resident of the city of Cedar Rapids. 73 The flood inundated much of the downtown, damaging more than 4,000 structures, including 80% of government offices, and displacing 25,000 people.74 The record flood at Cedar Rapids was the result of low reservoir capacity and extreme rainfall on soil already saturated from unusually wet conditions. Rainfall amounts comparable to those in 1993 (8 inches over two weeks) overwhelmed a flood control system designed largely for a once-in-100-year flood event. Such events are consistent with observations and projections of wetter springs and more intense precipitation events (see Figure 18.6). With the help of more than \$3 billion in funding from the federal and state government, Cedar Rapids is recovering and has taken significant steps to reduce future flood damage, with buyouts of more than 1,000 properties, and numerous buildings adapted with flood protection measures.



have increased non-point source pollution problems in recent years. This has led to increased phosphorus and nitrogen loading, which in turn is contributing to more and prolonged occurrences of low-oxygen "dead zones" and to harmful, lengthy, and dense algae growth in the Great Lakes and other Midwest water bodies. (Such zones and their causes are also discussed in Ch. 25: Coasts, Ch. 15: Biogeochemical Cycles, and Ch. 3: Water, Key Message 6). Watershed planning can be used to reduce water quantity and quality problems due to changing climate and land use.

While there was no apparent change in drought duration in the Midwest region as a whole over the past century, ⁸⁰ the average number of days without precipitation is projected to increase in the future. This could lead to agricultural drought and suppressed crop yields. ⁹ This would also increase thermoelectric power plant cooling water temperatures and decrease cooling efficiency and plant capacity because of the need to avoid discharging excessively warm water (see also Ch. 4: Energy, and Ch. 10: Energy, Water, and Land). ⁶⁰

Key Message 6: Increased Risks to the Great Lakes

Climate change will exacerbate a range of risks to the Great Lakes, including changes in the range and distribution of certain fish species, increased invasive species and harmful blooms of algae, and declining beach health. Ice cover declines will lengthen the commercial navigation season.

The Great Lakes, North America's largest freshwater feature, have recently recorded higher water temperatures and less ice cover as a result of changes in regional climate (see also Ch. 2: Our Changing Climate, Key Message 11). Summer surface water temperatures in Lakes Huron increased 5.2°F and in Lake Ontario, 2.7°F, between 1968 and 2002,81 with smaller increases in Lake Erie. 81,82 Due to the reduction in ice cover, the temperature of surface waters in Lake Superior during the summer increased 4.5°F, twice the rate of increase in air temperature. 83 These lake surface temperatures are projected to rise by as much as 7°F by 2050 and 12.1°F by 2100.84,85 Higher temperatures, increases in precipitation, and lengthened growing seasons favor production of blue-green and toxic algae that can harm fish, water quality, habitats, and aesthetics, 79,84,86 and could heighten the impact of invasive species already present.87

In the Great Lakes, the average annual maximum ice coverage during 2003-2013 was less than 43% compared to the 1962-2013 average of 52%,88 lower than any other decade during the period of measurements (Figure 18.7), although there is substantial variability from year to year. During the 1970s, which included several extremely cold winters, maximum ice coverage averaged 67%. Less ice, coupled with more frequent and intense storms (as indicated by some analyses of historical wind speeds), 89 leaves shores vulnerable to erosion and flooding and could harm property and fish habitat. 84,90 Reduced ice cover also has the potential to lengthen the shipping season.⁹¹ The navigation season increased by an average of eight days between 1994 and 2011, and the Welland Canal in the St. Lawrence River remained open nearly two weeks longer. Increased shipping days benefit commerce but could also increase shoreline scouring and bring in more invasive species. 91,92

Changes in lake levels can also influence the amount of cargo that can be carried on ships. On average, a 1000-foot ship sinks into the water by one inch per 270 tons of cargo; 93 thus if a ship is currently limited by water depth, any lowering of lake levels will result in a proportional reduction in the amount of cargo that it can transport to Great Lakes ports. However, current estimates of lake level changes are uncertain, even for continued increases in global greenhouse gas emissions (A2 scenario). The most recent projections suggest a slight decrease or even a small rise in levels. 94 Recent studies have also indicated that earlier approaches to computing evapotranspiration estimates from temperature may have overestimated evaporation losses. $^{\rm 94,95,96,97}$ The recent studies, along with the large spread in existing modeling results, indicate that projections of Great Lakes water levels represent evolving research and are still subject to considerable uncertainty (see Appendix 3: Climate Science Supplemental Message 8).

Ice Cover in the Great Lakes Ice Cover in the Great Lakes To payout 40 1963-1972 1973-1982 1983-1992 1993-2002 2003-2013 Years

Figure 18.7. Bars show decade averages of annual maximum Great Lakes ice coverage from the winter of 1962-1963, when reliable coverage of the entire Great Lakes began, to the winter of 2012-2013. Bar labels indicate the end year of the winter; for example, 1963-1972 indicates the winter of 1962-1963 through the winter of 1971-1972. The most recent period includes the eleven years from 2003 to 2013. (Data updated from Bai and Wang, 2012⁸⁸).

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PHOTO CREDITS

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SUPPLEMENTAL MATERIAL TRACEABLE ACCOUNTS

Process for Developing Key Messages:

The assessment process for the Midwest Region began with a workshop was that was held July 25, 2011, in Ann Arbor, Michigan. Ten participants discussed the scope and authors for a foundational Technical Input Report (TIR) report entitled "Midwest Technical Input Report." The report, which consisted of nearly 240 pages of text organized into 13 chapters, was assembled by 23 authors representing governmental agencies, non-governmental organizations (NGOs), tribes, and other entities.

The Chapter Author Team engaged in multiple technical discussions via teleconferences that permitted a careful review of the foundational TIR⁹⁸ and of approximately 45 additional technical inputs provided by the public, as well as the other published literature, and professional judgment. The Chapter Author Team convened teleconferences and exchanged extensive emails to define the scope of the chapter for their expert deliberation of input materials and to generate the chapter text and figures. Each expert drafted key messages, initial text and figure drafts and traceable accounts that pertained to their individual fields of expertise. These materials were then extensively discussed by the team and were approved by the team members.

KEY MESSAGE #1 TRACEABLE ACCOUNT

In the next few decades, longer growing seasons and rising carbon dioxide levels will increase yields of some crops, though those benefits will be progressively offset by extreme weather events. Though adaptation options can reduce some of the detrimental effects, in the long term, the combined stresses associated with climate change are expected to decrease agricultural productivity.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the Technical Input Report. ⁹⁸ Technical input reports on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence for altered growing seasons across the U.S. are discussed in Chapter 2 (Our Changing Climate, Key Message 4) and its Traceable Accounts. "Climate Trends and Scenarios for the U.S. National Climate Assessment" and its references provide specific details for the Midwest. Evidence for longer growing seasons in the Midwest is based on regional temperature records and is incontrovertible, as is evidence for increasing carbon dioxide concentrations.

U.S. Department of Agriculture data tables provide evidence for the importance of the eight Midwest states for U.S. agricultural production.8 Evidence for the effect of future elevated carbon dioxide concentrations on crop yields is based on scores of greenhouse and field experiments that show a strong fertilization response for C₃ plants such as soybeans and wheat and a positive but not as strong a response for C₄ plants such as corn. Observational data, evidence from field experiments, and quantitative modeling are the evidence base of the negative effects of extreme weather events on crop yield: early spring heat waves followed by normal frost events have been shown to decimate Midwest fruit crops; heat waves during flowering, pollination, and grain filling have been shown to significantly reduce corn and wheat yields; more variable and intense spring rainfall has delayed spring planting in some years and can be expected to increase erosion and runoff; and floods have led to crop losses. 12,13,14

New information and remaining uncertainties

Key issues (uncertainties) are: a) the rate at which grain yield improvements will continue to occur, which could help to offset the overall negative effect of extreme events at least for grain crops (though not for individual farmers); and b) the degree to which genetic improvements could make some future crops more tolerant of extreme events such as drought and heat stress. Additional uncertainties are: c) the degree to which accelerated soil carbon loss will occur as a result of warmer winters and the resulting effects on soil fertility and soil water availability; and d) the potential for increased pest and disease pressure as southern pests such as soybean rust move northward and existing pests better survive milder Midwest winters.

Assessment of confidence based on evidence

Because nearly all studies published to date in the peer-reviewed literature agree that Midwest crops benefit from CO₂ fertilization and some benefit from a longer growing season, there is **very high** confidence in this component of the key message.

Studies also agree that full benefits of climate change will be offset partly or fully by more frequent heat waves, early spring thaws followed by freezing temperatures, more variable and intense rainfall events, and floods. Again, there is **very high** confidence in this aspect.

There is less certainty (**high**) about pest effects and about the potential for adaptation actions to significantly mitigate the risk of crop loss.

Confidence Level

Very High

Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus

High

Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus

Medium

Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought

Low

Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Key Message #2 Traceable Account

The composition of the region's forests is expected to change as rising temperatures drive habitats for many tree species northward. The role of the region's forests as a net absorber of carbon is at risk from disruptions to forest ecosystems, in part due to climate change.

Description of evidence

The key message and supporting text summarize extensive evidence documented in the Technical Input Report. 98 Technical inputs on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence for increased temperatures and altered growing seasons across the U.S. is discussed in Chapter 2 (Our Changing Climate, Key Messages 3 and 4) and its Traceable Accounts. "Climate Trends and Scenarios for the U.S. National Climate Assessment," with its references, provides specific details for the Midwest. Evidence that species have been shifting northward or ascending in altitude has been mounting for numerous species, though less so for long-lived trees. Nearly all studies to date published in the peer-reviewed literature agree that many of the boreal species of the north will eventually retreat northward. The question is when. Multiple models and paleoecological evidence show these trends have occurred in the past and are projected to continue in the future. 36

The forests of the eastern United States (including the Midwest) have been accumulating large quantities of carbon over the past century, ²³ but evidence shows this trend is slowing in recent decades. There is a large amount of forest inventory data supporting the gradual decline in carbon accumulation throughout the eastern United States, ⁹⁹ as well as evidence of increasing disturbances and disturbance agents that are reducing overall net productivity in many of the forests.

New information and remaining uncertainties

A key issue (uncertainty) is the rate of change of habitats and for organisms adapting or moving as habitats move. The key questions are: How much will the habitats change (what scenarios and model predictions will be most correct)? As primary habitats move north, which species will be able to keep up with changing habitats on their own or with human intervention through assisted migration, management of migration corridors, or construction or maintenance of protected habitats within species' current land-scapes?

Viable avenues to improving the information base are determining which climate models exhibit the best ability to reproduce the historical and potential future change in habitats, and determining how, how fast, and how far various species can move or adapt.

An additional key source of uncertainty is whether projected disturbances to forests are chronic or episodic in nature.⁴⁵

Assessment of confidence based on evidence

There is **very high** confidence in this key message, given the evidence base and remaining uncertainties.

KEY MESSAGE #3 TRACEABLE ACCOUNT

Increased heat wave intensity and frequency, increased humidity, degraded air quality, and reduced water quality will increase public health risks.

Description of evidence

The key message and supporting text summarize extensive evidence documented in the Technical Input Report.⁹⁸ Technical inputs on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence for extreme weather such as heat waves across the U.S. are discussed in Chapter 2 (Our Changing Climate, Key Message 7) and its Traceable Accounts. Specific details for the Midwest are in "Climate Trends and Scenarios for the U.S. National Climate Assessment" with its references. A recent book 100 also contains chapters detailing the most current evidence for the region.

Heat waves: The occurrence of heat waves in the recent past has been well-documented, ^{1,15,49} as have health outcomes (particularly with regards to mortality). Projections of thermal regimes indicate increased frequency of periods with high air temperatures (and high apparent temperatures, which are a function of both air temperature and humidity). These projections are relatively robust and consistent between studies.

Humidity: Evidence on observed and projected increased humidity can be found in a recent study.⁴⁹

Air quality: In 2008, in the region containing North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, and Ohio, over 26 million people lived in counties that failed the National Ambient Air Quality Standards (NAAQS) for PM_{2.5} (particles with diameter below 2.5 microns), and over 24 million lived in counties that failed the NAAQS for ozone (O₃). Because not all counties have air quality measurement stations in place, these data must be considered a lower bound on the actual number of counties that violate the NAAQS. Given that the NAAQS were designed principally with the goal of protecting human health, failure to meet these standards implies a significant fraction of the population live in counties characterized by air quality that is harmful to human health. While only relatively few studies have sought to make detailed air quality projections for the future, those that have generally indicate declining air quality (see uncertainties below).

Water quality: The EPA estimates there are more than 800 billion gallons of untreated combined sewage released into the nation's waters annually. Combined sewers are designed to capture both sanitary sewage and stormwater. Combined sewer overflows lead to discharge of untreated sewage as a result of precipitation events, and can threaten human health. While not all urban areas within the Midwest have combined sewers for delivery to

wastewater treatment plants, many do (for example, Chicago and Milwaukee), and such systems are vulnerable to combined sewer overflows during extreme precipitation events. Given projected increases in the frequency and intensity of extreme precipitation events in the Midwest (Chapter 2: Our Changing Climate, Key Message 6), 75 it appears that sewer overflow will continue to constitute a significant current health threat and a critical source of climate change vulnerability for major urban areas within the Midwest.

New information and remaining uncertainties

Key issues (uncertainties) are: Human health outcomes are contingent on a large number of non-climate variables. For example, morbidity and mortality outcomes of extreme heat are strongly determined by a) housing stock and access to air-conditioning in residences; b) existence and efficacy of heat wave warning and response plans (for example, foreign-language-appropriate communications and transit plans to public cooling centers, especially for the elderly); and c) co-stressors (for example, air pollution). Further, heat stress is dictated by apparent temperature, which is a function of both air temperature and humidity. Urban heat islands tend to exacerbate elevated temperatures and are largely determined by urban land use and human-caused heat emissions. Urban heat island reduction plans (for example, planted green roofs) represent one ongoing intervention. Nevertheless, the occurrence of extreme heat indices will increase under all climate scenarios. Thus, in the absence of policies to reduce heat-related illness/death, these impacts will increase in the future.

Air quality is a complex function not only of physical meteorology but emissions of air pollutants and precursor species. However, since most chemical reactions are enhanced by warmer temperatures, as are many air pollutant emissions, warmer temperatures may lead to worsening of air quality, particularly with respect to tropospheric ozone (see Ch. 9: Human Health). Changes in humidity are more difficult to project but may amplify the increase in heat stress due to rising temperatures alone.

Combined sewer overflow is a major threat to water quality in some midwestern cities now. The tendency towards increased magnitude of extreme rain events (documented in the historical record and projected to continue in downscaling analyses) will cause an increased risk of waterborne disease outbreaks in the absence of infrastructure overhaul. However, mitigation actions are available, and the changing structure of cities (for example, reducing impervious surfaces) may offset the impact of the changing climate.

Assessment of confidence based on evidence

In the absence of concerted efforts to reduce the threats posed by heat waves, increased humidity, degraded air quality and degraded water quality, climate change will increase the health risks associated with these phenomena. However, these projections are contingent on underlying assumptions regarding socioeconomic conditions and demographic trends in the region. Confidence is therefore **high** regarding this key message.

KEY MESSAGE #4 TRACEABLE ACCOUNT

The Midwest has a highly energy-intensive economy with per capita emissions of greenhouse gases more than 20% higher than the national average. The region also has a large and increasingly utilized potential to reduce emissions that cause climate change.

Description of evidence

The key message and supporting text summarize extensive evidence documented in the Technical Input Report.⁹⁸ Technical inputs on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

The Midwest's disproportionately large reliance on coal for electricity generation and the energy intensity of its agricultural and manufacturing sectors are all well documented in both government and industry records, as is the Midwest's contribution to greenhouse gases.¹ The region's potential for zero- and lowercarbon energy production is also well documented by government and private assessments. Official and regular reporting by state agencies and non-governmental organizations demonstrates the Midwest's progress toward a decarbonized energy mix (Ch. 4: Energy; Ch. 10: Energy, Water, and Land).¹

There is evidence that the Midwest is steadily decarbonizing its electricity generation through a combination of new state-level policies (for example, energy efficiency and renewable energy standards) and will continue to do so in response to low natural gas prices, falling prices for renewable electricity (for example, wind and solar), greater market demand for lower-carbon energy from consumers, and new EPA regulations governing new power plants. Several midwestern states have established Renewable Portfolio Standards (see https://www.misoenergy.org/WhatWeDo/StrategicInitiatives/Pages/RenewablePortfolioStandards.aspx).

New information and remaining uncertainties

There are four key uncertainties. The first uncertainty is the net effect of emerging EPA regulations on the future energy mix of the Midwest. Assessments to date suggest a significant number of coal plants will be closed or repowered with lower-carbon natural gas; and even coal plants that are currently thought of as "must run" (to maintain the electric grid's reliability) may be able to be replaced in some circumstances with the right combination of energy efficiency, new transmission lines, demand response, and distributed generation. A second key uncertainty is whether or not natural gas prices will remain at their historically low levels. Given that there are really only five options for meeting electricity demand – energy efficiency, renewables, coal, nuclear, and natural gas - the replacement of coal with natural gas for electricity production would have a significant impact on greenhouse gas emissions in the region. Third is the uncertain future for federal policies that have spurred renewable energy development to date,

such as the Production Tax Credit for wind. While prices for both wind and solar continue to fall, the potential loss of tax credits may dampen additional market penetration of these technologies. A fourth uncertainty is the net effect of climate change on energy demand, and the cost of meeting that new demand profile. Research to date suggests the potential for a significant swing from the historically larger demand for heating in the winter to more demand in the summer instead, due to a warmer, more humid climate.³

Assessment of confidence based on evidence

There is no dispute about the energy intensity of the midwestern economy, nor its disproportionately large contribution of greenhouse gas emissions. Similarly, there is broad agreement about the Midwest's potential for—and progress toward—lower-carbon electricity production. There is therefore **very high** confidence in this statement.

KEY MESSAGE #5 TRACEABLE ACCOUNT

Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue, causing erosion, declining water quality, and negative impacts on transportation, agriculture, human health, and infrastructure.

Description of evidence

The key message and supporting text summarize extensive evidence documented in the Technical Input Report. ⁹⁸ Technical inputs on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence for extreme weather and increased precipitation across the U.S. are discussed in Chapter 2 (Our Changing Climate, Key Messages 5, 6, and 7) and its Traceable Accounts. Specific details for the Midwest are detailed in "Climate Trends and Scenarios for the U.S. National Climate Assessment" with its references. A recent book also contains chapters detailing the most current evidence for the region.

There is compelling evidence that annual total precipitation has been increasing in the region, with wetter winters and springs, drier summers, an increase in extreme precipitation events, and changes in snowfall patterns. These observations are consistent with climate model projections. Both the observed trends and climate models suggest these trends will increase in the future.

Recent records also indicate evidence of a number of high-impact flood events in the region. Heavy precipitation events cause increased kinetic energy of surface water and thus increase erosion. Heavy precipitation events in the historical records have been shown to be associated with discharge of partially or completely untreated sewage due to the volumes of water overwhelming combined sewer systems that are designed to capture both domestic sewage and stormwater.

Climate downscaling projections tend to indicate an increase in the frequency and duration of extreme events (both heavy precipitation and meteorological drought) in the future.

An extensive literature survey and synthetic analysis is presented in chapters in a recent book for impacts on water quality, transportation, agriculture, health, and infrastructure.

New information and remaining uncertainties

Precipitation is much less readily measured or modeled than air temperature.³ Thus both historical tendencies and projections for precipitation are inherently less certain than for temperature. Most regional climate models still have a positive bias in precipitation frequency but a negative bias in terms of precipitation amount in extreme events.

Flood records are very heterogeneous and there is some ambiguity about the degree to which flooding is a result of atmospheric conditions. 69 Flooding is not solely the result of incident precipitation but is also a complex function of the preceding conditions such as soil moisture content and extent of landscape infiltration. A key issue (uncertainty) is the future distribution of snowfall. Records indicate that snowfall is decreasing in the southern parts of the region, along with increasing lake effect snow. Climate models predict these trends will increase. There is insufficient knowledge about how this change in snowfall patterns will affect flooding and associated problems, but it is projected to affect the very large spring floods that typically cause the worst flooding in the region. In addition, recent data and climate predictions indicate drier summer conditions, which could tend to offset the effects of higher intensity summer storms by providing increased water storage in the soils. The relative effects of these offsetting trends need to be assessed. To determine future flooding risks, hydrologic modeling is needed that includes the effects of the increase in extreme events, changing snow patterns, and shifts in rainfall patterns. Adaptation measures to reduce soil erosion and combined sewer overflow (CSO) events are available and could be widely adopted.

The impacts of increased magnitude of heavy precipitation events on water quality, agriculture, human health, transportation, and infrastructure will be strongly determined by the degree to which the resilience of such systems is enhanced (for example, some cities are already implementing enhanced water removal systems).

Assessment of confidence based on evidence

There have been improvements in agreement between observed precipitation patterns and model simulations. Also an increase in extreme precipitation events is consistent with first-order reasoning and increased atmospheric water burdens due to increased air temperature. Recent data suggest an increase in flooding in the region but there is uncertainty about how changing snow patterns will affect flood events in the future. Thus there is **high** confidence in increases in high-magnitude rainfall events and extreme precipitation events, and that these trends are expected to continue.

There is **medium** confidence that, in the absence of substantial adaptation actions, the enhancement in extreme precipitation and other tendencies in land use and land cover result in a projected increase in flooding. There is **medium** confidence that, in the absence of major adaptation actions, the enhancement in extreme precipitation will tend to increase the risk of erosion, declines in water quality, and negative impacts on transportation, agriculture, human health, and infrastructure.³

KEY MESSAGE #6 TRACEABLE ACCOUNT

Climate change will exacerbate a range of risks to the Great Lakes, including changes in the range and distribution of certain fish species, increased invasive species and harmful blooms of algae, and declining beach health. Ice cover declines will lengthen the commercial navigation season.

Description of evidence

The key message and supporting text summarize extensive evidence documented in the Technical Input Report. ⁹⁸ Technical inputs on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence for changes in ice cover due to increased temperatures across the U.S. are discussed in Chapter 2 (Our Changing Climate, Key Message 11) and its Traceable Accounts. Specific details for the Midwest are detailed in "Climate Trends and Scenarios for the U.S. National Climate Assessment" with its references. A recent book 100 also contains chapters detailing the most current evidence for the region.

Altered fish communities: Warmer lakes and streams will certainly provide more habitat for warmwater species as conditions in northern reaches of the basin become more suitable for warmwater fish and as lakes and streams are vacated by cool- and coldwater species.

84 Habitat for coldwater fish, though not expected to disappear, will shrink substantially, though it could also expand in some areas, such as Lake Superior. Whether climate change expands the range of any type of fish is dependent on the availability of forage fish, as higher temperatures also necessitate greater food intake.

Increased abundances of invasive species: As climate change alters water temperatures, habitat, and fish communities, conditions that once were barriers to alien species become conduits for establishment and spread. This migration will alter drastically the fish communities of the Great Lakes basin. Climate change is also projected to heighten the impact of invasive species already present in the Great Lakes basin. Warmer winter conditions, for instance, have the potential to benefit alewife, round gobies, ruffe, sea lamprey, rainbow smelt, and other non-native species. These species have spread rapidly throughout the basin and have already inflicted significant ecological and economic harm.

Declining beach health and harmful algal blooms: Extreme events increase runoff, adding sediments, pollutants, and nutrients to the Great Lakes. The Midwest has experienced rising trends in precipitation and runoff. Agricultural runoff, in combination with increased water temperatures, has caused considerable non-point source pollution problems in recent years, with increased phosphorus and nitrogen loadings from farms contributing to more frequent and prolonged occurrences of anoxic "dead zones" and harmful, dense algae growth for long periods. Stormwater runoff that overloads urban sewer systems during extreme events adds to increased levels of toxic substances, sewage, and bacteria in the Great Lakes, affecting water quality, beach health, and human well-being. Increased storm events caused by climate change will lead to an increase in combined sewer overflows.⁸⁴

Decreased ice cover: Increasingly mild winters have shortened the time between when a lake freezes and when it thaws. Scientists have documented a relatively constant decrease in Great Lakes ice cover since the 1970s, particularly for Lakes Superior, Michigan, Huron, and Ontario. The loss of ice cover on the Great Lakes has both ecological and economic implications. Ice serves to protect shorelines and habitat from storms and wave power. Less ice—coupled with more frequent and intense storms—leaves shores vulnerable to erosion and flooding and could harm property and fish habitat.

Water levels: The 2009 NCA¹⁰² included predictions of a significant drop in Great Lakes levels by the end of the century, based on methods of linking climate models to hydrologic models. These methods have been significantly improved by fully coupling the hydrologic cycle among land, lake, and atmosphere. 97 Without accounting for that cycle of interactions, a study 66 concluded that increases in precipitation would be negated by increases in winter evaporation from less ice cover and by increases in summer evaporation and evapotranspiration from warmer air temperatures, under a scenario of continued increases in global emissions (SRES A2 scenario). Declines of 8 inches to 2 feet have been projected by the end of this century, depending on the specific lake in question. 96 A recent comprehensive assessment, 94 however, has concluded that with a continuation of current rising emissions trends (A2), the lakes will experience a slight decrease or even a rise in water levels; the difference from earlier studies is because earlier studies tended to overstress the amount of evapotranspiration expected to occur. The range of potential future lake levels remains large and includes the earlier projected decline. Overall, however, scientists project an increase in precipitation in the Great Lakes region (with extreme events projected to contribute to this increase), which will contribute to maintenance of or an increase in Great Lakes water levels. However, water level changes are not predicted to be uniform throughout the basin.

Shipping: Ice cover is expected to decrease dramatically by the end of the century, possibly lengthening the shipping season and, thus, facilitating more shipping activity. Current science suggests

water levels in the Great Lakes are projected to fall slightly or might even rise over the short run. However, by causing even a small drop in water levels, climate change could make the costs of shipping increase substantially. For instance, for every inch of draft a 1000-foot ship gives up, its capacity is reduced by 270 tons. ⁹³ Lightened loads today already add about \$200,000 in costs to each voyage.

New information and remaining uncertainties

Key issues (uncertainties) are: Water levels are influenced by the amount of evaporation from decreased ice cover and warmer air temperatures, by evapotranspiration from warmer air temperatures, and by potential increases in inflow from more precipitation. Uncertainties about Great Lakes water levels are high, though most models suggest that the decrease in ice cover will lead to slightly lower water levels, beyond natural fluctuations.

The spread of invasive species into the system is near-certain (given the rate of introductions over the previous 50 years) without major policy and regulatory changes. However, the changes in Great Lakes fish communities are based on extrapolation from known fishery responses to projected responses to expected changing conditions in the basin. Moreover, many variables beyond water temperature and condition affect fisheries, not the least of which is the availability of forage fish. Higher water temperatures necessitate greater food intake, yet the forage base is changing rapidly in many parts of the Great Lakes basin, thus making the projected impact of climate change on fisheries difficult to discern with very high certainty.

Assessment of confidence based on evidence

Peer-reviewed literature about the effects of climate change are in broad agreement that air and surface water temperatures are rising and will continue to do so, that ice cover is declining steadily, and that precipitation and extreme events are on the rise. For large lake ecosystems, these changes have well-documented effects, such as effects on algal production, stratification (change in water temperature with depth), beach health, and fisheries. Key uncertainties exist about Great Lakes water levels and the impact of climate change on fisheries.

A qualitative summary of climate stressors and coastal margin vulnerabilities for the Great Lakes is given in a technical input report.⁸⁴ We have high confidence that the sum of these stressors will exceed the risk posed by any individual stressor. However, quantifying the cumulative impacts of those stressors is very challenging.

Given the evidence and remaining uncertainties, there is **very high** confidence in this key message, except **high** confidence for lake levels changing, and **high** confidence that declines in ice cover will continue to lengthen the commercial navigation season. There is limited information regarding exactly how invasive species may respond to changes in the regional climate, resulting in **medium** confidence for that part of the key message.



Climate Change Impacts in the United States

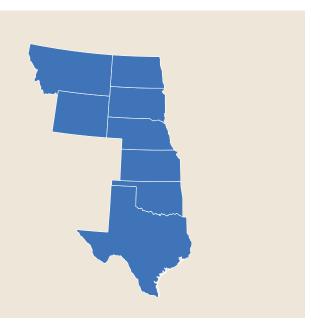
CHAPTER 19 GREAT PLAINS

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On the Web: http://nca2014.globalchange.gov/report/regions/great-plains



INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

19 GREAT PLAINS

KEY MESSAGES

- 1. Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs.
- 2. Changes to crop growth cycles due to warming winters and alterations in the timing and magnitude of rainfall events have already been observed; as these trends continue, they will require new agriculture and livestock management practices.
- 3. Landscape fragmentation is increasing, for example, in the context of energy development activities in the northern Great Plains. A highly fragmented landscape will hinder adaptation of species when climate change alters habitat composition and timing of plant development cycles.
- 4. Communities that are already the most vulnerable to weather and climate extremes will be stressed even further by more frequent extreme events occurring within an already highly variable climate system.
- 5. The magnitude of expected changes will exceed those experienced in the last century. Existing adaptation and planning efforts are inadequate to respond to these projected impacts.

The Great Plains is a diverse region where climate and water are woven into the fabric of life. Day-to-day, month-to-month, and year-to-year changes in the weather can be dramatic and challenging for communities and their commerce. The region experiences multiple climate and weather hazards, including

floods, droughts, severe storms, tornadoes, hurricanes, and winter storms. In much of the Great Plains, too little precipitation falls to replace that needed by humans, plants, and animals. These variable conditions in the Great Plains already stress communities and cause billions of dollars in damage; climate change will add to both stress and costs.

The people of the Great Plains historically have adapted to this challenging climate. Although projections suggest more frequent and more intense droughts, severe rainfall events, and heat waves, communities and individuals can reduce vulnerabilities through the use of new technologies, community-driven policies, and the judicious use of resources. Adaptation (means of coping with changed conditions) and mitigation (reducing emissions of heat-trapping gases

to reduce the speed and amount of climate change) choices can be locally driven, cost effective, and beneficial for local economies and ecosystem services.



Average Annual Temperature (*F) Average Annual Precipitation (inches) Average Annual Precipitation (inches)

Figure 19.1. The region has a distinct north-south gradient in average temperature patterns (left), with a hotter south and colder north. For precipitation (right), the regional gradient runs west-east, with a wetter east and a much drier west. Averages shown here are for the period 1981-2010. (Figure source: adapted from Kunkel et al. 2013⁴).

Significant climate-related challenges are expected to involve 1) resolving increasing competition among land, water, and energy resources; 2) developing and maintaining sustainable agricultural systems; 3) conserving vibrant and diverse ecological systems; and 4) enhancing the resilience of the region's people to the impacts of climate extremes. These growing challenges will unfold against a changing backdrop that includes a growing urban population and declining rural population, new economic factors that drive incentives for crop and energy production, advances in technology, and shifting policies such as those related to farm and energy subsidies.

The Great Plains region features relatively flat plains that increase in elevation from sea level to more than 5,000 feet at the base of mountain ranges along the Continental Divide. Forested mountains cover western Montana and Wyoming, extensive rangelands spread throughout the Plains, marshes extend along Texas' Gulf Coast, and desert landscapes distinguish far west Texas. A highly diverse climate results from the region's large north-south extent and change of elevation. This regional diversity also means that climate change impacts will vary across the region.

Great Plains residents already must contend with weather challenges from winter storms, extreme heat and cold, severe thunderstorms, drought, and flood-producing rainfall. Texas'

Gulf Coast averages about three tropical storms or hurricanes every four years, ² generating coastal storm surge and sometimes bringing heavy rainfall and damaging winds hundreds of miles inland. The expected rise in sea level will result in the potential for greater damage from storm surge along the Gulf Coast of Texas (see Ch. 25: Coasts).

Annual average temperatures range from less than 40°F in the mountains of Wyoming and Montana to more than 70°F in South Texas, with extremes ranging from -70°F in Montana to 121°F in North Dakota and Kansas.³ Summers are long and hot in the south; winters are long and often severe in the north. North Dakota's increase in annual temperature over the past 130 years is the fastest in the contiguous U.S. and is mainly driven by warming winters.⁴

The region has a distinct north-south gradient in average temperature patterns, with a hotter south and colder north (Figure 19.1). Average annual precipitation greater than 50 inches supports lush vegetation in eastern Texas and Oklahoma. For most places, however, average rainfall is less than 30 inches, with some of Montana, Wyoming, and far west Texas receiving less than 15 inches a year. Across much of the region, annual water loss from transpiration by plants and from evaporation is higher than annual precipitation, making these areas particularly susceptible to droughts.

Projected climate change

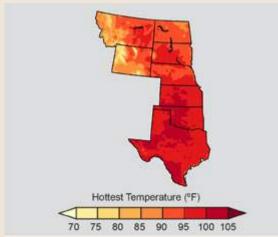
For an average of seven days per year, maximum temperatures reach more than 100°F in the Southern Plains and about 95°F

in the Northern Plains (Figure 19.2). These high temperatures are projected to occur much more frequently, even under a

scenario of substantial reductions in heat-trapping gas (also called greenhouse gas) emissions (B1), with days over 100°F projected to double in number in the north and quadruple in the south by mid-century (Ch. 2: Our Changing Climate, Key Message 7). Similar increases are expected in the number of nights with minimum temperatures higher than 80°F in the south and 60°F in the north (cooler in mountain regions; see Figure 19.3). These increases in extreme heat will have many

negative consequences, including increases in surface water losses, heat stress, and demand for air conditioning. These negative consequences will more than offset the benefits of warmer winters, such as lower winter heating demand, less cold stress on humans and animals, and a longer growing season, which will be extended by mid-century an average of 24 days relative to the 1971-2000 average. More overwintering insect populations are also expected.

Historical Temperature on the 7 Hottest Days of the Year



The historical (1971-2000) distribution of temperature for the hottest 2% of days (about seven days a year) echoes the distinct north-south gradient in average temperatures.

Projected Change in Number of Hot Days

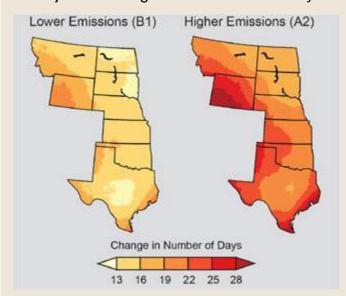
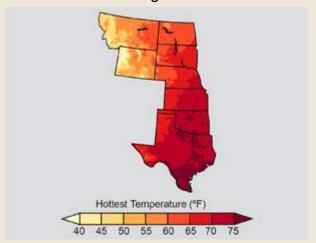


Figure 19.2. The number of days with the hottest temperatures is projected to increase dramatically. By mid-century (2041-2070), the projected change in the number of days exceeding those hottest temperatures is greatest in the western areas and Gulf Coast for both the lower emissions scenario (B1) and for the higher emissions scenario (A2). (Figure source: NOAA NCDC / CICS-NC).

Historical Temperature on the 7 Warmest Nights of the Year



The historical (1971-2000) distribution of temperature for the warmest 2% of nights (about seven days a year) echoes the distinct north-south gradient in average temperatures.

Projected Change in Number of Warm Nights

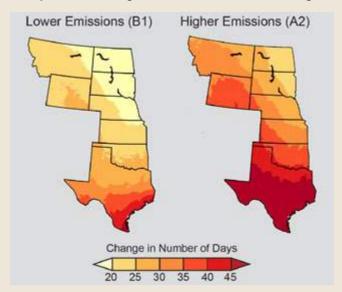


Figure 19.3. The number of nights with the warmest temperatures is projected to increase dramatically. By midcentury (2041-2070), the projected change in number of nights exceeding those warmest temperatures is greatest in the south for both the lower emissions scenario (B1) and for the higher emissions scenario (A2). (Figure source: NOAA NCDC / CICS-NC).

Winter and spring precipitation is projected to increase in the northern states of the Great Plains region under the A2 scenario, relative to the 1971-2000 average. In central areas, changes are projected to be small relative to natural variations (Ch. 2: Our Changing Climate, Key Message 5). Projected changes in summer and fall precipitation are small except for summer drying in the central Great Plains, although the exact locations

of this drying are uncertain. The number of days with heavy precipitation is expected to increase by mid-century, especially in the north (Ch. 2: Our Changing Climate, Key Message 6). Large parts of Texas and Oklahoma are projected to see longer dry spells (up to 5 more days on average by mid-century). By contrast, changes are projected to be minimal in the north (Ch. 2: Our Changing Climate, Key Message 7).⁴

Historical Amount of Precipitation on the 7 Wettest Days of the Year



The historical (1971-2000) distribution of the greatest 2% of daily precipitation (about seven days a year) echoes the regional west-east gradient in average precipitation.

Projected Change in Number of Heavy Precipitation Days

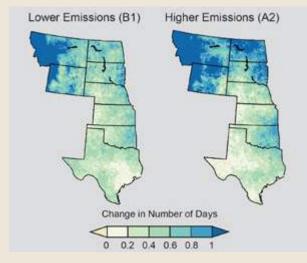


Figure 19.4. The number of days with the heaviest precipitation is not projected to change dramatically. By mid-century (2041-2070), the projected change in days exceeding those precipitation amounts remains greatest in the northern area for both the lower emissions scenario (B1) and for the higher emissions scenario (A2). (Figure source: NOAA NCDC / CICS-NC).

Projected Change in Number of Consecutive Dry Days

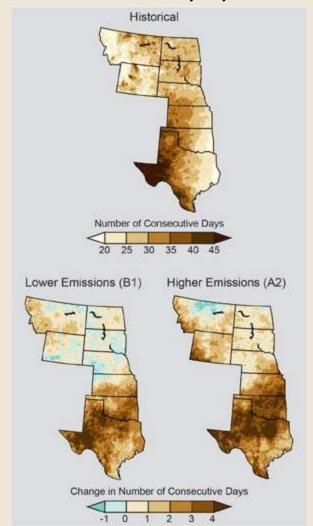


Figure 19.5. Current regional trends of a drier south and a wetter north are projected to become more pronounced by mid-century (2041-2070 as compared to 1971-2000 averages). Maps show the maximum annual number of consecutive days in which limited (less than 0.01 inches) precipitation was recorded on average from 1971 to 2000 (top), projected changes in the number of consecutive dry days assuming substantial reductions in emissions (B1), and projected changes if emissions continue to rise (A2). The southeastern Great Plains, which is the wettest portion of the region, is projected to experience large increases in the number of consecutive dry days. (Figure source: NOAA NCDC / CICS-NC).

Key Message 1: Energy, Water and Land Use

Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs.

Energy, water, and land use are inherently interconnected,^b and climate change is creating a new set of challenges for these critical sectors (Ch. 2: Our Changing Climate; Ch. 10: Energy, Water, and Land). 7,8,9 The Great Plains is rich with energy resources, primarily from coal, oil, and natural gas, with growing wind and biofuel industries. 10 Texas produces 16% of U.S. energy (mostly from crude oil and natural gas), and Wyoming provides an additional 14% (mostly from coal). North Dakota is the second largest producer of oil in the Great Plains, behind Texas. Nebraska and South Dakota rank third and fifth in biofuel production, and five of the eight Great Plains states have more than 1,000 megawatts of installed wind generation capacity, with Texas topping the list. 11 More than 80% of the region's land area is used for agriculture, primarily cropland, pastures, and rangeland. Other land uses include forests, urban and rural development, transportation, conservation, and industry.

Significant amounts of water are used to produce energy^{7,12} and to cool power plants.¹³ Electricity is consumed to collect, purify, and pump water. Although hydraulic fracturing to release oil and natural gas is a small component of total water use,¹⁴ it can be a significant proportion of water use in local and rural groundwater systems. Energy facilities, transmission lines, and wind turbines can fragment both natural habitats and agriculture lands (Ch. 10: Energy, Water, and Land).⁵

The trend toward more dry days and higher temperatures across the south will increase evaporation, decrease water supplies, reduce electricity transmission capacity, and increase cooling demands. These changes will add stress to limited water resources and affect management choices related to irrigation, municipal use, and energy generation.15 In the Northern Plains, warmer winters may lead to reduced heating demand while hotter summers will increase demand for air conditioning, with the summer increase in demand outweighing the winter decrease (Ch. 4: Energy, Key Message 2).15

Changing extremes in precipitation are projected across all seasons, including higher likelihoods of both increasing heavy rain and snow events⁴ and more

intense droughts (Ch. 2: Our Changing Climate, Key Messages 5 and 6). Winter and spring precipitation and very heavy precipitation events are both projected to increase in the northern portions of the area, leading to increased runoff and flooding that will reduce water quality and erode soils. Increased snowfall, rapid spring warming, and intense rainfall can combine to produce devastating floods, as is already common along the Red River of the North. More intense rains will also contribute to urban flooding.

Increased drought frequency and intensity can turn marginal lands into deserts. Reduced per capita water storage will continue to increase vulnerability to water shortages.¹⁷ Federal and state legal requirements mandating water allocations for ecosystems and endangered species add further competition for water resources.

Diminishing water supplies and rapid population growth are critical issues in Texas. Because reservoirs are limited and have high evaporation rates, San Antonio has turned to the Edwards Aquifer as a major source of groundwater storage. Nineteen water districts joined to form a Regional Water Alliance for sustainable water development through 2060. The alliance creates a competitive market for buying and selling water rights and simplifies transfer of water rights.



Key Message 2: Sustaining Agriculture

Changes to crop growth cycles due to warming winters and alterations in the timing and magnitude of rainfall events have already been observed; as these trends continue, they will require new agriculture and livestock management practices

The important agricultural sector in the Great Plains, with a total market value of about \$92 billion (the most important being crops at 43% and livestock at 46%), ¹⁸ already contends with significant climate variability (Ch. 6: Agriculture). Projected changes in climate, and human responses to it, will affect aspects of the region's agriculture, from the many crops that rely solely on rainfall, to the water and land required for increased energy production from plants, such as fuels made from corn or switchgrass (see Ch. 10: Energy, Water, and Land).

Water is central to the region's productivity. The High Plains Aquifer, including the Ogallala, is a primary source for irriga-

tion.¹⁹ In the Northern Plains, rain recharges this aquifer quickly, but little recharge occurs in the Southern Plains.^{20,21}

Projected changes in precipitation and temperature have both positive and negative consequences to agricultural productivity in the Northern Plains. Projected increases in winter and spring precipitation in the Northern Plains will benefit agricultural productivity by increasing water availability through soil moisture reserves during the early growing season, but this can be offset by fields too wet to plant. Rising temperatures will lengthen the growing season, possibly allowing a second annual crop in some places and some years. Warmer winters pose challenges. 22,23,24 For example, some pests and invasive weeds will be able to survive the warmer winters.²⁵ Winter crops that leave dormancy earlier are susceptible to spring freezes.²⁶ Rainfall events already have become more intense, 27 increasing erosion and nutrient runoff, and projections are that the frequency and severity of these heavy rainfall events will increase. 4,28 The Northern Plains will remain vulnerable to periodic drought because much of the projected increase in precipitation is expected to occur in the cooler months while increasing temperatures will result in additional evapotranspiration.

In the Central and Southern Plains, projected declines in precipitation in the south and greater evaporation everywhere due to higher temperatures will increase irrigation demand and exacerbate current stresses on agricultural productivity. Increased water withdrawals from the Ogallala Aquifer and High Plains Aquifer would accelerate ongoing depletion in the southern parts of the aquifers and limit the ability to irrigate. ^{21,29} Holding other aspects of production constant, the climate impacts of shifting from irrigated to dryland agriculture would reduce crop yields by about a factor of two. ³⁰ Under these climate-induced changes, adaptation of agricultural practices will be needed, however, there may be constraints on social-ecological adaptive capacity to make these adjustments (see also Ch. 28: Adaptation).

Increases in Irrigated Farmland in the Great Plains

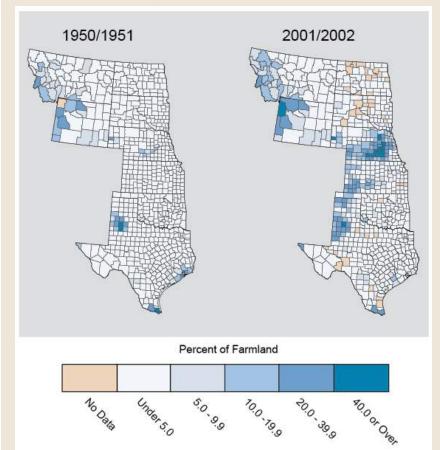


Figure 19.6. Irrigation in western Kansas, Oklahoma, and Texas supports crop development in semiarid areas. Declining aquifer levels threaten the ability to maintain production. Some aquifer-dependent regions, like southeastern Nebraska, have seen steep rises in irrigated farmland, from around 5% to more than 40%, during the period shown. (Figure source: reproduced from Atlas of the Great Plains by Stephen J. Lavin, Clark J. Archer, and Fred M. Shelley by permission of the University of Nebraska. Copyright 2011 by the Board of Regents of the University of Nebraska³³).

The projected increase in high temperature extremes and heat waves will negatively affect livestock and concentrated animal feeding operations.³¹ Shortened dormancy periods for winter wheat will lessen an important source of feed for the livestock industry. Climate change may thus result in a northward shift of crop and livestock production in the region. In areas projected to be hotter and drier in the future, maintaining agriculture on marginal lands may become too costly.

Adding to climate change related stresses, growing water demands from large urban areas are also placing stresses on limited water supplies. Options considered in some areas include

groundwater development and purchasing water rights from agricultural areas for transfer to cities. ³²

During the droughts of 2011 and 2012, ranchers liquidated large herds due to lack of food and water. Many cattle were sold to slaughterhouses; others were relocated to other pastures through sale or lease. As herds are being rebuilt, there is an opportunity to improve genetic stock, as those least adapted to the drought conditions were the first to be sold or relocated. Some ranchers also used the drought as an opportunity to diversify their portfolio, managing herds in both Texas and Montana.

Key Message 3: Conservation and Adaptation

Landscape fragmentation is increasing, for example, in the context of energy development activities in the northern Great Plains. A highly fragmented landscape will hinder adaptation of species when climate change alters habitat composition and timing of plant development cycles.

Land development for energy production, land transformations on the fringes of urban areas, and economic pressures to remove lands from conservation easements pose threats to natural systems in the Great Plains. ³⁴ Habitat fragmentation is already a serious issue that inhibits the ability of species to migrate as climate variability and change alter local habitats. ³⁵ Lands that remain out of production are susceptible to invasion from non-native plant species.

Many plant and animal species are responding to rising temperatures by adjusting their ranges at increasingly greater rates. These adjustments may also require movement of species that have evolved to live in very specific habitats, which may prove increasingly difficult for these species. The historic bison herds migrated to adapt to climate, disturbance, and associated habitat variability, that modern land-use patterns, roads, agriculture, and structures inhibit similar large-scale migration. In the playa regions of the southern Great Plains, agricultural practices have modified more than 70% of seasonal lakes larger than 10 acres, and these lakes will be further altered under warming conditions. These changes in seasonal lakes will further affect bird populations and fish populations in the region.

Observed climate-induced changes have been linked to changing timing of flowering, increases in wildfire activity and pest outbreaks, shifts in species distributions, declines in the abundance of native species, and the spread of invasive species (Ch. 8: Ecosystems). From Texas to Montana, altered flowering patterns due to more frost-free days have increased the length of pollen season for ragweed by as many as 16 days over the period from 1995 to 2009. ⁴³ Earlier snowmelt in Wyoming from

1961 to 2002 has been related to the American pipit songbird laying eggs about 5 days earlier. 44 During the past 70 years, observations indicate that winter wheat is flowering 6 to 10 days earlier as spring temperatures have risen. 23 Some species may be less sensitive to changes in temperature and precipitation, causing first flowering dates to change for some species but not for others. 22 Even small shifts in timing, however, can disrupt the integrated balance of ecosystem functions like predator-prey relationships, mating behavior, or food availability for migrating birds.

In addition to climate changes, the increase in atmospheric CO_2 concentrations may offset the drying effects from warming by considerable improvements in plant water-use efficiency, which occur as CO_2 concentrations increase. However, nutrient content of the grassland communities may be decreased under enriched CO_2 environments, affecting nutritional quality of the grasses and leaves eaten by animals.

The interaction of climate and land-use changes across the Great Plains promises to be challenging and contentious. Opportunities for conservation of native grasslands, including species and processes, depend primarily and most immediately on managing a fragmented network of untilled prairie. Restoration of natural processes, conservation of remnant species and habitats, and consolidation/connection of fragmented areas will facilitate conservation of species and ecosystem services across the Great Plains. However, climate change will complicate current conservation efforts as land fragmentation continues to reduce habitat connectivity. The implementation of adaptive management approaches provides robust options for multiple solutions.

Sage grouse and climate change

Habitat fragmentation inhibits the ability of species such as the Greater Sage Grouse, a candidate for Endangered Species Act protections, to migrate in response to climate change. Its current habitat is threatened by energy development, agricultural practices, and urban development. Rapid expansion of oil and gas fields in North Dakota, Wyoming, and Montana and development of wind farms from North Dakota through Texas are opening new lands to development and contributing to habitat fragmentation of important core Sage Grouse habitat. The health of Sage Grouse habitat is associated with other species' health as well. Climate change projections also suggest a shift in preferred habitat locations and increased susceptibility to West Nile Virus.

Historical and Current Range of Sage Grouse Habitat ALBERTA BRITISH COLUMBIA SASKATCHEWAN MONTANA ND VASHINGTON OREGON NE COLORADO CALIFORNIA ARIZONA Current Historical

Figure 19.7. Comparing estimates of Greater Sage Grouse distribution from before settlement of the area (light green: prior to about 1800) with the current range (dark green: 2000) shows fragmentation of the sagebrush habitat required by this species. Over the last century, the sagebrush ecosystem has been altered by fire, invasion by new plant species, and conversion of land to agriculture, causing a decline in Sage Grouse populations. (Figure source: adapted from Aldridge et al. 2008. Photo credit: U.S. Fish and Wildlife Service, Wyoming Ecological Services).

Key Message 4: Vulnerable Communities

Communities that are already the most vulnerable to weather and climate extremes will be stressed even further by more frequent extreme events occurring within an already highly variable climate system.

The Great Plains is home to a geographically, economically, and culturally diverse population. For rural and tribal communities, their remote locations, sparse development, limited local services, and language barriers present greater challenges in responding to climate extremes. Working-age people are moving to urban areas, leaving a growing percentage of elderly people in rural communities (see also Ch. 14: Rural Communities).

Overall population throughout the region is stable or declining, with the exception of substantial increases in urban Texas, tribal communities, and western North Dakota, related in large part to rapid expansion of energy development. ⁵⁰ Growing urban areas require more water, expand into forests and crop-

land, fragment habitat, and are at a greater risk of wildfire – all factors that interplay with climate.

Populations such as the elderly, low-income, and non-native English speakers face heightened climate vulnerability. Public health resources, basic infrastructure, adequate housing, and effective communication systems are often lacking in com-

Percentage | 50.0 or more | 25.0 to 49.9 | 10.0 to 24.9 | 0.0 to 9.9 | 9.9 to 0.0 | Less than -9.9 | Comparable data not available | U.S. Change: 9.7 percent

Figure 19.8. Demographic shifts continue to reshape communities in the Great Plains, with many central Great Plains communities losing residents. Rural and tribal communities will face additional challenges in dealing with climate change impacts due to demographic changes in the region (Ch. 14: Rural Communities; Ch. 12: Indigenous Peoples). Figure shows population change from 2000 to 2010. (Figure source: U.S. Census Bureau 2010⁵⁷).

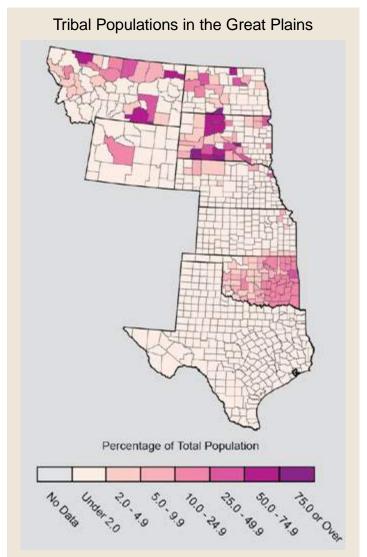


Figure 19.9. Tribal populations in the Great Plains are concentrated near large reservations, like various Sioux tribes in South Dakota and Blackfeet and Crow reservations in Montana; and in Cherokee, Chickasaw, Choctaw, and other tribal lands in Oklahoma (Figure source: reproduced from Atlas of the Great Plains by Stephen J. Lavin, Clark J. Archer, and Fred M. Shelley by permission of the University of Nebraska. Copyright 2011 by the Board of Regents of the University of Nebraska³³).

munities that are geographically, politically, and economically isolated. ⁵¹ Elderly people are more vulnerable to extreme heat, especially in warmer cities and communities with minimal air conditioning or sub-standard housing. ⁵² Language barriers for Hispanics may impede their ability to plan for, adapt to, and respond to climate-related risks. ⁵³

The 70 federally recognized tribes in the Great Plains are diverse in their land use, with some located on lands reserved from their traditional homelands, and others residing within

territories designated for their relocation, as in Oklahoma (see also Ch. 12: Indigenous Peoples). While tribal communities have adapted to climate change for centuries, they are now constrained by physical and political boundaries.⁵⁴ Traditional ecosystems and native resources no longer provide the support they used to.⁵⁵ Tribal members have reported the decline or disappearance of culturally important animal species, changes in the timing of cultural ceremonies due to earlier onset of spring, and the inability to locate certain types of ceremonial wild plants.⁵⁶

Key Message 5: Opportunities to Build Resilience

The magnitude of expected changes will exceed those experienced in the last century.

Existing adaptation and planning efforts are inadequate to respond to these projected impacts.

The Great Plains is an integrated system. Changes in one part, whether driven by climate or by human decisions, affect other parts. Some of these changes are already underway, and many pieces of independent evidence project that ongoing climate-related changes will ripple throughout the region.

Many of these challenges will cut across sectors: water, land use, agriculture, energy, conservation, and livelihoods. Com-

petition for water resources will increase within alreadystressed human and ecological systems, particularly in the Southern Plains, affecting crops, energy production, and how well people, animals, and plants can thrive. The region's ecosystems, economies, and communities will be further strained by increasing intensity and frequency of floods, droughts, and heat waves that will penetrate into the lives and livelihoods of Great Plains residents. Although some communities and

Oglala Lakota respond to climate change

The Oglala Lakota tribe in South Dakota is incorporating climate change adaptation and mitigation planning as they consider long-term sustainable development planning. Their *Oyate Omniciye* plan is a partnership built around six livability principles related to transportation, housing, economic competitiveness, existing communities, federal investments, and local values. Interwoven with this is a vision that incorporates plans to reduce future climate change and adapt to future climate change, while protecting cultural resources.⁵⁸



states have made efforts to plan for these projected changes, the magnitude of the adaptation and planning efforts do not match the magnitude of the expected changes.

Successful adaptation of human and natural systems to climate change would benefit from:

- recognition of and commitment to addressing these challenges;
- regional-scale planning and local-to-regional implementation;
- mainstreaming climate planning into existing natural resource, public health, and emergency management processes;⁶⁰
- renewed emphasis on restoration of ecological systems and processes;⁶¹
- recognition of the value of natural systems to sustaining life: ^{62,63}
- sharing information among decision-makers; and
- enhanced alignment of social and ecological goals.

Communities already face tradeoffs in efforts to make efficient and sustainable use of their resources. Jobs, infrastructure, and tax dollars that come with fossil fuel extraction or renewable energy production are important, especially for rural communities. There is also economic value in the conversion of native grasslands to agriculture. Yet the tradeoffs among this development, the increased pressure on water resources, and the effects on conservation need to be considered if the region is to develop climate-resilient communities.

Untilled prairies used for livestock grazing provide excellent targets for native grassland conservation. Partnerships among

many different tribal, federal, state, local, and private landowners can decrease landscape fragmentation and help manage the connection between agriculture and native habitats. Soil and wetland restoration enhances soil stability and health, water conservation, aquifer recharge, and food sources for wildlife and cattle. Healthy species and ecosystem services support social and economic systems where local products, tourism, and culturally significant species accompany largescale agriculture, industry, and international trade as fundamental components of society.

Although there is tremendous adaptive potential among the diverse communities of the Great Plains, many local government officials do not yet recognize climate change as a problem that requires proactive planning. 60,65 Positive steps toward greater community resilience have been achieved through local and regional collaboration and increased two-way communication between scientists and local decision-makers (see Ch. 28: Adaptation). For example, the Institute for Sustainable Communities conducts Climate Leadership Academies that promote peer learning and provides direct technical assistance to communities in a five-state region in the Southwest as part of their support of the Western Adaptation Alliance. 66 Other regions have collaborated to share information, like the Southeast Florida Regional Compact 2012. Programs such as NOAA's Regional Integrated Sciences and Assessments (RISA) support scientists working directly with communities to help build capacity to prepare for and adapt to both climate variability and climate change. 67 Climate-related challenges can be addressed with creative local engagement and prudent use of community assets. 68 These assets include social networks, social capital, indigenous and local knowledge, and informal institutions.

THE SUMMER OF 2011

Future climate change projections include more precipitation in the Northern Great Plains and less in the Southern Great Plains. In 2011, such a pattern was strongly manifest, with exceptional drought and recording-setting temperatures in Texas and Oklahoma and flooding in the Northern Great Plains.

Many locations in Texas and Oklahoma experienced more than 100 days over 100°F. Both states set new records for the hottest summer since record keeping began in 1895. Rates of water loss due in part to evaporation were double the long-term average. The heat and drought depleted water resources and contributed to more than \$10 billion in direct losses to agriculture alone. These severe water constraints strained the ability to meet electricity demands in Texas during 2011 and into 2012, a problem exacerbated by the fact that Texas is nearly isolated from the national electricity grid.

These recent temperature extremes were attributable in part to human-induced climate change (approximately 20% of the heat wave magnitude and a doubling of the chance that it would occur).⁶⁹ In the future, average temperatures in this region are expected to increase and will continue to contribute to the intensity of heat waves (Ch. 2: Our Changing Climate, Key Messages 3 and 7).

Days Above 100°F in Summer 2011

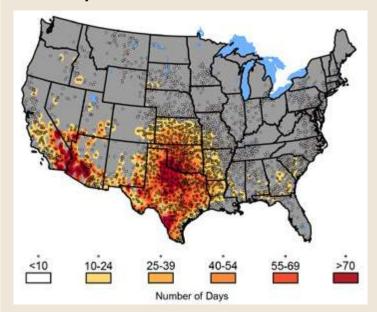


Figure 19.10. In 2011, cities including Houston, Dallas, Austin, Oklahoma City, and Wichita, among others, all set records for the highest number of days recording temperatures of 100°F or higher in those cities' recorded history. The black circles denote the location of observing stations recording 100°F days. (Figure source: NOAA NCDC 2012³).

By contrast to the drought in the Southern Plains, the Northern Plains were exceptionally wet in 2011, with Montana and Wyoming recording all-time wettest springs and the Dakotas and Nebraska not far behind. Record rainfall and snowmelt combined to push the Missouri River and its tributaries beyond their banks and leave much of the Crow Reservation in Montana underwater. The Souris River near Minot, North Dakota, crested at four feet above its previous record, with a flow five times greater than any in the past 30 years. Losses from the flooding were estimated at \$2 billion.



A Texas State Park police officer walks across a cracked lakebed in August 2011. This lake once spanned more than 5,400 acres.



Increases in heavy downpours contribute to flooding.

19: GREAT PLAINS

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SUPPLEMENTAL MATERIAL TRACEABLE ACCOUNTS

TRACEABLE ACCOUNTS

Process for Developing Key Messages:

A central component of the assessment process was the Great Plains Regional Climate assessment workshop that was held in August 2011 in Denver, CO, with approximately 40 attendees. The workshop began the process leading to a foundational Technical Input Report (TIR), the Great Plains Regional Climate Assessment Technical Report. The TIR consists of 18 chapters assembled by 37 authors representing a wide range of inputs including governmental agencies, non-governmental organizations, tribes, and other entities.

The chapter author team engaged in multiple technical discussions via regular teleconferences. These included careful review of the foundational TIR⁸ and of approximately 50 additional technical inputs provided by the public, as well as the other published literature, and professional judgment. These discussions were followed by expert deliberation of draft key messages by the authors during an in-person meeting in Kansas City in April 2012, wherein each message was defended before the entire author team prior to the key message being selected for inclusion in the report. These discussions were supported by targeted consultation with additional experts by the lead author of each message, and they were based on criteria that help define "key vulnerabilities".

KEY MESSAGE #1 TRACEABLE ACCOUNT

Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the Technical Input Report.⁵ Technical inputs (47) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Temperatures are rising across the United States (Ch. 2: Our Changing Climate, Key Message 3 and its Traceable Account).

Specific details for the Great Plains are provided in the Regional Climate Trends and Scenarios for the U.S. National Climate Assessment⁴ with its references.

Rising temperatures impact energy and water (Ch.10: Energy, Water, and Land; Ch. 4: Energy). Publications have explored the projected increase in water competition and stress for natural resources^{7,13,14,17} and the fragmentation of natural habitats and agricultural lands. These sources provided numerous references that were drawn from to lead to this key message.

New information and remaining uncertainties

A key uncertainty is the exact rate and magnitude of the projected changes in precipitation, because high inter-annual variability may either obscure or highlight the long-term trends over the next few years.

Confidence Level

Very High

Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus

High

Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus

Medium

Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought

Low

Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Also unknown is ecological demand for water. Water use by native and invasive species under current climate needs to be quantified so that it can be modeled under future scenarios to map out potential impact envelopes. There is also uncertainty over the projections of changes in precipitation due to difficulty of modeling projections of convective precipitation, which is the primary source of water for most of the Great Plains.

Assessment of confidence based on evidence

Very High for all aspects of the key message. The relationship between increased temperatures and higher evapotranspiration is well established. Model projections of higher temperatures are robust. Confidence is highest for the southern Great Plains, where competition among sectors, cities, and states for future supply is already readily apparent, and where population growth (demand-side) and projected increases in precipitation deficits are greatest.

KEY MESSAGE #2 TRACEABLE ACCOUNT

Changes to crop growth cycles due to warming winters and alterations in the timing and magnitude of rainfall events have already been observed; as these trends continue, they will require new agriculture and livestock management practices.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the Great Plains Technical Input Report.⁵ Technical inputs (47) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence for altered precipitation across the U.S. is discussed in Ch. 2: Our Changing Climate, Key Message 5 and 6 and their Traceable Accounts. Specific details for the Great Plains, such as warming winters and altered rainfall events are in the Climate Trends and Scenarios for the U.S. National Climate Assessment⁴ with its references.

Limitations of irrigation options in the High Plains aquifer have been detailed. The impacts of shifting from irrigated to rain-fed agriculture have also been detailed. Studies document negative impacts on livestock production through the Great Plains.

New information and remaining uncertainties

A key issue (uncertainty) is rainfall patterns. Although models show a general increase in the northern Great Plains and a decrease in the southern Great Plains, the diffuse gradient between the two leaves uncertain the location of greatest impacts on the hydrologic cycle. Timing of precipitation is critical to crop planting, development and harvesting; shifts in seasonality of precipitation therefore need to be quantified. Rainfall patterns will similarly affect forage production, particularly winter wheat that is essential to cattle production in the southern Great Plains.

Assessment of confidence based on evidence

The general pattern of precipitation changes and overall increases in temperature are robust. The implications of these changes are enormous, although assessing changes in more specific locations is more uncertain. Our assessment is based on the climate projections and known relationships to crops (for example, corn not being able to "rest" at night due to high minimum temperatures), but pinpointing where these impacts will occur is difficult. Additionally, other factors that influence productivity, such as genetics, technological change, economic incentives, and federal and state policies, can alter or accelerate the impacts. Given the evidence and remaining uncertainties, agriculture and livestock management practices will need to adjust to these changes in climate and derived aspects although specific changes are yet to be determined. Overall, confidence is high.

KEY MESSAGE #3 TRACEABLE ACCOUNT

Landscape fragmentation is increasing, for example, in the context of energy development activities in the northern Great Plains. A highly fragmented landscape will hinder adaptation of species when climate change alters habitat composition and timing of plant development cycles.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the Great Plains Technical Input Report.⁵ Technical inputs (47) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

A number of publications have explored the changes in habitat composition, ³⁹ plant distribution and development cycles ^{22,23,43} and animal distributions. ^{36,38,44}

New information and remaining uncertainties

In general, the anticipated carbon dioxide enrichment, warming, and increase in precipitation variability influence vegetation primarily by affecting soil-water availability to plants. This is especially important as the transition between water surplus and water deficit (based on precipitation minus evapotranspiration) occurs across the Great Plains, with eastern areas supporting more biomass than western areas, especially given the current east-to-west difference in precipitation and the vegetation it supports. These effects are evident in experiments with each of the individual aspects of climate change. It is difficult to project, however, all of the interactions with all of the vegetative species of the Great Plains, so as to better manage ecosystems.

Several native species have been in decline due to habitat fragmentation, including quail, ocelots, and lesser prairie chickens. Traditional adaptation methods of migration common to the Great Plains, such as bison herds had historically done, are less of an option as animals are confined to particular locations due to habitat fragmentation. As habitats change due to invasive species of

plant and animals and as climate change reduces viability of native vegetation, the current landscapes may be incapable of supporting these wildlife populations.³⁸

Assessment of confidence based on evidence

Confidence is **very high** that landscape is already fragmented and will continue to become more fragmented as energy exploration expands into less suitable agriculture lands that have not been developed as extensively. The effects of carbon dioxide and water availability on individual species are well known, but there is less published research on the interaction among different species. Evidence for the impact of climate change on species is **very high**, but specific adaptation strategies used by these species are less certain. Because of the more limited knowledge on adaptation strategies, we rate this key message overall has having **high** confidence. Our assessment is based upon historical methods, such as migration, used by species across the Great Plains to adapt to previous changes in climate and habitats and the incompatibility of those methods with current land-use practices.

KEY MESSAGE #4 TRACEABLE ACCOUNT

Communities that are already the most vulnerable to weather and climate extremes will be stressed even further by more frequent extreme events occurring within an already highly variable climate system.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the Technical Input Report. ⁵ Technical inputs (47) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Extreme events are documented for the nation (Ch. 2: Our Changing Climate, Key Message 7), and for the region in the Climate Trends and Scenarios for the U.S. National Climate Assessment.⁴

There are a few studies documenting the vulnerability of communities in remote locations with sparse infrastructure, limited local services, and aging populations (Ch. 14: Rural Communities), ⁵¹ with some areas inhibited by language barriers. ⁵³ Changes in the tribal communities have been documented on a number of issues. ^{54,55,56,58}

New information and remaining uncertainties

A key issue (uncertainty) is how limited financial resources will be dedicated to adaptation actions and the amount of will and attention that will be paid to decreasing vulnerability and increasing resilience throughout the region. Should the awareness of damage grow great enough, it may overcome the economic incentives for development and change perspectives, allowing for increased adaptive response. But if current trends continue, more vulnerable lands may be lost. Thus the outcome on rural and vulnerable populations is largely unknown.

Assessment of confidence based on evidence

Extensive literature exists on vulnerable populations, limited resources and ability to respond to change. However, because the expected magnitude of changes is beyond previous experience and societal response is unknown, so the overall confidence is **high**.

KEY MESSAGE #5 TRACEABLE ACCOUNT

The magnitude of expected changes will exceed those experienced in the last century. Existing adaptation and planning efforts are inadequate to respond to these projected impacts.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the Great Plains Technical Input Report. Technical inputs (47) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

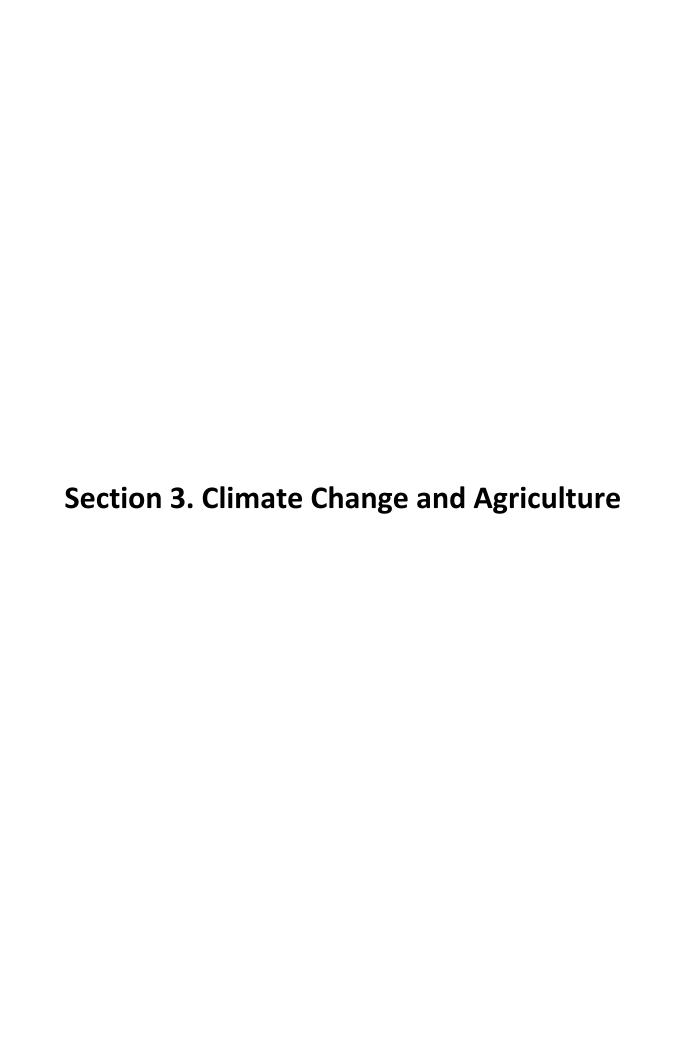
A number of publications have looked at the requirements for adaptation of human and natural systems to climate change. These requirements include large- and small-scale planning, ^{8,59,62} emphasis on restoring ecological systems and processes, ⁶¹ realizing the importance of natural systems, ^{62,63} and aligning the social and ecological goals. ⁶⁴

New information and remaining uncertainties

No clear catalog of ongoing adaptation activities exists for the Great Plains region. Initial steps towards such a catalog have been supported by the National Climate Assessment in association with NOAA's Regional Integrated Sciences and Assessments teams. The short-term nature of many planning activities has been described. ⁶⁵ Until a systematic assessment is conducted, most examples of adaptation are anecdotal. However, stresses in physical and social systems are readily apparent, as described in the other key messages. How communities, economic sectors, and social groups will respond to these stresses needs further study.

Assessment of confidence based on evidence

Climate trends over the past century, such as North Dakota warming more than any other state in the contiguous U.S., coupled with evidence of ecological changes and projections for further warming indicates **very high** confidence that climate patterns will be substantially different than those of the preceding century. While systematic evidence is currently lacking, emerging studies point toward a proclivity toward short-term planning and incremental adjustment rather than long-term strategies for evolving agricultural production systems, habitat management, water resources and societal changes. Evidence suggests that adaptation is *ad hoc* and isolated and will likely be inadequate to address the magnitude of social, economic, and environmental challenges that face the region. Overall confidence is **medium**.



Climate Change and Agriculture Fact Sheet Series E3149 April 2011

FIELD CROP AGRICULTURE AND CLIMATE CHANGE

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How are greenhouse gases related to agriculture?

Greenhouse gases such as carbon dioxide occur naturally in the atmosphere and keep the Earth warm, allowing us to survive on Earth. Over the last 200 years, the amount of greenhouse gases in the atmosphere has increased as a result of burning fossil fuels and other human activities¹. The majority of scientists agree that increased greenhouse gas levels are causing Earth's average global temperature to rise. Consequently, we experience changes in climate at the local level (see MSU Extension E3148).

Field crop agriculture both emits and consumes greenhouse gases that affect climate – so agricultural management and policies can help combat climate change.

Two of the most important greenhouse gases are related to field crop agriculture: carbon dioxide (CO₂) and nitrous oxide (N₂O). Field crop agricultural practices both emit these gases and remove them from the atmosphere. For example, through photosynthesis crops remove carbon dioxide from the atmosphere and use it to build plant tissue. Some of this carbon can be stored in the soil as soil organic matter. However, when soil is tilled, microbes are stimulated to more quickly

convert organic carbon to carbon to carbon dioxide, which escapes into the atmosphere. In most farmed soils, tillage has caused the release of 40–60% of original soil carbon². Soil microbes can also emit nitrous oxide, especially when there is excess nitrogen that plants do not use.

Ultimately, the way we farm the land can directly affect the amount of important greenhouse gases in the atmosphere.

In 2008, agriculture contributed about 7% of human-based greenhouse gas emissions in the United States³. Much of this impact comes from the more potent greenhouse gases (see MSU Extension E3148): methane largely from animal agriculture and nitrous oxide largely from field crop agriculture. Agricultural soil management was responsible for 68% of total nitrous oxide emissions; these emissions are greatly influenced by the amount of nitrogen fertilizer applied, the crop grown, and the weather patterns³. Figure 1 shows the relative contribution of major agricultural greenhouse gas sources in the United States.

How will climate change affect Michigan field crop agriculture?

Global warming is likely to bring local shifts in temperature and in the amount and seasonal distribution of precipitation. It is also likely to result in more extreme weather such as droughts and periods of heavy precipitation. Such changes can affect plant growth, the spread of pests and diseases, and water availability in both positive and negative ways (Table 1).

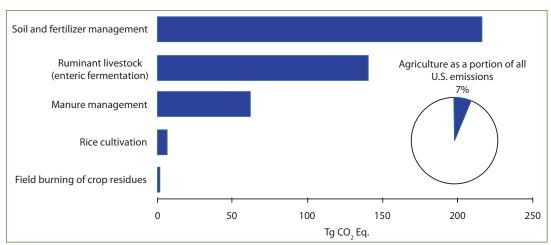


Figure 1: Relative contributions of agriculture to greenhouse gas emissions in 2008 (expressed in the unit CO₂-equivalents). Total emissions increased by 16% from 1990–2008 from the U.S. agricultural sector. (Figure adapted from EPA 2010³.)

There are feedbacks so the issue is consequently complicated. For example, while greater rainfall and a longer growing season can enhance crop growth, they can also lead to more plant disease and different and perhaps more virulent pests. Furthermore, if the greater precipitation occurs in winter rather than summer, then the longer growing season will not enhance rainfed yields and may delay springtime soil drying. If, on the other hand, the greater precipitation occurs in summer but in more intense storms, the benefit may be offset by nitrogen loss, erosion, and other fertility problems.

For now, the takeaway message is uncertainty. The climate is changing, and changes are likely to happen more rapidly in the future. We do not know exactly how climate change will affect Michigan field crops, but we know there will be change, and the better we are prepared for it the more we can use it to our benefit. Agriculture's ability to be nimble in adapting, as well as having good information about changes and adaptive measures is key⁴. Below we discuss how documented and predicted changes in climate have the potential to affect field crop agriculture. See MSU Extension E3152 and E3153 for a detailed description of crop adaptation and soil management in response to changes in climate.

Table 1: Representation of positive and negative impacts of climate change on field crop agriculture			
Good or Bad for Ag?	Good	Bad	
Increased CO ₂ concentrations	✓	✓	
Warmer temperatures	✓	✓	
Greater weather variability		✓	
Crops more vulnerable to pests		✓	
Longer growing season	1		
More precipitation	1	1	

Increased carbon dioxide concentrations in the atmosphere (carbon fertilization): Almost all plants utilize one of two types of photosynthesis, C3 or C4. The difference between these types is how the plant uses carbon dioxide in the growth process. Michigan C3 crops include soybeans and wheat while corn is a C4 plant. In general, crop yields are enhanced by more carbon dioxide, with C3 plants responding more strongly than C4 plants, so long as other factors such as water availability are not limiting their growth⁵. However, estimates of increased yield from elevated carbon dioxide may be overestimated as most of these experiments have been conducted in enclosures that fail to represent field conditions and do not account for interacting factors such as weeds, nutrients, soil water, and decreased air quality^{5,6}.

Warmer temperatures: The general warming trend of the Midwestern United States could allow varieties of crops typically planted in more southern climates to be planted further north^{7,8}. While warmer temperatures can increase crop productivity¹, there is an optimum temperature for reproductive growth. Once this maximum is exceeded, plant and seed growth is diminished. This can reduce yields⁹. Water availability also can become more limited as higher temperatures increase plant water use.

More precipitation: While more rainfall during the growing season could benefit plants, the likely increases in winter and spring precipitation, heavy downpours, and summer evaporation can lead to more times of floods and water deficits⁸. These predicted changes in precipitation and subsequent excesses or deficits of water in the Midwest would negatively affect field crop agriculture^{7,8}.

Greater weather variability: Though winters may be shorter due to warming temperatures, weather variability can pose an obstacle to some field crops. Unpredictable occurrences like the spring freeze in 2007 or extensive water logging of fields by excessive rainfall could become more common, harming crops⁷.

Crops more vulnerable to pests: Plant pathogens are highly responsive to increased rainfall. Similarly, insect abundance increases with temperatures⁹. Invasive weeds, insects, and pathogens from warmer climates may colonize northern soils, creating new, major pest

problems for field crop farmers⁷. Much more research is needed to understand changes in production due to climate-induced shifts in diseases and weed and insect pests⁵.

Longer growing season: The Upper Midwest stands to benefit from a longer growing season associated with warmer temperatures⁷. Longer growing seasons provide more management flexibility, reduce the risk of early frost, and allow longer-season varieties to be planted.

What can agriculture do about climate change?

Although agriculture contributes to excess greenhouse gases in the atmosphere, it is possible to reduce emissions and even remove carbon dioxide from the atmosphere through specific land management practices. There are three main concepts central to interactions between climate change and agriculture:

- 1) **Mitigation:** intervention to reduce the *sources* or enhance the *sinks* of greenhouse gases¹.
- 2) **Sequestration:** the removal of carbon dioxide from the atmosphere and subsequent storage in carbon sinks (such as oceans, forests, or soils) through physical or biological processes, most notably through photosynthesis¹⁰.
- 3) Adaptation: Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects¹.

Table 2: Mitigation and sequestration strategies for field crop agriculture 11,12				
Goal	Practice	Additional benefit to farmers		
Reduce fossil fuel consumption	Renewable energy sources, improved efficiency equipment, biofuel crop substitution	Saves money, potential new biofuel crops and markets.		
Restore (sequester) soil carbon: increase carbon inputs to soil	Crop diversity through cover crops and rotations; increase crop residue quantity in no-till; manure and compost additions	Improves soil and water quality. Reduces erosion.		
Restore (sequester) soil carbon: reduce carbon loss from soil	Permanent no-till, retain crop residue, perennial crops	Improves soil, water, and air quality. Reduces soil erosion and fuel use.		
Reduce nitrous oxide emissions	Better manage nitrogen fertilizer use	Improves water quality. Saves expenses, time, and labor.	A CONTROL OF THE PARTY OF THE P	

Photos courtesy of KBS LTER - MSU

Table 2 indicates some of the many specific strategies related to agriculture. For example, research in Michigan demonstrated the ability to manage nitrogen fertilizer in a way that maintains yields while reducing nitrous oxide emissions¹³. Likewise, Michigan State University scientists documented how no-till farming restores carbon in the soil¹⁴. Many of the management practices aimed at reducing greenhouse gas emissions have positive impacts on the environment¹², such as improved air, soil, and water quality (Table 2). These environmental benefits can also boost agricultural yields and may help agriculture adapt to changing environmental conditions.

A single mitigation practice such as carbon sequestration alone will not be enough. Table 2 highlights the need for a *portfolio approach*—a combination of management techniques combined with strategies such as alternative energy, reduced energy use, and more energy-efficient equipment (lower emissions). Policy and markets could help provide incentives for farmers though payments and other programs to increase carbon storage and reduce nitrous oxide emissions^{12,15}.

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MANAGEMENT OF NITROGEN FERTILIZER TO REDUCE NITROUS OXIDE (N₂O) EMISSIONS FROM FIELD CROPS

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Improving the management of nitrogen fertilizer for field crops can improve nitrogen use efficiency (saving farmers money) and reduce nitrous oxide emissions (helping the climate).

What is nitrous oxide and why is it important?

Nitrous oxide (N₂O) is an important greenhouse gas that contributes to climate change. Because it has a long atmospheric lifetime (over 100 years) and is about 300 times better at trapping heat than is carbon dioxide¹,

even small emissions of N₂O affect the climate.

Nitrous oxide is produced by microbes in almost all soils. In agriculture, N_2O is emitted mainly from fertilized soils and animal wastes—wherever nitrogen (N) is readily available. In the United States, agriculture accounts for approximately 8 percent of all greenhouse gas emissions but contributes about 75 percent of all N_2O emissions linked to human activity². Of

the three major greenhouse gases emitted naturally—carbon dioxide, methane and N₂O—N₂O is the most important in all field crops but rice³.

This fact sheet explains how better management of N fertilizer can reduce N₂O emissions from crop fields.

How does nitrogen fertilizer increase nitrous oxide emissions?

Farmers add new N to fields either as synthetic fertilizers such as urea or anhydrous ammonia, or as organic fertilizers such as manure. Most synthetic fertilizer N is readily available for uptake by plants; most of the N in organic fertilizer must be converted to inorganic N

before its N is available for uptake. When not taken up by plants, most fertilizer N is mobile, hard to contain in the field and susceptible to loss. Nitrogen from fertilizer can be lost as nitrate to groundwater or as the gases N_2O_2 , dinitrogen (N_3) or ammonia. Typically only about

half of the fertilizer N applied to a crop is taken up by the crop during that growing season⁴ (Figure 1).

Nitrogen applied in excess of crop needs is particularly susceptible to loss. Though the amounts of carbon and oxygen available in soil also affect microbial N₂O production, the presence of inorganic N usually matters most.



Automated greenhouse gas sampling chambers in a wheat field on the KBS Long-term Ecological Research site. These chambers measure nitrous oxide, carbon dioxide and methane emissions multiple times every day throughout the year, allowing researchers to accurately estimate greenhouse gas emissions. *Photo: J.E.Doll, Michigan State University*.

How can nitrogen fertilizer management decrease nitrous oxide emissions?

Because of the strong link between inorganic N in the soil and N_2O production, some emissions are unavoidable. But management that prevents the buildup of inorganic N reduces N_2O emissions. Numerous management strategies can keep soil N in check and minimize N_2O emissions⁵. Many of these strategies also help to keep other forms of N from being lost, including nitrate and ammonia. In general, practices that reduce N_2O emissions increase N use efficiency (NUE), which keeps more of the added N in the crop.

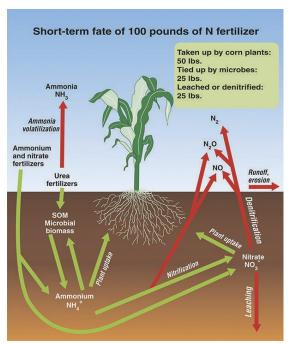


Figure 1: This simplified nitrogen (N) cycle shows the typical fate of 100 pounds of N fertilizer applied to a corn field. The exact amounts vary with soil type, weather and crop. (Source: *Ecologically Based Farming Systems*, 2007⁶.)

The four main management factors that help reduce N_2O emissions from applied N fertilizer are commonly known as the 4R's:

- Right N application rate;
- Right formulation (fertilizer type);
- Right timing of application; and,
- · Right placement.

Matching nitrogen fertilizer application rate to crop requirement

Nitrogen availability — the amount of inorganic N in soil at any given time — is the single best predictor of N_2O fluxes in cropped ecosystems^{7,8}. Michigan State University researchers have shown that N_2O emissions are especially high when N fertilizer is applied at rates greater than crop need. The emission rate grows exponentially with increases in fertilizer rate (see Figure 2), so at higher rates of fertilizer application N_2O emissions increase disproportionately, particularly after crop N demands are met⁹.

Recent fertilizer recommendations for Michigan corn crops provide farmers an improved capacity to predict crop N needs¹⁰. These recommendations are based on dozens of field fertilizer response trials that define the *maximum return to N rate* (MRTN), which is the rate at which adding any additional N is not repaid by higher yields. This rate is typically a bit lower than the *agronomically optimum N rate* (AONR: the maximum

level to which crops respond) by a margin that depends on the price of fertilizer vs. the price of grain¹¹. Typically, using the MRTN approach rather than the older yield-goal approach allows farmers to realize N fertilizer savings. Because both N₂O emissions¹² and nitrate leaching¹³ increase exponentially when N fertilizer exceeds crop N demand, these N savings also can result in substantially lower losses of N₃O and nitrate.

Better estimating the amount of fertilizer N needed by a crop is an effective way to reduce N_2O emitted from cropped fields.

Improving nitrogen fertilizer formulation

Fertilizer formulations also can alter N₂O emissions in some cropping systems. For example, in corn-soybean rotations, emissions can be two to four times greater following anhydrous ammonia than following urea ammonium nitrate or broadcast urea¹⁴. The trend toward using more urea in corn in the United States may help reduce N₂O emissions.

Fertilizer additives can also reduce N₂O emissions. Nitrification inhibitors such as nitrapyrin¹⁵, which delay the microbial transformation of soil ammonium to nitrate, can delay the formation of nitrate until closer to the time that plants can use it. Likewise, urease inhibitors can delay urea fertilizer's dissolving in soil water. Slow-release formulations such as polymer coatings can have the same effect. For example, in irrigated no-till corn, N₂O emissions can be reduced by using polymer-coated urea or a combined nitrification

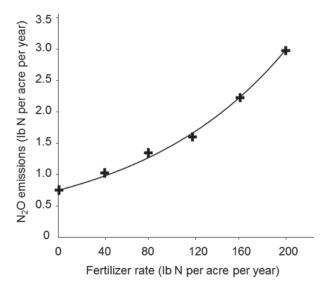


Figure 2: Data from Michigan corn fields¹² showing how nitrous oxide (N_2O) emissions increase exponentially with increasing fertilizer N rate. By more precisely estimating crop fertilizer N needs, farmers can greatly reduce N_3O emissions from their fields.

and urease inhibitor with urea ammonium nitrate, compared with using either urea or urea ammonium nitrate alone¹⁶. As yet, however, there have been too few field studies to fully judge the benefit of additives or fertilizer formulations for N₃O emissions.

Improving nitrogen fertilizer timing

Applying N fertilizer when it is most needed by plants can also help reduce N₂O emissions. Applying the majority of fertilizer a few weeks after planting rather than at or before planting increases the likelihood that the N will end up in the crop rather than be lost to groundwater or the atmosphere. Sidedressing N fertilizer at the V-6 stage in corn, for example, can increase N use efficiency¹⁷— especially if application is preceded by a pre-sidedress-nitrate test (PSNT) to allow residual N to be taken into account¹⁸.

Adding N fertilizer in the fall or spreading manure on frozen fields often leads to especially large nitrate¹⁹ and N_2O^{20} losses. In such cases, fertilizer applications are way out of sync with the timing of crop needs.

Improving nitrogen fertilizer placement

Placing N fertilizer close to plant roots also can reduce $\rm N_2O$ emissions. For example, applying urea in narrow bands next to the plants rather than broadcasting across the field can reduce $\rm N_2O$ emissions. Likewise, emissions are lower when canola and wheat are side-banded rather

than banded midrow²¹. In corn, shallow rather than deep placement of ammonium nitrate or anhydrous ammonia has led to reduced N₂O emissions²².

Precision fertilizer application can also improve NUE by tailoring N application to soil spatial variability. Adding less N to those parts of a field with low yield potential, as measured by yield monitoring, will avoid wasting N on locations in the field that are

not as likely to respond to N fertilizer. In one study, precision fertilizer application reduced the average N fertilizer rate by 22 lb N per acre (25 kg N per hectare)²³, substantially reducing N₂O emissions.

How can we best reduce nitrous oxide emissions from field crop agriculture?

An integrated approach is best suited to reduce N₂O emissions from field crop agriculture. The same principles of N fertilizer best management practices for increased NUE hold true for reducing emissions:

- Apply fertilizer at the economically optimum rate;
- Use an appropriate fertilizer formulation;
- Apply as close to the time of crop need as possible; and,
- Apply as close to the crop's root zone as possible.

Following these practices will, in general, result in more N in the crop and less lost to the environment. These and further potential N₂O mitigation strategies for croplands are summarized in Table 1²⁴.

Earning Carbon Credits for Nitrous Oxide Reductions

As previously mentioned, even small amounts of $\rm N_2O$ in the atmosphere can greatly affect the climate. Because of this, there is great interest in reducing emissions of $\rm N_2O$ from various economic sectors, including field crop agriculture. By using the N management practices described in this bulletin, farmers can reduce $\rm N_2O$ emissions from their fields without reducing crop yield or economic return. This is the basis for programs

offered through carbon credit organizations in the United States that use the marketplace to pay farmers for these reductions.

Most straightforward and accessible programs use a methodology that estimates N₂O emissions reductions on the basis of the reduction of N fertilizer rate. This methodology is based on data collected on commercial Michigan farms^{25,26} and was developed primarily by

developed primarily by Michigan State University scientists. It allows farmers to convert their N₂O emissions reductions to equivalent units of carbon dioxide. These can then be traded as carbon credits on environmental markets to generate income (http://www.deltanitrogen.org/).



Aerial view of the KBS Long-term Ecological Research experiment showing corn's response to varying levels of nitrogen fertilizer rates. Data from this and other experiments across Michigan showed how nitrogen rates can be reduced, resulting in lower nitrous oxide emissions without harming crop yield. *Photo: K.Stepnitz, Michigan State University*

Reductions in N fertilizer input without crop yield loss can best be achieved through the use of an integrated approach that uses corn and fertilizer prices to estimate recommended N rates, and improves management of the formulation, timing and placement of N fertilizer.

These changes in management practice, in combination with programs that pay for the environmental benefits they deliver, help to ensure the long-term sustainability of field crop agriculture, N use, and a stable climate.

Table 1. Proposed and potential nitrous oxide (N2O) mitigation technologies and practices for croplands. Adapted from Cavigelli et al., 2012²⁴.

Technology or Management Practice	Effectiveness and Comments	
Right N fertilizer application rate (applied at the economically optimum rate): N fertilizer refers to both synthetic and organic fertilizers (such as manure).	May reduce $\rm N_2^{}0$ emissions substantially where N fertilizer is applied at rates greater than the economic optimum rate.	
Right N fertilizer source: N fertilizer sources include urea, anhydrous ammonia, urea ammonium nitrate, ammonium nitrate and manure; slow-release fertilizers, such as polycoated urea, are not widely used because of increased costs.	Urea, urea ammonium nitrate and polycoated ureas can decrease N ₂ O emissions by 50 percent or more compared with anhydrous ammonia in some locations, but there is no impact in other locations.	
Right N fertilizer placement: N fertilizer may be broadcast or applied in bands, applied on the surface or below the surface.	Incorporating bands of N in soil can improve nutrient use efficiency and can reduce N ₂ O emissions by about 50 percent compared with broadcast application in some locations.	
Right N fertilizer timing: N fertilizer should be applied as close as possible to when the crop needs it.	Applying N at planting or at times of peak crop N demand can increase nutrient use efficiency and would be expected to decrease N ₂ O emissions, but results from field studies are mixed.	
N process (nitrification and urease) inhibitors	Can decrease N ₂ 0 emissions by 50 percent in dry climates, but results are mixed for humid climates.	
Cover crops	Winter cover crops can reduce N losses (for example, leaching and runoff), but may not affect N ₂ O emissions.	
Crop selection	Low N-demanding crops can reduce N ₂ 0 emissions by more than 50 percent in many places.	
Improved irrigation management: timing, application rate and application method	Reducing application rates to minimize soil wetness can reduce N ₂ 0 emissions. Subsurface drip irrigation can reduce N ₂ 0 emissions compared with overhead sprinkler irrigation because soil moisture is better regulated, but data are limited.	
Reduced tillage	A long-term no-till strategy can reduce $\rm N_2O$ emissions by up to 50 percent, but data are limited. Short-term no-till results are more mixed.	

Notes: The effectiveness of many mitigation options is influenced by soil type and climate, and there are major uncertainties about the effectiveness of most mitigation strategies.

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Climate Change Impacts in the United States

CHAPTER 3 WATER RESOURCES

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On the Web: http://nca2014.globalchange.gov/report/sectors/water



INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

3 WATER RESOURCES

KEY MESSAGES

Climate Change Impacts on the Water Cycle

- 1. Annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions. Very heavy precipitation events have increased nationally and are projected to increase in all regions. The length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States.
- 2. Short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.
- 3. Flooding may intensify in many U.S. regions, even in areas where total precipitation is projected to decline.
- 4. Climate change is expected to affect water demand, groundwater withdrawals, and aquifer recharge, reducing groundwater availability in some areas.
- 5. Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands.
- 6. Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality in many ways, including increases in sediment, nitrogen, and other pollutant loads.

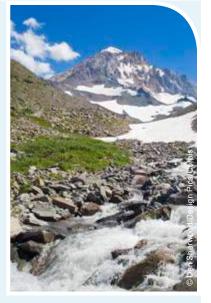
Climate Change Impacts on Water Resources Use and Managment

- 7. Climate change affects water demand and the ways water is used within and across regions and economic sectors. The Southwest, Great Plains, and Southeast are particularly vulnerable to changes in water supply and demand.
- 8. Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses.
- 9. Increasing flooding risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the United States.

Adaptation and Institutional Responses

- 10. In most U.S. regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed within existing practices.
- 11. Increasing resilience and enhancing adaptive capacity provide opportunities to strengthen water resources management and plan for climate change impacts. Many institutional, scientific, economic, and political barriers present challenges to implementing adaptive strategies.

This chapter contains three main sections: climate change impacts on the water cycle, climate change impacts on water resources use and management, and adaptation and institutional responses. Key messages for each section are summarized above.



The cycle of life is intricately joined with the cycle of water.

- Jacques-Yves Cousteau

Climate Change Impacts on the Water Cycle

Water cycles constantly from the atmosphere to the land and the oceans (through precipitation and runoff) and back to the atmosphere (through evaporation and the release of water from plant leaves), setting the stage for all life to exist. The water cycle is dynamic and naturally variable, and societies and ecosystems are accustomed to functioning within this variability. However, climate change is altering the water cycle in multiple ways over different time scales and geographic areas, presenting unfamiliar risks and opportunities.

Key Message 1: Changing Rain, Snow, and Runoff

Annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions. Very heavy precipitation events have increased nationally and are projected to increase in all regions. The length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States.

Annual average precipitation over the continental U.S. as a whole increased by close to two inches (0.16 inches per decade) between 1895 and 2011. ^{1,2} In recent decades, annual average precipitation increases have been observed across the Midwest, Great Plains, the Northeast, and Alaska, while decreases have been observed in Hawai'i and parts of the Southeast and Southwest (Ch. 2: Our Changing Climate, Figure 2.12). Average annual precipitation is projected to increase across the northern U.S., and decrease in the southern U.S., especially the Southwest. (Ch. 2: Our Changing Climate, Figures 2.14 and 2.15). ³

The number and intensity of very heavy precipitation events (defined as the heaviest 1% of all daily events from 1901 to 2012) have been increasing significantly across most of the United States. The amount of precipitation falling in the heaviest daily events has also increased in most areas of the United States (Ch. 2: Our Changing Climate, Figure 2.17). For example, from 1950 to 2007, daily precipitation totals with 2-, 5-, and 10-year average recurrence periods increased in the Northeast and western Great Lakes. Very heavy precipitation events are projected to increase everywhere (Ch. 2: Our Changing Climate, Figure 2.19). Heavy precipitation events that historically occurred once in 20 years are projected to occur as frequently as every 5 to 15 years by late this century. The number and magnitude of the heaviest precipitation events is projected to increase everywhere in the United States (Ch. 2: Our Changing Climate, Figure 2.13).

Dry spells are also projected to increase in length in most regions, especially in the southern and northwestern portions of the contiguous United States (Ch. 2: Our Changing Climate, Figure 2.13). Projected changes in total average annual precipitation are generally small in many areas, but both wet and dry extremes (heavy precipitation events

Projected Changes in Snow, Runoff, and Soil Moisture

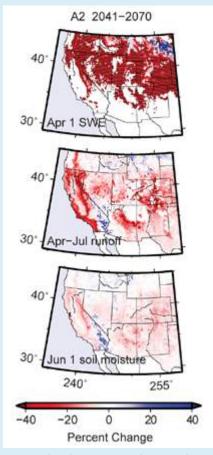


Figure 3.1. These projections, assuming continued increases in heat-trapping gas emissions (A2 scenario; Ch. 2: Our Changing Climate), illustrate: a) major losses in the water content of the snowpack that fills western rivers (snow water equivalent, or SWE); b) significant reductions in runoff in California, Arizona, and the central Rocky Mountains; and c) reductions in soil moisture across the Southwest. The changes shown are for mid-century (2041-2070) as percentage changes from 1971-2000 conditions (Figure source: Cayan et al. 2013¹⁸).

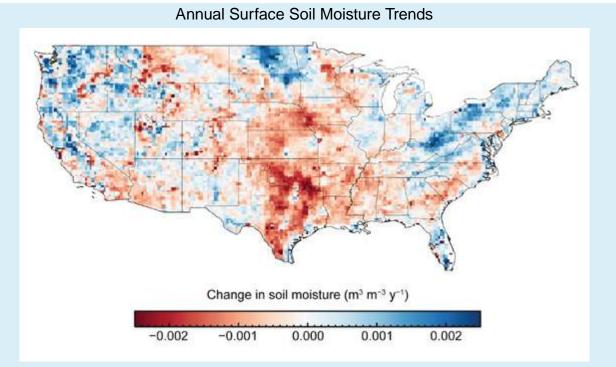


Figure 3.2. Changes in annual surface soil moisture per year over the period 1988 to 2010 based on multisatellite datasets. Surface soil moisture exhibits wetting trends in the Northeast, Florida, upper Midwest, and Northwest, and drying trends almost everywhere else. (Images provided by W. Dorigo³⁵).

and length of dry spells) are projected to increase substantially almost everywhere.

The timing of peak river levels has changed in response to warming trends. Snowpack and snowmelt-fed rivers in much of the western U.S. have earlier peak flow trends since the middle of the last century, including the past decade (Ch. 2: Our Changing Climate). 7,8 This is related to declines in spring snowpack, earlier snowmelt-fed streamflow, and larger percentages of precipitation falling as rain instead of snow. These changes have taken place in the midst of considerable year-to-year variability and long-term natural fluctuations of the western U.S. climate, as well as other influences, such as the effects of dust and soot on snowpacks. 7,9 There are both natural and human influences on the observed trends. 10,111 However, in studies specifically designed to differentiate between natural and human-induced causes, up to 60% of these changes have been attributed to human-induced climate warming, 10 but only among variables that are more responsive to warming than to precipitation variability, such as the effect of air temperature on snowpack.12

Other historical changes related to peak river-flow have been observed in the northern Great Plains, Midwest, and Northeast, ^{13,14} along with striking reductions in lake ice cover (Ch. 2: Our Changing Climate). ^{15,16}

Permafrost is thawing in many parts of Alaska, a trend that not only affects habitats and infrastructure but also mobilizes subsurface water and reroutes surface water in ways not previously witnessed.¹⁷ Nationally, all of these trends are projected to become even more pronounced as the climate continues to warm (Figure 3.1).

Evapotranspiration (ET – the evaporation of moisture from soil, on plants and trees, and from water bodies; and transpiration, the use and release of water from plants), is the second largest component of the water cycle after precipitation. ET responds to temperature, solar energy, winds, atmospheric humidity, and moisture availability at the land surface and regulates amounts of soil moisture, groundwater recharge, and runoff. Transpiration comprises between 80% and 90% of total ET on land (Ch. 6: Agriculture). In snowy settings, sublimation of snow and ice (loss of snow and ice directly into water vapor without passing through a liquid stage) can increase these returns of water to the atmosphere, sometimes in significant amounts. These interactions complicate estimation and projection of regional losses of water from the land surface to the atmosphere.

Globally-averaged ET increased between 1982 and 1997 but stopped increasing, or has decreased, since about 1998. In North America, the observed ET decreases occurred in waterrich rather than water-limited areas. Factors contributing to these ET decreases are thought to include decreasing wind

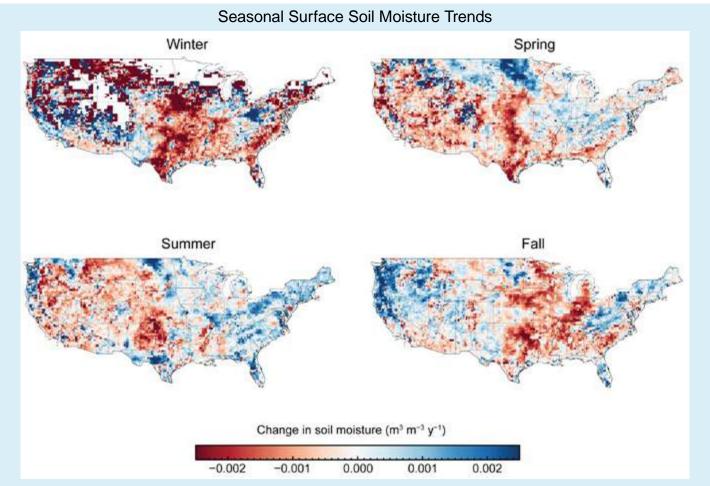


Figure 3.3. Changes in seasonal surface soil moisture per year over the period 1988 to 2010 based on multi-satellite datasets. Seasonal drying is observed in central and lower Midwest and Southeast for most seasons (with the exception of the Southeast summer), and in most of the Southwest and West (with the exception of the Northwest) for spring and summer. Soil moisture in the upper Midwest, Northwest, and most of the Northeast is increasing in most seasons. (Images provided by W. Dorigo).

speed,^{23,24} decreasing solar energy at the land surface due to increasing cloud cover and concentration of small particles (aerosols),²⁵ increasing humidity,²³ and declining soil moisture (Figure 3.2).²⁶

Evapotranspiration projections vary by region, ^{27,28,29,30} but the atmospheric potential for ET is expected to increase; actual ET will be affected by regional soil moisture changes. Much more research is needed to confidently identify historical trends, causes, and implications for future ET trends. ³¹ This represents a critical uncertainty in projecting the impacts of climate change on regional water cycles.

Soil moisture plays a major role in the water cycle, regulating the exchange of water, energy, and carbon between the land surface and the atmosphere, the production of runoff, and the recharge of groundwater aquifers. Soil moisture is projected to decline with higher temperatures and attendant increases in the potential for ET in much of the country, especially in the Great Plains, Southwest, Southwest, and Southeast.

Runoff and streamflow at regional scales declined during the last half-century in the Northwest.³⁶ Runoff and streamflow increased in the Mississippi Basin and Northeast, with no clear trends in much of the rest of the continental U.S.,³⁷ although a declining trend is emerging in annual runoff in the Colorado River Basin.³⁸ These changes need to be considered in the context of tree-ring studies in California's Central Valley, the Colorado River and Wind River basins, and the southeastern U.S. that indicate that these regions have experienced prolonged, even drier and wetter conditions at various times in the past two thousand years.^{8,39,40} Human-caused climate change, when superimposed on past natural variability, may amplify these past extreme conditions. Projected changes in runoff for eight basins in the Northwest, northern Great Plains, and Southwest are illustrated in Figure 3.4.

Basins in the southwestern U.S. and southern Rockies (for example, the Rio Grande and Colorado River basins) are projected to experience gradual runoff declines during this century. Basins in the Northwest to north-central U.S. (for example, the

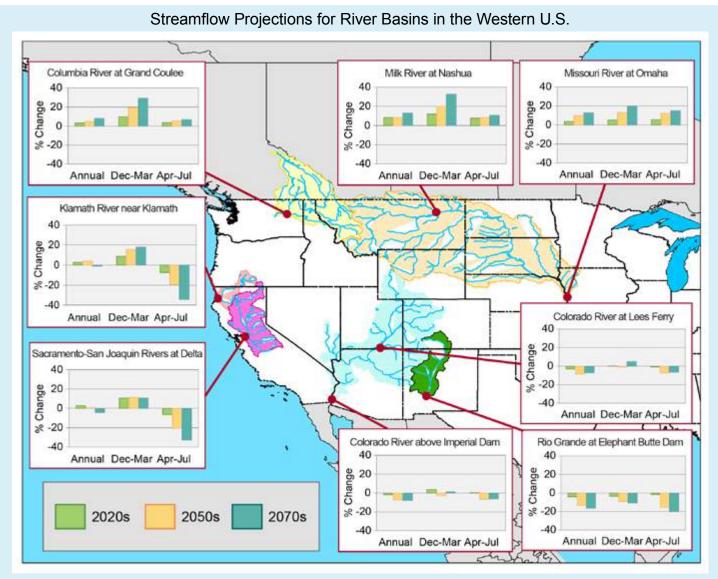


Figure 3.4. Annual and seasonal streamflow projections based on the B1 (with substantial emissions reductions), A1B (with gradual reductions from current emission trends beginning around mid-century), and A2 (with continuation of current rising emissions trends) CMIP3 scenarios for eight river basins in the western United States. The panels show percentage changes in average runoff, with projected increases above the zero line and decreases below. Projections are for annual, cool, and warm seasons, for three future decades (2020s, 2050s, and 2070s) relative to the 1990s. (Source: U.S. Department of the Interior – Bureau of Reclamation 2011; Data provided by L. Brekke, S. Gangopadhyay, and T. Pruitt)

Columbia and the Missouri River basins) are projected to experience little change through the middle of this century, and increases by late this century.

Projected changes in runoff differ by season, with cool season runoff increasing over the west coast basins from California to Washington and over the north-central U.S. (for example, the San Joaquin, Sacramento, Klamath, Missouri, and Columbia River basins). Basins in the southwestern U.S. and southern Rockies are projected to see little change to slight decreases in the winter months.

Warm season runoff is projected to decrease substantially over a region spanning southern Oregon, the southwestern U.S., and southern Rockies (for example, the Klamath, Sacramento, San Joaquin, Rio Grande, and the Colorado River basins), and change little or increase slightly north of this region (for example, the Columbia and Missouri River basins).

In most of these western basins, these projected streamflow changes are outside the range of historical variability, especially by the 2050s and 2070s. The projected streamflow changes and associated uncertainties have water management implications (discussed below).

Key Message 2: Droughts Intensify

Short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.

Annual runoff and related river-flow are projected to decline in the Southwest 42,43 and Southeast, 34 and to increase in the Northeast, Alaska, Northwest, and upper Midwest regions, 52,43,44,45 broadly mirroring projected precipitation patterns. 54 Observational studies 74 have shown that decadal fluctuations in average temperature (up to 1.5°F) and precipitation changes of 10% have occurred in most areas of the U.S. during the last century. Fluctuations in river-flow indicate that effects of temperature are dominated by fluctuations in precipitation. Nevertheless, as warming affects water cycle processes, the amount of runoff generated by a given amount of precipitation is generally expected to decline. 37

Droughts occur on time scales ranging from season-to-season to multiple years and even multiple decades. There has been no universal trend in the overall extent of drought across the continental U.S. since 1900. However, in the Southwest, wide-

spread drought in the past decade has reflected both precipitation deficits and higher temperatures⁸ in ways that resemble projected changes. 48 Long-term (multi-seasonal) drought conditions are also projected to increase in parts of the Southeast and possibly in Hawai'i and the Pacific Islands (Ch. 23: Hawai'i and Pacific Islands). Except in the few areas where increases in summer precipitation compensate, summer droughts (Ch. 2: Our Changing Climate) are expected to intensify almost everywhere in the continental U.S. 49 due to longer periods of dry weather and more extreme heat,³³ leading to more moisture loss from plants and earlier soil moisture depletion in basins where snowmelt shifts to earlier in the year. 50,51 Basins watered by glacial melt in the Sierra Nevada, Glacier National Park, and Alaska may experience increased summer river-flow in the next few decades, until the amounts of glacial ice become too small to contribute to river-flow. 52,53

Key Message 3: Increased Risk of Flooding in Many Parts of the U.S.

Flooding may intensify in many U.S. regions, even in areas where total precipitation is projected to decline.

There are various types of floods (see "Flood Factors and Flood Types"), some of which are projected to increase with continued climate change. Floods that are closely tied to heavy precipitation events, such as flash floods and urban floods, as well as coastal floods related to sea level rise and the resulting increase in storm surge height and inland impacts, are expected to increase. Other types of floods result from a more complex set of causes. For example, river floods are basin specific and dependent not only on precipitation but also on pre-existing soil moisture conditions, topography, and other factors, including important human-caused changes to watersheds and river courses across the United States. 54,55,56,57

Significant changes in annual precipitation (Ch. 2: Our Changing Climate) and soil moisture (Figures 3.2 and 3.3), among other factors, are expected to affect annual flood magnitudes (Figure 3.5) in many regions. ⁵⁸ River floods have been increasing in the Northeast and Midwest, and decreasing in the Southwest and Southeast. ^{56,57,58,59} These decreases are not surprising, as short duration very heavy precipitation events often occur during the summer and autumn when rivers are generally low.

However, these very heavy precipitation events can and do lead to flash floods, often exacerbated in urban areas by the effect of impervious surfaces on runoff.

Heavy rainfall events are projected to increase, which is expected to increase the potential for flash flooding. Land cover, flow and water-supply management, soil moisture, and channel conditions are also important influences on flood generation and must be considered in projections of future flood risks. Region-specific storm mechanisms and seasonality also affect flood peaks. Because of this, and limited capacity to project future very heavy events with confidence, evaluations of the relative changes in various storm mechanisms may be useful. Warming is likely to directly affect flooding in many mountain settings, as catchment areas receive increasingly more precipitation as rain rather than snow, or more rain falling on existing snowpack. In some such settings, river flooding may increase as a result – even where precipitation and overall river flows decline (Ch. 2: Our Changing Climate).

Trends in Flood Magnitude



Figure 3.5. Trend magnitude (triangle size) and direction (green = increasing trend, brown = decreasing trend) of annual flood magnitude from the 1920s through 2008. Flooding in local areas can be affected by multiple factors, including land-use change, dams, and diversions of water for use. Most significant are increasing trends for floods in Midwest and Northeast, and a decreasing trend in the Southwest. (Figure source: Peterson et al. 2013⁶³).

Key Message 4: Groundwater Availability

Climate change is expected to affect water demand, groundwater withdrawals, and aquifer recharge, reducing groundwater availability in some areas.

Groundwater is the only perennial source of fresh water in many regions and provides a buffer against climate extremes. As such, it is essential to water supplies, food security, and ecosystems. Though groundwater occurs in most areas of the U.S., the capacity of aquifers to store water varies depending on the geology of the region. (Figure 3.6b illustrates the importance of groundwater aquifers.) In large regions of the Southwest, Great Plains, Midwest, Florida, and some other coastal areas, groundwater is the primary water supply. Groundwater aquifers in these areas are susceptible to the combined stresses of climate and water-use changes. For example, during the 2006–2009 California drought, when the source of irrigation shifted from surface water to predominantly groundwater, groundwater storage in California's Central Valley declined by an amount roughly equivalent to the storage capacity of Lake Mead, the largest reservoir in the United States. 64

Climate change impacts on groundwater storage are expected to vary from place to place and aquifer to aquifer. Although precise responses of groundwater storage and flow to climate change are not well understood nor readily generalizable, recent and ongoing studies^{65,66,67,68} provide insights on various underlying mechanisms:

 Precipitation is the key driver of aquifer recharge in waterlimited environments (like arid regions), while evapotranspiration (ET) is the key driver in energy-limited environments (like swamps or marshlands).

- Climate change impacts on aquifer recharge depend on several factors, including basin geology, frequency and intensity of high-rainfall periods that drive recharge, seasonal timing of recharge events, and strength of groundwater-surface water interaction.
- 3) Changes in recharge rates are amplified relative to changes in total precipitation, with greater amplification for drier areas.

With these insights in mind, it is clear that certain groundwater-dependent regions are projected to incur significant climate change related challenges. In some portions of the country, groundwater provides nearly 100% of the water supply (Figure 3.6b). Seasonal soil moisture changes are a key aquifer recharge driver and may provide an early indication of general aquifer recharge trends. Thus, the observed regional reductions in seasonal soil moisture for winter and spring (Figure 3.3) portend adverse recharge impacts for several U.S. regions, especially the Great Plains, Southwest, and Southeast.

Despite their critical national importance as water supply sources (see Figure 3.6), aquifers are not generally monitored

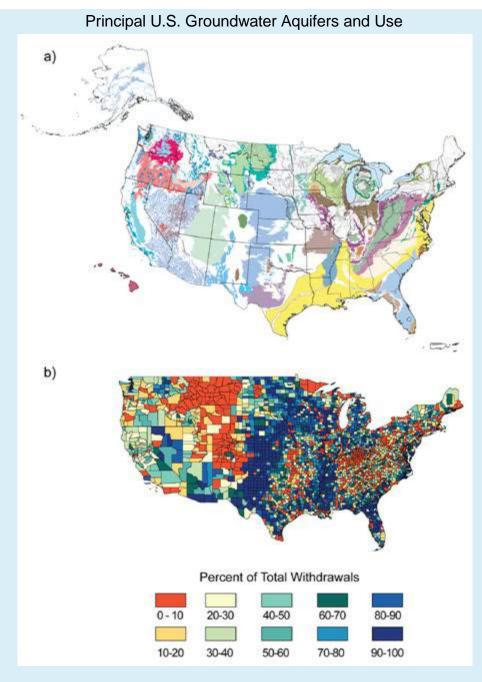


Figure 3.6. (a) Groundwater aquifers are found throughout the U.S., but they vary widely in terms of ability to store and recharge water. The colors on this map illustrate aquifer location and geology: blue colors indicate unconsolidated sand and gravel; yellow is semi-consolidated sand; green is sandstone; blue or purple is sandstone and carbonate-rock; browns are carbonate-rock; red is igneous and metamorphic rock; and white is other aquifer types. (Figure source: USGS). (b) Ratio of groundwater withdrawals to total water withdrawals from all surface and groundwater sources by county. The map illustrates that aquifers are the main (and often exclusive) water supply source for many U.S. regions, especially in the Great Plains, Misssissippi Valley, east central U.S., Great Lakes region, Florida, and other coastal areas. Groundwater aquifers in these regions are prone to impacts due to combined climate and water-use change. (Data from USGS 2005).

in ways that allow for clear identification of climatic influences on groundwater recharge, storage, flows, and discharge. Nearly all monitoring is focused in areas and aquifers where variations are dominated by groundwater pumping, which largely masks climatic influences, ⁶⁹ highlighting the need for a national framework for groundwater monitoring. ⁷⁰

Generally, impacts of changing demands on groundwater systems, whether due directly to climate changes or indirectly through changes in land use or surface-water availability and management, are likely to have the most immediate effects on groundwater availability; ^{67,71} changes in recharge and storage may be more subtle and take longer to emerge. Groundwater models have only recently begun to include detailed represen-

tations of groundwater recharge and interactions with surface-water and land-surface processes, with few projections of groundwater responses to climate change. However, surface water declines have already resulted in larger groundwater withdrawals in some areas (for example, in the Central Valley of California and in the Southeast) and may be aggravated by climate change challenges. In many mountainous areas of the U.S., groundwater recharge is disproportionately generated from snowmelt infiltration, suggesting that the loss of snowpack will affect recharge rates and patterns. Models do not yet include dynamic representations of the groundwater reservoir and its connections to streams, the soil-vegetation system, and the atmosphere, limiting the understanding of the

potential climate change impacts on groundwater and groundwater-reliant systems. 75

As the risk of drought increases, groundwater can play a key role in enabling adaptation to climate variability and change. For example, groundwater can be augmented by surface water during times of high flow through aquifer recharge strategies, such as infiltration basins and injection wells. In addition, management strategies can be implemented that use surface water for irrigation and water supply during wet periods, and groundwater during drought, although these approaches face practical limitations within current management and institutional frameworks. 71,76

Key Message 5: Risks to Coastal Aquifers and Wetlands

Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands.

With more than 50% of the nation's population concentrated near coasts (Chapter 25: Coasts), 77 coastal aquifers and wetlands are precious resources. These aquifers and wetlands, which are extremely important from a biological/biodiversity perspective (see Ch. 8: Ecosystems; Ch. 25: Coasts), may be particularly at risk due to the combined effects of inland droughts and floods, increased surface water impoundments and diversions, increased groundwater withdrawals, and accelerating sea level rise and greater storm surges. 78,79 Estuaries are particularly vulnerable to changes in freshwater inflow and sea level rise by changing salinity and habitat of these areas.

Several coastal areas, including the Delaware, Susquehanna, and Potomac River deltas on the Northeast seaboard, most of Florida, the Apalachicola and Mobile River deltas and bays, the Mississippi River delta in Louisiana, and the delta of the Sacramento-San Joaquin rivers in northern California, are particularly vulnerable due to the combined effects of climate change and other human-caused stresses. In response, some coastal communities are among the nation's most proactive in adaptation planning (Chapter 25: Coasts).

Key Message 6: Water Quality Risks to Lakes and Rivers

Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality in many ways, including increases in sediment, nitrogen, and other pollutant loads.

Water temperature has been increasing in some rivers. ⁸⁰ The length of the season that lakes and reservoirs are thermally stratified (with separate density layers) is increasing with increased air and water temperatures. ^{81,82} In some cases, seasonal mixing may be eliminated in shallow lakes, decreasing dissolved oxygen and leading to excess concentrations of nutrients (nitrogen and phosphorous), heavy metals (such as mercury), and other toxins in lake waters. ^{81,82}

Lower and more persistent low flows under drought conditions as well as higher flows during floods can worsen water quality. Increasing precipitation intensity, along with the effects of wild-fires and fertilizer use, are increasing sediment, nutrient, and contaminant loads in surface waters used by downstream water users and ecosystems. Mineral weathering products, like calcium, magnesium, sodium, and silicon and nitrogen loads have been increasing with higher streamflows. Changing land

cover, flood frequencies, and flood magnitudes are expected to increase mobilization of sediments in large river basins. 87



Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease water quality in many ways. Here, middle school students in Colorado learn about water quality.

Changes in sediment transport are expected to vary regionally and by land-use type, with potentially large increases in some areas, ⁸⁸ resulting in alterations to reservoir storage and river channels, affecting flooding, navigation, water supply, and dredging. Increased frequency and duration of droughts, and associated low water levels, increase nutrient concentrations and residence times in streams, potentially increasing the like-

lihood of harmful algal blooms and low oxygen conditions.⁸⁹ Concerns over such impacts and their potential link to climate change are rising for many U.S. regions including the Great Lakes,⁹⁰ Chesapeake Bay,⁹¹ and the Gulf of Mexico.^{85,86} Strategies aiming to reduce sediment, nutrient, and contaminant loads at the source remain the most effective management responses.⁹²

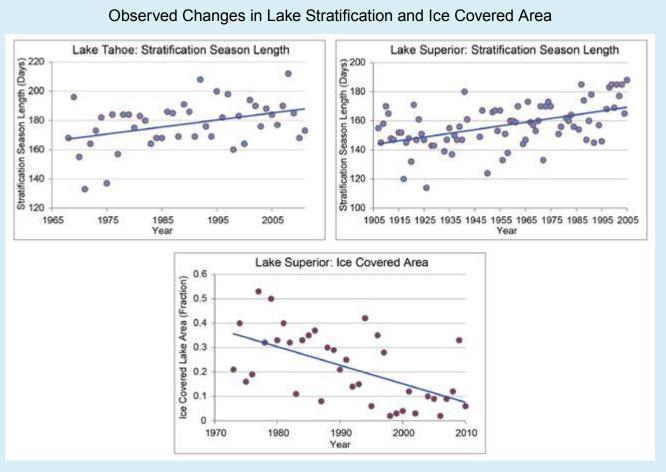


Figure 3.7. The length of the season in which differences in lake temperatures with depth cause stratification (separate density layers) is increasing in many lakes. In this case, measurements show stratification has been increasing in Lake Tahoe (top left) since the 1960s and in Lake Superior (top right) since the early 1900s in response to increasing air and surface water temperatures (see also Ch. 18: Midwest). In Lake Tahoe, because of its large size (relative to inflow) and resulting long water-residence times, other influences on stratification have been largely overwhelmed, and warming air and water temperatures have caused progressive declines in near-surface density, leading to longer stratification seasons (by an average of 20 days), decreasing the opportunities for deep lake mixing, reducing oxygen levels, and causing impacts to many species and numerous aspects of aquatic ecosytems. Similar effects are observed in Lake Superior, where the stratification season is lengthening (top right) and annual ice-covered area is declining (bottom); both observed changes are consistent with increasing air and water temperatures.

Relationship between Historical and Projected Water Cycle Changes

Natural climate variations occur on essentially all time scales from days to millennia, and the water cycle varies in much the same way. Observations of changes in the water cycle over time include responses to natural hydroclimatic variability as well as other, more local, human influences (like dam building or land-use changes), or combinations of these influences with human-caused climate change. Some recent studies

have attributed specific observed changes in the water cycle to human-induced climate change (for example, Barnett et al. 2008¹⁰). For many other water cycle variables and impacts, the observed and projected responses are consistent with those expected by human-induced climate change and other human influences. Research aiming to formally attribute these responses to their underlying causes is ongoing.

FLOOD FACTORS AND FLOOD TYPES

A flood is defined as any high flow, overflow, or inundation by water that causes or threatens damage.⁹³ Floods are caused or amplified by both weather- and human-related factors. Major weather factors include heavy or prolonged precipitation, snowmelt, thunderstorms, storm surges from hurricanes, and ice or debris jams. Human factors include structural failures of dams and levees, inadequate drainage, and land cover alterations (such as pavement or deforestation) that reduce the capacity of the land surface to absorb water. Increasingly, humanity is also adding to weather-related factors, as human-induced warming increases heavy downpours, causes more extensive storm surges due to sea level rise, and leads to more rapid spring snowmelt.

Worldwide, from 1980 to 2009, floods caused more than 500,000 deaths and affected more than 2.8 billion people. In the U.S., floods caused 4,586 deaths from 1959 to 2005 while property and crop damage averaged nearly \$8 billion per year (in 2011 dollars) over 1981 through 2011. The risks from future floods are significant, given expanded development in coastal areas and floodplains, unabated urbanization, land-use changes, and human-induced climate change. He was a significant of the coastal area and floodplains, unabated urbanization, land-use changes, and human-induced climate change.

Major flood types include flash, urban, riverine, and coastal flooding:

Flash floods occur in small and steep watersheds and waterways and can be caused by short-duration intense precipitation, dam or levee failure, or collapse of debris and ice jams. Snow cover and frozen ground conditions can exacerbate flash flooding during winter and early spring by increasing the fraction of precipitation that runs off. Flash floods develop within minutes or hours of the causative event, and can result in severe damage and loss of life due to high water velocity, heavy debris load, and limited warning. Most flood-related deaths in the U.S. are associated with flash floods.

Urban flooding can be caused by short-duration very heavy precipitation. Urbanization creates large areas of impervious surfaces (such as roads, pavement, parking lots, and buildings) and increases immediate runoff. Stormwater drainage removes excess surface water as quickly as possible, but heavy downpours can exceed the capacity of drains and cause urban flooding.

Flash floods and urban flooding are directly linked to heavy precipitation and are expected to increase as a result of projected increases in heavy precipitation events. In mountainous watersheds, such increases may be partially offset in winter and spring due to projected snowpack reduction.

Riverine flooding occurs when surface water drains from a watershed into a stream or a river exceeds channel capacity, overflows the



Flash Flooding: Cave Creek, Arizona (Photo credit: Tom McGuire).





Riverine Flooding: In many regions, infrastructure is currently vulnerable to flooding, as demonstrated in these photos. Left: The Fort Calhoun Nuclear Power Plant in eastern Nebraska was surrounded by a Missouri River flood on June 8, 2011, that also affected Louisiana, Mississippi, Missouri, Illinois, Kentucky, Tennessee, and Arkansas (photo credit: Larry Geiger). Right: The R.M. Clayton sewage treatment plant in Atlanta, Georgia, September 23, 2009, was engulfed by floodwaters forcing it to shut down and resulting in the discharge of raw sewage into the Chattahoochee River (photo credit: Reuters/David Tulis). Flooding also disrupts road and rail transportation, and inland navigation.

Continued

FLOOD FACTORS AND FLOOD TYPES (CONTINUED)

banks, and inundates adjacent low lying areas. Riverine flooding is commonly associated with large watersheds and rivers, while flash and urban flooding occurs in smaller natural or urban watersheds. Because heavy precipitation is often localized, riverine flooding typically results from multiple heavy precipitation events over periods of several days, weeks, or even months. In large basins, existing soil moisture conditions and evapotranspiration rates also influence the onset and severity of flooding, as runoff increases with wetter soil and/or lower evapotranspiration conditions. Snow cover and frozen ground conditions can also exacerbate riverine flooding during winter and spring by increasing runoff associated with rain-on-snow events and by snowmelt, although these effects may diminish in the long term as snow accumulation decreases due to warming. Since riverine flooding depends on precipitation as well as many other factors, projections about changes in frequency or intensity are more uncertain than with flash and urban flooding.

Coastal flooding is predominantly caused by storm surges that accompany hurricanes and other storms. Low storm pressure creates strong winds that create and push large sea water domes, often many miles across, toward the shore. The approaching domes can raise the water surface above normal tide levels (storm surge) by more than 25 feet, de-

pending on various storm and shoreline factors. Inundation, battering waves, and floating debris associated with storm surge can cause deaths, widespread infrastructure damage (to buildings, roads, bridges, marinas, piers, boardwalks, and sea walls), and severe beach erosion. Stormrelated rainfall can also cause inland flooding (flash, urban, or riverine) if, after landfall, the storm moves slowly or stalls over an area. Inland flooding can occur close to the shore or hundreds of miles away and is responsible for more than half of the deaths associated with tropical storms.93 Climate change affects coastal flooding through sea level rise and storm surge, increases in heavy rainfall during hurricanes and coastal rivers.



other storms, and related increases in flooding in (Photo credit: New Jersey National Guard/Scott Anema).

In some locations, early warning systems have helped reduce deaths, although property damage remains considerable (Ch. 28: Adaptation). Further improvements can be made by more effective communication strategies and better landuse planning.⁹⁴

Climate Change Impacts on Water Resource Uses and Management

People use water for many different purposes and benefits. Our water use falls into five main categories: 1) municipal use, which includes domestic water for drinking and bathing; 2) agricultural use, which includes irrigation and cattle operations; 3) industrial use, which includes electricity production from coal- or gas-fired power plants that require water to keep the machinery cool; 4) providing ecosystem benefits, such as supporting the water needs of plants and animals we depend on; and 5) recreational uses, such as boating and fishing.

Water is supplied for these many uses from two main sources:

- freshwater withdrawals (from streams, rivers, lakes, and aquifers), which supply water for municipal, industrial, agricultural, and recirculating thermoelectric plant cooling water supply;
- instream surface water flows, which support hydropower production, once-through thermoelectric plant cooling, navigation, recreation, and healthy ecosystems.

Key Message 7: Changes to Water Demand and Use

Climate change affects water demand and the ways water is used within and across regions and economic sectors. The Southwest, Great Plains, and Southeast are particularly vulnerable to changes in water supply and demand.

Climate change, acting concurrently with demographic, landuse, energy generation and use, and socioeconomic changes, is challenging existing water management practices by affecting water availability and demand and by exacerbating competition among uses and users (see Ch. 4: Energy; Ch. 6: Agriculture; Ch. 10: Energy, Water, and Land; Ch. 12: Indigenous Peoples; and Ch. 13: Land Use & Land Cover Change). In some regions, these current and expected impacts are hastening efficiency improvements in water withdrawal and use, the deployment of more proactive water management and adaptation approaches, and the reassessment of the water infrastructure and institutional responses.¹

Water Withdrawals

Total freshwater withdrawals (including water that is withdrawn and consumed as well as water that returns to the original source) and consumptive uses have leveled off nationally

U.S. Freshwater Withdrawal, Consumptive Use, and Population Trends

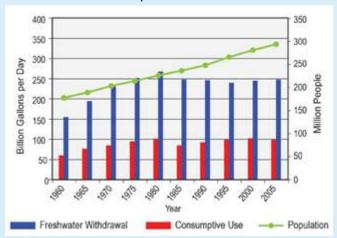


Figure 3.8. Trends in total freshwater withdrawal (equal to the sum of consumptive use and return flows to rivers) and population in the contiguous United States. This graph illustrates the remarkable change in the relationship between water use and population growth since about 1980. Reductions in per capita water withdrawals are directly related to increases in irrigation efficiency for agriculture, more efficient cooling processes in electrical generation, and, in many areas, price signals, more efficient indoor plumbing fixtures and appliances, and reductions in exterior landscape watering, in addition to shifts in land-use patterns in some areas. ⁹⁷ Efficiency improvements have offset the demands of a growing population and have resulted in more flexibility in meeting water demand. In some cases these improvements have also reduced the flexibility to scale back water use in times of drought because some inefficiencies have already been removed from the system. With drought stress projected to increase in many U.S. regions, drought vulnerability is also expected to rise.1

since 1980 at 350 billion gallons of withdrawn water and 100 billion gallons of consumptive water per day, despite the addition of 68 million people from 1980 to 2005 (Figure 3.8). Irrigation and all electric power plant cooling withdrawals account for approximately 77% of total withdrawals, municipal and industrial for 20%, and livestock and aquaculture for 3%. Most thermoelectric withdrawals are returned back to rivers after cooling, while most irrigation withdrawals are consumed by the processes of evapotranspiration and plant growth. Thus, consumptive water use is dominated by irrigation (81%) followed distantly by municipal and industrial (8%) and the remaining water uses (5%). See Figure 3.9.

Water sector withdrawals and uses vary significantly by region. There is a notable east-west water use pattern, with the largest regional withdrawals occurring in western states (where the climate is drier) for agricultural irrigation (Figure 3.10a,d). In the east, water withdrawals mainly serve municipal, industrial, and thermoelectric uses (Figure 3.10a,b,c). Irrigation is also dominant along the Mississippi Valley, in Florida, and in southeastern Texas. Groundwater withdrawals are especially intense in parts of the Southwest, Southeast, Northwest, and

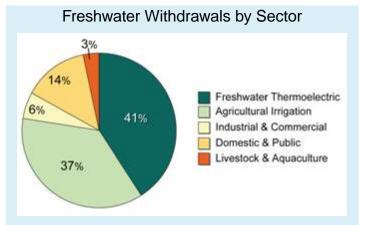


Figure 3.9. Total water withdrawals (groundwater and surface water) in the U.S. are dominated by agriculture and energy production, though the primary use of water for thermoelectric production is for cooling, where water is often returned to lakes and rivers after use (return flows). (Data from Kenny et al. 2009⁹⁶)

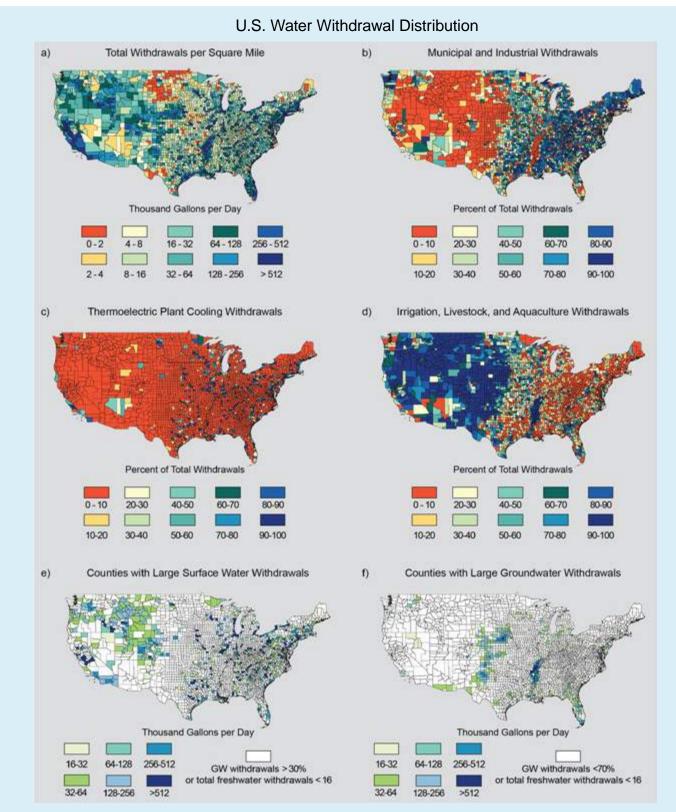


Figure 3.10. Based on the most recent USGS water withdrawal data (2005). This figure illustrates water withdrawals at the U.S. county level: (a) total withdrawals (surface and groundwater) in thousands of gallons per day per square mile; (b) municipal and industrial (including golf course irrigation) withdrawals as percent of total; (c) irrigation, livestock, and aquaculture withdrawals as percent of total; (d) thermoelectric plant cooling withdrawals as percent of total; (e) counties with large surface water withdrawals; and (f) counties with large groundwater withdrawals. The largest withdrawals occur in the drier western states for crop irrigation. In the east, water withdrawals mainly serve municipal, industrial, and thermoelectric uses. Groundwater withdrawals are intense in parts of the Southwest and Northwest, the Great Plains, Mississippi Valley, Florida and South Georgia, and near the Great Lakes (Figure source: Georgia Water Resources Institute, Georgia Institute of Technology; Data from Kenny et al. 2009; USGS 2013 98).

Great Plains, the Mississippi Valley, Florida and South Georgia, and near the Great Lakes (Figure 3.10f). Surface waters are most intensely used in all other U.S. regions.

Per capita water withdrawal and use are decreasing due to many factors. These include demand management, new plumbing codes, water-efficient appliances, efficiency improvement programs, and pricing strategies, especially in the municipal sector. Other factors contributing to decreasing per capita water use include changes from water-intensive manufacturing and other heavy industrial activities to service-oriented businesses, and enhanced water-use efficiencies in response to environmental pollution legislation (in the industrial and commercial sector). In addition, replacement of older once-through-cooling electric power plants by plants that recycle their cooling water, and switching from flood irrigation to more efficient methods in the western United States have also contributed to these trends.

Notwithstanding the overall national trends, regional water withdrawal and use are strongly correlated with climate; hotter and drier regions tend to have higher per capita usage, and water demand is affected by both temperature and precipitation on a seasonal basis (see also Ch. 28: Adaptation).

Water demand is projected to increase as population grows, and will increase substantially more in some regions as a result of climate change. In the absence of climate change but in response to a projected population increase of 80% and a 245% increase in total personal income from 2005 to 2060, simulations under the A1B scenario indicate that total water demand in the U.S. would increase by 3%. 99 Under these conditions, approximately half of the U.S. regions would experience an overall decrease in water demand, while the other half would experience an increase (Figure 3.11a). If, however, climate change projections based on the A1B emissions scenario (with gradual reductions from current emission trends beginning around mid-century) and three climate models are also factored in, the total water demand is projected to rise by an average of 26% over the same period (Figure 3.11b). 99 Under the population increase scenario that also includes climate change, 90% of the country is projected to experience a total demand increase, with decreases projected only in parts of the Midwest, Northeast and Southeast. Compared to an 8% increase in demand under a scenario without climate change, projections under the A2 emissions scenario (which assumes continued increases in global emissions) and three climate models over the 2005 to 2060 period result in a 34% increase in total water demand. By 2090, total water demand is projected to increase by 42% over 2005 levels under the A1B scenario and 82% under the higher A2 emissions scenario.

Crop irrigation and landscape watering needs are directly affected by climate change, especially by projected changes in temperature, potential evapotranspiration, and soil moisture. Consequently, the projected climate change impacts on water demand are larger in the western states, where irrigation dominates total water withdrawals (see Figure 3.10). Uncertainties in the projections of these climate variables also affect water demand projections. However, it is clear that the impacts of projected population, socioeconomic, and climate changes amplify the effects on water demand in the Southwest and Southeast, where the observed and projected drying water cycle trends already make these regions particularly vulnerable.

This vulnerability will be exacerbated by physical and operational limitations of water storage and distribution systems. River reservoirs and associated dams are usually designed to handle larger-than-historical streamflow variability ranges. Some operating rules and procedures reflect historical seasonal and interannual streamflow and water release patterns, while others include information about current and near-term conditions, such as snowpack depth and expected snowmelt volume. Climate change threatens to alter both the streamflow variability that these structures must accommodate and their opportunities to recover after doing so (due to permanent changes in average streamflow). Thus, as streamflow and demand patterns change, historically based operating rules and procedures could become less effective in balancing water supply with other uses. 104

Some of the highest water demand increases under climate change are projected in U.S. regions where groundwater aquifers are the main water supply source (Figure 3.11b), including the Great Plains and parts of the Southwest and Southeast. The projected water demand increases combined with potentially declining recharge rates (see water cycle section) further challenge the sustainability of the aquifers in these regions.

Power plant cooling is a critical national water use, because nearly 90% of the U.S. electrical energy is produced by thermoelectric power plants. 105 Freshwater withdrawals per kilowatt hour have been falling in recent years due to the gradual replacement of once-through cooling of power plant towers with plants that recycle cooling water. Thermal plant cooling is principally supported by surface water withdrawals (Figure 3.10e,f) and has already been affected by climate change in areas where temperatures are increasing and surface water supplies are diminishing, such as the southern United States. Higher water temperatures affect the efficiency of electric generation and cooling processes. It also limits the ability of utilities to discharge heated water to streams from once-through cooled power systems due to regulatory requirements and concerns about how the release of warmer water into rivers and streams affects ecosystems and biodiversity (see Ch. 4: Energy). 106

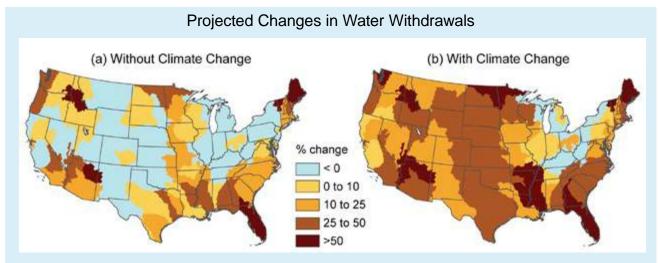


Figure 3.11. The effects of climate change, primarily associated with increasing temperatures and potential evapotranspiration, are projected to significantly increase water demand across most of the United States. Maps show percent change from 2005 to 2060 in projected demand for water assuming (a) change in population and socioeconomic conditions based on the underlying A1B emissions scenario, but with no change in climate, and (b) combined changes in population, socioeconomic conditions, and climate according to the A1B emissions scenario (gradual reductions from current emission trends beginning around mid-century). (Figure source: Brown et al. 2013⁹⁹).

Instream Water Uses

Hydropower contributes 7% of electricity generation nationwide, but provides up to 70% in the Northwest and 20% in California, Alaska, and the Northeast. 107 Climate change is expected to affect hydropower directly through changes in runoff (average, extremes, and seasonality), and indirectly through increased competition with other water uses. Based on runoff projections, hydropower is expected to decline in the southern U.S. (especially the Southwest) and increase in the Northeast and Midwest (though actual gains or losses will depend on facility size and changes in runoff volume and timing). Where non-power water demands are expected to increase (as in the southern U.S.), hydropower generation, dependable capacity, and ancillary services are likely to decrease. Many hydropower facilities nationwide, especially in the Southeast, Southwest, and the Great Plains, are expected to face water availability constraints. 108 While some hydropower facilities may face water-related limitations, these could be offset to some degree by the use of more efficient turbines as well as innovative new hydropower technologies.

Inland navigation, most notably in the Great Lakes and the Missouri, Mississippi, and Ohio River systems, is particularly important for agricultural commodities (transported from the Midwest to the Gulf Coast and on to global food markets), coal, and iron ore. Navigation is affected by ice cover and by floods and droughts. Seasonal ice cover on the Great Lakes has been decreasing thick may allow increased shipping. However, lake level declines are also possible in the long term, decreasing vessel draft and cargo capacity. Future lake levels may also depend on non-climate factors and are uncertain both in direction and magnitude (see Ch. 2: Our Changing Climate; Ch. 5: Transportation; and Ch. 18: Midwest). Similarly, although

the river ice cover period has been decreasing⁵³ (extending the inland navigation season), seasonal ice cover changes^{111,112} could impede lock operations.¹¹² Intensified floods are likely to hinder shipping by causing waterway closures and damaging or destroying ports and locks. Droughts have already been shown to decrease reliability of flows or channel depth, adversely impacting navigation (Ch. 5: Transportation). Both floods and droughts can disrupt rail and road traffic and increase shipping costs¹¹³ and result in commodity price volatility (Ch. 19: Great Plains).

Recreational activities associated with water resources, including boating, fishing, swimming, skiing, camping, and wildlife watching, are strong regional and national economic drivers. Recreation is sensitive to weather and climate, and climate change impacts to recreation can be difficult to project. Rising temperatures affect extent of snowcover and mountain snowpack, with impacts on skiing and snowmobiling. As the climate warms, changes in precipitation and runoff are expected to result in both beneficial (in some regions) and adverse impacts to water sports, with potential for considerable economic dislocation and job losses. 118

Changing climate conditions are projected to affect water and wastewater treatment and disposal in ways that depend on system-specific and interacting attributes. For example, elevated stream temperatures, combined with lower flows, may require wastewater facilities to increase treatment to meet stream water quality standards. More intense precipitation and floods, combined with escalating urbanization and associated increasing impermeable surfaces, may amplify the likelihood of contaminated overland flow or combined sewer over-

flows.¹²⁰ Moderate precipitation increases, however, could result in increased stream flows, improving capacity to dilute contaminants in some regions. Sea level rise and more frequent coastal flooding could damage wastewater utility infrastructure and reduce treatment efficiency (Ch. 25: Coasts).¹²¹

Changes in streamflow temperature and flow regimes can affect aquatic ecosystem structure and function (see Ch. 8: Ecosystems). Water temperature directly regulates the physiology, metabolism, and energy of individual aquatic organisms, as well as entire ecosystems. Streamflow quantity influences the extent of available aquatic habitats, and streamflow variability regulates species abundance and persistence. Flow also influences water temperature, sediment, and nutrient concentrations. ¹²² If the rate of climate change ¹²³ outpaces plant and animal species' ability to adjust to temperature change,

additional biodiversity loss may occur. Furthermore, climate change induced water cycle alterations may exacerbate existing ecosystem vulnerability, especially in the western United States¹²⁴ where droughts and water shortages are likely to increase. But areas projected to receive additional precipitation, such as the northern Great Plains, may benefit. Lastly, hydrologic alterations due to human interventions have without doubt impaired riverine ecosystems in most U.S. regions and globally. 125 The projected escalation of water withdrawals and uses (see Figure 3.11) threatens to deepen and widen ecosystem impairment, especially in southern states where climate change induced water cycle alterations are pointing toward drier conditions (see Ch. 8: Ecosystems). In these regions, balancing socioeconomic and environmental objectives will most likely require more deliberate management and institutional responses.

Major Water Resource Vulnerabilities and Challenges

Many U.S. regions are expected to face increased drought and flood vulnerabilities and exacerbated water management challenges. This section highlights regions where such issues are expected to be particularly intense.

Key Message 8: Drought is Affecting Water Supplies

Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses.

Many southwestern and western watersheds, including the Colorado, Rio Grande, ^{38,43,126} and Sacramento-San Joaquin, ^{127,128} have recently experienced drier conditions. Even larger runoff reductions (about 10% to 20%) are projected over some of these watersheds in the next 50 years. ^{48,129} Increasing evaporative losses, declining runoff and groundwater recharge, and changing groundwater pumpage are expected to affect surface and groundwater supplies ^{65,66,67,71} and increase the risk of water shortages for many water uses. Changes in

streamflow timing will exacerbate a growing mismatch between supply and demand (because peak flows are occurring earlier in the spring, while demand is highest in mid-summer) and will present challenges for the management of reservoirs, aquifers, and other water infrastructure. Rising stream temperatures and longer low flow periods may make electric power plant cooling water withdrawals unreliable, and may affect aquatic and riparian ecosystems by degrading habitats and favoring invasive, non-native species. 131

Key Message 9: Flood Effects on People and Communities

Increasing flooding risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the U.S.

Flooding affects critical water, wastewater, power, transportation, and communications infrastructure in ways that are difficult to foresee and can result in interconnected and cascading failures (see "Flood Factors and Flood Types"). Very heavy precipitation events have intensified in recent decades in most U.S. regions, and this trend is projected to continue (Ch. 2: Our Changing Climate). Increasing heavy precipitation is an important contributing factor, but flood magnitude changes also depend on specific watershed conditions (including soil moisture, impervious area, and other human-caused alterations).

Projected changes in flood frequency based on climate projections and hydrologic models have recently begun to emerge

(for example, Das et al. 2012;⁶⁰ Brekke et al. 2009;¹³² Raff et al. 2009;¹³³ Shaw and Riha 2011;¹³⁴ Walker et al. 2011¹³⁵), and suggest that flood frequency and severity increases may occur in the Northeast and Midwest (Ch. 16: Northeast; Ch. 18: Midwest). Flooding and sea water intrusion from sea level rise and increasing storm surge threaten New York, Boston, Philadelphia, Virginia Beach, Wilmington, Charleston, Miami, Tampa, Naples, Mobile, Houston, New Orleans, and many other cities on U.S. coasts (Chapter 25: Coasts).

The devastating toll of large floods (human life, property, environment, and infrastructure) suggests that proactive management measures could minimize changing future flood risks and

consequences (Ch. 28: Adaptation). In coastal areas, sea level rise may act in parallel with inland climate changes to intensify water-use impacts and challenges (Ch. 12: Indigenous Peoples; Ch. 17: Southeast). Increasing flooding risk, both coastal and inland, could also exacerbate human health risks associated with failure of critical infrastructure, and an increase in both waterborne diseases (Ch. 9: Human Health) and air-borne diseases.

Changes in land use, land cover, development, and population distribution can all affect flood frequency and intensity. The nature and extent of these projected changes results in increased uncertainty and decreased accuracy of flood forecasting in both the short term ¹³³ and long term. ¹⁴¹ This lack of certainty could hinder effective preparedness (such as evacuation planning) and the effectiveness of structural and non-structural flood risk reduction measures. However, many climate change

projections are robust (Ch. 2: Our Changing Climate), and the long lead time needed for the planning, design, and construction of critical infrastructure that provides resilience to floods means that consideration of long-term changes is needed.

Effective climate change adaptation planning requires an integrated approach ^{45,118,142} that addresses public health and safety issues (Ch. 28: Adaptation). ¹⁴³ Though numerous flood risk reduction measures are possible, including levees, landuse zoning, flood insurance, and restoration of natural floodplain retention capacity, ¹⁴⁴ economic and institutional conditions may constrain implementation. The effective use of these measures would require significant investment in many cases, ¹⁴⁵ as well as updating policies and methods to account for climate change ^{42,146} in the planning, design, operation, and maintenance of flood risk reduction infrastructure. ^{132,147}

Adaptation and Institutional Responses

Key Message 10: Water Resources Management

In most U.S. regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed within existing practices.

Water managers and planners strive to balance water supply and demand across all water uses and users. The management process involves complex tradeoffs among water-use benefits, consequences, and risks. By altering water availability and demand, climate change is likely to present additional management challenges. One example is in the Sacramento-San Joaquin River Delta, where flooding, sea water intrusion, and changing needs for environmental, municipal, and agricultural water uses have created significant management challenges. This California Bay-Delta experience suggests that managing risks and sharing benefits requires re-assessment of very complex ecosystems, infrastructure systems, water rights, stakeholder preferences, and reservoir operation strategies as well as significant investments. All of these considerations are subject to large uncertainties. 54,148 To some extent, all U.S. regions are susceptible, but the Southeast and Southwest are highly vulnerable because climate change is projected to reduce water availability, increase demand, and exacerbate shortages (see "Water Management").

Recent assessments illustrate water management challenges facing California, ^{127,129,149,150} the Southwest, ^{130,151} Southeast (Ch.

17: Southeast), 136,152 Northwest, 153 Great Plains, 154 and Great Lakes. 155 A number of these assessments demonstrate that while expanding supplies and storage may still be possible in some regions, effective climate adaptation strategies can benefit from innovative management strategies. These strategies can include domestic water conservation programs that use pricing incentives to curb use; more flexible, risk-based, better-informed, and adaptive operating rules for reservoirs; the integrated use of combined surface and groundwater resources; and better monitoring and assessment of statewide water use. 129,149,156,157 Water management and planning would benefit from better coordination among public sectors at the national, state, and local levels (including regional partnerships and agreements), and the private sector, with participation of all relevant stakeholders in well-informed, fair, and equitable decision-making processes. Better coordination among hydrologists and atmospheric scientists, and among these scientists and the professional water management community, is also needed to facilitate more effective translation of knowledge from science to practice (Ch. 26: Decision Support; Ch. 28: Adaptation). 158

Water challenges in a southeast river basin

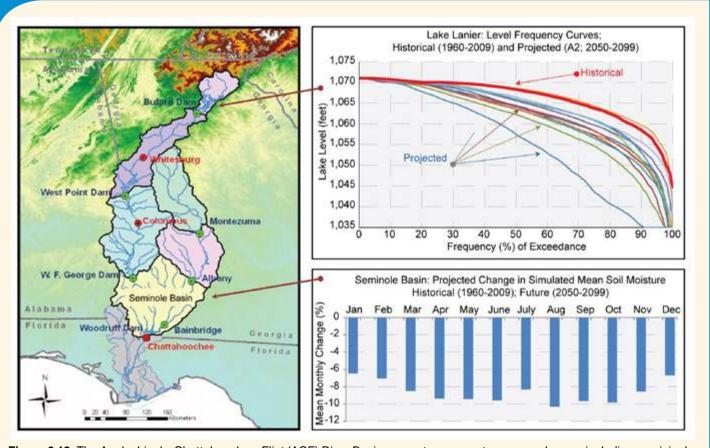


Figure 3.12. The Apalachicola-Chattahoochee-Flint (ACF) River Basin supports many water uses and users, including municipal, industrial, and agricultural water supply; flood management; hydroelectric and thermoelectric energy generation; recreation; navigation; fisheries; and a rich diversity of environmental and ecological resources. In recent decades, water demands have risen rapidly in the Upper Chattahoochee River (due to urban growth) and Lower Chattahoochee and Flint Rivers (due to expansion of irrigated agriculture). At the same time, basin precipitation, soil moisture, and runoff are declining, creating challenging water sharing tradeoffs for the basin stakeholders. The historical water demand and supply trends are expected to continue in the coming decades. Climate assessments for 50 historical (1960-2009) and future years (2050-2099) based on a scenario of continued increases in emissions (A2) for the Seminole and all other ACF sub-basins show that soil moisture is projected to continue to decline in all months, especially during the crop growing season from April to October (bottom right). Mean monthly runoff decreases (up to 20%, not shown) are also projected throughout the year and especially during the wet season from November to May. The projected soil moisture and runoff shifts are even more significant in the extreme values of the respective distributions. In addition to reduced supplies, these projections imply higher water demands in the agricultural and other sectors, exacerbating management challenges. These challenges are reflected in the projected response of Lake Lanier, the main ACF regulation project, the levels of which are projected (for 2050-2099) to be lower, by as much as 15 feet, than its historical (1960-2009) levels, particularly during droughts (top right). Recognizing these critical management challenges, the ACF stakeholders are earnestly working to develop a sustainable and equitable management plan that balances economic, ecological, and social values. 160 (Figure source: Georgia Water Resources Institute, Georgia Institute of Technology. 152).

Key Message 11: Adaptation Opportunities and Challenges

Increasing resilience and enhancing adaptive capacity provide opportunities to strengthen water resources management and plan for climate change impacts.

Many institutional, scientific, economic, and political barriers present challenges to implementing adaptive strategies.

Climate adaptation involves both addressing the risks and leveraging the opportunities that may arise as a result of the climate impacts on the water cycle and water resources. Efforts to increase resiliency and enhance adaptive capacity may create opportunities for a wide-ranging public discussion of water demands, improved collaboration around water use, increased public support for scientific and economic information, and the deployment of new technologies supporting adaptation. In addition, adaptation can promote the achievement of multiple water resource objectives through improved infrastructure planning, integrated regulation, and planning and management approaches at regional, watershed, or ecosystem scales. Pursuing these opportunities may require assessing how current institutional approaches support adaptation in light of the anticipated impacts of climate change. ¹⁶¹

Climate change will stress the nation's aging water infrastructure to varying degrees by location and over time. Much of the country's current drainage infrastructure is already overwhelmed during heavy precipitation and high runoff events, an impact that is projected to be exacerbated as a result of climate change, land-use change, and other factors. Large percentage increases in combined sewage overflow volumes, associated with increased intensity of precipitation events, have been projected for selected watersheds by the end of this century in the absence of adaptive measures. 106,162 Infrastructure planning, especially for the long planning and operation horizons often associated with water resources infrastructure, can be improved by incorporating climate change as a factor in new design standards and in asset management and rehabilitation of critical and aging facilities, emphasizing flexibility, redundancy, and resiliency. 106,132,163

Adaptation strategies for water infrastructure include structural and non-structural approaches. These may include changes in system operations and/or demand management changes, adopting water conserving plumbing codes, and improving flood forecasts, telecommunications, and early warning systems¹⁶⁴ that focus on both adapting physical structures and innovative management. Such strategies could take advantage of conventional ("gray") infrastructure upgrades (like raising flood control levees); adjustments to reservoir operating rules; new demand management and incentive strategies; land-use management that enhances adaptive capacity; protection and restoration at the scale of river basins, watersheds, and ecosystems; hybrid strategies that blend "green" infrastructure with gray infrastructure; and pricing strategies. ^{1,106,132,166,167} Green infrastructure approaches that are

increasingly being implemented by municipalities across the country include green roofs, rain gardens, roadside plantings, porous pavement, and rainwater harvesting (Ch. 28: Adaptation). These techniques typically utilize soils and vegetation in the built environment to absorb runoff close to where it falls, limiting flooding and sewer backups. ¹⁶⁸ There are numerous non-infrastructure related adaptation strategies, some of which could include promoting drought-resistant crops, flood insurance reform, and building densely developed areas away from highly vulnerable areas.

In addition to physical adaptation, capacity-building activities can build knowledge and enhance communication and collaboration within and across sectors. In particular, building networks, partnerships, and support systems has been identified as a major asset in building adaptive capacity (Ch. 26: Decision Support; Ch. 28: Adaptation).

In addition to stressing the physical infrastructure of water systems, future impacts of climate change may reveal the weaknesses in existing water law regimes to accommodate novel and dynamic water management conditions. The basic paradigms of environmental and natural resources law are preservation and restoration, both of which are based on the assumption that natural systems fluctuate within an unchanging envelope of variability ("stationarity"). 171 However, climate change is now projected to affect water supplies during the multi-decade lifetime of major water infrastructure projects in wide-ranging and pervasive ways. 132 Under these circumstances, stationarity will no longer be reliable as the central assumption in water-resource risk assessment and planning. 42,171 For example, in the future, water rights administrators may find it necessary to develop more flexible water rights systems conditioned to address the uncertain impacts of climate change. 172 Agencies and courts may seek added flexibility in regulations and laws to achieve the highest and best uses of limited water resources and to enhance water management capacity in the context of new and dynamic conditions. 132,173

In the past few years, many federal, state, and local agencies and tribal governments have begun to address climate change adaptation, integrating it into existing decision-making, planning, or infrastructure-improvement processes (Ch. 28: Adaptation). ^{43,174} Drinking water utilities are increasingly utilizing climate information to prepare assessments of their supplies, ¹⁷⁵ and utility associations and alliances, such as the Water Research Foundation and Water Utility Climate Alliance, have undertaken original research to better understand the

implications of climate change on behalf of some of the largest municipal water utilities in the United States. 119,156,176

The economic, social, and environmental implications of climate change induced water cycle changes are very significant, as is the cost of inaction. Adaptation responses need to address considerable uncertainties in the short-, medium-, and long-term; be proactive, integrated, and iterative; and be developed through well-informed stakeholder decision processes functioning within a flexible institutional and legal environment.

3: WATER RESOURCES

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SUPPLEMENTAL MATERIAL TRACEABLE ACCOUNTS

Process for Developing Key Messages:

The chapter author team engaged in multiple technical discussions via teleconferences from March – June 2012. These discussions followed a thorough review of the literature, which included an interagency prepared foundational document, over 500 technical inputs provided by the public, as well as other published literature. The author team met in Seattle, Washington, in May 2012 for expert deliberation of draft key messages by the authors wherein each message was defended before the entire author team before this key message was selected for inclusion in the Chapter. These discussions were supported by targeted consultation with additional experts by the lead author of each message, and they were based on criteria that help define "key vulnerabilities." Key messages were further refined following input from the NCADAC report integration team and authors of Ch. 2: Our Changing Climate.

KEY MESSAGE #1 TRACEABLE ACCOUNT

Annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions. Very heavy precipitation events have increased nationally and are projected to increase in all regions. The length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document, Ch. 2: Our Changing Climate, Ch. 20: Southwest, other technical input reports, and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

Numerous peer-reviewed publications describe precipitation trends (Ch. 2: Our Changing Climate)^{4,7,8,34} and river-flow trends.^{13,41} As discussed in Chapter 2, the majority of projections available from climate models (for example, Orlowsky and Seneviratne 2012;³ Kharin et al. 2013⁵) indicate small projected changes in total average annual precipitation in many areas, while heavy precipitation⁶ and the length of dry spells are projected to increase across the entire country. Projected precipitation responses (such as changing extremes) to increasing greenhouse gases are robust in a wide variety of models and depictions of climate.

The broad observed trends of precipitation and river-flow increases have been identified by many long-term National Weather Service (NWS)/National Climatic Data Center (NCDC) weather monitoring networks, USGS streamflow monitoring networks, and analyses of records therefrom (Ch. 2: Our Changing Climate; ^{34,36,37}). Ensembles of climate models ^{3,42} (see also Ch. 2: Our Changing Climate, Ch. 20: Southwest) are the basis for the reported projections.

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings from the 2009 National Climate Assessment. 177

Observed trends: Precipitation trends are generally embedded amidst large year-to-year natural variations and thus trends may be difficult to detect, may differ from site to site, and may be reflections of multi-decadal variations rather than external (human) forcings. Consequently, careful analyses of longest-term records from many stations across the country and addressing multiple potential explanations are required and are cornerstones of the evidentiary studies described above.

Efforts are underway to continually improve the stability, placement, and numbers of weather observations needed to document trends; scientists also regularly search for other previously unanalyzed data sources for use in testing these findings.

Projected trends: The complexity of physical processes that result in precipitation and runoff reduces abilities to represent or predict them as accurately as would be desired and with the spatial and temporal resolution required for many applications; however, as noted, the trends at the scale depicted in this message are very robust among a wide variety of climate models and projections, which lends confidence that the projections are appropriate lessons from current climate (and streamflow) models. Nonetheless, other influences not included in the climate change projections might influence future patterns of precipitation and runoff, including changes in land cover, water use (by humans and vegetation), and streamflow management.

Climate models used to make projections of future trends are continually increasing in number, resolution, and in the number of additional external and internal influences that might be confounding current projections. For example, much more of all three of these

directions for improvement are already evident in projection archives for the next IPCC assessment.

Assessment of confidence based on evidence

Observed trends have been demonstrated by a broad range of methods over the past 20+ years based on best available data; projected precipitation and river-flow responses to greenhouse gas increases are robust across large majorities of available climate (and hydrologic) models from scientific teams around the world.

Confidence is therefore judged to be **high** that annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions.

Confidence is **high** that very heavy precipitation events have increased nationally and are projected to increase in all regions.

Confidence is **high** that the length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States.

Confidence Level

Very High

Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus

High

Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus

Medium

Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought

Low

Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

KEY MESSAGE #2 TRACEABLE ACCOUNT

Short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document, ¹ Ch. 16: Northeast, Ch 17: Southeast, Ch. 2: Our Changing Climate, Ch. 18: Midwest, Ch. 19: Great Plains, Ch. 20: Southwest, Ch. 21: Northwest, Ch. 23: Hawai'i and Pacific Islands, and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

Projected drought trends derive directly from climate models in some studies (for example, Hoerling et al. 2012; Wehner et al. 2011; Gao et al. 2012; Gao et al. 2011; From hydrologic models responding to projected climate trends in others (for example, Georgakakos and Zhang 2011; Cayan et al. 2010; From considerations of the interactions between precipitation deficits and either warmer or cooler temperatures in historical (observed) droughts, Aland from combinations of these approaches (for example, Trenberth et al. 2004) in still other studies.

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings from the 2009 National Climate Assessment. 177

Warmer temperatures are robustly projected by essentially all climate models, with what are generally expected to be directly attendant increases in the potentials for greater evapotranspiration, or ET (although it is possible that current estimates of future ET are overly influenced by temperatures at the expense of other climate variables, like wind speed, humidity, net surface radiation, and soil moisture that might change in ways that could partly ameliorate rising ET demands). As a consequence, there is a widespread expectation that more water from precipitation will be evaporated or transpired in the warmer future, so that except in regions where precipitation increases more than ET increases, less overall water will remain on the landscape and droughts will intensify and become more common. Another widespread expectation is that precipitation variability will increase, which may result in larger swings in moisture availability, with swings towards the deficit side resulting in increased frequencies and intensities of drought conditions on seasonal time scales to times scales of multiple decades. An important remaining uncertainty, discussed in the supporting text for Key Message #1, is the extent to which the types of models used to project future droughts may be influencing results with a notable recent tendency for studies with more complete, more resolved land-surface models, as well as climate models, to yield more moderate projected changes.

Other uncertainties derive from the possibility that changes in other variables or influences of CO₂-fertilization and/or land cover change may also partly ameliorate drought intensification. Furthermore in many parts of the country, El Niño-Southern Oscillation (and other oceanic) influences on droughts and floods are large, and can overwhelm climate change effects during the next few decades. At present, however, the future of these oceanic climate influences remains uncertain.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties:

Confidence is judged to be **medium-high** that short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Confidence is **high** that longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.

KEY MESSAGE #3 TRACEABLE ACCOUNT

Flooding may intensify in many U.S. regions, even in areas where total precipitation is projected to decline.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document, Ch. 16: Northeast, Ch 17: Southeast, Ch. 2: Our Changing Climate, Ch. 18: Midwest, Ch. 19: Great Plains, Ch. 20: Southwest, Ch. 21: Northwest, Ch. 23: Hawai'i and Pacific Islands, and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

The principal observational bases for the key message are careful national-scale flood-trend analyses⁵⁸ based on annual peak-flow records from a selection of 200 USGS streamflow gaging stations measuring flows from catchments that are minimally influenced by upstream water uses, diversions, impoundments, or land-use changes with more than 85 years of records, and analyses of two other subsets of USGS gages with long records (including gages both impacted by human activities and less so), including one analysis of 50 gages nationwide⁵⁶ and a second analysis of 572 gages in the eastern United States.⁵⁷ There is some correspondence among regions with significant changes in annual precipitation (Ch. 2: Our Changing Climate) and soil moisture (Figures 3.2 and 3.3), and annual flood magnitudes (Figure 3.5).⁵⁸

Projections of future flood-frequency changes result from detailed hydrologic models (for example, Das et al. 2012;⁶⁰ Raff et al. 2009;¹³³Walker et al. 2011¹³⁵) of rivers that simulate responses to projected precipitation and temperature changes from climate models; such simulations have only recently begun to emerge in the peerreviewed literature.

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings from the 2009 National Climate Assessment. 177

Large uncertainties remain in efforts to detect flood-statistic changes attributable to climate change, because a wide range of local factors (such as dams, land-use changes, river channelization) also affect flood regimes and can mask, or proxy for, climate change induced alterations. Furthermore, it is especially difficult to detect any kinds of trends in what are, by definition, rare and extreme events. Finally, the response of floods to climate changes are expected to be fairly idiosyncratic from basin to basin, because of the strong influences of within-storm variations and local, basin-scale topographic, soil and vegetation, and river network characteristics that influence the size and extent of flooding associated with any given storm or season.

Large uncertainties still exist as to how well climate models can represent and project future extremes of precipitation. This has – until recently – limited attempts to make specific projections of future flood frequencies by using climate model outputs directly or as direct inputs to hydrologic models. However, precipitation extremes are expected to intensify as the atmosphere warms, and many floods result from larger portions of catchment areas receiving rain as snowlines recede upward. As rain runs off more quickly than snowfall this results in increased flood potential; furthermore, occasional rain-on-snow events exacerbates this effect. This trend is broadly expected to increase in frequency under general warming trends, particularly in mountainous catchments. Existing sea levels and projected increase in hurricane-associated storm intensity and rainfall rates provide first-principles bases for expecting intensified flood regimes in coastal settings (see Ch. 2: Our Changing Climate).

Assessment of confidence based on evidence

Future changes in flood frequencies and intensities will depend on a complex combination of local to regional climatic influences, and the details of complex surface-hydrologic conditions in each catchment (for example, topography, land cover, and upstream management). Consequently, flood frequency changes may be neither simple nor regionally homogeneous, and basin by basin projections may need to be developed. Early results now appearing in the literature have most often projected intensifications of flood regimes, in large part as responses to projections of more intense storms and increasingly rainy (rather than snowy) storms in previously snow-dominated settings. Confidence in current estimates of future changes in flood frequencies and intensities is overall judged to be **low**.

KEY MESSAGE #4 TRACEABLE ACCOUNT

Climate change is expected to affect water demand, groundwater withdrawals, and aquifer recharge, reducing groundwater availability in some areas.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document, regional chapters of the NCA, and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

Several recent studies 65,66,67,68,71,72 have evaluated the potential impacts of changes in groundwater use and recharge under scenarios including climate change, and generally they have illustrated the common-sense conclusion that changes in pumpage can have immediate and significant effects in the nation's aquifers. This has certainly been the historical experience in most aguifers that have seen significant development; pumpage variations usually tend to yield more immediate and often larger changes on many aquifers than do historical climate variations on time scales from years to decades. Meanwhile, for aquifers in the Southwest, there is a growing literature of geochemical studies that fingerprint various properties of groundwater and that are demonstrating that most western groundwater derives preferentially from snowmelt, rather than rainfall or other sources. 50,51,66,74 This finding suggests that much western recharge may be at risk of changes and disruptions from projected losses of snowpack, but as yet provides relatively little indication whether the net effects will be recharge declines, increases, or simply spatial redistribution.

New information and remaining uncertainties

The precise responses of groundwater storage and flow to climate change are not well understood, but recent and ongoing studies provide insights on underlying mechanisms. ^{65,66,67} The observations and modeling evidence to make projections of future responses of groundwater recharge and discharge to climate change are thus far very limited, primarily because of limitations in data availability and in the models themselves. New forms and networks of observations and new modeling approaches and tools are needed to provide projections of the likely influences of climate changes on groundwater recharge and discharge. Despite the uncertainties about the specifics of climate change impacts on groundwater, impacts of reduced groundwater supply and quality would likely be detrimental to the nation.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence is judged to be **high** that climate change is expected to affect water demand, groundwater withdrawals, and aquifer recharge, reducing groundwater availability in some areas.

KEY MESSAGE #5 TRACEABLE ACCOUNT

Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands.

Description of evidence base

This message has a strong theoretical and observational basis, in-

cluding considerable historical experience with seawater intrusion into many of the nation's coastal aquifers and wetlands under the influence of heavy pumpage, some experience with the influences of droughts and storms on seawater intrusion, and experience with seepage of seawater into shallow coastal aquifers under storm and storm surge conditions that lead to coastal inundations with seawater. The likely influences of sea level rise on seawater intrusion into coastal (and island) aquifers and wetlands are somewhat less certain, as discussed below, although it is projected that sea level rise may increase opportunities for saltwater intrusion (see Ch. 25: Coasts).

New information and remaining uncertainties

There are few published studies describing the kinds of groundwater quality and flow modeling that are necessary to assess the real-world potentials for sea level rise to affect seawater intrusion. Studies in the literature and historical experience demonstrate the detrimental impacts of alterations to the water budgets of the freshwater lenses in coastal aquifers and wetlands around the world (most often by groundwater development), but few evaluate the impacts of sea level rise alone. More studies with real-world aquifer geometries and development regimes are needed to reduce the current uncertainty of the potential interactions of sea level rise and seawater intrusion.

Assessment of confidence based on evidence

Confidence is **high** that sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands.

KEY MESSAGE #6 TRACEABLE ACCOUNT

Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality in many ways, including increases in sediment, nitrogen, and other pollutant loads.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document, ¹ Ch. 8: Ecosystems, Ch. 15: Biogeochemical Cycles, and over 500 technical inputs on a wide range of topics that were reviewed as part of the Federal Register Notice solicitation for public input.

Thermal stratification of deep lakes and reservoirs has been observed to increase with increased air and water temperatures, ^{1,81,82} and may be eliminated in shallow lakes. Increased stratification reduces mixing, resulting in reduced oxygen in bottom waters. Deeper set-up of vertical thermal stratification in lakes and reservoirs may reduce or eliminate a bottom cold water zone; this, coupled with lower oxygen concentration, results in a degraded aquatic ecosystem.

Major precipitation events and resultant water flows increase watershed pollutant scour and thus increase pollutant loads. ⁸⁴ Fluxes of mineral weathering products (for example, calcium, magnesium,

sodium, and silicon) have also been shown to increase in response to higher discharge. ⁸⁶ In the Mississippi drainage basin, increased precipitation has resulted in increased nitrogen loads contributing to hypoxia in the Gulf of Mexico. ⁸⁵ Models predict and observations confirm that continued warming will have increasingly negative effects on lake water quality and ecosystem health. ⁸¹

Future re-mobilization of sediment stored in large river basins will be influenced by changes in flood frequencies and magnitudes, as well as on vegetation changes in the context of climate and other anthropogenic factors. Model projections suggest that changes in sediment delivery will vary regionally and by land-use type, but on average could increase by 25% to 55%.

New information and remaining uncertainties

It is unclear whether increasing floods and droughts cancel each other out with respect to long-term pollutant loads.

It is also uncertain whether the absolute temperature differential with depth will remain constant, even with overall lake and reservoir water temperature increases. Further, it is uncertain if greater mixing with depth will eliminate thermal stratification in shallow, previously stratified lakes. Although recent studies of Lake Tahoe provide an example of longer stratification seasons, ⁸³ lakes in other settings and with other geometries may not exhibit the same response.

Many factors influence stream water temperature, including air temperature, forest canopy cover, and ratio of baseflow to streamflow.

Assessment of confidence based on evidence

Given the evidence base, confidence is **medium** that increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality in many ways, including increases in sediment, nitrogen, and pollutant loads.

KEY MESSAGE #7 TRACEABLE ACCOUNT

Climate change affects water demand and the ways water is used within and across regions and economic sectors. The Southwest, Great Plains, and Southeast are particularly vulnerable to changes in water supply and demand.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document, 1 Ch. 2: Our Changing Climate, Ch. 17: Southeast, Ch. 19: Great Plains, Ch. 20: Southwest, Ch. 23: Hawai'i and Pacific Islands, and many technical inputs on a wide range of topics that were received and reviewed as part of the Federal Register Notice solicitation for public input.

Observed Trends: Historical water withdrawals by sector (for example, municipal, industrial, agricultural, and thermoelectric) have

been monitored and documented by USGS for over 40 years and represent a credible database to assess water-use trends, efficiencies, and underlying drivers. Water-use drivers principally include population, personal income, electricity consumption, irrigated area, mean annual temperature, growing season precipitation, and growing season potential evapotranspiration. Water-use efficiencies are also affected by many non-climate factors, including demand management, plumbing codes, water efficient appliances, efficiency improvement programs, and pricing strategies; to changes from water intensive manufacturing and other heavy industrial activities to service-oriented businesses, and enhanced water-use efficiencies in response to environmental pollution legislation; replacement of older once-through-cooling electric power plants by plants that recycle their cooling water; and switching from flood irrigation to more efficient methods in the western United States.

Projected Trends and Consequences: Future projections have been carried out with and without climate change to first assess the water demand impacts of projected population and socioeconomic increases, and subsequently combine them with climate change induced impacts. The main findings are that in the absence of climate change total water withdrawals in the U.S. will increase by 3% in the coming 50 years, 99 with approximately half of the U.S. experiencing a total water demand decrease and half an increase. If, however, climate change projections are also factored in, the demand for total water withdrawals is projected to rise by an average of 26%, 99 with more than 90% of the U.S. projected to experience a total demand increase, and decreases projected only in parts of the Midwest, Northeast, and Southeast. When coupled with the observed and projected drying water cycle trends (see key messages in "Climate Change Impacts on the Water Cycle" section), the water demand impacts of projected population, socioeconomic, and climate changes intensify and compound in the Southwest and Southeast, rendering these regions particularly vulnerable in the coming decades.

New information and remaining uncertainties

The studies of water demand in response to climate change and other stressors are very recent and constitute new information on their own merit. ⁹⁹ In addition, for the first time, these studies make it possible to piece together the regional implications of climate change induced water cycle alterations in combination with projected changes in water demand. Such integrated assessments also constitute new information and knowledge building.

Demand projections include various uncertain assumptions which become increasingly important in longer term (multi-decadal) projections. Because irrigation demand is the largest water demand component most sensitive to climate change, the most important climate-related uncertainties are precipitation and potential evapotranspiration over the growing season. Non-climatic uncertainties relate to future population distribution, socioeconomic changes, and water-use efficiency improvements.

Assessment of confidence based on evidence

Considering that (a) droughts are projected to intensify in large areas of the Southwest, Great Plains, and the Southeast, and (b) that these same regions have experienced and are projected to experience continuing population and demand increases, confidence that these regions will become increasingly vulnerable to climate change is judged to be **high**.

KEY MESSAGE #8 TRACEABLE ACCOUNT

Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document, ¹ Ch. 2: Our Changing Climate, Ch. 17: Southeast, Ch. 19: Great Plains, Ch. 20: Southwest, Ch. 23: Hawai'i and Pacific Islands, and over 500 technical inputs on a wide range of topics that were received and reviewed as part of the Federal Register Notice solicitation for public input.

Observed Trends: Observations suggest that the water cycle in the Southwest, Great Plains, and Southeast has been changing toward drier conditions (Ch. 17: Southeast). Furthermore, paleoclimate tree-ring reconstructions indicate that drought in previous centuries has been more intense and of longer duration than the most extreme drought of the 20th and 21st centuries.

Projected Trends and Consequences: Global Climate Model (GCM) projections indicate that this trend is likely to persist, with runoff reductions (in the range of 10% to 20% over the next 50 years) and intensifying droughts.⁴⁸

The drying water cycle is expected to affect all human and ecological water uses, especially in the Southwest. Decreasing precipitation, rising temperatures, and drying soils are projected to increase irrigation and outdoor watering demand (which account for nearly 90% of consumptive water use) by as much as 34% by 2060 under the A2 emissions scenario. Decreasing runoff and groundwater recharge are expected to reduce surface and groundwater supplies, increasing the annual risk of water shortages from 25% to 50% by 2060. Changes in streamflow timing will increase the mismatch of supply and demand. Earlier and declining streamflow and rising demands will make it more difficult to manage reservoirs, aquifers, and other water infrastructure. 1310

Such impacts and consequences have been identified for several southwestern and western river basins including the Colorado, ³⁸ Rio Grande, ¹²⁶ and Sacramento-San Joaquin. ^{127,128,129}

New information and remaining uncertainties

The drying climate trend observed in the Southwest and Southeast in the last decades is consistent across all water cycle variables (precipitation, temperature, snow cover, runoff, streamflow, reservoir levels, and soil moisture) and is not debatable. The debate is over whether this trend is part of a multi-decadal climate cycle and whether it will reverse direction at some future time. However, the rate of change and the comparative GCM assessment results with and without historical CO₂ forcing (Ch. 2: Our Changing Climate) support the view that the observed trends are due to both factors acting concurrently.

GCMs continue to be uncertain with respect to precipitation, but they are very consistent with respect to temperature. Runoff, streamflow, and soil moisture depend on both variables and are thus less susceptible to GCM precipitation uncertainty. The observed trends and the general GCM agreement that the southern states will continue to experience streamflow and soil moisture reductions ^{34,41} provides confidence that these projections are robust.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence is **high** that changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. Confidence is **high** that these trends are expected to continue, increasing the likelihood of water shortages for many uses.

KEY MESSAGE #9 TRACEABLE ACCOUNT

Increasing flooding risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the U.S.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document, Ch. 2: Our Changing Climate, Ch. 21: Northwest, Ch. 19: Great Plains, Ch. 18: Midwest, Ch. 16: Northeast, and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

Observed Trends: Very heavy precipitation events have intensified in recent decades in most U.S. regions, and this trend is projected to continue (Ch. 2: Our Changing Climate). Increasing heavy precipitation is an important contributing factor for floods, but flood magnitude changes also depend on specific watershed conditions (including soil moisture, impervious area, and other human-caused alterations). There is, however, some correspondence among regions with significant changes in annual precipitation (Ch. 2: Our Changing Climate), soil moisture (Figures 3.2 and 3.3), and annual flood magnitudes (Figure 3.5).

Flooding and seawater intrusion from sea level rise and increasing storm surge threaten New York, Boston, Philadelphia, Virginia Beach, Wilmington, Charleston, Miami, Tampa, Naples, Mobile,

Houston, New Orleans, and many other coastal cities (Chapter 25: Coasts).

Projected Trends: Projections of future flood-frequency changes result from detailed hydrologic ^{60,133,135} and hydraulic models of rivers that simulate responses to projected precipitation and temperature changes from climate models.

Consequences: Floods already affect human health and safety and result in substantial economic, ecological, and infrastructure damages. Many cities are located along coasts and, in some of these cities (including New York, Boston, Miami, Savannah, and New Orleans), sea level rise is expected to exacerbate coastal flooding issues by backing up flood flows and impeding flood-management responses (see Ch. 16: Northeast and Ch. 25: Coasts).

Projected changes in flood frequency and severity can bring new challenges in flood risk management. For urban areas in particular, flooding impacts critical infrastructure in ways that are difficult to foresee and can result in interconnected and cascading failures (for example, failure of electrical generating lines can cause pump failure, additional flooding, and failure of evacuation services). Increasing likelihood of flooding also brings with it human health risks associated with failure of critical infrastructure (Ch. 11: Urban), ¹³⁷ from waterborne disease that can persist well beyond the occurrence of very heavy precipitation (Ch. 9: Human Health), ¹³⁹ from water outages associated with infrastructure failures that cause decreased sanitary conditions, ¹³⁸ and from ecosystem changes that can affect airborne diseases (Ch. 8: Ecosystems). ¹⁴⁰

New information and remaining uncertainties

Large uncertainties still exist as to how well climate models can represent and project future precipitation extremes. However, precipitation extremes are expected to intensify as the atmosphere warms, and many floods result from larger portions of catchment areas receiving rain as snowlines recede upward. As rain runs off more quickly than snowfall, this results in increased flood potential; furthermore occasional rain-on-snow events exacerbate this effect. This trend is broadly expected to increase in frequency under general warming trends, particularly in mountainous catchments.

Assessment of confidence based on evidence

Future changes in flood frequencies and intensities will depend on a complex combination of local to regional climatic influences and on the details of complex surface-hydrologic conditions in each catchment (for example, topography, land cover, and upstream managements). Consequently, flood frequency changes may be neither simple nor regionally homogeneous, and basin by basin projections may need to be developed. Nonetheless, early results now appearing in the literature have most often projected intensifications of flood

regimes, in large part as responses to projections of more intense storms and more rainfall runoff from previously snowbound catchments and settings.

Therefore, confidence is judged to be **medium** that increasing flooding risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the U.S.

KEY MESSAGE #10 TRACEABLE ACCOUNT

In most U.S. regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed within existing practices.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document, other chapters of the NCA, and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

Observed and Projected Trends: Many U.S. regions are facing critical water management and planning challenges. Recent assessments illustrate water management challenges facing California, ^{127,128,129,149} the Southwest, Southeast (Ch. 17: Southeast), Northwest, ¹⁵³ Great Plains, ¹⁵⁴ and Great Lakes. ¹⁵⁵

The Sacramento-San Joaquin Bay Delta is already threatened by flooding, seawater intrusion, and changing needs for environmental, municipal, and agricultural water uses. Managing these risks and uses requires reassessment of a very complex system of water rights, levees, stakeholder consensus processes, reservoir system operations, and significant investments, all of which are subject to large uncertainties. ^{54,148} Given the projected climate changes in the Sacramento-San Joaquin Bay Delta, adherence to historical management and planning practices may not be a long-term viable option, ^{128,129} but the supporting science is not yet fully actionable, ⁴² and a flexible legal and policy framework embracing change and uncertainty is lacking.

The Apalachicola-Chattahoochee-Flint (ACF) River basin in Georgia, Alabama, and Florida supports a wide range of water uses and the regional economy, creating challenging water-sharing tradeoffs for the basin stakeholders. Climate change presents new stresses and uncertainties. ACF stakeholders are working to develop a management plan that balances economic, ecological, and social values. 160

New information and remaining uncertainties

Changes in climate, water demand, land use, and demography combine to challenge water management in unprecedented ways. This is happening with a very high degree of certainty in most U.S. regions. Regardless of its underlying causes, climate change poses difficult

challenges for water management because it invalidates stationarity – the perception that climate varies around a predictable mean based on the experience of the last century – and increases hydrologic variability and uncertainty. These conditions suggest that past management practices will become increasingly ineffective and that water management can benefit by the adoption of iterative, risk-based, and adaptive approaches.

Assessment of confidence based on evidence

The water resources literature is unanimous that water management should rely less on historical practices and responses and more on robust, risk-based, and adaptive decision approaches.

Therefore confidence is **very high** that in most U.S. regions, water resources managers and planners will face new risks, vulnerabilities, and opportunities that may not be properly managed with existing practices.

KEY MESSAGE #11 TRACEABLE ACCOUNT

Increasing resilience and enhancing adaptive capacity provide opportunities to strengthen water resources management and plan for climate change impacts. Many institutional, scientific, economic, and political barriers present challenges to implementing adaptive strategies.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document¹ and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

There are many examples of adaptive strategies for water infrastructure ^{106,132,164,165} as well as strategies for demand management, land-use and watershed management, and use of "green" infrastructure. 1,106,132,166,167

Building adaptive capacity ultimately increases the ability to develop and implement adaptation strategies and is considered a no-regrets strategy. ^{1,169} Building networks, partnerships, and support systems has been identified as a major asset in building adaptive capacity (Ch. 26: Decision Support; Ch. 28: Adaptation). ¹⁷⁰

Water utility associations have undertaken original research to better understand the implications of climate change on behalf of some of the largest municipal water utilities in the United States. 119,156,176

Challenges include "stationarity" no longer being reliable as the central assumption in water-resource planning, 171 considerable uncertainties, insufficient actionable science ready for practical application, the challenges of stakeholder engagement, and a lack of agreement on "post-stationarity" paradigms on which to base water laws, regulations, and policies. Water administrators may find it necessary to develop more flexible water rights and regulations. 132,172,173

New information and remaining uncertainties

Jurisdictions at the state and local levels are addressing climate change related legal and institutional issues on an individual basis. An ongoing assessment of these efforts may show more practical applications.

Assessment of confidence based on evidence

Confidence is **very high** that increasing resilience and enhancing adaptive capacity provide opportunities to strengthen water resources management and plan for climate change impacts.

Confidence is **very high** that many institutional, scientific, economic, and political barriers present challenges to implementing adaptive strategies.



Climate Change Impacts in the United States

CHAPTER 6 AGRICULTURE

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INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

6 AGRICULTURE

KEY MESSAGES

- 1. Climate disruptions to agricultural production have increased in the past 40 years and are projected to increase over the next 25 years. By mid-century and beyond, these impacts will be increasingly negative on most crops and livestock.
- 2. Many agricultural regions will experience declines in crop and livestock production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses.
- 3. Current loss and degradation of critical agricultural soil and water assets due to increasing extremes in precipitation will continue to challenge both rainfed and irrigated agriculture unless innovative conservation methods are implemented.
- 4. The rising incidence of weather extremes will have increasingly negative impacts on crop and livestock productivity because critical thresholds are already being exceeded.
- 5. Agriculture has been able to adapt to recent changes in climate; however, increased innovation will be needed to ensure the rate of adaptation of agriculture and the associated socioeconomic system can keep pace with climate change over the next 25 years.
- 6. Climate change effects on agriculture will have consequences for food security, both in the U.S. and globally, through changes in crop yields and food prices and effects on food processing, storage, transportation, and retailing. Adaptation measures can help delay and reduce some of these impacts.

The United States produces nearly \$330 billion per year in agricultural commodities, with contributions from livestock accounting for roughly half of that value (Figure 6.1). Production of all commodities will be vulnerable to direct impacts (from changes in crop and livestock development and yield due to changing climate conditions and extreme weather events) and indirect impacts (through increasing pressures from pests and pathogens that will benefit from a changing climate). The agricultural sector continually adapts to climate change through changes in crop rotations, planting times, genetic selection, fertilizer management, pest management, water management, and shifts in areas of crop production. These have proven to be effective strategies to allow previous agricultural production to increase, as evidenced by the continued growth in production and efficiency across the United States.

Climate change poses a major challenge to U.S. agriculture because of the critical dependence of the agricultural system on climate and because of the complex role agriculture plays in rural and national social and economic systems (Figure 6.2). Climate change has the potential to both positively and nega-

tively affect the location, timing, and productivity of crop, live-stock, and fishery systems at local, national, and global scales. It will also alter the stability of food supplies and create new food security challenges for the United States as the world seeks to feed nine billion people by 2050. U.S. agriculture exists as part of the global economy and agricultural exports have outpaced imports as part of the overall balance of trade. However, climate change will affect the quantity of produce available for export and import as well as prices (Figure 6.3).

The cumulative impacts of climate change will ultimately depend on changing global market conditions as well as responses to local climate stressors, including farmers adjusting planting patterns in response to altered crop yields and crop species, seed producers investing in drought-tolerant varieties, and nations restricting trade to protect food security. Adaptive actions in the areas of consumption, production, education, and research involve seizing opportunities to avoid economic damages and decline in food quality, minimize threats posed by climate stress, and in some cases increase profitability.

Key Message 1: Increasing Impacts on Agriculture

Climate disruptions to agricultural production have increased in the past 40 years and are projected to increase over the next 25 years. By mid-century and beyond, these impacts will be increasingly negative on most crops and livestock.

Impacts on Crop Production

Producers have many available strategies for adapting to the average temperature and precipitation changes projected (Ch. 2: Our Changing Climate)² for the next 25 years. These strategies include continued technological advancements, expansion of irrigated acreage, regional shifts in crop acreage and crop species, other adjustments in inputs and outputs, and changes in livestock management practices in response to changing climate patterns.^{3,4} However, crop production projections often fail to consider the indirect impacts from weeds, insects, and diseases that accompany changes in both average trends and extreme events, which can increase losses significantly.^{2,5} By mid-century, when temperature increases are projected to be between 1.8°F and 5.4°F and precipitation extremes are

further intensified, yields of major U.S. crops and farm profits are expected to decline. There have already been detectable impacts on production due to increasing temperatures. Over time, climate change is expected to increase the annual variation in crop and livestock production because of its effects on weather patterns and because of increases in some types of extreme weather events. Overall implications for production are for increased uncertainty in production totals, which affects both domestic and international markets and food prices. Recent analysis suggests that climate change has an outsized influence on year-to-year swings in corn prices in the United States.

U.S. Agriculture

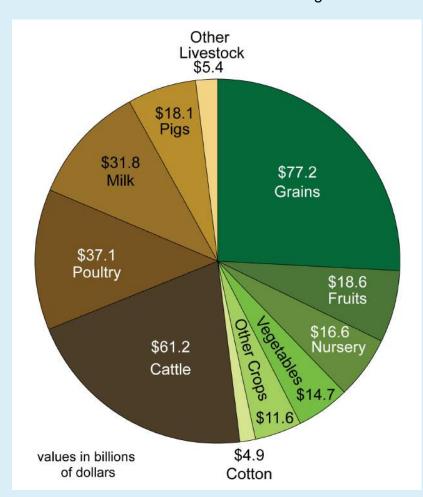


Figure 6.1. U.S. agriculture includes 300 different commodities with a nearly equal division between crop and livestock products. This chart shows a breakdown of the monetary value of U.S. agriculture products by category. (Data from 2007 Census of Agriculture, USDA National Agricultural Statistics Service 2008¹²).



Agricultural Distribution



Figure 6.2. Agricultural activity is distributed across the U.S. with market value and crop types varying by region. In 2010, the total market value was nearly \$330 billion. Wide variability in climate, commodities, and practices across the U.S. will likely result in differing responses, both in terms of yield and management. (Figure source: USDA National Agricultural Statistics Service 2008¹³).

U.S. Agricultural Trade 150 120 Billion Dollars 90 60 **Exports** 30 **Imports** 0 1940 1950 1960 1970 1980 1990 2000 2010

Figure 6.3. U.S. agriculture exists in the context of global markets. Climate is among the important factors that affect these markets. For example, the increase in U.S. food exports in the 1970s is attributed to a combination of rising incomes in other nations, changes in national currency values and farm policies, and poor harvests in many nations in which climate was a factor. Through seasonal weather impacts on harvests and other impacts, climate change will continue to be a factor in global markets. The graph shows U.S. imports and exports for 1935-2011 in adjusted dollar values. (Data from USDA Economic Research Service 2012¹⁴).

Plant response to climate change is dictated by complex interactions among carbon dioxide (CO₂), temperature, solar radiation, and precipitation. Each crop species has a temperature range for growth, along with an optimum temperature. Plants have specific temperature tolerances, and can only be grown in areas where their temperature thresholds are not exceeded. As temperatures increase over this century, crop production areas may shift to follow the temperature range for optimal growth and yield of grain or fruit. Temperature effects on crop production are only one component; production over years in a given location is more affected by available soil water during the growing season than by temperature, and increased variation in seasonal precipitation, coupled with shifting patterns of precipitation within the season, will create more variation in soil water availability. 9,15 The use of a model to evaluate the effect of changing temperatures in the absence of changes in water availability reveals that crops in California's Central Valley will respond differently to projected temperature increases, as illustrated in Figure 6.4. This example demonstrates one of the methods available for studying the potential effects of climate change on agriculture.

Crop Yield Response to Warming in California's Central Valley

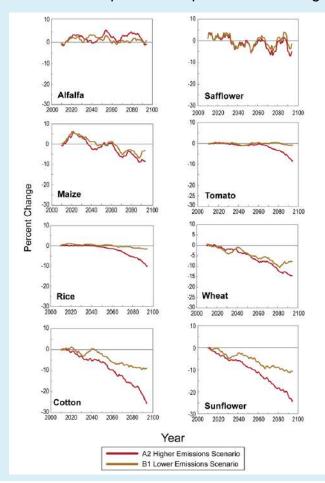


Figure 6.4. Changes in climate through this century will affect crops differently because individual species respond differently to warming. This figure is an example of the potential impacts on different crops within the same geographic region. Crop yield responses for eight crops in the Central Valley of California are projected under two emissions scenarios, one in which heat-trapping gas emissions are substantially reduced (B1) and another in which these emissions continue to grow (A2). This analysis assumes adequate water supplies (soil moisture) and nutrients are maintained while temperatures increase. The lines show five-year moving averages for the period from 2010 to 2094, with the yield changes shown as differences from the year 2009. Yield response varies among crops, with cotton, maize, wheat, and sunflower showing yield declines early in the period. Alfalfa and safflower showed no yield declines during the period. Rice and tomato do not show a yield response until the latter half of the period, with the higher emissions scenario resulting in a larger yield response. (Figure source: adapted from Lee et al. 2011¹⁶).

One critical period in which temperatures are a major factor is the pollination stage; pollen release is related to development of fruit, grain, or fiber. Exposure to high temperatures during this period can greatly reduce crop yields and increase the risk of total crop failure. Plants exposed to high nighttime temperatures during the grain, fiber, or fruit production period experience lower productivity and reduced quality. These effects have already begun to occur; high nighttime temperatures affected corn yields in 2010 and 2012 across the Corn Belt. With the number of nights with hot temperatures projected to increase as much as 30%, yield reductions will become more prevalent.



Projected Changes in Key Climate Variables Affecting Agricultural Productivity

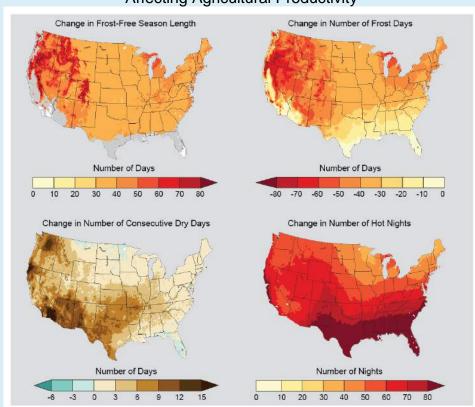


Figure 6.5. Many climate variables affect agriculture. The maps above show projected changes in key climate variables affecting agricultural productivity for the end of the century (2070-2099) compared to 1971-2000. Changes in climate parameters critical to agriculture show lengthening of the frost-free or growing season and reductions in the number of frost days (days with minimum temperatures below freezing), under an emissions scenario that assumes continued increases in heat-trapping gases (A2). Changes in these two variables are not identical, with the length of the growing season increasing across most of the United States and more variation in the change in the number of frost days. Warmer-season crops, such as melons, would grow better in warmer areas, while other crops, such as cereals, would grow more quickly, meaning less time for the grain itself to mature, reducing productivity. ⁹ Taking advantage of the increasing length of the growing season and changing planting dates could allow planting of more diverse crop rotations, which can be an effective adaptation strategy. On the frost-free map, white areas are projected to experience no freezes for 2070-2099, and gray areas are projected to experience more than 10 frost-free years during the same period. In the lower left graph, consecutive dry days are defined as the annual maximum number of consecutive days with less than 0.01 inches of precipitation. In the lower right graph, hot nights are defined as nights with a minimum temperature higher than 98% of the minimum temperatures between 1971 and 2000. (Figure source: NOAA NCDC / CICS-NC).

Temperature and precipitation changes will include an increase in both the number of consecutive dry days (days with less than 0.01 inches of precipitation) and the number of hot nights (Figure 6.5). The western and southern parts of the nation show the greatest projected increases in consecutive dry days, while the number of hot nights is projected to increase throughout the U.S. These increases in consecutive dry days and hot nights will have negative impacts on crop and animal production. High nighttime temperatures during the grain-filling period (the period between the fertilization of the ovule and the production of a mature seed in a plant) increase the rate of grain-filling and decrease the length of the grain-filling period, resulting in reduced grain yields. Exposure to multiple hot nights increases the degree of stress imposed on animals resulting in reduced rates of meat, milk, and egg production.17

Though changes in temperature, CO₂ concentrations, and solar radiation may benefit plant growth rates, this does not equate to increased production. Increasing temperatures cause cultivated plants to grow and mature more quickly. But because the soil may not be able to supply nutrients at required rates for faster growing plants, plants may be smaller, reducing grain, forage, fruit, or fiber production. Reduction in solar radiation in agricultural areas due to increased clouds and humidity in the last 60 years¹⁸ is projected to continue¹⁹ and may partially offset the acceleration

of plant growth due to higher temperatures and CO_2 levels, depending on the crop. In vegetables, exposure to temperatures in the range of 1.8°F to 7.2°F above optimal moderately reduces yield, and exposure to temperatures more than 9°F to 12.6°F above optimal often leads to severe if not total production losses. Selective breeding and genetic engineering for both plants and animals provides some opportunity for adapting to climate change; however, development of new varieties in perennial specialty crops commonly requires 15 to 30 years or more, greatly limiting adaptive opportunity, unless varieties could be introduced from other areas. Additionally, perennial crops require time to reach their production potential.

A warmer climate will affect growing conditions, and the lack of cold temperatures may threaten perennial crop production (Figure 6.6). Perennial specialty crops have a winter chilling requirement (typically expressed as hours when temperatures are between 32°F and 50°F) ranging from 200 to 2,000 cumulative hours. Yields decline if the chilling requirement is not completely satisfied, because flower emergence and viability is low. ²⁰ Projections show that chilling requirements for fruit and nut trees in California will not be met by the middle to the end of this century. ²¹ For most of the Northeast, a 400-hour chilling requirement for apples is projected to continue to be met during this century, but crops with prolonged chilling re-

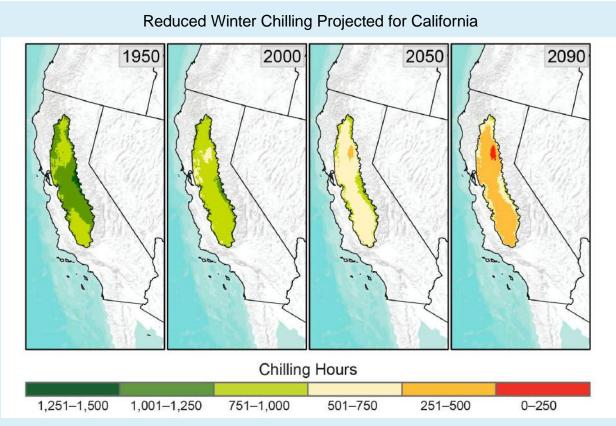


Figure 6.6. Many perennial plants (such as fruit trees and grape vines) require exposure to particular numbers of chilling hours (hours in which the temperatures are between 32°F and 50°F over the winter). This number varies among species, and many trees require chilling hours before flowering and fruit production can occur. With rising temperatures, chilling hours will be reduced. One example of this change is shown here for California's Central Valley, assuming that observed climate trends in that area continue through 2050 and 2090. Under such a scenario, a rapid decrease in the number of chilling hours is projected to occur.

By 2000, the number of chilling hours in some regions was 30% lower than in 1950. Based on the A2 emissions scenario that assumes continued increases in heat-trapping gases relative to 1950, the number of chilling hours is projected to decline by 30% to 60% by 2050 and by up to 80% by 2100. These are very conservative estimates of the reductions in chilling hours because climate models project not just simple continuations of observed trends (as assumed here), but temperature trends rising at an increasing rate. To adapt to these kinds of changes, trees with a lower chilling requirement would have to be planted and reach productive age.

Various trees and grape vines differ in their chilling requirements, with grapes requiring 90 hours, peaches 225, apples 400, and cherries more than 1,000. ²¹ Increasing temperatures are likely to shift grape production for premium wines to different regions, but with a higher risk of extremely hot conditions that are detrimental to such varieties. ²⁴ The area capable of consistently producing grapes required for the highest-quality wines is projected to decline by more than 50% by late this century. ²⁴ (Figure source: adapted from Luedeling et al. 2009²¹).

quirements, such as plums and cherries (with chilling requirements of more than 700 hours), could be negatively affected, particularly in southern parts of the Northeast. Warmer winters can lead to early bud burst or bloom of some perennial plants, resulting in frost damage when cold conditions occur in late spring sa was the case with cherries in Michigan in 2012, leading to an economic impact of \$220 million (Andresen 2012, personal communication).

The effects of elevated CO₂ on grain and fruit yield and quality are mixed. Some experiments have documented that elevated CO₂ concentrations can increase plant growth while increasing water use efficiency. ^{25,26} The magnitude of CO₂ growth stimulation in the absence of other stressors has been extensively analyzed for crop and tree species ^{27,28} and is relatively well understood; however, the interaction with changing temperature, ozone, and water and nutrient constraints creates uncertainty in the magnitude of these responses. ²⁹ In plants such as

soybean and alfalfa, elevated CO_2 has been associated with reduced nitrogen and protein content, causing a reduction in grain and forage quality and reducing the ability of pasture and rangeland to support grazing livestock. The growth stimulation effect of increased atmospheric CO_2 concentrations has a disproportionately positive impact on several weed species. This effect will contribute to increased risk of crop loss due to weed pressure. 28,31

The advantage of increased water-use efficiency due to elevated CO_2 in areas with limited soil water supply may be offset by other impacts from climate change. Rising average temperatures, for instance, will increase crop water demand, increasing the rate of water use by the crop. Rising temperatures coupled with more extreme wet and dry events, or seasonal shifts in precipitation, will affect both crop water demand and plant production.

Impacts on Animal Production from Temperature Extremes

Animal agriculture is a major component of the U.S. agriculture system (Figure 6.1). Changing climatic conditions affect animal agriculture in four primary ways: 1) feed-grain production, availability, and price; 2) pastures and forage crop production and quality; 3) animal health, growth, and reproduction; and 4) disease and pest distributions. The optimal environmental conditions for livestock production include temperatures and other conditions for which animals do not need to significantly alter behavior or physiological functions to maintain relatively constant core body temperature.

Optimum animal core body temperature is often maintained within a 4°F to 5°F range, while deviations from this range can cause animals to become stressed. This can disrupt performance, production, and fertility, limiting the animals' ability to produce meat, milk, or eggs. In many species, deviations in core body temperature in excess of 4°F to 5°F cause significant reductions in productive performance, while deviations of 9°F to 12.6°F often result in death.³³ For cattle that breed during spring and summer, exposure to high temperatures reduces conception rates. Livestock and dairy production are more affected by the number of days of extreme heat than by increases in average temperature.³⁴ Elevated humidity exacerbates the impact of high temperatures on animal health and performance.

Animals respond to extreme temperature events (hot or cold) by altering their metabolic rates and behavior. Increases in extreme temperature events may become more likely for animals, placing them under conditions where their efficiency in meat, milk, or egg production is affected. Projected increases in extreme heat events (Ch. 2: Our Changing Climate, Key Message 7) will further increase the stress on animals, leading to the potential for greater impacts on production.³⁴ Meat animals are managed for a high rate of weight gain (high metabolic rate), which increases their potential risk when exposed to high temperature conditions. Exposure to heat stress disrupts metabolic functions in animals and alters their internal temperature when exposure occurs. Exposure to high temperature events can be costly to producers, as was the case in 2011, when heat-related production losses exceeded \$1 billion.³⁵

Livestock production systems that provide partial or total shelter to reduce thermal environmental challenges can reduce the risk and vulnerability associated with extreme heat. In general, livestock such as poultry and swine are managed in housed systems where airflow can be controlled and housing temperature modified to minimize or buffer against adverse environmental conditions. However, management and energy costs associated with increased temperature regulation will increase for confined production enterprises and may require modification of shelter and increased water use for cooling.

Key Message 2: Weeds, Diseases, and Pests

Many agricultural regions will experience declines in crop and livestock production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses.

Weeds, insects, and diseases already have large negative impacts on agricultural production, and climate change has the potential to increase these impacts. Current estimates of losses in global crop production show that weeds cause the largest losses (34%), followed by insects (18%), and diseases (16%). Further increases in temperature and changes in precipitation patterns will induce new conditions that will affect insect populations, incidence of pathogens, and the geographic distribution of insects and diseases. Increasing CO₂ boosts weed growth, adding to the potential for increased competition between crops and weeds. Several weed species benefit more than crops from higher temperatures and CO₂ levels.

One concern involves the northward spread of invasive weeds like privet and kudzu, which are already present in the southern states. ³⁹ Changing climate and changing trade patterns are likely to increase both the risks posed by, and the sources of, invasive species. ⁴⁰ Controlling weeds costs the U.S. more than \$11 billion a year, with most of that spent on herbicides. Both herbicide use and costs are expected to increase as temperatures and CO₂ levels rise. ⁴¹ Also, the most widely used herbicide in the United States, glyphosate (also known as RoundUpTM and other brand names), loses its efficacy on weeds grown at CO₂ levels projected to occur in the coming decades. ⁴² Higher concentrations of the chemical and more frequent sprayings thus will be needed, increasing economic and environmental costs associated with chemical use.

Climate change effects on land-use patterns have the potential to create interactions among climate, diseases, and crops. 37,43 How climate change affects crop diseases depends upon the effect that a combination of climate changes has on both the host and the pathogen. One example of the complexity of the interactions among climate, host, and pathogen is aflatoxin (Aspergillus flavus). Temperature and moisture availability are crucial for the production of this toxin, and both pre-harvest and post-harvest conditions are critical in understanding the impacts of climate change. High temperatures and drought stress increase aflatoxin production and at the same time reduce the growth of host plants. The toxin's impacts are augmented by the presence of insects, creating a potential for climate-toxin-insect-plant interactions that further affect

crop production.⁴⁴ Earlier spring and warmer winter conditions are also expected to increase the survival and proliferation of disease-causing agents and parasites.

Insects are directly affected by temperature and synchronize their development and reproduction with warm periods and are dormant during cold periods. Higher winter temperatures increase insect populations due to overwinter survival and, coupled with higher summer temperatures, increase reproductive rates and allow for multiple generations each year. An example of this has been observed in the European corn borer (*Ostrinia nubialis*) which produces one generation in the northern Corn Belt and two or more generations in the southern Corn Belt. Thanges in the number of reproductive generations coupled with the shift in ranges of insects will alter insect pressure in a given region.

Superimposed on these climate change related impacts on weed and insect proliferation will be ongoing land-use and land-cover changes (Ch. 13: Land Use & Land Cover Change). For example, northward movement of non-migratory butterflies in Europe and changes in the range of insects were associated with land-use patterns and climate change. 48

Livestock production faces additional climate change related impacts that can affect disease prevalence and range. Regional warming and changes in rainfall distribution have the potential to change the distributions of diseases that are sensitive to temperature and moisture, such as anthrax, blackleg, and hemorrhagic septicemia, and lead to increased incidence of ketosis, mastitis, and lameness in dairy cows.^{33,49}

These observations illustrate some of the interactions among climate change, land-use patterns, and insect populations. Weeds, insects, and diseases thus cause a range of direct and indirect effects on plants and animals from climate change, although there are no simple models to predict the potential interactions. Given the economic impact of these pests and the potential implications for food security, research is critical to further understand these dynamics.

Key Message 3: Extreme Precipitation and Soil Erosion

Current loss and degradation of critical agricultural soil and water assets due to increasing extremes in precipitation will continue to challenge both rainfed and irrigated agriculture unless innovative conservation methods are implemented.

Several processes act to degrade soils, including erosion, compaction, acidification, salinization, toxification, and net loss of organic matter (Ch. 15: Biogeochemical Cycles). Several of these processes, particularly erosion, will be directly affected by climate change. Rainfall's erosive power is expected to increase as a result of increases in rainfall amount in northern portions of the United States (see Ch. 2: Our Changing Climate), accompanied by further increases in precipitation intensity. Projected increases in rainfall intensity that include more extreme events will increase soil erosion in the absence of conservation practices. 51,52

Soil and water are essential resources for agricultural production, and both are subject to new conditions as climate changes. Precipitation and temperature affect the *potential* amount of water available, but the *actual* amount of available water also depends on soil type, soil water holding capacity, and the rate at which water filters through the soil (Figure 6.7 and 6.8). Such soil characteristics, however, are sensitive to changing climate conditions; changes in soil carbon content and soil loss will be affected by direct climate effects through changes in soil temperature, soil water availability, and the amount of organic matter input from plants.⁵³

IT IS ALL ABOUT THE WATER!

Soil is a critical component of agricultural systems, and the changing climate affects the amount, distribution, and intensity of precipitation. Soil erosion occurs when the rate of precipitation exceeds the ability of the soil to maintain an adequate infiltration rate. When this occurs, runoff from fields moves water and soil from the field into nearby water bodies.



Figure 6.7

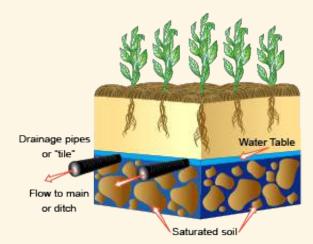


Figure 6.8

Water and soil that are lost from the field are no longer available to support crop growth. The increasing intensity of storms and the shifting of rainfall patterns toward more spring precipitation in the Midwest may lead to more scenes similar to this one (Figure 6.7). An analysis of the rainfall patterns across lowa has shown there has not been an increase in total annual precipitation; however, there has been a large increase in the number of days with heavy rainfall (Figure 6.9). The increase in spring precipitation is evidenced by a decrease of three days in the number of workable days in the April to May period during 2001 through 2011 in lowa compared to the period 1980-2000. To offset this increased precipitation, producers have been installing subsurface drainage to remove more water from the fields at a cost of \$500 per acre (Figure 6.8). These are elaborate systems designed to move water from the landscape to allow agricultural operations to occur in the spring. Water erosion and runoff is only one portion of the spectrum of extreme precipitation. Wind erosion could increase in areas with persistent drought because of the reduction in vegetative cover. (Photo credit (left): USDA Natural Resources Conservation Service; Figure source (right): NOAA NCDC / CICS-NC).

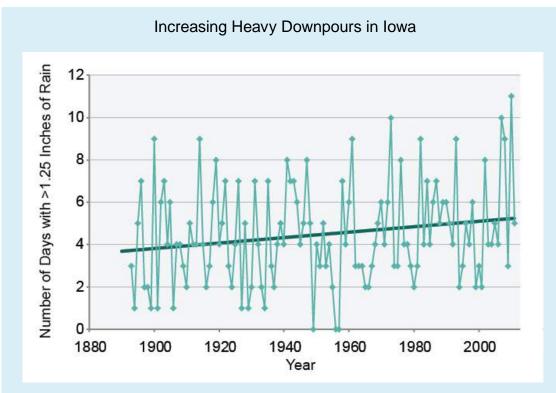


Figure 6.9. Iowa is the nation's top corn and soybean producing state. These crops are planted in the spring. Heavy rain can delay planting and create problems in obtaining a good stand of plants, both of which can reduce crop productivity. In Iowa soils with even modest slopes, rainfall of more than 1.25 inches in a single day leads to runoff that causes soil erosion and loss of nutrients and, under some circumstances, can lead to flooding. The figure shows the number of days per year during which more than 1.25 inches of rain fell in Des Moines, Iowa. Recent frequent occurrences of such events are consistent with the significant upward trend of heavy precipitation events documented in the Midwest. ^{51,55} (Figure source: adapted from Takle 2011 ⁵⁶).

A few of the many important ecosystem services provided by soils include the provision of food, wood, fiber such as cotton, and raw materials; flood mitigation; recycling of wastes; biological control of pests; regulation of carbon and other heat-trapping gases; physical support for roads and buildings; and cultural and aesthetic values. ⁵⁴ Productive soils are characterized by levels of nutrients necessary for the production of healthy plants, moderately high levels of organic matter, a soil structure with good binding of the primary soil particles, moderate pH levels, thickness sufficient to store adequate water for plants, a healthy microbial community, and the absence of elements or compounds in concentrations that are toxic for plant, animal, and microbial life.

Changes in production practices can have more effect than climate change on soil erosion; however, changes in climate will exacerbate the effects of management practices that do not protect the soil surface from the forces of rainfall. Erosion is managed through maintenance of cover on the soil surface to reduce the effect of rainfall intensity. Studies have shown that a reduction in projected crop biomass (and hence the amount of crop residue that remains on the surface over the winter) will increase soil loss. ^{57,58} Expected increases in soil erosion under climate change also will lead to increased off-site,

non-point-source pollution. Soil conservation practices will therefore be an important element of agricultural adaptation to climate change. $^{\rm 59}$

Rising temperatures and CO_2 and shifting precipitation patterns will alter crop-water requirements, crop-water availability, crop productivity, and costs of water access across the agricultural landscape. Higher temperatures are projected to increase both evaporative losses from land and water surfaces and transpiration losses (through plant leaves) from non-crop land cover, potentially reducing annual runoff and streamflow for a given amount of precipitation. The resulting shift in crop health will, in turn, drive changes in cropland allocations and production systems.



Key Message 4: Heat and Drought Damage

The rising incidence of weather extremes will have increasingly negative impacts on crop and livestock productivity because critical thresholds are already being exceeded.

Climate change projections suggest an increase in extreme heat, severe drought, and heavy precipitation. 60 Extreme climate conditions, such as dry spells, sustained droughts, and heat waves all have large effects on crops and livestock. The timing of extreme events will be critical because they may occur at sensitive stages in the life cycles of agricultural crops or reproductive stages for animals, diseases, and insects. Extreme events at vulnerable times could result in major impacts on growth or productivity, such as hot-temperature extreme weather events on corn during pollination. By the end of this century, the occurrence of very hot nights and the duration of periods lacking agriculturally significant rainfall are projected to increase. Recent studies suggest that increased average temperatures and drier conditions will amplify future drought severity and temperature extremes. 6,61,62 Crops and livestock will be at increased risk of exposure to extreme heat events. Projected increases in the occurrence of extreme heat events will expose production systems to conditions exceeding maximum thresholds for given species more frequently. Goats, sheep, beef cattle, and dairy cattle are the livestock species most widely managed in extensive outdoor facilities. Within physiological limits, animals can adapt to and cope with gradual thermal changes, though shifts in thermoregulation may result in a loss of productivity. 63 Lack of prior conditioning to rapidly changing or adverse weather events, however, often results in catastrophic deaths in domestic livestock and losses of productivity in surviving animals.³⁴



Key Message 5: Rate of Adaptation

Agriculture has been able to adapt to recent changes in climate; however, increased innovation will be needed to ensure the rate of adaptation of agriculture and the associated socioeconomic system can keep pace with climate change over the next 25 years.

There is emerging evidence about the economic impacts of climate change on agriculture and the potential for adaptive strategies. 64 Much of the economic literature suggests that in the short term, producers will continue to adapt to weather changes and shocks as they always have, with changes in the timing of field operations, shifts in crops grown, and changing tillage or irrigation practices. 64 In the longer term, however, existing adaptive technologies will likely not be sufficient to buffer the impacts of climate change without significant impacts to domestic producers, consumers, or both. New strategies for building long-term resilience include both new technologies and new institutions to facilitate appropriate, informed producer response to a changing climate. Furthermore, there are both public and private costs to adjusting agricultural production and infrastructure in a manner that enables adaptation. Limits to public investment and constraints on private investment could slow the speed of adaptation, yet potential constraints and limits are not well understood or integrated into economic impact assessments. The economic implications of changing biotic pressures on crops and livestock, and on the agricultural system as a whole, are not well understood, either in the short or long term. ¹⁵ Adaptation may also be limited by the availability of inputs (such as land or water), changing prices of other inputs with climate change (such as energy and fertilizer), and by the environmental implications of intensifying or expanding agricultural production.

Adaptation strategies currently used by U.S. farmers to cope with weather and climate changes include changing selection of crops, the timing of field operations, and the increasing use of pesticides to control increased pressure from pests. Technological innovation increases the tools available to farmers in some agricultural sectors. Diversifying crop rotations, integrating livestock with crop production systems, improving soil quality, minimizing off-farm flows of nutrients and pesticides, and other practices typically associated with sustainable agriculture also increase the resiliency of the agricultural system to productivity impacts of climate change. ^{65,66} In the Midwest,

there have been shifts in the distribution of crops and land-use change partially related to the increased demand for biofuels (see also Ch. 10: Energy, Water, and Land for more discussion on biofuels). In California's Central Valley, an adaptation plan consisting of integrated changes in crop mix, irrigation methods, fertilization practices, tillage practices, and land management may be an effective approach to managing climate risk. ⁶⁸ These practices are available to all agricultural regions of the United States as potential adaptation strategies.

Based on projected climate change impacts in some areas of the United States, agricultural systems may have to undergo more transformative changes to remain productive and profitable in the long term. ⁶⁵ Research and development of sustainable natural resource management strategies inform adaptation options for U.S. agriculture. More transformative adaptive strategies, such as conversion to integrated crop-livestock farming, may reduce environmental impacts, improve profitability and sustainability, and enhance ecological resilience to climate change in U.S. livestock production systems. ⁶⁹

There are many possible responses to climate change that will allow agriculture to adapt over the next 25 years; however, potential constraints to adaptation must be recognized and addressed. In addition to regional constraints on the availability of critical basic resources such as land and water, there are potential constraints related to farm financing and credit availability in the U.S. and elsewhere. Research suggests that such constraints may be significant, especially for small family farms with little available capital. ^{22,64,70} In addition to the technical

and financial ability to adapt to changing average conditions, farm resilience to climate change is also a function of financial capacity to withstand increasing variability in production and returns, including catastrophic loss. The climate change intensifies, "climate risk" from more frequent and intense weather events will add to the existing risks commonly managed by producers, such as those related to production, marketing, finances, regulation, and personal health and safety factors. The role of innovative management techniques and government policies as well as research and insurance programs will have a substantial impact on the degree to which the agricultural sector increases climate resilience in the longer term.

Modern agriculture has continually adapted to many changing factors, both within and outside of agricultural systems. As a result, agriculture in the U.S. over the past century has steadily increased productivity and integration into world markets. Although agriculture has a long history of successful adaptation to climate variability, the accelerating pace of climate change and the intensity of projected climate change represent new and unprecedented challenges to the sustainability of U.S. agriculture. In the short term, existing and evolving adaptation strategies will provide substantial adaptive capacity, protecting domestic producers and consumers from many of the impacts of climate change, except possibly the occurrence of protracted extreme events. In the longer term, adaptation will be more difficult and costly because the physiological limits of plant and animal species will be exceeded more frequently, and the productivity of crop and livestock systems will become more variable.

Key Message 6: Food Security

Climate change effects on agriculture will have consequences for food security, both in the U.S. and globally, through changes in crop yields and food prices and effects on food processing, storage, transportation, and retailing. Adaptation measures can help delay and reduce some of these impacts.



Climate change impacts on agriculture will have consequences for food security both in the U.S. and globally. Food security includes four components: availability, stability, access, and utilization of food. Following this definition, in 2011, 14.9% of U.S. households did not have secure food supplies at some point during the year, with 5.7% of U.S. households experiencing very low food security. Food security is affected by a variety of supply and demand-side pressures, including economic conditions, globalization of markets, safety and quality of food, land-use change, demographic change, and disease and poverty.

Within the complex global food system, climate change is expected to affect food security in multiple ways. In addition to altering agricultural yields, projected rising temperatures, changing weather patterns, and increases in frequency of extreme weather events will affect distribution of food- and

water-borne diseases as well as food trade and distribution. 78 This means that U.S. food security depends not only on how climate change affects crop yields at the local and national level, but also on how climate change and changes in extreme events affect food processing, storage, transportation, and retailing, through the disruption of transportation as well as the ability of consumers to purchase food. And because about one-fifth of all food consumed in the U.S. is imported, our food supply and security can be significantly affected by climate variations and changes in other parts of the world. The import share has increased over the last two decades, and the U.S. now imports 13% of grains, 20% of vegetables (much higher in winter months), almost 40% of fruit, 85% of fish and shellfish, and almost all tropical products such as coffee, tea, and bananas (Figure 6.3). 79 Climate extremes in regions that supply these products to the U.S. can cause sharp reductions in production and increases in prices.

In an increasingly globalized food system with volatile food prices, climate events abroad may affect food security in the U.S. while climate events in the U.S. may affect food security globally. The globalized food system can buffer the local impacts of weather events on food security, but can also increase the global vulnerability of food security by transmitting price shocks globally. 80

The connections of U.S. agriculture and food security to global conditions are clearly illustrated by the recent food price spikes in 2008 and 2011 that highlighted the complex connections of climate, land use, demand, and markets. The doubling of the United Nations Food and Agriculture Organization (FAO) food price index over just a few months in 2010 was caused partly by weather conditions in food-exporting countries such as Australia, Russia, and the United States, but was also driven by increased demand for meat and dairy in Asia, increased energy costs and demand for biofuels, and commodity speculation in financial markets.⁸¹

Adapting food systems to limit the impacts of climate extremes and changes involves strategies to maintain supply and manage demand as well as an understanding of how other regions of the world adapt their food systems in ways that might affect U.S. agricultural competitiveness, imports, and prices. Supplies can be maintained through adaptations such as reducing waste in the food system, making food distribution systems more resilient to climate risks, protecting food quality and safety in higher temperatures, and policies to ensure food access for disadvantaged populations and during extreme events (Ch. 28 Adaptation). ^{15,75,76,80,81}

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PHOTO CREDITS

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SUPPLEMENTAL MATERIAL TRACEABLE ACCOUNTS

Process for Developing Key Messages

A central component of the process was the development of a foundational technical input report (TIR), "Climate Change and Agriculture in the United States: An Assessment of Effects and Potential for Adaptation". A public session conducted as part of the Tri-Societies (https://www.acsmeetings.org/home) meeting held in San Antonio, Texas, on Oct. 16-19, 2011, provided input to this report.

The report team engaged in multiple technical discussions via teleconference, which included careful review of the foundational TIR¹⁵ and of approximately 56 additional technical inputs provided by the public, as well as other published literature and professional judgment. Discussions were followed by expert deliberation of draft key messages by the authors and targeted consultation with additional experts by the lead author of each message.

KEY MESSAGE #1 TRACEABLE ACCOUNT

Climate disruptions to agricultural production have increased in the past 40 years and are projected to increase over the next 25 years. By midcentury and beyond, these impacts will be increasingly negative on most crops and livestock.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the Agriculture TIR, "Climate Change and Agriculture in the United States: An Assessment of Effects and Potential for Adaptation.¹⁵ Additional Technical Input Reports (56) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence that climate change has had and will have impacts on crops and livestock is based on numerous studies and is incontrovertible. ^{6,7,8}

The literature strongly suggests that carbon dioxide, temperature, and precipitation affect livestock and crop production. Plants have an optimal temperature range to which they are adapted, and regional crop growth will be affected by shifts in that region's temperatures relative to each crop's optimal range. Large shifts in temperature can significantly affect seasonal biomass growth,

while changes in the timing and intensity of extreme temperature effects are expected to negatively affect crop development during critical windows such as pollination. Crop production will also be affected by changing patterns of seasonal precipitation; extreme precipitation events are expected to occur more frequently and negatively affect production levels. Livestock production is directly affected by extreme temperature as the animal makes metabolic adjustments to cope with heat stress. Further, production costs in confined systems markedly increase when climate regulation is necessary.

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings in the past Synthesis and Assessment Product on agriculture, 82 which informed the 2009 National Climate Assessment. 83

There is insufficient understanding of the effects on crop production of rising carbon dioxide, changing temperatures and more variable precipitation patterns. The combined effects on plant water demand and soil water availability will be critical to understanding regional crop response. The role of increasing minimum temperatures on water demand and growth and senescence rates of plants is an important factor. There is insufficient understanding of how prolonged exposure of livestock to high or cold temperatures affects metabolism and reproductive variables. For grazing animals, climate conditions during the growing season are critical in determining feed availability and quality on rangeland and pastureland.

The information base can be enhanced by evaluating crop growth and livestock production models. This evaluation would further the understanding of the interactions of climate variables and the biological system. Better understanding of projected changes in precipitation will narrow uncertainty about future yield reductions. ^{9,69}

Assessment of confidence based on evidence

There are a range of controlled environment and field studies that provide the evidence for these findings. Confidence in this key message is therefore judged to be **high**.

Confidence Level

Very High

Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus

High

Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus

Medium

Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought

Low

Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

KEY MESSAGE #2 TRACEABLE ACCOUNT

Many agricultural regions will experience declines in crop and livestock production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the Agriculture TIR, "Climate Change and Agriculture in the United States: An Assessment of Effects and Potential for Adaptation". Additional Technical Input Reports (56) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Numerous peer-reviewed publications describe the direct effects of climate on the ecological systems within which crop and livestock operations occur. Many weeds respond more strongly to CO₂ than do crops, and it is believed that the range of many diseases and pests (for both crop and livestock) will expand under warming conditions. Pests may have increased overwinter survival and fit more generations into a single year, which may also facilitate faster evolution of pesticide resistance. Changing patterns of pressure from weeds, other pests, and disease can affect crop and livestock production in ways that may be costly or challenging to address. Page 19,15

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings in the past Synthesis and Assessment Product on agriculture. By which informed the 2009 National Climate Assessment. By

In addition to extant species already in the U.S., exotic weeds, diseases, and pests have particular significance in that: 1) they can often be invasive (that is, arrive without normal biological/ecological controls) and highly damaging; 2) with increasing international trade, there are numerous high-threat, high-impact species that will arrive on commodities from areas where some species even now are barely known to modern science, but which have the potential to emerge under a changed climate regime to pose significant risk of establishment in the U.S. and economic loss; and 3) can take advantage of "disturbances," where climate variability acts as an additional ecological disturbance. Improved models and observational data related to how many agricultural regions will experience declines in animal and plant production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses will need to be developed.

A key issue is the extent of the interaction between components of the natural biological system (for example, pests) and the economic biological system (for example, crop or animal). For insects, increased populations are a factor; however, their effect on the plant may be dependent upon the phenological stage of the plant when the insect is at specific phenological stages.¹⁵

To enhance our understanding of these issues will require a concerted effort to begin to quantify the interactions of pests and the economic crop or livestock system and how each system and their interactions are affected by climate.¹⁵

Assessment of confidence based on evidence

The scientific literature is beginning to emerge; however, there are still some unknowns about the effects of biotic stresses, and there may well be emergent "surprises" resulting from departures from past ecological equilibria. Confidence is therefore judged to be **medium** that many agricultural regions will experience declines in animal and plant production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses.

KEY MESSAGE #3 TRACEABLE ACCOUNT

Current loss and degradation of critical agricultural soil and water assets due to increasing extremes in precipitation will continue to challenge both rainfed and irrigated agriculture unless innovative conservation methods are implemented.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the Agriculture TIR, "Climate Change and Agriculture in the United States: An Assessment of Effects and Potential for Adaptation." Additional Technical Input Reports (56) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Soil erosion is affected by rainfall intensity and there is evidence of increasing intensity in rainfall events even where the annual

mean is reduced.⁵³ Unprotected soil surfaces will have increased erosion and require more intense conservation practices.^{58,59} Shifts in seasonality and type of precipitation will affect both timing and impact of water availability for both rainfed and irrigated agriculture. Evidence is strong that in the future there will be more precipitation globally, and that rain events will be more intense, even if separated by longer periods without rain.⁶

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings in the past Synthesis and Assessment Product on agriculture, ⁸² which informed the 2009 National Climate Assessment. ⁸³ Both rainfed and irrigated agriculture will increasingly be challenged, based on improved models and observational data related to the effects of increasing precipitation extremes on loss and degradation of critical agricultural soil and water assets. ^{51,52}

Precipitation shifts are the most difficult to project, and uncertainty in regional projections increases with time into the future. To improve these projections will require enhanced understanding of shifts in timing, intensity, and magnitude of precipitation events. In the northern U.S., more frequent and severe winter and spring storms are projected, while there is a projected reduction in precipitation in the Southwest (see Ch. 2: Our Changing Climate).

Assessment of confidence based on evidence

The precipitation forecasts are the limiting factor in these assessments; the evidence of the impact of precipitation extremes on soil water availability and soil erosion is well established. Confidence in this key message is therefore judged to be **high**.

KEY MESSAGE #4 TRACEABLE ACCOUNT

The rising incidence of weather extremes will have increasingly negative impacts on crop and livestock productivity because critical thresholds are already being exceeded.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the Agriculture TIR, "Climate Change and Agriculture in the United States: An Assessment of Effects and Potential for Adaptation". Additional Technical Input Reports (56) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Numerous peer-reviewed publications^{6,61,62} provide evidence that the occurrence of extreme events is increasing, and exposure of plants or animals to temperatures and soil water conditions (drought, water-logging, flood) outside of the biological range for the given species will cause stress and reduce production.^{6,61,62} The direct effects of an extreme event will depend upon the timing of the event relative to the growth stage of the biological system.

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings in the past Synthesis and Assessment Product on agriculture, ⁸² which informed the 2009 National Climate Assessment.⁸³

One key area of uncertainty is the timing of extreme events during the phenological stage of the plant or the growth stage of the animal. For example, plants are more sensitive to extreme high temperatures during the pollination stage compared to vegetative growth stages. A parallel example for animals is relatively strong sensitivity to high temperatures during the conception phase. Milk and egg production are also vulnerable to temperature extremes. The effects of extreme combinations of weather variables must be considered, such as elevated humidity in concert with high temperatures. As a selevated humidity in concert with high temperatures.

Other key uncertainties include inadequate precision in simulations of the timing of extreme events relative to short time periods of crop vulnerability, and temperatures close to key thresholds such as freezing. The uncertainty is amplified by the rarity of extreme events; this rarity means there are infrequent opportunities to study the impact of extreme events. In general, a shift of the distribution of temperatures can increase the frequency of threshold exceedance.

The information base can be enhanced by improving the forecast of extreme events, given that the effect of extreme events on plants or animals is known.^{3,61}

Assessment of confidence based on evidence

There is **high** confidence in the effects of extreme temperature events on crops and livestock, and the agreement in the literature is good.

KEY MESSAGE #5 TRACEABLE ACCOUNT

Agriculture has been able to adapt to recent changes in climate; however, increased innovation will be needed to ensure the rate of adaptation of agriculture and the associated socioeconomic system can keep pace with climate change over the next 25 years.

Description of evidence base

There is emerging evidence about the economic impacts of climate change on agriculture and the potential for adaptive strategies. In the case of crop production, much of the economic literature suggests that in the short term, producers will continue to adapt to weather changes and shocks as they always have, with changes in the timing of field operations, shifts in crops grown, and changing tillage or irrigation practices. In the longer term, however, existing adaptive technologies will likely not be sufficient to buffer the impacts of climate change without significant impacts to domestic producers, consumers, or both.

New strategies for building long-term resilience include both new technologies and new institutions to facilitate appropriate, informed producer response to a changing climate. Furthermore, there are both public and private costs to adjusting agricultural production and infrastructure in a manner that enables adaptation.²

New information and remaining uncertainties

Limits to public investment and constraints on private investment could slow the speed of adaptation, yet potential constraints and limits are not well-understood or integrated into economic impact assessments. The economic implications of changing biotic pressures on crops and livestock, and on the agricultural system as a whole, are not well-understood, either in the short or long term. ¹⁵ Adaptation may also be limited by availability of inputs (such as land or water), changing prices of other inputs with climate change (such as energy and fertilizer), and by the environmental implications of intensifying or expanding agricultural production.

It is difficult to fully represent the complex interactions of the entire socio-ecological system within which agriculture operates, to assess the relative effectiveness and feasibility of adaptation strategies at various levels. Economic impact assessments require improved understanding of adaptation capacity and agricultural resilience at the system level, including the agri-ecosystem impacts related to diseases and pests. Economic impact assessments also require improved understanding of adaptation opportunities, economic resilience, and constraints to adaptation at the producer level. ^{2,64} The economic value of ecological services, such as pollination services, is particularly difficult to quantify and incorporate into economic impact efforts. ¹⁵

Assessment of confidence based on evidence

Emerging evidence about adaptation of agricultural systems to changing climate is beginning to be developed. The complex interactions among all of the system components present a limitation to a complete understanding, but do provide a comprehensive framework for the assessment of agricultural responses to climate change. Given the overall and remaining uncertainty, there is **medium** confidence in this message.

KEY MESSAGE #6 TRACEABLE ACCOUNT

Climate change effects on agriculture will have consequences for food security, both in the U.S. and globally, through changes in crop yields and food prices and effects on food processing, storage, transportation, and retailing. Adaptation measures can help delay and reduce some of these impacts.

Description of evidence base

The relationships among agricultural productivity, climate change, and food security have been documented through ongoing investigations by the Food and Agriculture Organization, 81,84 as well as

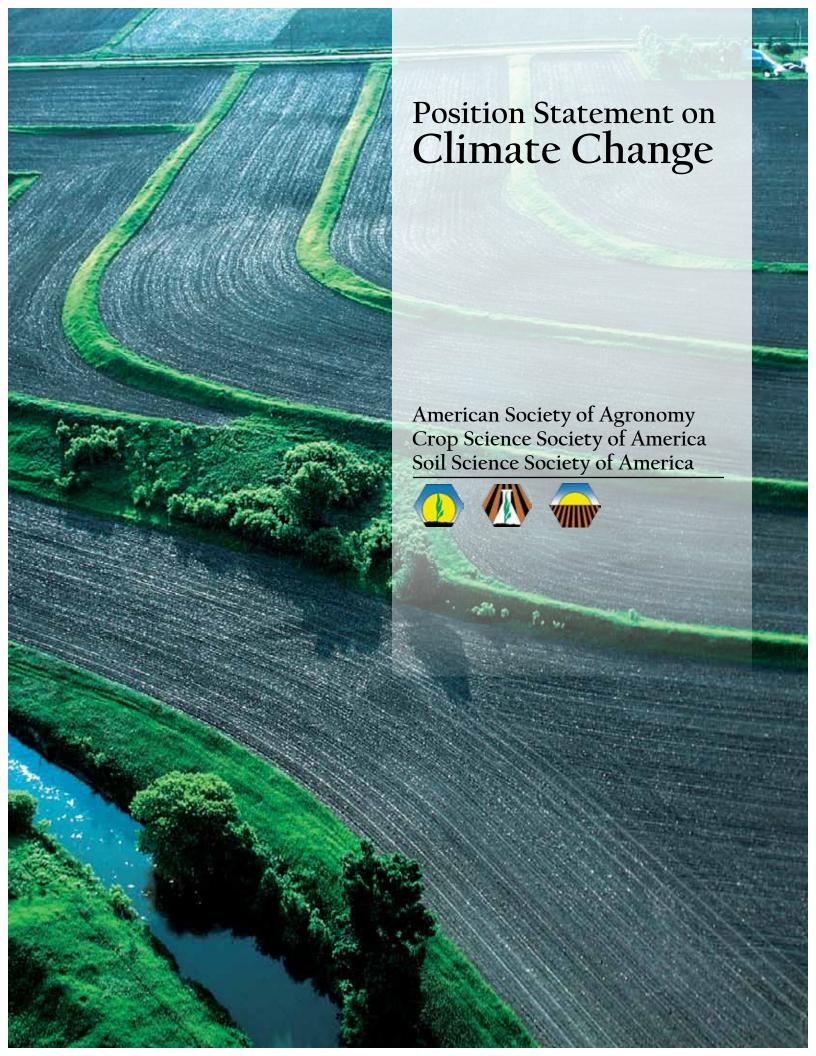
the U.S. Department of Agriculture, ⁸⁵ and the National Research Council.⁷⁷ There are many factors that affect food security, and agricultural yields are only one of them. Climate change is also expected to affect distribution of food- and waterborne diseases, and food trade and distribution.⁷⁸

New information and remaining uncertainties

The components of food security derive from the intersection of political, physical, economic, and social factors. In many ways the impact of climate change on crop yields is the least complex of the factors that affect the four components of food security (availability, stability, access, and utilization). As the globalized food system is subject to conflicting pressures across scales, one approach to reducing risk is a "cross-scale problem-driven" approach to food security. This and other approaches to understanding and responding to the complexities of the global food system need additional research. Climate change will have a direct impact on crop and livestock production by increasing the variability in production levels from year to year, with varying effects across different regions. Climate change will also affect the distribution of food supplies as a result of disruptions in transportation routes. Addressing food security will require integration of multiple factors, including the direct and indirect impacts of climate change.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainty, there is **high** confidence that climate change impacts will have consequences for food security both in the U.S. and globally through changes in crop yields and food prices, and **very high** confidence that other related factors, including food processing, storage, transportation, and retailing will also be affected by climate change. There is **high** confidence that adaptation measures will help delay and reduce some of these impacts.



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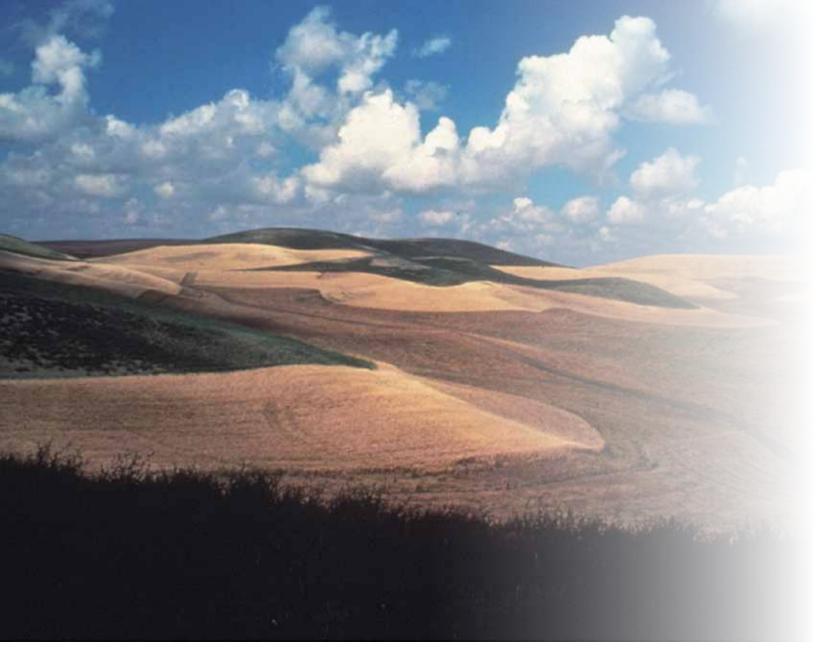
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The American Society of Agronomy (ASA) is an international scientific society, founded in 1907, with 8,000+ members who work to advance the disciplines and practices of agronomy by supporting professional growth. ASA members include scientists, graduate and undergraduate students, and practitioners who are experts in land management, agroclimatology, education and extension, environmental quality, international agronomy, and integrated systems.

The Crop Science Society of America (CSSA), founded in 1955, is an international scientific society comprised of 6,000+ members with its headquarters in Madison, WI. Members advance the discipline of crop science by acquiring and disseminating information about crop breeding and genetics; crop physiology; crop ecology, management, and quality; seed physiology, production, and technology; turfgrass science; forage and grazinglands; genomics, molecular genetics, and biotechnology; and biomedical and enhanced plants.

The Soil Science Society of America (SSSA) is a progressive, international scientific society that fosters the transfer of knowledge and practices to sustain global soils. Based in Madison, WI, and founded in 1936, SSSA is the professional home for 6,000+ members dedicated to advancing the field of soil science, providing information about soils in relation to crop production, environmental quality, ecosystem sustainability, bioremediation, waste management, recycling, and wise land use.

Citation: Climate Change Position Statement Working Group. 2011. Position Statement on Climate Change. Working Group Rep. ASA, CSSA, and SSSA, Madison, WI, May 11, 2011.



Preamble

The American Society of Agronomy (ASA), Crop Science Society of America (CSSA), and Soil Science Society of America (SSSA) have developed the following position statement on climate change based on a review of current scientific knowledge and understanding. Because the potential changes in climate are significant for the practice of agriculture and land management, ASA, CSSA, and SSSA issue this statement to describe the state of the science and facilitate ongoing discussion, decision-making, and research. The statement expresses the findings of a panel of scientists with national and international expertise in climate processes and impacts, mitigation strategies, and adaptation methods for natural and managed ecosystems.¹

1 This statement will be updated periodically as new evidence and understanding of climate change evolves. For more information on ASA, CSSA, and SSSA activities and policies visit the society websites (www.agronomy.org, www.crops.org, and www.soils.org).

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Position Statement on Climate Change

American Society of Agronomy Crop Science Society of America Soil Science Society of America

I. Introduction

A comprehensive body of scientific evidence indicates beyond reasonable doubt that global climate change is now occurring and that its manifestations threaten the stability of societies as well as natural and managed ecosystems. Increases in ambient temperatures and changes in related processes are directly linked to rising anthropogenic greenhouse gas (GHG) concentrations in the atmosphere. The potential related impacts of climate change on the ability of agricultural systems, which include soil and water resources, to provide food, feed, fiber, and fuel, and maintenance of ecosystem services (e.g., water supply and habitat for crop landraces, wild relatives, and pollinators) as well as the integrity of the environment, are major concerns.

Around the world and in the United States (US), agriculture—which is comprised of field, vegetable, and tree crops, as well as livestock production—constitutes a major land use which influences global ecosystems. Globally, crop production occupies approximately 1.8 Billion (B) hectares out of a total terrestrial land surface of about 13.5 B hectares. In addition, animal production utilizes grasslands, rangelands, and savannas, which altogether cover about a quarter of the Earth's land. Even in 2010, agriculture remains the most basic and common human occupation on the planet and a major contributor to human well-being.

Changes in climate are already affecting the sustainability of agricultural systems and disrupting production. While climate is the average weather conditions in given locations over multiple decades, weather consists of the hourly and day-to-day variations in temperature, precipitation, and other variables. In many places around the world, increased incidence of extreme events such as heatwaves, droughts, and floods have been documented.

Although no singular event can be attributed to climate change, collectively recent extreme weather events have had a significant impact on agricultural production. There have been several major weather events in Iowa, the Northern Great Plains, Europe, Australia, and Ukraine that have affected agriculture, for example:

- The 2008 floods in Iowa which affected nearly 10% of corn and soybean acreage, causing over \$1 B in Iosses to crops, livestock, property, and income;
- back-to-back 100-year floods in the Northern Great Plains during 2009 and 2010;
- extreme heatwaves during the summer of 2003 in Europe;
- recent multi-year droughts in Australia that peaked in 2007;
- the 2010 failure of the Ukrainian grain crop;
- and devastating drought in Niger during the summer of 2010.

Agriculture has an important role to play in responding to climate change, both mitigating its causes and adapting to its unavoidable impacts. Agriculture contributes to mitigation through minimizing GHG emissions, sequestering atmospheric carbon, and sustainably producing biofuels. The overall aim of the response to climate change is to ensure food security and other essential human enterprises, while protecting ecosystems and their vital services.

The agricultural sector faces a significant challenge: to increase global production for the purpose of providing food security for 9 billion people by the middle of the 21st century, while also protecting the environment and enhancing function of global ecosystems. Rising and more volatile food prices are also threatening food security. This challenge is further compounded by factors of climate change that now require mitigation and reduction of agricultural GHG emissions, sequestration of carbon in soils, and aversion of factors that limit agricultural production. Therefore, agricultural practices must be developed and applied to mitigate climate change and adapt cropping systems to the portending changes, so as to ensure adequate production of food, feed, fiber, and bioenergy, as well as protection of natural resources.

The American Society of Agronomy (ASA), Crop Science Society of America (CSSA), and Soil Science Society of America (SSSA) are dedicated to seeking ways to mitigate climate change to the extent possible, and to adapt the practices of agriculture and other land uses to the climate manifestations that cannot be prevented.

Climate Effects on Crops

- **Higher temperatures and heatwaves** affect the growth and development of crops, influencing potential yields. A critical variable is the numbers of days a crop is exposed to temperatures exceeding specific thresholds during critical growth stages—e.g. flowering, pollination, fruiting, or grain filling—reducing the quantity and quality of yield.
- Changes in the patterns of precipitation alters water supply for crops. Climate change is expected to destabilize pre-existing rainfall regimes in many regions, resulting in changes in duration and intensity of flooding episodes and periods of drought. This is likely to increase the extent and intensity of erosion, water-logging, and periods of desiccation, with negative effects on yields.
- Increased atmospheric carbon dioxide (CO₂) concentrations may have positive effects on some crops, the effects being species-dependent. The photosynthesis, growth, and yield of C3 plants such as wheat and rice tend to benefit more from high CO₂ than do C4 plants such as maize. Higher CO₂ in the air also increases the efficiency of water use by crops.
- Changes in temperature, precipitation, and CO₂ will interact with other environmental stresses, such as ozone, which tend to reduce crop productivity.



Climate Effects on Soils

- Higher soil temperatures alter nutrient and carbon cycling by modifying the habitat of soil biota, which in turn affects the diversity and structure of species and their abundance.
- Heavier downpours in some regions will lead to increased soil erosion. In addition increased precipitation will result in water-logging of soils, thereby limiting oxygen supply to crop roots and increasing emissions of nitrous oxide and methane. Altered rainfall, whether through increased or decreased precipitation, will affect soil chemistry and biology.
- Soil water retention capacity will be affected by rising temperatures and by a decline in soil organic matter due to both climate change and land-management changes. Maintaining water retention capacity is important to reducing the impacts of intense rainfall and droughts, which are projected to become more frequent and severe.
- Prolonged spells of heat and drought between rainy periods may cause wilting, desiccation, and soil salinization, which may in combination reduce crop yields.
- Increased temperature and decreased moisture tend to accelerate the decomposition of organic material in soils, leading to a decline in soil organic carbon stocks and an increase in CO₂ emissions to the atmosphere.



II. Key Concerns for Agriculture

Unless the emissions of GHGs are curbed significantly, their concentrations will continue to rise, leading to changes in temperature, precipitation, and other climate variables that will undoubtedly affect agriculture around the world. These projections hold significant repercussions for water, carbon, and nutrient cycling in agricultural and natural ecosystems. Global temperatures rose 1.25 degrees F (0.75 degrees C) in the 20th century, and are projected to increase 3.22 to 7.20 degrees F (1.8 to 4.0 degrees C) by the end of the 21st century. Changes in temperature have already begun to affect crops, water availability, and pests in some areas. Such changes have advanced spring green-up of perennial crops in the Northern Hemisphere, and contributed (along with drier conditions) to an increase in forest fires and pests in North America and the Mediterranean Basin. These effects are projected to become increasingly severe as climate change becomes more pronounced.

Crop production will face increasing challenges linked to climate change. Even though long-term projections suggest that temperatures will increase gradually, potential increases in variations of temperature and rainfall can produce profound impacts on food and energy security. In near-term decades, higher CO₂ may provide some benefits to plant growth and water use, but these are likely to be offset by negative effects of rising temperatures and altered rainfall, especially in subsequent decades. Such impacts and their interactions will have region-specific and global effects on agricultural systems. Understanding the impacts of climate change variables and their progressive interactions is critical to developing agricultural systems that will enhance productivity even in a changing climate.

Agriculture's Role in Temperature-Enhancing Gas Emissions

Carbon Dioxide

Carbon dioxide (CO₂) is the most abundant of the increasing greenhouse gases. Land plants fix atmospheric CO₂ via photosynthesis and respire part of it back to the atmosphere. When plant biomass is harvested, burned, or returned to the soil, much of the carbon in plant matter is oxidized and released as CO₂ to the atmosphere as a result of soil microbial respiration or direct combustion. Otherwise, plant matter exists in soil and is broken down over time.

Measured rates of soil carbon storage with the adoption of sequestering practices range from 100 to 1000 kg/ha/year, depending on climate, soil type, and site-specific management. Beneficial agronomic practices which increase yields, while also increasing organic residue in soil include:

- Use of improved crop varieties,
- Cultivation of cover crops,
- Incorporation of perennial crops into crop rotations (to allocate carbon belowground),
- Scheduling irrigation more efficiently,
- · Conserving soil moisture, and
- Reducing or avoiding tillage and soil-baring fallow periods.

Carbon sequestration and land restoration practices can have compound benefits. While mitigating CO_2 emissions, they improve the productivity of the cultivated soil. Additionally, building soil carbon provides the indirect benefit of enhanced water filtering capacity, contributing to water quality and nutrientuse efficiency, while effectively increasing the adaptive capacity of soils and crops to climate change.

Methane

Methane ($\mathrm{CH_4}$), is a short-lived gas with a low atmospheric concentration (only 0.5% that of $\mathrm{CO_2}$), however its per-molecule absorption of infrared radiation is over 20 times stronger than $\mathrm{CO_2}$. Agricultural sources of methane include flooded rice paddies, enteric (bacterial) fermentation by domesticated ruminants (e.g. cows, goats, bison, sheep, and buffalo), farm animal wastes, and biomass burning. Drainage of wetlands for agriculture can also result in methane emissions, as can thawing of permafrost in boreal (subarctic and subantarctic) regions. Furthermore, permafrost2 thaws increase with increasing temperature, resulting in greater methane emission and thus more warming.

2 Soil at or below the freezing point of water (0 $^{\circ}\text{C}$ or 32 $^{\circ}\text{F})$ for two or more years.

Methods to reduce CH₄ emissions from livestock, the primary source of methane in North America, may include:

- genetic development,
- changes in feed formulation, and
- improved manure management.

Limiting CH₄ emissions from rice paddies requires adjustment of cultural practices, including crop, water, and nutrient management. Such practices involve changing:

- rice varieties,
- tillage techniques,
- planting dates,
- fertilization, and
- · modes of irrigation.

Nitrous Oxide

Nitrous oxide (N_2O) is a persistent (mean residence time about 120 years) trace gas that is also a much stronger (>290 times) infrared absorber than CO_2 . In the soil, N_2O evolves mainly from the metabolic process of soil microorganisms. Factors that determine the level of N_2O emissions include soil aeration, temperature, moisture content, soil texture and the amount of nitrogen fertilizer. Nitrous oxide also originates from the decomposition of livestock manure and other organic residues incorporated into the soil.

Specific agronomic techniques to reduce N₂O emissions include:

- adjusting nitrogen application rates to crop needs,
- improving the timing and placement of nitrogen additions to the soil,
- · avoiding excess nitrogen applications,
- using fertilizer approaches that increase fertilizer-use efficiency and reduce N₂O emissions, and
- benefitting, when possible, from biological N fixation.

III. Mitigation Actions for Agriculture

Agricultural activities account for 10-15% of total global emissions of the three main greenhouse gases – CO_2 , CH_4 , and N_2O – although estimates vary. While agricultural, forest, and grazing land-management emit greenhouse gases, many opportunities exist to mitigate these emissions and to sequester carbon in the soil and in the biomass of perennial vegetation.

Effective climate change mitigation strategies reduce emissions of GHGs, while enhancing carbon sequestration from the atmosphere into stable forms in the soil and vegetation. The global mitigation potential for agriculture is estimated to range between 5,500 and 6,000 Mt CO₂-eq/yr through the large-scale application of practices that improve productivity, reduce GHG emissions, and conserve soil. Increasing soil carbon sequestration will produce additional benefits, enhancing soil fertility, as well as the resilience and adaptability of agriculture systems.

IV. Adapting to Climate Change

Adaptation refers to the process of system adjustment to changes in environmental conditions. It includes actions taken in response to actual climate changes and those that prepare for future climate changes, helping to reduce impacts and/or take advantage of benefits. Given the projected direction of climate change, management strategies can be identified that have the potential to achieve productivity goals in a changing environment while simultaneously enhancing environmental quality.

Currently Available Agricultural Adaptation Strategies

- Increasing crop diversity including both widening the array of crop varieties and broadening the range of crops – can be an effective way to moderate the effects of weather variability and extreme events associated with climate change.
- Use of drip irrigation can help to manage limited water supplies more efficiently as hydrological regimes become more unstable and periods of drought become more severe.
- **Integrated pest management** is a means to help agricultural systems respond to changing pest regimes resulting from climate change.
- Soil management such as reduced tillage and residue management can be used to conserve water, reduce erosion, and increase soil productivity.

Stages of Adaptation:

As climate changes proceed in agricultural regions, there are three stages of adaptation related to the level of effort required.

Stage 1: When climate changes are relatively small, many current techniques are available to help farmers adapt. These early-stage adaptations include varying sowing dates and cultivars, fertilization, and irrigation scheduling; as well as changing to better-adapted alternative crops.

Stage 2: As climate change proceeds, more extensive changes may be needed including the genetic improvement of crops to create greater tolerance to elevated temperatures and drought and improved responsiveness to rising CO₂ and the development of new technologies.

Stage 3: In later decades, severe climate changes in agricultural regions may necessitate transformative shifts to entirely different agricultural systems, such as from temperate-zone to subtropical or semiarid-zone forms of agriculture.

V. Conclusion

Agricultural production will manifest large climate change impacts. There is pressing need to improve agricultural productivity for food security while simultaneously protecting the environment as climate is changing. The goal is to produce higher yields with reduced greenhouse gas emissions per unit of production and to conserve and enrich the organic content of soils, and to promote efficient water use, and ecosystem integrity. This goal can be implemented through advanced agronomic management aimed at intensifying and sustaining agricultural production and targeting breeding programs based on improved fundamental understanding of crop genetics and physiology, while preserving natural ecosystems in nonagricultural land.

Climate change has the potential to increase weather variability as well as gradually increase global temperatures. Both of these impacts have the potential to negatively impact the adaptability and resilience of the world's food production capacity; current research indicates climate change is already reducing the productivity of vulnerable cropping systems.



Appendix: Major Tasks for Climate Change

Research in Agriculture

For the agricultural sector to anticipate and respond to climate change, the research and development community must develop the knowledge and methods required to ensure food security and ecosystem services. As a result, intensified and focused research is needed in several broad areas.

To ensure food security in a changing climate

- Develop and evaluate locally-based adaptive management and mitigation strategies to enhance the resilience of cropping and rangeland/pasture production systems.
- Develop and employ transdisciplinary assessment tools that incorporate the systematic resource constraints that affect agricultural productivity and include climate and socioeconomic scenarios, including improved characterization of policy and program environments and options.
- Undertake integrated research in genetics, crop physiology, and soil-nutrient-water-crop management to enhance agricultural yields and environmental quality.
- Actively conserve genetic resources to safeguard these assets for use in the future development of improved varieties.
- Use private and public breeding programs to improve overall abiotic and biotic stress resistance of crops, increase nutrient and water use efficiency, and capitalize on atmospheric CO₂.

To understand the effects of elevated carbon dioxide and climate variability on soils and crops

- Advance understanding of the potential impacts of elevated abiotic stresses (increased CO₂, variable temperatures, and unpredictable precipitation patterns) on biological factors in managed and natural systems.
- Characterize interactions among plants, microbes, and soils that affect the resilience and adaptability of agroecosystems.

To improve efficacy of agricultural mitigation practices

 Adopt a whole-systems approach to greenhousegas mitigation in agroecosystems by incorporating assessments of both carbon and nitrogen cycling.

- Evaluate agronomic practices based on optimization of both soil carbon sequestration and nitrogen use efficiency.
- Study the role of microorganisms in soil carbon and nitrogen stabilization.
- Develop and incorporate life-cycle analysis to evaluate the energy efficiency of current and alternative farming practices at the local, regional, and national scale.

Carbon Dioxide

- Quantify carbon sequestration resulting from various management practices and evaluate and document other beneficial services, such as changes in soil quality, productivity, erosion, and water and air quality.
- Conduct long-term field studies that enhance process-based understanding and improve models to ensure carbon sequestration practices that result in soil carbon with long-term stability.
- Create programs that coordinate national and international on-farm measurements to reduce uncertainty in estimates of carbon stock change, incorporating existing datasets.
- Build a monitoring network of multiple sites to provide observations that support model-based systems which integrate information from existing long-term field experiments and are capable of using site-specific data on climate, soils, and management practices.
- Implement near-real time methodologies to document soil carbon changes over large areas
 using field observations, simulation modeling,
 and remote sensing.

Methane

- Research ways to reduce CH₄ emissions from enteric fermentation.
- Develop methods for livestock manure management that lessen CH₄ emissions.
- Improve efficiency of rice-production systems to reduce CH₄ emissions.

Nitrous Oxide

- Analyze the potential for nitrogen fertilizer-use reduction without negatively impacting crop quality as a climate-change mitigation strategy through studies of cover-crop management, residues, and microbial and physical processes that regulate soil nitrogen cycling and availability.
- Establish monitoring networks, field agricultural experimental sites, and measurement programs for indirect sources to create an inventory of accurate annual N₂O flux estimates in agriculture.

 Use appropriate biogeochemical simulation models that predict N₂O fluxes in simulations with scenarios of climate change.

To improve adaptation options

- Use appropriate models to define crop traits that can provide tolerance to environments with increased climate variability and that take advantage of rising CO₂.
- Develop drought- and/or heat-resistant crops that have been tested for yield stability when subjected to periods of extended water shortage.
- Organize long-term global testing sites and data collection and dissemination efforts, using standard protocols, to conduct adaptive breeding and assess the performance of existing and new genetic material and management systems in today's range of agroclimatic conditions.
- Establish continuous field testing programs to track climate change, resistance to new diseases and

- pests, and changes in pollinator distribution in order to address adaptation of crops. Field testing should extend beyond traditional areas of crops in order to begin anticipating the performance of crops and cropping systems to new environmental conditions.
- Conduct multi-climate and crop-model ensemble simulations to better characterize uncertainty in agricultural impacts and adaptation projections.
- Model path dependence and optimal timing for a range of adaptation strategies by region.
- Develop management systems that will increase the genetic diversity in the landscape. In many areas, the crop plant genetic diversity has decreased to a point where unexpected climate or pest problems can threaten world food security.

American Society of Agronomy Crop Science Society of America Soil Science Society of America









United States Department of Agriculture

Natural Resources Conservation Service



Opportunities for Managing Carbon Sequestration and Greenhouse Gas Emissions in Agricultural Systems

Producers have opportunities to employ conservation practices that save money and time while reducing greenhouse gas emissions and growing a new crop, carbon.

Agricultural and forestry production systems offer a wide variety of opportunities to reduce greenhouse gas (GHG) emissions and increase carbon storage, called sequestration, in soils and vegetation. Many conservation practices used by agricultural producers can mitigate negative effects attributed to climate change. These practices can help reduce GHG emissions and increase carbon storage, while providing many other benefits and enhancements to the producer and society.

The U.S. Department of Agriculture (USDA) is providing incentives and supporting voluntary actions by private landowners in targeting GHG and carbon sequestration through a portfolio of beneficial conservation

programs: Conservation Reserve Program (CRP), Conservation Security Program (CSP), Wetlands Reserve Program (WRP), Wildlife Habitat Incentives Program (WHIP), Conservation Reserve Enhancement Program (CREP), Environmental Quality Incentives Program (EQIP), Grassland Reserve Program (GRP), Rural Development Renewable Energy Systems and Energy Efficiency Improvements, the USDA/DOE/EPA AgSTAR, as well as many other programs and initiatives.

USDA has instituted new standards and is targeting specific incentives that encourage carbon sequestration and GHG emission reduction efforts. USDA also is sponsoring improved monitoring and reporting guidelines for voluntary initiatives. USDA agencies and their partners

are developing tools to estimate the amount of carbon stored and GHG emissions reduced at the field and producer level. COMET-VR (CarbOn Management Evaluation Tool - Voluntary Reporting), a webbased, interactive tool for estimating carbon sequestration and GHG reductions under the Department of Energy's Voluntary **Greenhouse Gas Reporting** Registry, at http://cometvr.colostate.edu, is an example of one of these cooperative efforts. Such tools will make it easier for producers to estimate carbon storage and GHG emissions reductions.

These activities also are expected to stimulate and facilitate other actions including participation in carbon and environmental benefits markets. New markets could create opportunities for producers to supplement their income through production of bioenergy crops and agricultural by-products. As new environmental voluntary market mechanisms continue to develop, agricultural producers will provide both GHG emission reductions and carbon as commodities.











A Wide Range of Agricultural Activities with Technical Assistance...

can be used to manage GHG levels through sequestration of carbon in soils and woody biomass, reduction in GHG emissions, or fossil fuel substitutions. These activities are most often adopted for the other ecosystem services they provide, such as improved air, soil, and water quality; wildlife habitat; and alternative sources of income. Here are just a few of the practices that producers may want to consider in their management plans:

Conservation Practice	GHG Objectives	Additional Benefits
CROPS		
Conservation tillage and reduced field pass intensity	Sequestration, emission reduction	Improves soil, water, and air quality. Reduces soil erosion and fuel use.
Efficient nutrient management	Sequestration, emission reduction	Improves water quality. Saves expenses, time, and labor.
Crop diversity through rotations and cover crops	Sequestration	Reduces erosion and water requirements. Improves soil and water quality.
ANIMALS		
Manure management	Emission reduction	On-farm sources of biogas fuel and possibly electricity for large operations provides nutrients for crops.
Rotational grazing and improved forage	Sequestration, emission reduction	Reduces water requirements. Helps withstand drought. Increases long-term grassland productivity.
Feed management	Emission reduction	Reduces quantity of nutrients. Improves water quality. More efficient use of feed.
AGROFORESTRY		
Windbreaks for crops and livestock	Sequestration, emission reduction	Improves crop and livestock protection and wildlife habitat. Provides alternative income source (specialty crops, hunting fees).
Silvopasture with rotational grazing and improved forage	Sequestration, emission reduction	Provides annual income from grazing; long-term income from wood products.
Riparian forest buffer	Sequestration	Improves water quality and wildlife habitat. Provides alternative income source (specialty crops, hunting fees).

To Learn More About ...

climate change, greenhouse gases, implications for agricultural production, and opportunities for producers, contact your local USDA Service Center or Resource Conservation & Development Area office. Information can also be found at:

- USDA Natural Resources Conservation Service: http://www.nrcs.usda.gov
- USDA Farm Service Agency: http://www.fsa.usda.gov
- USDA FS/NRCS National Agroforestry Center: http://www.unl.edu/nac
- USDA Global Change Program Office: http://usda.gov/agency/oce/gcpo/index.htm\

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CLIMATE CHANGE FACTS

CORNELL COOPERATIVE EXTENSION

FARMING SUCCESS IN AN UNCERTAIN CLIMATE

Climate preparedness makes good business sense. The Earth's climate is always in flux, but today's pace of change is far beyond what previous generations of farmers have had to face. Climate change is already posing new challenges, such as increased risk of flooding, summer heat stress, and more intense pest and weed pressures.

Some farmers are beginning to plan to minimize the risks and capitalize on opportunities. In New York, there will be plenty of both. Making business decisions on future scenarios is always a hair-raising endeavor, even more so with the complication of trying to discern between normal weather variability and long-term climate shifts. Many of the commodities that currently dominate the New York agricultural sector, like dairy products, apples, cabbage, and potatoes, are not well suited for the warming trends predicted for this century. However, there will be profitable opportunities to experiment with new crops or new crop varieties as temperatures rise and the growing season lengthens.



FLOODING

More precipitation is occurring in heavy rainfall events (more than 2 in / 48 hrs), and this trend is expected to continue.

Flooding Challenges:

- · Springtime flooding can delay planting
- · Root damage and reduced yield due to flooding
- Soil compaction from use of heavy machinery on wet soils
- Soil loss from erosion during heavy rain events
- Contamination of waterways from agricultural run-off

Flooding Solutions:

- Increase soil organic matter for better drainage with practices such as reduced tillage, cover cropping, and use of composts or other organic amendments
- Invest in tile or other drainage systems for problem fields
- Shift to more flood tolerant crops
- Buy or lease new acreage with better drainage
- · Shift planting dates to avoid wet conditions





DROUGHT

New York does not face the severe water shortages predicted for some other regions, but the risk of short-term summer drought is expected to increase over this century. Warmer temperatures and longer growing seasons will increase crop water demand, while summer rainfall will remain about the same or possibly decline.

Drought Challenges:

- Declining and more variable yields of rain-fed crops
- Decline in quality of high-value fruit and vegetable crops

Drought Solutions:

- Increase irrigation capacity, particularly for high-value crops
- Shift to drought-tolerant crop varieties
- Shift plant dates to avoid dry periods



HEAT STRESS

The growing season across the state has already increased on average by 8 days. The number of summer heat stress days (e.g., exceeding 90°F) is expected to increase substantially, while winters grow milder. These changes will create both opportunities and challenges for farmers.

New Crops for a New Climate

The increase in average temperatures and longer growing season will allow experimentation with new crops, varieties, and markets. Peaches, melons, tomatoes, and European red wine grapes are a few examples of longer growing season crops that will be favored by a warming climate.



Heat Stress Challenges:

- Warmer summer temperatures have been shown to lower yields for certain varieties of grain crops (field corn, wheat, and oats) by speeding the development cycle and shortening the period during which grain heads mature
- Hot daytime or nighttime temperatures during critical phases of plant development can reduce yield and quality of even those crops considered heat-adapted
- Potatoes, cabbage, snap beans, apples, and other heat-sensitive plants will be more challenging to grow
- Warmer and more variable winters can ironically increase the chance of frost and freeze damage for perennial fruit crops by inducing premature leaf-out and interfering with cold-mediated winter hardening

Heat Stress Solutions:

- Shift planting dates to avoid heat stress during critical periods of plant development
- Explore new varieties of heat-resistant crops, and be prepared to diversify production to reduce reliance on heat-sensitive crops
- Capitalize on the opportunity to grow longer season crops. For example, some field corn growers are already experimenting with new longer growing-season varieties



INSECT INVASIONS AND SUPER WEEDS

Interactions between climate, crops, insects, and disease are complex, but evidence suggests that climate change will require New York farmers to invest in earlier and more intensive pest and weed management. Anticipating the challenge of increased weed and pest pressure will allow for better control and more cost-effective management.

Insect Challenges:

- Spring populations of insect pests will expand, as survivorship rates of marginally over-wintering insect species increase, and migratory insects arrive earlier
- A longer growing season means more insect generations per season, requiring increased intensity of management

Case-Study: Brown Marmorated Stink Bug

If not for its diminutive size, the brown marmorated stink bug (BMSB) could be the subject of a 1950's horror movie. Described as "the bug from hell" after BMSB ate \$37 million of the 2010 MD apple crop, the hungry bugs will munch on anything from orchard crops, to corn and soybeans. First introduced in PA during the '90s, BMSB are teeming northward, taking advantage of recent warm winters and long summers. BMSB was first sighted in NY in 2008, increasing yearly since then. Some pesticides have proven effective against BMSB, but control has been limited.



Weed Challenges:

- Warmer weather and increasing concentrations of carbon dioxide in the atmosphere favor weed growth over crop plants in many cases
- Weeds will have to be controlled for longer and weed seed production will be greater
- Certain weed species currently restricted to the warmer south are migrating northward, such as kudzu, while some familiar weed species, e.g. lambsquarters, are projected to become stronger competitors
- Pressure to use chemical control methods will increase as pest and weed infestation intensifies, but studies have shown the climate change may reduce the efficacy of certain commonly used pesticides (pyrethroids, spinosad) and herbicides (e.g. glyphosphate)

Insect and Weed Management Solutions:

- Improved rapid response plans and regional monitoring efforts will allow for targeted control of new weeds and pests before they become established
- Enhanced monitoring and implementation of integrated pest management (IPM) will help farmers balance pest and weed control while avoiding the economic, environmental and health-related costs of increased chemical application



CHANGE IN THE DAIRY AND LIVESTOCK INDUSTRIES

Heat stress can have devastating consequences for livestock. Keeping cool in the heat of the next century will be critical for maintaining the milk production levels that have made dairy the dominant industry in New York's agricultural sector.

Livestock Challenges:

- Heat stress associated with hotter summers will create dangerous and unhealthy conditions for livestock, reducing productivity and reproductive capacity
- Availability and cost of animal feed will fluctuate as climate affects crops like corn grain and silage
- New costs will be incurred from investments to improve cooling capacity of livestock facilities

Heat Stress and Dairy

- Even moderately warm temperatures, e.g. above 80°F, when combined with moderate humidity, can lead to milk production decline
- In 2005, unusually warm temperatures reduced milk production 5 to 15 lbs per cow per day for many dairies (leading to losses of 8 to 20%)
- The frequency of heat-stress events is expected to increase with climate change



Livestock Solutions-Low Cost:

- Reduce over-crowding and improve barn ventilation
- Minimize heat exposure, e.g. feed during the cool part of the day and maximize shade
- Increase water availability and adjust diet (more fat, less protein)

Livestock Solutions-Moderate to High Cost:

- Improve cooling capacity with additional fans, sprinkler or mister systems, and ventilation renovations
- Insulate barns to buffer extreme heat and save on cooling costs
- Build new barns with adequate cooling capacity for future heat loads

When is it Time to Make a Change?

This will be the critical question for farmers. Climate scientists can provide useful information to help determine when a poor season or two is due to just "normal" bad weather, and when it is due to a shift in the climate that will likely be here to stay. At Cornell, we are working on new decision tools that will allow farmers to examine different future climate scenarios for their region, impacts these might have on crops and livestock, and evaluate various options for timing adaptation investments to minimize negative effects or take advantage of opportunities brought about by climate change.

Prepared by: David Wolfe, Jeff Beem-Miller, Lauren Chambliss, Allison Chatrchyan, and Holly Menninger. Designed by DragonFishStudio.com



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CLIMATE CHANGE FACTS

CORNELL COOPERATIVE EXTENSION

FARM ENERGY, CARBON, AND GREENHOUSE GASES

Farmers today face rising energy costs and uncertainty about future energy policies that affect agriculture. Many farmers are responding by improving the energy efficiency of their operations and exploring alternatives to traditional fossil fuels such as wind, solar, and biofuel crops. Improving nitrogen fertilizer use efficiency is another important strategy. Fertilizer cost is important because it is tightly linked to energy prices, and excessive applications increase the release of nitrous oxide (N2O), a very potent greenhouse



gas (GHG). More efficient fertilizer management is just one of many win-win strategies for farmers that make economic sense and also address concerns about GHG emissions and climate change.

ENERGY EFFICIENCY AND RENEWABLES

Farmers have always sought ways to improve energy efficiency and reduce input costs. For example, most farm vehicles run on diesel, which is a much more efficient fuel than gasoline. Perennial concerns about energy costs, combined with new concerns about GHGs, such as carbon dioxide (CO2) emitted from the burning of fossil fuels, have created incentives to take more control of our energy future. Being "energy-smart" when it comes to farm design and management improves the bottom line, is good for crops and soils, and reduces emissions of GHGs to the atmosphere.

Energy Challenges:

- Fluctuating and rising energy costs reduce profits, making it hard to plan ahead.
- Dependence on foreign oil is a long-term risk.
- Nitrogen fertilizer input costs are linked to energy prices.
- Burning of fossil fuels contributes to climate change.

Energy Solutions:

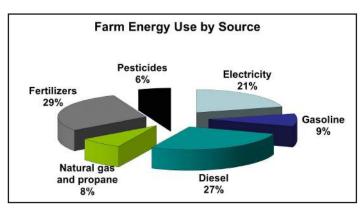
- Optimize building insulation and ventilation; design landscapes for shade and evaporative cooling.
- Select site and building orientation to optimize summer cooling, winter warming, and natural lighting.
- Replace heating and cooling equipment to meet needs with maximum efficiency.
- Use energy-efficient appliances and keep them well-maintained.
- Periodically conduct a comprehensive whole-farm energy audit.



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Crop Production:

- Reduce fuel consumption, e.g., by reducing tillage frequency and intensity.
- Reduce transportation costs and fuel consumption by buying local inputs and exploring local market outlets.
- Purchase fuel-efficient vehicles and equipment and keep them well- maintained.
- Explore use of biodiesel and other renewable fuel alternatives for vehicles or greenhouse heating.
- Minimize use of energy-intensive products such as synthetic fertilizers, pesticides, and herbicides.



A large fraction of farm energy use is associated with the manufacture and transport of fertilizers and pesticides (USEPA 2008).

Renewable Energy

Traditional fossil fuels (e.g., oil, gas, and coal) bring up carbon-rich energy from deep in the earth and add new CO2 to the atmosphere when burned. In contrast, renewables essentially recycle carbon and energy already at the surface, and so do not add to the CO2 in the atmosphere. Many farmers are exploring renewable energy options such as "growing" their own fuel in the form of biofuel crops, using animal or other waste as an energy source, or investing in solar or wind energy systems.

- Fuel crops (e.g., corn, switchgrass, soybeans, and willow) produce abundant biomass, starch and sugars, or vegetable oils that can be used for energy, either directly or after various levels of processing.
- Anaerobic digesters, including covered lagoon systems, decompose manure or other farm waste to create "biogas" fuel. Currently economical for larger-scale operations
 - (greater than 250 head), costs are expected to come down as demand increases and manufacturing becomes more efficient. In the meantime, farmers have found ways to defray some of the costs through grants, low-cost loans, or cost-sharing among several farms.
- Solar power systems range from passive approaches that optimize the use of sunlight for heating or lighting, to the use of photovoltaic (PV) solar cells to generate electricity. Smaller PV systems (e.g., less than 1 kW) are economical for running electric fences, water pumps, and other farm equipment, especially in remote locations.



Anaerobic digesters turn animal wastes into valuable fuel.

Small wind turbines producing 75 kW or less are becoming increasingly popular to supplement electricity needs. Factors to consider before investment include adequate wind, local ordinances that restrict height of structures, and net metering/ billing laws that affect whether you can store or sell excess energy generated during peak periods.

Energy Conservation Financial Assistance and Incentive Programs

- The New York State Energy Research and Development Authority (NYSERDA) website describes programs that assist with farm energy audits, improve facility energy efficiency, and explore options with anaerobic digesters or solar and wind systems (www.nyserda.org/programs/agriculture).
- The USDA Natural Resources Conservation Service (NRCS) has an Environmental Quality Incentives Program that can be helpful in meeting energy-efficiency goals (www.nrcs.usda.gov).



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Carbon Sequestration: Capturing and Storing Carbon in Soils, Crops, and Trees

The energy solutions discussed above reduce CO2 emissions on the farm, but farmers can do more than that. Trees, crops, and soils can capture atmospheric CO2 and store (sequester) it in the form of carbon-rich living biomass and soil organic matter. Building up the organic carbon content in agricultural soils has the added benefit of helping crops thrive. Some best management practices are:

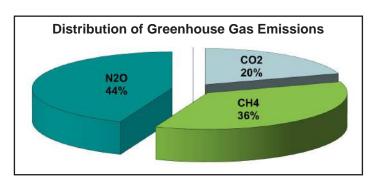
- Reduce tillage to minimize soil aeration, which stimulates the breakdown of organic matter and releases CO2.
- Use manure, composts, biochar, or other high-carbon soil amendments for improved crop productivity and carbon storage.
- Plant winter cover crops to increase annual carbon capture from the atmosphere.
- Manage woodlots to maximize long-term carbon uptake and storage in trees.



Soils store carbon in the upper organic layers.

The Other GHGs: Nitrous Oxide (N2O) and Methane (CH4)

Nationally and globally, CO2 is the biggest contributor to climate change, but for the agricultural sector, nitrous oxide (N2O) and methane (CH4) are of particular concern. They are such potent GHGs that on a CO2 equivalent basis, their emissions from the agricultural sector contribute more to global warming potential than CO2 emissions from the burning of fossil fuels.



GHG Emissions from U.S. Agriculture (CO2 equivalent basis, 2007, USEPA).

Nitrous Oxide Challenges:

- The concentration of N2O in the atmosphere has risen by about 20% since the pre-industrial era. It is a potent GHG with 310 times the global warming potential as CO2. On a CO2 equivalent basis, N2O accounts for almost half of GHG emissions from U.S. agriculture.
- Over 70% of annual U.S. N2O emissions can be attributed to agriculture cropping practices, in particular the use of nitrogen fertilizers.

Nitrous Oxide Solutions:

- Use green manure (legume) rotation crops that provide "free" nitrogen, reducing fertilizer requirements.
- Use manure and composts instead of synthetic nitrogen fertilizers.
- Split fertilizer applications, optimize timing and amount applied based on crop demand, soil tests, and new web tools such as Cornell's Adapt-N program (http://adapt-n.cals.cornell.edu/).
- Plant winter cover crops, such as winter rye, to help store
 soil nitrogen within the root zone, reducing nitrate leaching a



Legume Rotation Crop (Rye-Vetch Mix).



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Methane Challenges:

- The atmospheric concentration of CH₄ has more than doubled since the pre-industrial era. Methane has about 23 times the global warming potential as CO₂. On a CO₂ equivalent basis, CH₄ accounts for over a third of total GHG emissions from U.S. agriculture.
- On an annual basis, over 25% of U.S. CH4 emissions can be attributed to agriculture.
- These emissions are largely linked to ruminant livestock (e.g., cattle, sheep) and the bacterial enteric fermentation process of their digestive system.
- To a lesser extent, methane emissions from decomposing manures on wet soils, uncovered lagoons, and from flooded rice fields play a role.

Methane Solutions:

- Utilize new feeding strategies and feed amendments to reduce dairy cow methane emissions and boost milk production efficiency.
- Use covered or tank storage of manure and store at low temperatures.
- Remove manure promptly from barn floors.
- Calibrate manure spreaders for crop fertilizer needs and incorporate manure into soils immediately.
- Create energy from manure waste with an anaerobic digester.



Summary of Best Management Practices

- Improve energy efficiency and minimize use of synthetic fertilizers and other energy-intensive inputs to lower costs and reduce carbon dioxide emissions.
- Explore renewable energy options, such as biofuel crops, biogas capture from manure waste, wind turbines, and solar systems.
- Enhance ruminant animal digestion efficiency to reduce methane emissions.
- Improve manure handling and storage to reduce methane and carbon dioxide emissions.
- Improve nitrogen fertilizer use efficiency to reduce nitrous oxide emissions, and use organic sources of nitrogen such as legume rotation crops and manure when possible.
- Build up soil organic matter to improve soil health, crop productivity and soil carbon sequestration by reducing tillage, planting winter cover crops, and applying organic matter amendments such as compost.

Prepared by: David Wolfe, Jeff Beem-Miller, Allison Chatrchyan, and Lauren Chambliss. Designed by DragonFishStudio.com





Agriculture Sector Midwest Technical Input Report National Climate Assessment

Agriculture in the Midwest

WHITE PAPER PREPARED FOR THE U.S. GLOBAL CHANGE RESEARCH PROGRAM NATIONAL CLIMATE ASSESSMENT MIDWEST TECHNICAL INPUT REPORT

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At the request of the U.S. Global Change Research Program, the Great Lakes Integrated Sciences and Assessments Center (GLISA) and the National Laboratory for Agriculture and the Environment formed a Midwest regional team to provide technical input to the National Climate Assessment (NCA). In March 2012, the team submitted their report to the NCA Development and Advisory Committee. This whitepaper is one chapter from the report, focusing on potential impacts, vulnerabilities, and adaptation options to climate variability and change for the agriculture sector.





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Introduction

Agriculture in the Midwest United States (Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin) represents one of the most intense areas of agriculture in the world. This area is not only critically important for the United States economy but also for world exports of grain and meat. In the 2007 Census of Agriculture these states had a market value of crop and livestock products sold of \$76,989,749,000 (USDA Census of Agriculture, 2007). Within the U.S., Illinois, Iowa, and Minnesota ranked 2, 3, and 4 in the value of crops sold and Iowa ranked 3rd in the value of livestock, poultry and their products and Wisconsin ranked 7th in the value of livestock, poultry and their products sold. The economic value of agriculture in the Midwest encompasses corn, soybean, livestock, vegetables, fruits, tree nuts, berries, nursery and greenhouse plants. The economic value of the crop and livestock commodities in these states continues to increase because of the rising prices.

Midwestern states are considered to be the Corn Belt; however, there is a diversity of agricultural production beyond corn and soybean. Area in corn for the Midwest in 2007 was 20,360,396 hectares followed by soybean with 14,277,472 hectares. The diversity of agricultural production is shown in Table 1 for the amount of the commodity produced and the state rank based on the 2007 Census of Agriculture (USDA, 2007).

The impact of climate on agricultural production in the Midwest varies among years particularly in grain, vegetable, and fruit production. Fortunately, there are extensive records of agricultural production across the Midwest which allow for a detailed examination of the variation among years, the relationship to changes in the weather in each growing season, and the changing climate over a long time period in the Midwest. Variation among the years for corn grain can be seen in the records since 1866 for Iowa and Michigan production (Fig. 1), soybean for Illinois and Indiana (Fig. 2), sweet corn in Minnesota and Wisconsin (Fig. 3), and potato in Michigan and Wisconsin (Fig. 4).

Historical Impacts on Production

Climate impacts on production are detectable throughout the history of observations in the United States. There is another trend which is noteworthy in these observations which is related to the rapid and steady increase in annual production for crops beginning after the mid-1940's with the introduction of commercial fertilizers and enhanced genetic materials. However, the introduction of improved agronomic practices has not alleviated the effect from years with large impacts caused by unfavorable weather during the growing season. Soybean production has shown a steady increase since records began for the Midwest in 1924 and there are years with large reductions in yield

Table 1. Commodities produced and state rank for the Midwest region of the United States.

Commodity	Illinois		Indiana		Iowa		Michiga	n	Minneso	ta	Ohio		Wiscons	in
	Amount	Rank	Amount	Rank	Amount	Rank	Amount	Rank	Amount	Rank	Amount	Rank	Amount	Rank
Livestock (millions	Livestock (millions of animals)													
Layers	5.3	18	24.2	3	53.8	1	9.0	14	10.6	11	20.1	2	4.9	19
Hogs and pigs	4.3	4	3.7	5	19.3	1	1.0	14	7.6	3	1.8	10	1.1	
Pullets	0.9	28	6.9	5	11.4	1	2.0	16	3.2	12	6.8	6	1.2	22
Turkeys	0.8	19	6.0	7	4.0	9	2.0	16	18.3	1	2.0	14	3.7	10
Cattle and calves	1.2	26	0.6		3.9	7	1.0	30	1.5		0.8		3.4	9
Broilers	0.3		5.5	23	10.2		4.0		8.6	21	10.0	20	7.1	22
Milk and other dairy	Milk and other dairy products from cows (\$100,000)													
	340.3	20	583.2	14	689.7	12	1,285.6	7	1,475.9	6	861.3	11	4,573.3	2
Crop Production (10	000 Hecta	res)												
Corn for grain	5,300.0	2	2,574.9	5	5,614.1	1	951.3	11	3,157.1	4	1,459.4	8	1,315.6	10
Soybean	3,356.5	2	1,936.0	4	3,485.6	1	694.3	12	2,539.0	3	1,714.4	6	551.6	15
Forage	240.1	32	221.3	33	455.5	23	469.6	21	964.7	15	468.0	22	1,132.1	7
Corn for silage	30.4		42.9	17	89.3	8	120.3	7	175.4		74.0	11	296.5	1
Oats for grain	1				27.0	7								
Wheat for grain	360.8	12	146.7	19	11.9		211.7	17	691.4	10	296.3	15	113.5	
Sorghum for grain	31.0	11												
Sugarbeets for sugar									196.5	1				
Vegetables													120.3	4

¹ Cells with no values entered represent a very small land area and production of the specific commodity.

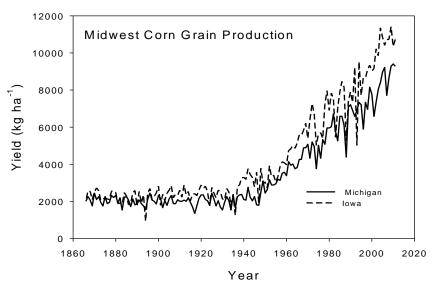


Figure 1. Annual corn grain yields for lowa and Michigan from 1866 through 2011 (Source: USDA-NASS).

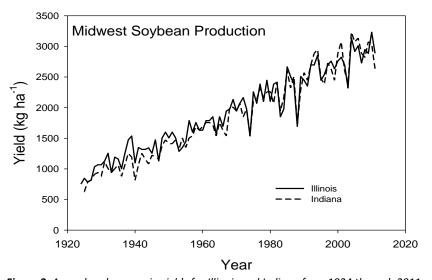


Figure 2. Annual soybean grain yields for Illinois and Indiana from 1924 through 2011 (Source: USD A-NASS).

which are related to extremes due to drought (1988) or flooding (1993). In the grain crops, exposure to extremes, e.g., drought in 1988 created a 30% reduction in yield and the floods of 1993 caused a 44% reduction in the potential sweet corn yield for that year as defined by Hatfield (2010). Water availability is the dominant climatic factor causing yield variation among years. These are significant decreases in crop yield which are observed in all states because of the geographical extent of major climatic events. However, yield decreases in most years average between 15-20% from the potential yield due to short-term exposure to stresses. These stresses can be characterized as periods in which soil water is not available to meet the atmospheric demand or the temperatures are not in the optimal range

for growth. It is important to realize that there is only a small fraction of the years in which there is no stress imposed by weather on crop growth or yield.

Sensitivity to Temperature

Temperature effects on plant growth have been extensively studied and future impacts of climate change may be more related to changes in temperature compared to other climatic factors. Each of the crops grown in the Midwest has a specific temperature range characterized by a lower and upper limit at which growth ceases and an optimum temperature at which growth proceeds at a rate for maximum size of the plant. These temperature limits have been recently defined for several species relative to climate change by Hatfield et al. (2011). The effects of temperature as a climate change parameter has been recently evaluated by several different groups in which they suggest that temperature stresses may be extremely significant in terms of affecting crop growth and yield. Lobell et al. (2011) observed that the changes in temperature which have already occurred from 1980 to 2008 have reduced crop productivity. They concluded that corn (Zea mays L.) yields already declined 3.8% and wheat (Triticum aestivum L.) declined 5.5% compared to the yields without climate trends. An important conclusion from this research was the observation that climate trends have been significant enough effect to offset the yield gains from technology and CO2 increases. Kucharik and Serbin (2008) reported that projected corn and soybean (Glycine max (L.) Merr.) yields for Wisconsin would be significantly impacted because of rising temperatures. Analyses such as these and the results reported by Hatfield (2010) reveal that

climate has already affected crop production. The recent study by Schlenker and Roberts (2009) discussed the potential nonlinear effects of warming temperatures on crop yields in the United States and showed there would be large impacts on productivity because of plants being exposed to conditions which are outside the thermal boundaries for optimal growth. A challenge for research is to begin the process of quantifying the temperature response of plants.

One of the changes in the climate which has a negative impact on plant growth and yield is the increase in the nighttime temperatures. The effect of minimum temperatures on plant growth has been observed in the

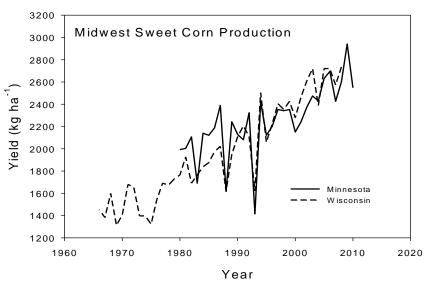


Figure 3. Annual sweet corn production from 1968 through 2010 for Minnesota and Wisconsin (Source: USDA-NASS).

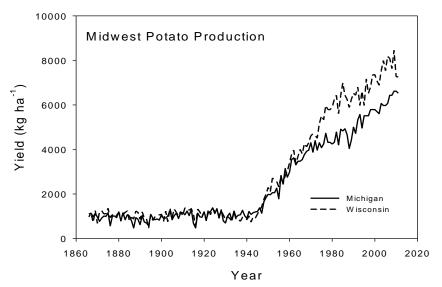


Figure 4. Annual potato production for Michigan and Wisconsin from 1866 through 2011 (Source: USDA- NASS).

small grains, e.g., wheat and rice (*Oryza sativa* L.) When temperatures increased above 14°C there was a decreased photosynthesis after 14 days of stress causing wheat grain yields to decrease linearly with increasing nighttime temperatures from 14 to 23°C which in turn leads to lower harvest indices (Prasad et al., 2008). In their studies, when nighttime temperatures increased above 20°C there was a decrease in spikelet fertility, grains per spike, and grain size. Temperature effects on pollination and kernel set in corn may be one of the critical responses related to climate change. Pollen viability decreases when plants are exposed to temperatures above 35°C (Herrero and Johnson, 1980; Schoper et al., 1987; Dupuis and Dumas, 1990). Pollen viability (prior to silk reception) is a function of pollen moisture content and strongly dependent on vapor

pressure deficit (Fonseca and Westgate, 2005). Although there is limited data on sensitivity of kernel set in maize to elevated temperature, there is evidence suggesting the thermal environment during endosperm cell division phase (8 to 10 days post-anthesis) is critical (Jones et al., 1984). Temperatures of 35°C compared to 30°C during the endosperm division phase reduced subsequent kernel growth rate (potential) and final kernel size, even after the plants were returned to 30°C (Jones et al., 1984). When corn plants are exposed to temperatures above 30°C, cell division was affected which reduced the strength of the grain sink and ultimately yield (Commuri and Jones, 2001). Leaf photosynthesis rate has a high temperature optimum of 33 to 38°C with a reduction in photosynthesis rate when corn plants are above 38°C (Crafts-Brandner and Salvucci, 2002). In a controlled environment study on sweet corn (Zea mays L. var. rugosa), Ben-Asher et al. (2008) found the highest photosynthetic rates occurred at temperatures of 25/20°C while at 40/35°C (light/dark) photosynthetic rates were 50-60% lower. They concluded from these observations that photosynthetic rate declined for each 1°C increase in temperature above 30°C. The expectation is that corn grain plants would show a similar response. In soybean, there is a temperature effect and a comparison of growth at 38/30°C versus 30/22°C (day/night) temperatures, revealed elevated temperatures reduced pollen production by 34%, pollen germination by 56%, and pollen tube elongation by 33% (Salem et al., 2007). Exposure to air temperatures above 23°C caused a progressive reduction in seed size (single seed growth rate) with a reduction in fertility above 30°C leading to a reduced seed harvest index at temperatures above

23°C (Baker et al., 1989).

Potential Future Impacts

The chances for continued impacts for climate change are increasing according to a recent study by Rahmstorf and Coumou (2011) in which they attributed the extreme heat events in Russia during 2010 to climate change and concluded these extremes would not have occurred without climate change. They projected an increase in extremes to occur around the world as a result of climate change. The expectation for a changing climate both in means and extremes will cause impacts on agriculture.

High Temperatures

Increases in high temperatures are not the only effect on crops. Although there has been a warming trend in temperatures, the freeze-free season has only lengthened slightly. As perennial plants produce flower buds earlier in the spring due to warmer temperatures, they could be exposed to relatively normal freezing conditions later in the season that destroy the crop. Fruit and berry crops across the Midwest will be subjected to more extreme conditions and negatively impact growth and production. While there is evidence of changing climate, the overall impacts on perennial crops becomes more uncertain because of the uncertainty in chilling requirements.

CO₂ Concentration and Evapotranspiration

Changes in CO_2 , temperature, and precipitation will impact agriculture in the Midwest. For plant types that respond well to CO_2 enrichment, (C_3 plants), CO_2 may exert a positive influence on growth until temperatures warm more significantly. The positive effect on grain yield, however, has not been as large (Hatfield et al., 2011). An analysis by Bernacchi et al. (2007) using soybean grown in a free air carbon dioxide enrichment (FACE) system at 550 compared to 375 μ mol mol⁻¹ showed a 9 to 16% decrease in evapotranspiration (ET) with the range of differences over the three years caused by seasonal effects among years. There has been evidence that the reduction in ET caused by increasing CO_2 will diminish with increasing temperatures; however, this has not been evaluated in Midwestern crops.

Precipitation

Changes in the seasonal timing of precipitation will be more evident than changes in precipitation totals. There is evidence of an increase in spring precipitation across the Midwest and an increase in the intensity of storm events, though climate model projections for precipitation changes don't exhibit the same degree of confidence compared to the observations across the Midwest. The shifts in precipitation will affect field preparation time in the spring. An analysis of workable field days for April through mid-May in Iowa has shown a decrease from 22.65 days in the period from 1976 through 1994 compared to 19.12 days in 1995 through 2010. This is a major change in the days available during the spring for field work. There is an increased risk for both field work and soil erosion because of these shifts in precipitation. There has been little attention directed toward the workable days in the fall during harvest periods and the potential impact on grain, fruit, or berry quality. Impacts of increased precipitation and intense events are associated with increased erosion and water quality impacts (nutrients and pesticides). It is expected that these impacts will increase with increased

spring precipitation because of the lack of ground cover with vegetation.

Water Quality

Water quality impacts relative to a changing climate have not been thoroughly investigated, but many impacts are related to soil water excesses. Shifts in precipitation patterns to more spring precipitation coupled with more intense storms creates the potential for increased water quality (sediment, nitrate-N, and phosphorus). In an analysis of the Raccoon River watershed in Iowa, Lucey and Goolsby (1993) observed nitrate-N concentrations were related to streamflow in the river. Hatfield et al. (2009) showed that annual variations in nitrate-N loads are related to the annual precipitation amounts because the primary path into the stream and river network was leaching through subsurface drains. The Midwest is an extensively subsurface drained area and these drains would carry nitrate-N from the fields and across the Midwest with the current cropping patterns which do not have amount of water use during the early spring (Hatfield et al., 2009). Increased intensity of spring precipitation has the potential for increased surface runoff and erosion in the spring across the Midwest. Potential increases in soil erosion with the increases in rainfall intensity show that runoff and sediment movement from agricultural landscapes will increase (Nearing, 2001). Water movement from the landscape will transport sediment and nutrients into nearby water bodies and further increases in erosion events can be expected to diminish water quality.

Weeds, Pests, and Disease

Indirect impacts from climate change on crop, fruit, vegetable, and berry production will occur because of the climate change impacts on weeds, insects, and diseases. This has not been extensively evaluated across the Midwest and presents a potential risk to production. Significant effects on production may result from weed pressure caused by a positive response of weeds to increasing CO_2 (Ziska, 2000; 2003 a; 2003b; Ziska et al., 1999; Ziska et al., 2005). The effects of CO_2 on increasing weed growth may lead to increased competition in fields without adequate weed management. A void of knowledge is the effect of changing climate on insects and diseases and the extent of a changing risk pattern on agricultural production.

Stresses on Livestock

Climate stresses on livestock in the Midwest are reduced because most of the species are grown in confined production facilities where there is control of the temperature and humidity and the animals are not exposed to the natural environment. In these systems, there may be a greater effort directed toward energy efficiency in these facilities and management to ensure a limited exposure to extreme conditions during transport of animals to

processing facilities. Dairy cattle are often grown in unconfined facilities, but shelter is provided for these animals from severe weather events. Increases in temperature and humidity occurring and projected to continue to occur under climate change will impose a significant impact on production of the different species shown in Table 1. Exposure of livestock species to the combination of temperature and humidity factors will increase stress levels. These effects, however, have not been extensively quantified across the Midwest. The indirect impacts of climate change on livestock will occur because of the potential for a changing climate to affect the occurrence of insects and diseases. There is an increased risk of the exposure of animals to insect and disease pressure as a result of climate change, but these relationships have not been established for the animal species of the Midwest. Another indirect impact of climate change may be through the availability of feedstock derived from crop production. Reductions in grain production would have an impact on the number of animals which could be produced.

Adaptation

Agriculture is a very fluid system and within annual crop production there is continual adaptation to adjust to the changing climate conditions. There are shifts in planting dates dictated by the precipitation amounts that occur each year. In order for producers to make large shifts in agronomic practices, e.g., maturity dates on crops, there would have to be a consistent pattern in the climate trends and events each year. Adaptation strategies for Midwest crop agriculture will have to include practices which protect the soil from erosion events while at the same time increasing the soil organic matter content through carbon sequestration via improved soil management (Hatfield et al., 2012). Adaptation strategies for livestock across the Midwest would be relatively minor because of the majority of the production systems already occurring under confined spaces with controlled environments.

Crop insurance has been used as a process to offset losses to producers due to weather events during the growing season. Given the uncertainty in the climate change it is difficult to evaluate how crop insurance payments will change in the future (Beach et al., 2010). There have been shifts in the perils which have triggered crop insurance payments for the past 20 years with a shift from drought to flooding and excess water being the major cause of insurance claims.

Adaptation of agricultural systems will occur through many different paths. Producers have readily adopted changes which entail changes in planting date and maturity selections. Other changes, such as the changing of cropping systems to increase water availability in the soil via increases in organic matter content or reductions in soil water evaporation, may be more difficult to implement.

Adoption of improved nutrient management systems to prevent losses of nutrients either by leaching, runoff, or in the case of nitrogen fertilizers, nitrous oxide emissions, represent strategies to enhance crop performance under variable climates. Development of plant genetic resources for annual crops to increase their tolerance to stress will be a necessary component of adaptation to climate change. The potential options for crop adaptation to climate change have been described by Redden et al. (2011). There have been many proposed strategies for adaptation to climate change for annual crops; however, there may fewer options for perennial crops. For livestock, adaptation strategies will typically involve some aspect of the housing facilities for animals and may entail a greater cost of implementation than in cropping systems.

Risk Assessment

Exposure to extreme events for both temperature and precipitation can cause reductions in plant production and yield. There is evidence in the observed yield history for crops grown in the Midwest that extremes can have significant impacts on production levels; however, there are impacts on yields from variability in weather during the growing season caused by short-term weather impacts, e.g., less than normal rainfall but not enough deficiency to trigger drought. With the likelihood of an increase in the occurrence of extreme events across the Midwest, we could expect a greater variation in production amounts. It is also interesting to note in these records that not all extreme events impact the entire Midwest. Some events (flooding or drought) are more localized and affect the production within a state or are even isolated to a few counties. Development of a risk assessment for assessment of climate impacts on agriculture will require the application of crop simulation models into which climate scenarios can be incorporated to evaluate potential adaptation strategies. There is an effort to begin to intercompare and improve crop models for the purpose of providing better simulations of crop production around the world this effort know as the Agriculture Model Intercomparison and Improvement project (AgMIP, www.agmip.org). Efforts are underway to provide intercomparisons for corn, soybean, wheat, rice, sugarcane, peanut, and millet using models developed by the international community and evaluated against data sets from different locations around the world. This approach would allow for an assessment of the potential impacts of climate on future production levels but also allow for the evaluation of the efficacy of various adaptation strategies.

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Section 4. Communicating About Climate Change



Mapping the future of southern pine management in a changing world





Extension

NC STATE UNIVERSITY

Challenges in Communicating Climate Change to Extension Audiences

AUTHORED BY: MARTHA C. MONROE, CLAIRE NEEDHAM BODE, MARK MEGALOS

This fact sheet, the first in a series on climate change, outlines four areas of communication challenges. The second in this series, "Strategies for Communicating Climate Change to Extension Audiences," provides useful strategies for beginning climate conversations with audiences and clients. The third, "Risk Perceptions and Needs: Defining Extension's Climate Change Adaptation Role," suggests themes that link climate concepts to various audiences.



Unusual weather, high fuel prices, coastal erosion, and severe wildfires have one thing in common: they generate headlines that suggest climate change is upon us. Media reports often spawn editorials that present alternate interpretations of the evidence, point to uncertainty in the climate models, and rebuke the implications. Anyone can be easily confused by the plethora of information. Extension agents are trusted sources of information and can play a valuable role providing educational programs to clients seeking to understand climate changes and appropriate adaptation strategies (Franz, Piercy, Donaldson, Westbrook, and Richard 2010). This fact

sheet explains four key challenges of climate change communication to help Extension agents successfully provide science-based perspectives and avoid ideological conflicts and problems.

CHALLENGE #1: CLIMATE CHANGE IS COMPLEX, UNCERTAIN, AND VARIABLE

Introducing an issue as complex as climate change to a group of citizens can be a minefield for Extension agents accustomed to presenting issues with more simple solutions, such as building a compost bin to reduce solid waste. It seems obvious to begin the discussion with weather, but even that is problematic. We experience and remember daily weather events, but climate is a function of decades of averaged data, not anomalies. As powerful as our brains are, they do not easily compute long term trends from experience (Kahneman 2011). If an Extension agent began a conversation with, "In what ways is the weather now different from the ways it used to be?" people would be invited to compare observations to their sense of long-term climate assumptions. This might help



switch their attention to those climate trends. If audiences are most concerned about solutions to variable weather phenomena, the program could continue with strategies to reduce risk by preparing for extreme events.

The climate system is complex and some of the most important variables (such as carbon emissions) could change in the future, creating uncertainty in the forecasts. Climate predictions for specific locations are not easily created from large scale datasets. Changes in temperature can impact a number of other variables, such as wind and ocean currents, which can affect precipitation patterns, which can change the location and extent of snowfall and rainfall events (NRC 2012). Complex feedback loops and relationships between climate variables are still being explored as more scientists investigate the relationships in complex climate systems.

Many scientists rely on models, which are by definition a simplification of reality. A model can predict an accurate outcome only if all of the important variables and relationships are included. Models for the planet may not address local geography, so projecting what changes will happen at any place on the planet is extremely challenging. Any good scientist will explain the degree to which their projection is likely, and this statement of uncertainty makes it that much harder for the public to understand and believe the message (Shome & Marx 2009).

News articles commonly mention "global climate change," as if the entire planet will experience the same changes. The Earth normally has both very wet and very dry regions, and climate projections suggest some will be wetter and others will be drier. Even locally there will be variability. Plants and animals that live on the edge of their range may find the future habitat more challenging, or more conducive to range expansion. The variety of possible outcomes of climate change may be too numerous to imagine, which leads people to focus on either the most likely scenarios or the most impactful.

So a good deal of why climate change communication is a challenge is simply a function of the topic (Weber & Stern 2011). It is complicated, hard to simplify, uncertain, yet likely to manifest in many different ways depending on where you are. If agents can offer local examples of visible

differences, research-based evidence of changes over time, and suggestions for how people are likely to be affected by climate change in the local region, audiences will be more likely to listen.

CHALLENGE #2: PEOPLE LEARN AND REMEMBER SELECTIVELY

People learn most easily from their experience. The more likely an experience is to be repeated, the more likely we are to commit our reactions to memory and better prepare for the next time (Kaplan & Kaplan 1982). After burning a finger while taking a pan from the oven, we will likely readjust the mitt the next time. Painful impacts command our attention.

When we are not guided by experience, we learn from the next best thing. This might be through stories, vivid examples, or television coverage that mimics experience and can assist us in learning about the possibilities of beating Goliath or setting foot on the moon (Kaplan & Kaplan 1982). It might also be from people we trust to give us good advice and to whom we pay close attention (Kahneman & Tversky 1973). A friend's complaints about a new car, for example, may be enough to cause people to avoid that model when they consider a purchase.

In addition to these characteristics that affect what we choose to remember, people are also selective when it comes to what they perceive (Kaplan & Kaplan 1982). The world is loaded with information that competes for our attention so we tend to perceive those things that match what we expect to see (Nickerson 1998, Jones & Sugden 2001) or that confirm what we think. Competing sports fans do not see the same evidence the referees see, despite the replayed telecast. We even avoid reading articles that we deem to be wastes of time if we do not agree with the line of reasoning presented. This tendency to perceive selectively makes it difficult for people to learn information that conflicts with what they believe to be true (Centola, Gonzalez-Avella, Eguiluz, and Miguel 2007; McCright & Dunlap 2011).

These features of human perception have several implications for learning about climate change. First, if climate changes have not been experienced, it is difficult to accept the new information as fact. Second, if personal



experiences have not been significant, important, or obvious, once again new information is more likely to be ignored. Climate changes may be everywhere but if people are not living on mountaintops or in the Arctic the change may be too subtle to perceive or not relevant enough to warrant concern. Third, we believe those we trust. For Extension agents who are trusted purveyors of science-based information, this is an important lever for climate change education and worth additional background to better understand (see challenge #3). And fourth, we are most likely to listen to what we already believe. Including information that people trust, and therefore, believe, while introducing new information may help people begin to listen.

CHALLENGE #3: PEOPLE PAY ATTENTION TO PEOPLE WHO ARE LIKE THEM

The Cooperative Extension Service has become a leading agency in encouraging behavior change, in part because we hire agents who are similar to the audiences with whom they work (Rogers 2003). County staff shop, send their children to school, and participate in the communities they serve. To the extent that Extension agents are similar to their audience, they can be trusted to provide reasonable, useful, and helpful information.

When it comes to an issue as divisive as climate change, researchers suggest that something else is affecting how people perceive information. Rather than accepting all information as neutral and equivalent, the Identity

Protective Cognition theory posits that along with content, information carries cultural meanings. Prior beliefs and expectations are activated, and so are attitudes, values, and worldviews (McCright & Dunlap 2011). Messages that conflict with cultural norms can be more easily dismissed than messages that recognize and support those norms, even if the information is similar.

Thus, the implications for climate change communication are important. Not only are we more likely to pay attention to someone who is similar to us, we also trust information from those we respect (McPherson, Smith-Lovin & Cook 2001, Moser 2010). For example, political leaders and celebrities may not be climatologists, but their views carry weight among the general public. A careful communicator can create a message or communication 'frame' that resonates with an audience by establishing a bond that speaks to a common culture, using key phrases, and addressing cherished values (Nesbit 2009).

CHALLENGE #4: AUDIENCES VARY

The final challenge for communicating about climate change is that many groups are likely to include people who have different and even opposite perspectives about climate change (Leiserowitz, Maibach, Roser-Renouf & Hmielowski 2012). Researchers at Yale and George Mason Universities have surveyed public opinion over the last decade to ascertain beliefs about climate, risk, and willingness to act. They categorized respondents into six groups (Maibach, Leiserowitz, Roser-Renouf & Mertz 2011)

Six Americas Audience Categories	Description	You might hear
Alarmed	Convinced global warming is a serious and urgent threat; highly engaged; most likely to change behavior.	I'm so upset and worried about the future.
Concerned	Convinced global warming is a serious threat; somewhat engaged; less likely to change behavior	l think this is something politicians should address.
Cautious	Believe global warming is a problem but not a personal or urgent threat	So what is it all about?
Disengaged	Give little thought to global warming; change beliefs easily; not perceived as a problem for them	I have other things to think about, like how to pay the bills
Doubtful	Not sure if global warming is happening	Seems like climate always changes. This is a political issue.
Dismissive	Firmly believe global warming is not occurring; highly engaged in preventing change in policies; very knowledgeable	It's arrogant to believe people can change the climate. There is evidence the scientists are wrong.

Table 1. Six Americas Categories, adapted from Leiserowitz et al. 2012



based on respondents' perceptions. Table 1 describes these six categories of perceptions of global warming, which they defined as recent increase in temperature and interpret as perceptions of recent climate change, and offers sample comments that portray how people think about this issue. Extension agents who embark on climate education programs may wish to ask a few questions of an audience to determine whether the full range of possible perceptions are present (e.g., Do you believe natural causes of climate variation are equally or more important in explaining recent changes? Do you trust climate scientists to convey accurate and honest information?). Individuals are not likely to shift between categories quickly, and conversion should not be a goal of an Extension program. Rather, answering questions and providing information in a way that people can hear and understand it would be more feasible.

SUMMARY

Extension agents can use human characteristics and psychological theories to inform approaches to climate change programming (Fraisse, Breuer, Zierden & Ingram 2009, Pike, Doppelt & Herr 2010, Shome & Marx 2009). Relaying an understanding climate change is not easily accomplished in one presentation or program, so agents might consider a strategy that introduces information over time and then asks participants what they want to know more about to guide the development of future programs and selection of speakers. An Extension agent may be more likely to be a respected source of information when they use communication frames that the audience is likely to care about, such as the health and welfare of their families

and the community, or the responsibility they might feel for vulnerable populations of people and animals in more distant places. Those who are firmly convinced that humans have not altered the climate may still be willing to think about how they can adapt to an uncertain future, since recent evidence suggests that some effects of climate change are happening more quickly than anticipated. Those who feel responsible for the impacts their actions may be causing may be curious to learn more about alternative strategies they can adopt to mitigate climate change. Fact Sheet #2 explores general guidelines and offers specific tips for how to engage stakeholders in constructive dialogue and learning about climate change.

Extension agents may be unaccustomed to engaging audiences who perceive climate change information as controversial, scientists to be untrustworthy, or the media to be conveying falsehoods. Understanding that the sources of these perceptions arise from our human nature may make it easier to plan a program that conveys a position that with everyone working together and with all of the available evidence, we can determine the most practical solutions to our climate challenges.

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Mapping the future of southern pine management in a changing world







Strategies for Communicating Climate Change to Extension Audiences

AUTHORED BY: CLAIRE NEEDHAM BODE, MARTHA C. MONROE, MARK MEGALOS

This fact sheet is in the second in a series on climate change communication. The first, "Challenges in Communicating Climate Change to Extension Audiences," outlines four areas of communication challenges. This fact sheet provides strategies in response to each of the four challenges presented in factsheet 1.



CHALLENGE #1: CLIMATE CHANGE IS COMPLEX, UNCERTAIN, AND VARIABLE.

Climate change is complicated, hard to simplify, and uncertain, yet likely to manifest in all facets of community life. Planning and zoning, agriculture, transportation, and public health are impacted by climatic change. Yet active campaigns by groups with a financial interest in fossil fuels (McCright and Dunlap) have led to wide-spread misperceptions in the American public about the scientific community's agreement that climate change is happening now and that humans are contributing to it. Strategy: Provide simple, clear messages

about the scientific consensus on humancaused climate change.

Clearly and simply communicate that 97% of climate scientists are convinced that human-caused climate change is happening.¹ Most Americans are not aware that the vast majority of climate scientists agree about climate change and its causes.2 Correcting this misperception can have significant impact: those who recognize it are much more likely to agree that climate change is happening, will impact their lives, and that there is still time to take action. (Maibach et al., 2014; Kotcher et al., 2014). Consider using analogies and framing climate change agreement in terms of risk management: "If 97% of physicians agreed on a diagnosis, would you search for further evidence?" Or, "If 97% of engineers agreed that a bridge was structurally unsound, would you seek another opinion?" (van der Linden et. al. 2014)

Climate communication experts agree that, in addition to communicating the scientific consensus, these other four simple messages, repeated often by a variety of

¹Methods used to arrive at the 97% consensus include surveys of climate scientists and reviews of peer-reviewed literature. See Doran and Zimmerman, 2009; Cook et al., 2013, Oreskes, 2004; Anderegg et al., 2010; Cook et al., 2013. In 2013, only 42% of American adults agreed that, "Most scientists agree that global warming is happening," and 33% believed that "there is widespread disagreement among scientists about whether or not global warming is happening." (Leiserowitz, 2014)



trusted messengers, make a difference:

- 1. Climate change is real
- 2. People are causing it
- 3. Climate change is harmful to people
- 4. People can limit it. (Maibach et. al., 2014)

Oversimplifying climate science can lead to misunderstandings and confusion. Yet it is not difficult to reduce the scientific consensus down to a few key sentences, and then point people to reliable sources (some of which are detailed here in this fact sheet).

CHALLENGE #2: PEOPLE LEARN AND REMEMBER SELECTIVELY.

Daily, we are deluged with information and problems competing for our attention. One way we filter and decide which issues deserve our attention is to seek out information that confirms what we already believe (known as "confirmation bias"), and tune out information about problems we think don't affect us personally. Strategy: Harness participant observations and reflections about local climate change impacts. Lectures and presentations on climate change should include ample time for discussion, so participants can learn from those who are both like them, and who have varying opinions and experiences.

Extension agents frequently are viewed as trusted messengers, because we reflect the values of the stakeholders we serve. Therefore, we are able to convene discussions and facilitate conversations around a variety of contentious topics, including climate change. Consider hosting climate change education sessions that link what the audience already knows to new information about climate science. One option is to use a timeline, where participants collectively remember major weather events in their community from the last 30 years. While it is important to differentiate weather from climate, this exercise can begin a conversation about that distinction.

Often, climate change education sessions can turn into debating the finer points of the science. Many times these arguments about scientific uncertainties are actually substitutions for disagreements about underlying values. During well-facilitated discussions, however, values can be openly aired, rather than couched in debates about

the science. Consider using small group discussion and ground rules that encourage open exchange and encourage deliberation. In addition, stories and scenarios are good strategies for introducing new information in a way that leads to consideration and discussion, rather than defensive posturing.

CHALLENGE #3: PEOPLE PAY ATTENTION TO THOSE WHO ARE LIKE THEM.

People generalize from their own experience and, when that isn't available, from the stories of those whom they trust. They tend to seek out information and sources that confirm their own beliefs and values. *Strategy: Engage learners around group norms and values*.

Because climate change affects so many aspects of our daily lives, it is possible to frame the problems and solutions in ways that speak to a broad spectrum of stakeholders. It is helpful to think about the importance of values when framing climate change. (Nesbit, 2009). Values are core belief sets about the world that guide actions and decisions. They include beliefs such as fairness, compassion, and justice; are relatively stable throughout one's life; and are ordered by relative importance. (Schwartz SH, Bilsky W (1987). They reflect what one wants in the *ideal world*.

Research has shown that values cluster into two main categories: individualistic and egalitarian. Those who value individualism more than egalitarian tend to favor business solutions rather than government action, as they believe competition leads to better and fairer outcomes. (Kahan, 2010). Those with egalitarian values tend to favor government action, as they believe government puts more people on equal footing. For individualistic audiences, consider framing messages around the benefits associated with more renewable energy, such as American innovation and less dependence on foreign oil. For egalitarian audiences, consider the frames of biodiversity, and global interconnectedness.

No matter the audience, framing climate change with fear-based messages has been shown to be ineffective at motivating behavior change. People across all spectrums, even those in the "Alarmed" category, end up feeling hopeless and helpless when they hear messages about how climate change will be the end of us all.



Instead, provide examples of local solutions and benefits to adapting to and mitigating climate change. Give local case studies of how businesses, governments, individuals, and communities have reduced their energy consumption or greenhouse gas emissions, or how they are implementing climate adaptation plans. Raising fear without providing solutions only leads to ignoring the problem.

CHALLENGE #4: AUDIENCES VARY.

Communication experts remind us to target our message to the audiences. In Extension, however, in any given

- audience we are likely to encounter people from a variety of backgrounds and attitudes concering climate change. If that is the case, research has shown that these value-based frames resonate well with most people:
- 1. Changing to cleaner energy and reducing emissions will result in a better future for our children.
- 2. We have a responsibility to conserve finite resources.
- 3. Transitioning to a greener economy will make (our community, our country) more competitive.

 In the event you are able to determine which of the "Six Americas" audience segment your stakeholders reflect, consider framing education around these key messages and resources found in the table, below.

Six Americas Audience Categories	Description of audience segment	Frames and key messages	Examples and resources
Alarmed	Convinced global warming is a serious and urgent threat; highly engaged; most likely to change behavior	 "We can solve this problem." Specific actions they can take to reduce harmful effects of cc. Encourage discussing climate change with friends and family. 	Examples of community-wide reduction of carbon footprint, from the EPA state, local, or climate webpage. Extension's Climate Change handbook, available at Oregon State University, www.cof.orst.edu/ cof/extended/sustain/Plan C, Community Solutions, www.communitysolution.org/index/html.
Concerned	Convinced global warming is a serious threat; somewhat engaged; less likely to change behavior	 "Small actions do add up". Provide information about taking steps to reduce carbon footprint. Provide resources for contacting state and federal legislators 	EPA Household Carbon Footprint Calculator: includes sections to explore actions to reduce greenhouse gas emissions and to determine savings: EarthLab Carbon Footprint Calculator (get your score, take action to reduce your score, track your score)
Cautious	Believe global warming is a problem but not a personal or urgent threat	 "Climate change is happening now, here" Ask for examples of how weather patterns have changed in their lifetimes Cautious audiences mostly interested in how scientists know climate change is occurring and that humans are causing it. Provide Q/A or discussion with scientists. 	Climate Matters contains interactive, regional tools on climate change in the U.S., Citizen Science, and Phrenology. www.usanpn.org/ For simple explanations, see www.skeptical science.org or "Frequently Asked Questions about Climate Change," by MSU Extension.
Disengaged	Give little thought to global warming; change beliefs easily; not perceived as a problem for them	Appeal to social norms, use narratives and humor. Personalize it. Use highly credible sources.	Emphasize that "acting green" is widespread, growing in popularity, and characteristic of admired individuals: This is popular and it's socially approved. Emphasize local impacts and local solutions.
Doubtful	Not sure if global warming is happening	"Sometimes life calls on us to act responsibly, even when we are not 100% certain."	Second lowest in egalitarian, second highest in individualism (of the 6 Americas). Would like to know how scientists know that climate change is real. A six-minute video (https://www.youtube.com/watch?v=FxaWVlzgkX4&Ir=1) from the National Academy of Sciences, "America's Climate Choices," explains how we know that climate change is real.
Dismissive	Firmly believe global warming is not occurring; highly engaged in preventing change in policies; very knowledgeable	Individual responsibility, choice, American ingenuity. Health frame: reducing ghg emissions would lessen smog and improve air quality.	Lowest in egalitarian, highest in individualism. Unlikely to be persuaded that climate change is happening. May believe scientists receive funding to prove climate change. Any chance to engage with them using the words "climate change" may reinforce dismissive attitudes. Engage around adapting to increased variability and ways others like them are adapting.



SUMMARY

Climate change is unlike other educational topics Extension professionals encounter. The complexity of climate science, the seemingly distant and vague impacts of climate change, and the political polarization on the topic result in many people tuning out, disengaging, or learning selectively. Simplifying the message to scientific consensus, facilitating dialogue and discussion, and engaging stakeholders around local impacts and solutions can result in increased adaptation and mitigation behaviors.

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Mapping the future of southern pine management in a changing world

Risk Perception and Needs: Defining Extension's Climate Change Adaptation Role

AUTHORED BY: MARK A. MEGALOS, MARTHA C. MONROE, AND CLAIRE NEEDHAM BODE

Many Extension professionals are unsure of the best approach to educate clients about climate adaptation. This fact sheet identifies differences in risk perception as a basis for addressing climate adaptation needs. It is the third in an Extension series and builds upon concepts covered in "Challenges in Communicating Climate Change to Extension Audiences," and "Strategies for Communicating Climate Change to Extension Audiences."





Climate variability threatens the productivity, profitability, and, potentially, the viability of traditional agriculture, livestock and forestry operations, and existing community infrastructure. Our clientele may be united in seeking solutions to offset risk, even though they differ in their views on the causes of climate variability. Addressing audiences' needs is the first step to successfully increase resilience or adopt new methods for minimizing loss, reducing temperature stress and diversifying management to avoid catastrophic crop, feed, livestock or capital loss. Perhaps more than ever, Extension professionals will be the research conduit to farmers, communities and forest landowners on climate adaptation strategies and actions. This foray into adaptive changes on a grander scale may demand heightened use of facilitation and communication skill sets to assist farm and forest decision-making and dissemination (James, Estwick and Bryant, 2014).

After the challenge of communicating climate change, the biggest obstacle to climate adaptation programming is understanding audience perceptions of risk. Risk perception can be the common denominator for addressing appropriate adaptation programming. This discussion will begin with an overview of risk, then move on to unique client needs and broader audience concerns.

RISK PERCEPTION

Americans on the whole do not perceive climate change as a threat to their wellbeing. This moderate perception of risk



constrains the likelihood of political, economic and social actions (Leiserowitz, 2006). Two parallel modes help explain how individuals process information when perceiving risk: 1) Rational and 2) Experiential systems (Epstein, 1994). The two informational processing systems (modes) are contrasted below (Table 1.)

The relevance of this table is twofold. As Extensionists we are most comfortable in the rational mode--conveying science or research results in an effort to transfer new knowledge and better practices with numbers and words. However, in the case of climate adaptation, we are more likely to move individuals to action by adopting a more affective (emotionally influenced feeling) educational approach based on imagery, case-studies and stories. Stated more succinctly," "experientially derived knowledge is often more compelling and more likely to influence behavior than is abstract knowledge" (Epstein, 1994).

The experiential approach will seem straightforward in regions of the country where clientele have already begun to "experience" climate variability in the form of longer-growing seasons, higher temperatures and deviations in average precipitation, and less so in regions where climate variability is less pronounced. Fortunately our goal is to prompt climate adaptation actions, rather than change audience mental models or belief systems regarding political or religious views. In order to accomplish our adaptive mission, we will have to draw on historical success with innovation adoption (Rogers, 2003). This will entail fully utilizing communication networks, trusted expert delivery, opinion leaders, and the five diffusion stages: knowledge, persuasion, decision, implementation and confirmation.

More importantly, perhaps, is the likelihood that everyone

will be experimenting locally to find appropriate adaptive solutions that fit within the operational philosophy of the clientele that we serve. In essence, the roles of researcher and farmer, rancher, forest landowner will be reversed. Our role as change agent will be to encourage and support this experimentation, and then communicate solutions among producers (Westley et al. 2011). Researchers will be working to prove the scientific worth of local solutions that bubble up from producers. This wholesale change of the traditional land-grant delivery system is illustrated in the organic farming movement, where researchers are bringing scientific legitimacy to locally-derived management in cooperation with innovative growers—often after the local techniques are established or proven.

Below are examples of five such audiences and general trends for Extension programs that may be useful.

Farmers are keenly aware of weather patterns and trends, since their profitability depends on a successful harvest. Farmers are acutely aware of changing weather patterns, yet may not attribute changes in the earth's atmosphere to human activities. So, begin farm adaptation programming with observations of changes in flowering times, migration, or weather to encourage discussion and explore risk avoidance actions.

Changes in atmospheric carbon dioxide, temperature, and precipitation patterns will affect agricultural productivity in some areas of the nation more than others (Walthall et al. 2012). Some regions and crops will be "winners" whereas others may experience climate problems. Fortunately, there are low-cost, lower-risk management changes that farmers can make to respond to changing forecasts, including altered planting times, using a seed source from a different latitude, changing varieties, and altering

RATIONAL	EXPERIENTIAL
Factually based	Emotionally driven
Analytical	Holistic
Logical	Affective
Deliberative	Intuitive
Communicated as:	Communicated as:
Abstract symbols	Concrete images
Words	Metaphors
Numbers	Narratives

Table 1. Contrasting Two Dominant Risk Information Processing Modes



irrigation regimes. Encouraging farmers to experiment on a small scale may generate an experiential basis for local farming suggestions and successes. Using research from local universities combined with peer solutions may be more helpful than national guidelines. Changing climatic conditions are already impacting the ranges of weed and pest species, making some crops more vulnerable at their ecological margins.

Agriculture in the United States has historically been most successful when dynamic and adaptive: changing to capitalize on emergent markets, vagaries of weather, input prices and market prices. While the climate has been relatively stable over last 100 years, increased climate variability will prompt flexibility, adaptation, farmer ingenuity and marketing prowess. Capturing and sharing success stories and examples of other useful solutions will be important; building a network of farmers willing to share their ideas and outcomes could be a critical Extension role for the future.

A small sample of projections for crop farmers follows: (James, Estwick and Bryant, 2014)

A shift in climate and agricultural zones toward the poles. A boost in agricultural productivity due to increased carbon dioxide in the atmosphere. Pronounced droughts and floods due to changing climatic conditions. Rising temperatures, which are expected to bring heat waves, melting glaciers, and ice sheets; and rising sea levels, with major consequences for global food security. Numerous weeds, pests, and diseases thriving under warmer temperatures, wetter climates, and increased CO₂ levels.

An increase in heat waves, which could negatively affect the livestock industry and eventually increase livestock susceptibility to disease, reduce fertility, and reduce milk production.

Drought-related significant reduction in quality of available pastures for livestock grazing and threaten pasture and feed supplies.

UNDERSTANDING FARMER ACCEPTANCE OF ADAPTIVE OPTIONS

Agents have always understood intuitively how the social acceptability of certain practices has direct bearing on their likelihood for adoption. By understanding farmer acceptance of adaptive techniques, educators can focus efforts on actions most likely to be deployed. For instance, a recent survey of Southeastern farmers showed that conservation tillage, high-residue cover crops, nitrogen management and web-based "Agroclimate" decision-making tools were significantly more likely to be deployed by farmers than four other techniques suggested by specialists and technology transfer agents (Bartels and others, 2012).

Ranchers are invested in their livestock. In some regions, temperature stress on livestock and poultry is a concern (Walthall, et al., 2012). Climate change will affect U.S. rangeland vegetation growth and distribution as temperature and precipitation variability affect. Climate extremes, drought and livestock stress will be distributed asymmetrically. Expected climate challenges to livestock operations include: increased diseases, pests, livestock stress, extreme weather and storm events, drought and market uncertainty (http://animalagclimatechange. org/). Uncertainty abounds within the agriculture sector and topics for further research include: regional climate variability, vegetation dynamics, and complicated

AGRICULTURE ON THE EDGE

Climate change also affects agriculture and crop yields around the world. With 40% of the Earth's surface occupied by cropland and pastures, a shifting climate may alter agricultural locations, techniques, crop choices and yields.

IPPC reports predict that climate change will bring drier conditions to already dry areas while bringing more precipitation to temperate and tropical areas.

An increase in atmospheric CO₂ and temperature may have positive effects for one crop, while having negative effects on others. Scientists have shown that with an increase in atmospheric CO₂, there will be an increase in corn crop yields from an increase in net CO₂ assimilation by corn plants.

However, an increase in atmospheric CO_2 may cause a decrease in yields in grains such as rice and wheat. (Dovetail Partners, 2014)



interactions and feedbacks related to temperature and precipitation variability.

Climate changes on U.S. rangelands brought about by drought and extreme storms alter growing seasons. These changes will affect productivity/profitability most notably from the economic costs of adaptation (like shade, shelter, ventilation, misting and watering systems) and disease prevention. While predictions for northern latitudes seem beneficial with warming and increased precipitation, successful adaptation will involve capturing market advantage, emerging markets within an atmosphere of cost reduction and risk avoidance investments. Livestock vulnerability is a harbinger of threats to human populations from disease, heat-related illness and death, allergens and vector-borne diseases; thus, future research on climate drivers and confounding factors has potential benefits for human and animal agriculture sectors (National Academy of Science, 2011). Linking ranch/livestock programming to locally identified risks and audience needs will be key to success. Staying informed and instantaneously alerting producers of heat waves, extreme weather can be instrumental in becoming a trusted adaptation source and developing future program support and success.

Forests rely upon fewer human inputs than agricultural systems (less irrigation, fertilizer, and pesticide treatment) but are growing through climate variations over a much longer time. Forests may become more stressed by changes in atmospheric carbon dioxide, precipitation, temperature and nitrogen deposition, but the more significant changes are likely to be due to wildfires, insect pests, disease, erosion, flooding, and drought (Vose, Peterson, and Patel-Weynand 2012). Some areas will be more vulnerable than others. Forest landowners have an opportunity to manage their resources to help mitigate climate change by maximizing carbon sequestered in wood, root and forest soil. Some audiences may opt for carbon management over traditional wood products as carbon markets become established and provide income. Wood products may become more popular where they can replace materials that emit or generate carbon, such as concrete and steel in building construction and fossil fuels in energy production (Perez and others, 2005).

Forest landowners constitute a challenge to interpreting climate change needs because of their diversity in ownership objectives and the scarcity of research. The National Woodland Owner Survey offers a unique insight on the interest and needs of this audience. The 2011-2013

FORESTS AT RISK

- 1. Rising temperatures, drought, and fires may lead to forests becoming a weaker sink or a net carbon source by 2100, and as soon as 2030 in some U.S. Regions, USDA, 2012.
- 2. Pervasive droughts, fire and insect outbreaks put mitigation benefits of the forests at risk.
- 3. Forest disturbances and climate extremes will effect carbon balance- some forest ecosystems already responding.
- 4. In North America, growing seasons are lengthening, which are causing an increase in carbon intake through photosynthesis.
- 5. In North America increased growing season will cause a northward shift of the geographic ranges of many species affecting landscapes and habitats. (see USFS Climate Change Tree Atlas)
- 6.Droughts and precipitation increases will likely alter the range of forest species at their ecological edge.
- 7. Projections of 24 and 38 million acres of forests will likely be converted to other uses between 1997 and 2060- with more than half of the forecasted forest losses in the South, more than 90 percent to occur in the Eastern United States (Urbanization and Development).

Citations: 1,2,3 (IPCC AR5,2014.Ch11. Agriculture, Forestry and other Land Use 179 p, p 45. 4,5,6 (Dovetail Partners,2014). 5 Prasad and others,2007. USFS Climate Change Tree Atlas. 7 (Wear,2011)



preliminary data from North Carolina suggests the top five "environmental" concerns all have a link to future climate variability, in descending order they listed: wildfire, insects and disease, wind and ice storms, water pollution and invasive species (Butler and others, 2014). Forest owners tend a long-term resource that typically requires very little management suggesting that forest landowners may perceive that there is not much they can do, and thus may not have not invested much energy to learn about the problem or solutions (Krantz and Monroe 2013).

Interested private landowners who are Extension audiences may be motivated less by income from their forest and more by being a good steward of their forest resources (Krantz 2014). Targeting economic and stewardship objectives can foster management strategies that increase forest resilience and solutions that yield multiple benefits, like maintaining healthy forests for wildlife, water quality or to minimize invasive plants or disease. Landowners who are motivated by stewardship of the land may value the results of adaptive climate actions regardless of resistance to climate change acceptance.

Coastal Residents and Planners are in the beginning stages of planning for sea level rise, extreme weather, coastal storm surge and flood from extreme events. Risk and vulnerability assessment are often spurned by the local threat: such as devastating storm surges, hurricanes, seasonal high tides, subsidence and eroding shorelines

(Burkett and Davidson, 2013). The adaptive decision to stop repairing or reinforcing infrastructure (transportation systems, water systems, waste treatment facilities, etc.) is most often financially constrained but the priority to plan for such events is being prompted by federal grants and visionary decision makers.

Leadership, facilitation and community involvement are strengths that Extensionists can bring to the table once threats are prioritized, such as saltwater intrusion to water supplies, flooding and inundation, faltering estuary ecosystems, or compromised waste water treatment systems. One noteworthy Extension effort for community adaptive capacity building is Vulnerability and Consequences Adaptation Planning Scenario (VCAPS). The VCAPS process prompts community decision-makers to diagram potential climate stressors, impacts, and consequence on municipal management issues. The result is a diagram of locally tailored information about climate change issues, impacts and potential consequences for coastal communities (VCAPS, 2011).

Homeowners and Citizens who are not specifically connected to any of the above audiences may wish to be engaged in climate solutions. Their sense of moral responsibility or their interest in maintaining a comfortable world for future generations may fuel this concern. They may wish to mitigate their contribution to greenhouse gas emissions by conserving energy, reducing reliance on fossil

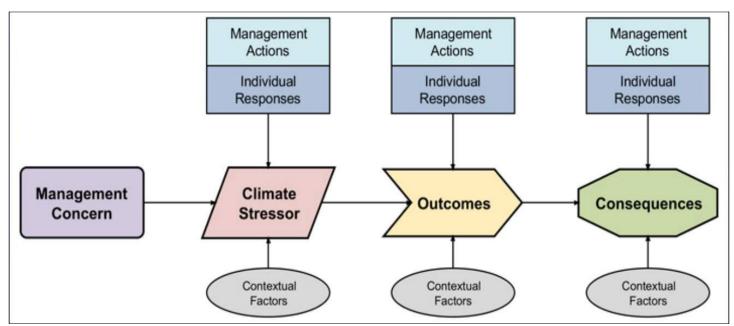


Figure 1. VCAP Vulnerability Diagramming Process for Community Climate Change Stressors



fuels (installing solar panels or water heaters; investing in a hybrid vehicle), reducing consumption of products in general, relying more on locally produced food and resources, and helping to build a community of concerned and responsible citizens. Extension can support all of these efforts by providing information about local resources and strategies for making decisions about preferred products. The Sustainable Living program, now Living Green (livinggreen.ifas.ufl.edu), offers suggestions for resources, workshops, and strategies for leading groups to consider a variety of options for mitigating climate changes, including: carpooling, public transit or bike commuting, insulation, weather stripping, replacing energy inefficient appliances, lighter roofing colors in warmer climates, opting for fuel efficiency at next car replacement, and energy saving replacement windows (Apel and others, 2010).

Best Practices for Climate Communication:

Once Extension professionals have established trust as a source of useful adaptation strategies, clients will likely request additional climate background information for decision-making in context. Colleagues from across the U.S. have noted successful practices that can advance clientele toward climate resilience. Fischhoff (2007) suggests that climate change communication campaigns (4C) are best approached as a team effort (with interdisciplinary focus):

- Climate scientists (Know the nature of the risks and potential responses),
- Social and decision scientists (Know how to craft useful information to target audience), and
- Communication professionals (Know how to get the information conveyed (reach and frequency) to be noticed and considered by target audience).

For additional insight on successful communication strategies please see the first two factsheets in this series: "Challenges in Communicating Climate Change to Extension Audiences," and "Strategies for Communicating Climate Change to Extension Audiences."

This interdisciplinary approach has been successful with Extension organizations across the U.S. and is ideally suited for presenting adaptive climate actions which must work and "sell" locally where they are proposed.

SUMMARY

The Cooperative Extension Service has a cherished legacy of helping communities and individuals solve problems and reduce risks by providing information and skills. Addressing climate change is the grand current challenge and will involve many existing and new skills to address pest management, family finance, emergency response, community planning, farm efficiency, and forest resilience. Providing this information in a manner that respects audience values, interests, and concerns will always be critical, and suggests that Extension agents may wish to engage their audiences in conversations about what concerns them as well as perceived or experiential changes in weather patterns, growing seasons and the legacy they will leave their children. People do not need to accept anthropogenic climate change to be willing to adapt to current changing conditions. Those who care about sustainability, natural resources and their community do not require economic incentives to make changes in their management or lifestyles. Providing people with the information they need and desire, in a manner that makes sense to them, is our challenge, as always.

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The Scientific Guide to Global Warming Skepticism



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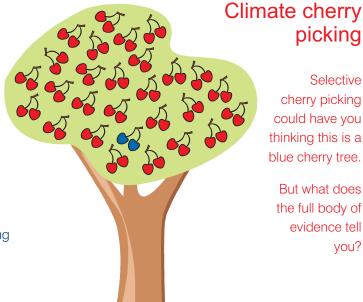


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What does it mean to be skeptical?

Scientific skepticism is healthy. In fact, science by its very nature is skeptical. Genuine skepticism means considering the full body of evidence before coming to a conclusion. However, when you take a close look at arguments expressing climate 'skepticism', what you often observe is cherry picking of pieces of evidence while rejecting any data that don't fit the desired picture. This isn't skepticism. It is ignoring facts and the science.

This guide looks at both the evidence that human activity is causing global warming and the ways that climate 'skeptic' arguments can mislead by presenting only small pieces of the puzzle rather than the full picture.



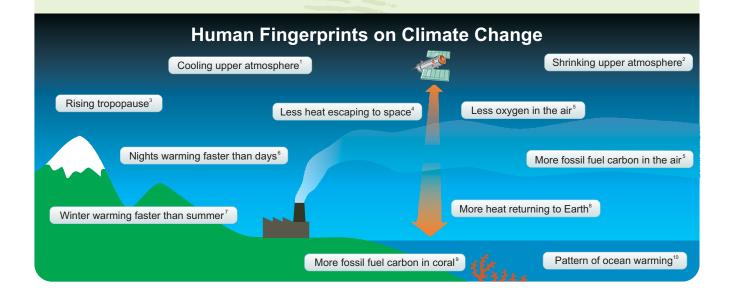
Human fingerprints on climate change

Scientists look for independent lines of evidence pointing to a single, consistent answer. The full body of evidence in climate science shows us a number of distinct, discernible human fingerprints on climate change.

Measurements of the type of carbon found in the atmosphere show that fossil fuel burning is dramatically increasing levels of carbon dioxide (CO₂) in the atmosphere. Satellite and surface

measurements find that extra CO₂ is trapping heat that would otherwise escape out to space. There are a number of warming patterns consistent with an increased greenhouse effect. The whole structure of our atmosphere is changing.

The evidence for human caused global warming is not just based on theory or computer models but on many independent, direct observations made in the real world.



Humans are raising CO₂ levels

When you look through the many arguments from global warming 'skeptics', a pattern emerges. They tend to focus on small pieces of the puzzle while neglecting the bigger picture. A good example of this is the argument that human carbon dioxide (CO₂) emissions are tiny compared to natural emissions.

The argument goes like this. Each year, we send over 20 billion tonnes of CO₂ into the atmosphere. Natural emissions come from plants breathing out CO₂ and outgassing from the ocean.¹¹ Natural emissions add up to 776 billion tonnes per year.¹² Without a full understanding of the carbon cycle, our emissions seem tiny when compared to nature's contribution.

An incomplete picture of the carbon cycle

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Fossil Fuel Vegetation & Land

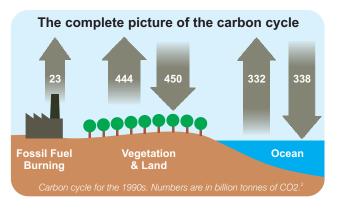
Carbon cycle for the 1990s. Numbers are in billion tonnes of CO2.12

The missing part of the picture is that nature doesn't just emit CO₂ - it also **absorbs** CO₂. Plants breathe in

CO₂ and huge amounts of CO₂ dissolve into the ocean. Nature absorbs 788 billion tonnes every year. Natural absorptions roughly balance natural emissions. What we do is upset the balance. While some of our CO₂ is being absorbed by

The weight of CO₂ emitted by humans each day is comparable to 8,000 Gulf of Mexico oil spills.¹³

the ocean and land plants, around half of our CO₂ emissions remain in the air.



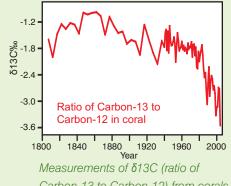
Because of fossil fuel burning, atmospheric CO₂ is at its highest level in at least 2 million years.¹⁴ And it's still going up! The "human CO₂ is tiny" argument misleads by only giving you half the picture.

Human Fingerprint #1 Fossil fuel signature in the air & coral

There are different types of carbon in the air known as carbon isotopes. The most common type is Carbon-12. A heavier type of carbon is Carbon-13. Plants prefer the lighter Carbon-12.

Fossil fuels like coal or oil come from ancient plants. So when we burn fossil fuels, we're sending more of the lighter Carbon-12 into the air. So we expect to see the ratio of Carbon-13 to Carbon-12 fall.

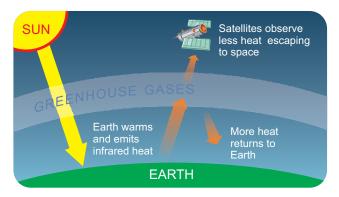
This is just what we observe, in measurements of the atmosphere⁵, in corals⁹ and sea sponges.¹⁵ So we have strong evidence that the increase in carbon dioxide in the air is directly linked to human emissions.



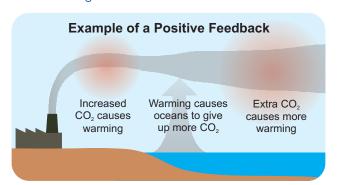
Measurements of δ13C (ratio of Carbon-13 to Carbon-12) from corals in the Great Barrier Reef.⁹

The evidence that more CO₂ causes warming

Carbon dioxide traps infrared radiation (commonly known as thermal radiation). This has been proven by laboratory experiments¹⁶ and satellites which find less heat escaping out to space over the last few decades⁴ (see *Human Fingerprint #2*). This is direct evidence that more CO₂ is causing warming.⁵



The past also tells an interesting story. Ice cores show that in the Earth's past, CO₂ went up **after** temperature initially increased. This "CO₂ lag" means temperature affects the amount of CO₂ in the air. So warming causes more CO₂ and more CO₂ causes extra warming. Put these two together and you get positive feedback. Positive or negative feedback don't necessarily mean good or bad. Positive feedbacks strengthen any climate change already underway while negative feedbacks suppress (weaken) any climate change.



In the past when climate warmed due to changes in the Earth's orbit, this caused the ocean to release more CO₂ into the atmosphere resulting in the following effects:

- The extra CO₂ in the atmosphere amplified the original warming. That's the positive feedback.
- The extra CO₂ mixed through the atmosphere, spreading greenhouse warming across the globe. 17,18

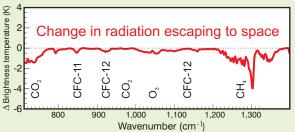
The ice core record is entirely consistent with the warming effect of CO₂. In fact, the dramatic warming as the planet comes out of an ice age cannot be explained without the feedback from CO₂. The CO₂ lag doesn't disprove the warming effect of CO₂. On the contrary, it provides evidence of a positive climate feedback.

Human Fingerprint #2

Less heat is escaping out to space

Satellites measure infrared radiation as it escapes out to space, clearly observing the greenhouse effect. A comparison between satellite data from 1970 to 1996 found that even less energy is escaping to space at the wavelengths that greenhouse gases absorb energy. Researchers described this result as "direct experimental evidence for a significant increase in the Earth's greenhouse effect".⁴

This has since been confirmed by subsequent measurements from several different satellites. 19,20

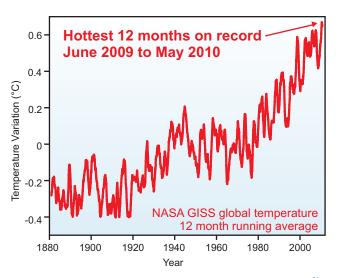


Change in outgoing radiation spectrum from 1970 to 1996 due to increasing greenhouse gases. Negative values mean less outgoing heat.⁴

The evidence that global warming is happening

One 'skeptic' argument is so misleading, it requires three levels of cherry picking. This argument is "global warming stopped in 1998".

The first cherry pick is that it relies on temperature records that don't cover the entire globe, such as data from the Hadley Centre in the U.K.²¹ The Hadley Centre record doesn't include the Arctic region where the fastest warming on the planet is occurring.²² Records covering the entire planet find the hottest calendar year on record is 2005. The hottest 12 months were June 2009 to May 2010.²³

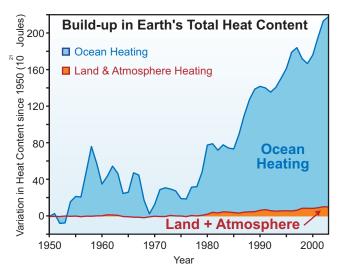


12 month running average of global temperature variations.²⁴

The second cherry pick is asserting a long-term trend based on selected end-point years. Ocean cycles like El Niño exchange massive amounts of heat between the ocean and atmosphere, so surface temperature jumps up and down from year to year. To work out the long-term trend, scientists use techniques such as moving averages or linear regression that take into account *all the data*. These show that surface temperatures continue to rise since 1998.^{23,25}

The third cherry pick is looking only at surface temperature, which is a measurement of atmospheric temperature. Over 80% of the extra energy from the increased greenhouse effect goes into warming the oceans. To find out if global warming continued past 1998, look at all the heat accumulating in the climate

system. When we add up the heat going into the oceans, warming the land and air and melting the ice, we see the planet continues to accumulate heat.²⁶

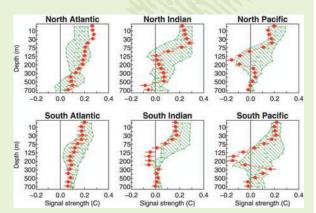


Cumulative heat for the Earth since 1950.²⁶ The rate of energy building up since 1970 is equivalent to 2.5 Hiroshima bombs every second.²⁷

Human Fingerprint #3

The ocean warming pattern

The world's oceans have steadily been building up heat over the past 40 years. The specific pattern of ocean warming, with heat penetrating from the surface, can only be explained by greenhouse warming.¹⁰



Observed ocean temperature (red) compared to model results that include greenhouse warming (green). 10

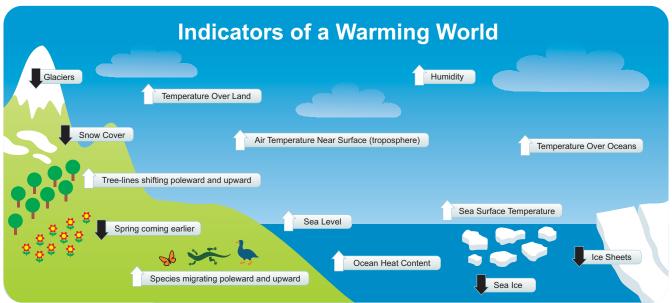
More evidence of the reality of global warming

Some claim that much of the measured global warming is due to weather stations positioned near air conditioners and car parks. We know this isn't true for several reasons. We can compare temperatures from well-placed weather stations to the poorly-sited weather stations. Both well-placed and poorly-sited sites show the same amount of warming.²⁸

Another way to check thermometer measurements is to compare them to satellite data. Satellite measurements show a similar rate of global warming.²⁹ This is confirmation that thermometers are giving us an accurate picture.

As well as the compelling temperature record, we have a large body of observations in many different systems that are consistent with a warming world. Ice sheets are melting, losing billions of tonnes of ice each year.³⁰ Sea levels are rising at an accelerating rate.³¹ Species are migrating toward the poles and glaciers are retreating (threatening water supplies for many millions of people).^{32,33}

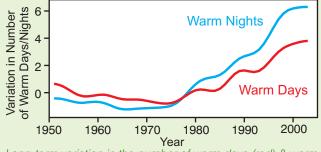
To gain a proper understanding of climate, we need to look at all the evidence. What we see are many independent observations all pointing to the same conclusion - global warming is happening.



Parmesan & Yohe 2003³², NOAA³⁴

Human Fingerprint #4 Nights warming faster than days

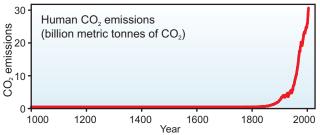
An increased greenhouse effect means nights should warm faster than days. During the day, the sun warms the Earth's surface. At nighttime, the surface cools by radiating its heat out to space. Greenhouse gases slow down this cooling process. If global warming was caused by the sun, we would expect the warming trend to be greatest in daytime. Instead, what we see is the number of warm nights increasing faster than the number of warm days. 6



Long-term variation in the number of warm days (red) & warm nights (blue) per year. Warm is defined as the top 10%.⁶

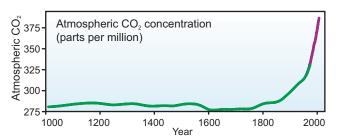
Hockey stick or hockey league?

The 'hockey stick' commonly refers to a reconstruction of temperature going back over the last millennium. The steep warming in recent times is seen as the blade of the stick. However, there are many hockey sticks found in climate science. The amount of CO₂ emitted by humans, mostly through the burning of fossil fuels, has a distinct hockey stick shape over the last 1000 years.



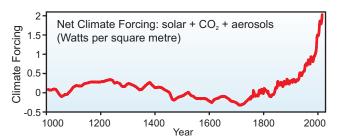
Total yearly CO₂ emissions (billions of tonnes).¹¹

The dramatic increase in CO₂ emissions is matched by a steep rise in atmospheric CO₂ levels, which have now reached levels unseen for at least 2 million years.¹⁴



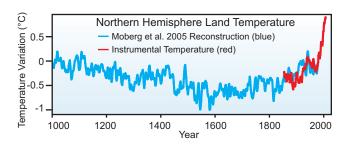
CO₂ levels (parts per million) from ice cores at Law Dome, East Antarctica (green)³⁶ and direct measurements from Mauna Loa, Hawaii (purple).³⁷

Climate forcing is a change in the planet's energy balance - when our climate builds up or loses heat. Various factors cause these changes, such as variations in solar activity, aerosols (tiny particles suspended in the air), changes in the Earth's orbit and CO₂. Over the past 1000 years, the major drivers of long-term climate change have been the sun, aerosols and CO₂. The **combined** climate forcing from these influences shows a familiar shape.



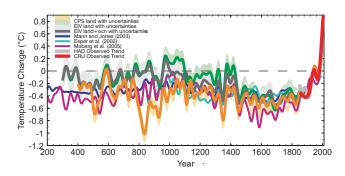
Combined climate forcing from solar variations, CO₂ and aerosols - the short-term effects of volcanoes are omitted.³⁸

This shows our climate has been building up heat in recent times. We see a corresponding warming:



Northern hemisphere temperature reconstruction (blue)³⁹ plus instrumental measurements of northern hemisphere land temperature (red - 5 year average).²¹

Over the last decade, a number of independent studies have reconstructed temperature over the last 1800 years, using a multitude of data and different data analysis techniques.⁴⁰



Various northern hemisphere temperature reconstructions. 40

All these hockey sticks tell a similar and consistent story - humans have caused a profound and rapid disturbance to our climate system.

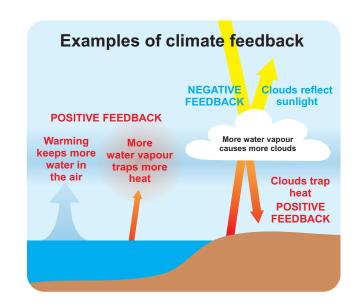
What does past climate change tell us?

A common 'skeptic' argument is that "climate has changed naturally in the past and therefore recent global warming can't be caused by humans". This argument is like saying "forest fires have happened naturally in the past so any recent forest fires can't be caused by humans".

Scientists are well aware that climate has changed in the past. In fact, the past gives us vital clues about how our planet responds to the various drivers of climate. We can see what happens when the Earth builds up heat, whether it be due to more sunlight or rising greenhouse gases. The crucial discovery from examining different periods throughout Earth's history is that positive feedbacks amplify any initial warming.⁴¹

This is why climate has changed so dramatically in the past. Positive feedbacks take any temperature changes and amplify them. Feedbacks are why our climate is so sensitive to greenhouse gases, of which CO₂ is the most important driver of climate change.⁴²

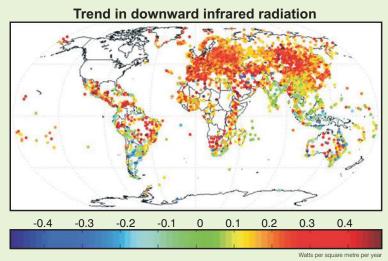
So there is a great irony when past climate change is invoked as disproving the human influence on global warming. The peer-reviewed science actually comes to the opposite conclusion. Past climate change provides strong evidence for positive feedback that amplifies the warming caused by our CO₂ emissions.



Human Fingerprint #5 More heat is returning to Earth

An increased greenhouse effect means we should see more infrared radiation returning down to Earth from the atmosphere. This has been directly observed. When we take a close look at the spectrum of the downward radiation, we can work out how much each greenhouse gas is contributing to the warming effect. From these results, it was concluded:

"This experimental data should effectively end the argument by skeptics that no experimental evidence exists for the connection between greenhouse gas increases in the atmosphere and global warming." ⁸



Trend in downward infrared radiation over 1973 to 2008. North America is blank because data in those regions don't cover the entire 1973 to 2008 period.⁴³

How sensitive is our climate?

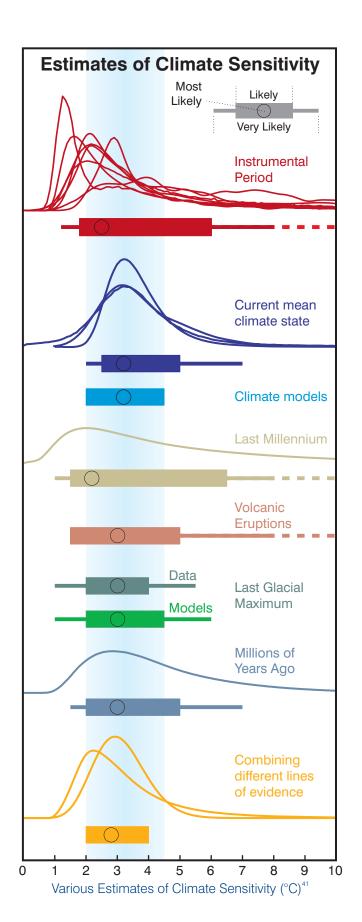
Climate sensitivity is a measure of how much global temperature warms if atmospheric CO₂ is doubled. It's well-established that the direct warming from a doubling of CO₂ (hypothetically assuming no climate feedbacks) is around 1.2°C. The big question is how feedbacks react to this initial greenhouse warming. Do positive feedbacks amplify the initial warming? Or do negative feedbacks suppress warming?

Climate sensitivity has been determined using a variety of different techniques. Instrumental measurements, satellite readings, ocean heat, volcanic eruptions, past climate change and climate models have all been examined to calculate the climate's reaction to a build-up in heat. We have a number of independent studies covering a range of periods, studying different aspects of climate and employing various methods of analysis.⁴¹

This variety of methods paints a consistent picture - a climate sensitivity range from 2 to 4.5°C, with a most likely value of 3°C. This means positive feedbacks amplify the initial CO₂ warming.

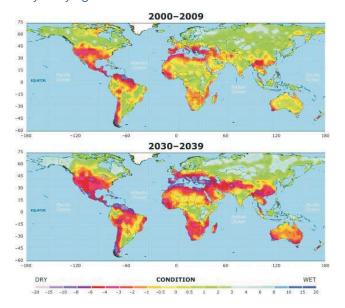
A few assert that climate sensitivity is much lower than 3°C, citing a study by Lindzen and Choi. 44 This study uses satellite measurements of outgoing radiation, suggesting strong negative feedback. However, it looks only at tropical data. The tropics are not a closed system - a great deal of energy is exchanged between the tropics and subtropics. 45 To properly calculate global climate sensitivity, you need global observations. Several studies analysing near-global satellite data find positive feedback. 46,47

A proper understanding of climate sensitivity requires the full body of evidence. To claim low climate sensitivity based on a single study is to ignore the many lines of evidence that find positive feedback and high climate sensitivity.



Impacts of global warming

To claim that global warming will be good for humanity is to turn a blind eye to the many negative impacts. The most common argument along these lines is that carbon dioxide is 'plant food', implying that CO₂ emissions are a good thing. This ignores the fact that plants rely on more than CO₂ to survive. The "CO₂ fertilizer" effect is limited and will be quickly overwhelmed by the negative effects of heat stress and drought, which are expected to increase in the future. ^{48,49} Over the past century, drought severity has increased globally and is predicted to intensify in the future. ¹² Plants cannot take advantage of extra CO₂ if they're dying of thirst. ⁵⁰



Past & future drought, using the Palmer Drought Severity Index. Blue represents wet conditions, red represents dry. A reading of -4 or below is considered extreme drought.⁵¹

There are many climate change impacts that have no positive aspects. Between 18 to 35% of plant and animal species could be committed to extinction by 2050. ⁵² Oceans are absorbing much of the CO₂ in the air, which leads to ocean acidification. ⁵³ This is predicted to have severe destabilising effects on the entire oceanic food-chain, on top of the negative effects of coral bleaching from warming waters (a one-

two punch from global warming).⁵⁴ An estimated 1 billion people depend on the ocean for a substantial portion (>30%) of their animal protein.⁵⁵

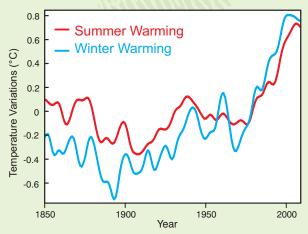
As glaciers and snowfields dwindle, so does the water supply for millions of people who are deeply reliant on those freshwater supplies, especially for irrigated agriculture. ³³ Similarly, sea level rise and increased storm activity will affect millions over this century as rice paddies are inundated with salt water, seawater contaminates rivers, aquifers become polluted and populations are displaced. This will force many millions of people to move inland, increasing the risk of conflict. ⁵⁶

When someone says global warming is a good thing, citing isolated positive impacts, remember that the full body of evidence indicates the negatives far outweigh the positives.

Human Fingerprint #6

Winter warming faster

As greenhouse warming increases, winters are expected to warm faster than summers. This is because the greenhouse effect has a greater influence over winter. This is what is observed in the instrumental record.^{7,68}



Smoothed temperature variations for winter and summer, averaged over land only, from 1850 to 2009.²¹

Shooting the messenger

In November 2009, the email servers at the University of East Anglia were hacked and emails were stolen. When a selection of emails between climate scientists were published on the Internet, a few suggestive quotes were taken out of context and interpreted as revealing global warming was all just a conspiracy. This has been labelled 'climategate' by some. To determine if there had been any wrong-doing, six independent enquiries from England and the United

"...no evidence of any deliberate scientific malpractice in any of the work of the Climatic Research Unit."

UNIVERSITY OF EAST ANGLIA IN CONSULTATION WITH THE ROYAL SOCIETY 58

States have investigated the stolen emails. Every single investigation cleared the climate scientists of any wrong doing. 57,58,59,60,61,62

The most quoted email is Phil Jones' "hide the decline", which is commonly misinterpreted. The 'decline' actually refers to a decline in tree-ring growth since the 1960s. As tree growth is affected by

temperature, tree-ring widths closely match thermometer measurements in the past. However, some tree-rings diverge from thermometer measurements after 1960. This issue has been openly discussed in the peer-reviewed literature as early as 1995. 63 When you look at Phil Jones' email in the

context of the science discussed, it is not conspiratorial scheming but a technical discussion of data-handling techniques readily available in the peerreviewed literature.

"The scientists'
rigour and
honesty are not
in doubt."
INDEPENDENT
CLIMATE CHANGE
EMAIL REVIEW 59

It's important to put the

stolen emails in perspective. A handful of scientists discuss a few pieces of climate data. Even without this data, there is still an overwhelming and consistent body of evidence, painstakingly compiled by

independent scientific teams across the globe. A few suggestive quotes taken out of context may serve as a distraction for those wishing to avoid the physical realities of climate change, but change nothing about our scientific understanding of humanity's role in global warming. 'Climategate' attempts to point the finger at scientists but deflects attention from what matters: the science.

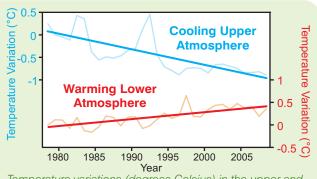
"There exists no credible evidence that Dr. Mann had or has ever engaged in, or participated in, directly or indirectly, any actions with an intent to suppress or to falsify data." 60

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Human Fingerprint #7

Cooling upper atmosphere

As greenhouse gases trap more heat in the lower atmosphere, less heat reaches the upper atmosphere (the stratosphere and higher layers). So we expect to see a warming lower atmosphere and cooling upper atmosphere. This has been observed by satellites and weather balloons.¹



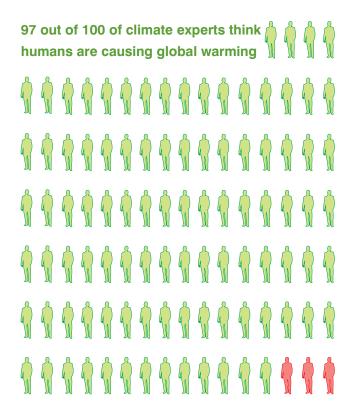
Temperature variations (degrees Celsius) in the upper and lower atmosphere, measured by satellites (RSS).⁶⁴

The scientific consensus on global warming

Occasionally, you might encounter petitions listing scientists who are skeptical of human-caused global warming. However, very few of the signatories on these lists are involved in climate research. There are medical scientists, zoologists, physicists and engineers but very few whose area of expertise is climate science.

So what do the real experts think? Several studies have surveyed climate scientists who are actively publishing climate research. Each study found the same answer - over 97% of climate experts are convinced humans are changing global temperature. 65,66

This is confirmed by peer-reviewed research. A survey of all peer-reviewed research on the subject 'global climate change' published between 1993 and 2003 found that among the 928 papers found, *not a single paper* rejected the consensus position that human activities are causing global warming.⁶⁷



The consensus of evidence

The case for human-caused global warming isn't based on a show of hands but on direct observations. Multiple, independent lines of evidence all point to the same answer.

There's a consensus of evidence that humans are raising carbon dioxide levels in the atmosphere. This is confirmed by measuring the type of carbon in the air. What we find is more of that carbon is coming from fossil fuels.

There's a consensus of evidence that rising CO₂ is causing warming. Satellites measure less heat escaping to space.

Surface observations find more heat returning to Earth. This is happening at the exact wavelengths where CO₂ traps heat - a distinct human fingerprint.

There's a consensus of evidence that global warming is happening. Thermometers and satellites measure the same warming trend. Other signs of warming are found all over the globe - shrinking ice

sheets, retreating glaciers, rising sea levels and shifting seasons.

The pattern of warming shows the tell-tale signatures of an increased greenhouse effect. Nights are warming faster than days. Winters are warming faster than summers. The lower atmosphere is warming while the upper atmosphere is cooling.

On the question of whether humans are causing climate change, there's not just a consensus of scientists - there's a consensus of evidence.

There's not just a consensus of scientists - there's a consensus of evidence.

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The case for human-caused global warming is based on many independent lines of evidence. Global warming 'skepticism' often focuses on narrow pieces of the puzzle while denying the full body of evidence.

Our climate is changing and we are the major cause through our emissions of greenhouse gases. The facts about climate change are essential to understand the world around us, and to make informed decisions about the future.



For more information, visit:



CONNECTING ON CLIMATE:

A Guide to Effective Climate Change Communication



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About the Center for Research on Environmental Decisions

CRED is an interdisciplinary center that studies individual and group decision making under climate uncertainty and decision making in the face of environmental risk. CRED's objectives address the human responses to climate change and climate variability as well as improved communication and increased use of scientific information on climate variability and change. Located at Columbia University, CRED is affiliated with the Earth Institute. For more information visit cred.columbia.edu.

About ecoAmerica

ecoAmerica grows the base of popular support for climate solutions in America with research-driven marketing, partnerships, and national programs that connect with Americans' core values to bring about and support change in personal and civic voices and behaviors. For more information, visit ecoAmerica.org.

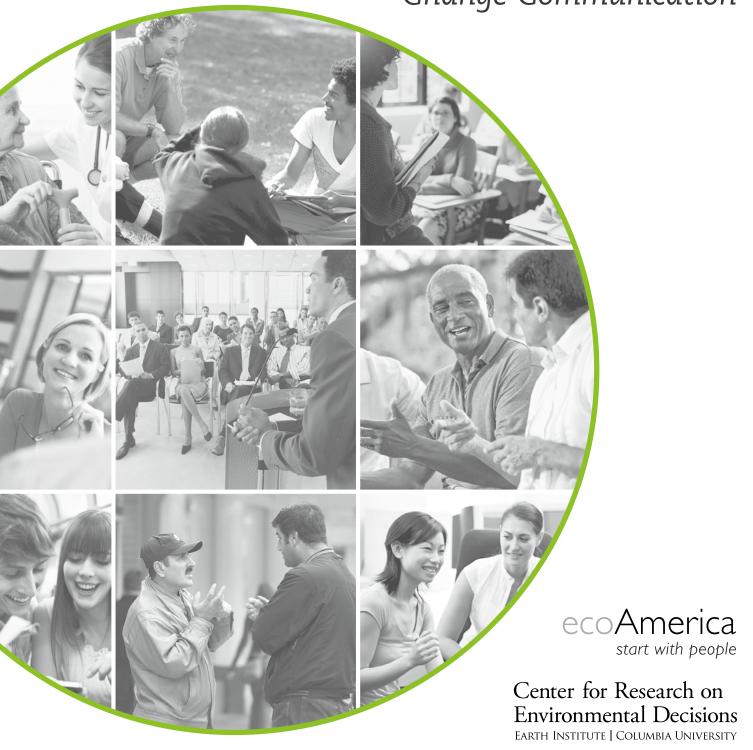
We welcome feedback on this guide. Please send emails to connectingonclimate@gmail.com.



This book was printed with a Certified Green Partner, ensuring that the paper contains fibers from sustainable and well-managed forests, and the use of CGP-EGC/PR-1001 vegetable-based inks.

CONNECTING ON CLIMATE:

A Guide to Effective Climate Change Communication



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FOREWORD: A CONTEXT FOR CLIMATE CHANGE COMMUNICATION

For most of the past two centuries climate change has been discussed as a scientific phenomenon. The creation of fossil fuels, the chemistry of combustion, and the resulting changes in the atmosphere and planetary temperatures could be explained in no other way.

Then, in the 1980s, from his post at NASA's Goddard Institute for Space Studies, Dr. Jim Hansen began to describe the implications of the planet's rising temperatures. His testimony before Congress in 1988, coupled with Bill McKibben's book *The End of Nature* in 1989, brought the issue to the public's eye.¹ Hansen and McKibben framed global warming in dramatic terms—rising sea levels, melting Arctic sea ice, and extreme flood and droughts—and ushered in an era of framing climate change as planetary destruction.

This pairing of scientific analysis and potentially catastrophic implications moved America and other nations toward action. The formation of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and passage of the United States Global Change Research Act of 1990 led to the UN Framework on Climate Change process, which yielded the Kyoto Protocol in 1997 and legally binding obligations for nations to reduce their greenhouse gas emissions.

In the midst of these major changes, some businesses came to view climate change as a threat to profits. In the 1990s, certain groups began organizing and funding activities to discredit climate science and to stop progress on climate solutions. This ushered in an era of opposition messaging and political polarization on climate change.²

The first decade of the new millennium saw an ongoing battle between these two forces. On one side, the Bush administration opposed action on climate change, seeing it as a trade-off with economic growth. On the other side, in 2006, former vice president Al Gore surfaced with the film and the book An Inconvenient Truth, which attempted to galvanize further large-scale action on climate change.

In 2009, the incoming Obama administration shifted away from Gore in its approach to communicating climate change. Research and experience suggested that fear-based arguments had run their course as effective tools for inspiring action. So Obama pivoted his focus toward the

co-benefits of climate action, prompting a focus on the economic, social, and health benefits of climate solutions.³

On one hand, it seems that none of these communication frames has been decisive. Yet the opposite perspective is in fact more accurate. Each of these arguments has influenced the political, economic, cultural, and psychological factors that mold today's climate debate. It has been a pitched battle to a draw, which is a loss for humanity and the planet.

Then, beginning with no specific event or time, the impacts of a warming planet began emerging. From California to Pakistan, from New Orleans to Bangkok, unprecedented and costly droughts, floods, and extreme weather emerged across the planet. A new era of climate communication emerged—the era of climate impacts.

So where do we go from here? The reality of climate change is upon us. Whether directly or latently, people are becoming more concerned about the issue. They seek guidance on what climate change is, what it means for their loved ones, and what they can do about it in a complex communication climate. Moreover, hundreds of people and organizations seek to refine their communication approaches to help further the case for meaningful action on the issue.

The Center for Research on Environmental Decisions (CRED) at The Earth Institute, Columbia University, and ecoAmerica, a nonprofit that works to build public support for climate solutions, have been leaders in climate communication research. With this guide, we synthesize what others and we have learned about climate change communication over the years into a single useful tool. It is our hope that leaders and communicators will put the insights in this guide into practice, designing and sharing ever more effective communication and practices to motivate an era of climate engagement that pushes America—and the planet—to a tipping point for climate solutions.

USING THIS GUIDE TO UNLOCK SUCCESS IN CLIMATE CHANGE COMMUNICATION

Climate change is not a new issue, but the need for meaningful and sustainable solutions is more urgent than ever. Climate communicators and mainstream leaders are still grappling with how to help Americans find meaningful, actionable paths forward and overcome the social, political, psychological, and emotional barriers that have hindered progress on climate solutions.

To connect with audiences and unlock success in climate change communication, communicators need to shift their approach. Communicators need to go beyond simply providing people with the facts about climate change. They need to connect with people's values and worldviews and put solutions at the forefront to make climate change personally relevant to Americans and those they love.

Getting climate communication right is becoming increasingly important for at least three reasons. First, the issue and timing are both critical. The impacts of climate change are accelerating, and delaying meaningful action to reduce carbon emissions increases the probability of harmful impacts. Second, climate change remains abstract, remote, and distant for many Americans, most of whom are focused on their more immediate needs.⁴ Third, influential political and economic actors are organizing solidly against actions to reduce the carbon emissions driving climate change.

With this guide, we have brought together both researchers and practitioners to consolidate the best insights and evidence about how to communicate effectively about climate change. We have combined research from the Center for Research on Environmental Decisions (CRED) at The Earth Institute, Columbia University; ecoAmerica; and other institutions with insights that ecoAmerica has gleaned from communicating about climate change and other environmental issues with mainstream Americans and their leaders. This guide presents information on effective climate change communication in a digestible, actionable form to enable communicators to "up their game" when engaging Americans on climate solutions of all types and scales.

This guide isn't just for people who work in environmental organizations. It's also meant for mainstream business leaders, city planners, educators,

nurses, ministers, and journalists—anyone who wants to benefit from cutting-edge research insights and communicate more effectively about climate change. These recommendations can help anyone be a more successful communicator, whether you are a seasoned expert or just getting started. And while this guide is not intended for an international audience, some of its findings may be applicable beyond the United States.

We have organized this guide into four parts ("The Basics," "Crafting Your Message," "Overcoming Barriers," and "Taking It to the Next Level"), each of which builds on the previous. Throughout the guide, we use **bold italicized text** to identify important terms and their definitions. We use **bold text** to identify key insights and takeaways critical for communicators to understand. We also include stories about how practitioners and researchers are putting research into practice; these stories are highlighted in sidebars throughout the guide. In addition, we feature in-depth explanations of certain concepts, for communicators interested in diving deeper into some topics, which are also included in sidebars throughout the guide.

Just one word of advice: communicating on climate is not a one-size-fits-all exercise. The United States is a diverse nation, and messages that appeal to one group may alienate others. For any and all of us to connect on climate change, we need to understand our audiences, respect their concerns, and communicate and engage by example, wherever we live and work. With a little practice and forethought, anyone can be an effective climate communicator. We hope this guide will help you do just that.

4	Connecting on Climate: A Guide to Effective Climate Change Communication

THE BASICS:

Putting People First

THE BASICS: PUTTING PEOPLE FIRST

The vast majority of Americans report that they have heard of climate change. Yet Americans hold a wide array of opinions and beliefs about the issue.⁵ Understanding one's audience, where its members are coming from, and how they arrived there is the first key to unlocking success as a climate communicator. This part of the guide describes why different groups of people have such different responses to climate change information, explains how people process information and make decisions about the issue, and gives tips for understanding one's audience and targeting climate communication accordingly.

Most of the time, people seek out information that supports their existing beliefs and values and reject information that contradicts the beliefs and values that are most important to them.



1 Put Yourself in Your Audience's Shoes

"No one else I know cares about climate change."

Many climate communicators erroneously believe that the main factor shaping people's engagement with climate change is their level of understanding of the science behind it.⁶ The latest social science research, however, suggests quite a different story. People interpret new information through the lens of their past experiences, knowledge, and social context. This is particularly the case when it comes to complex scientific and societal issues such as climate change, where objective facts about the state of the world are not the only factors that influence what people believe and how they respond. This section explains how people's values, worldviews, and identities influence their responses to climate change. It also describes how climate communicators can relate that many elements of a comprehensive response to climate change align with Americans' worldviews and that climate solutions can go hand in hand with existing values and goals.

Identify How Values Shape Climate Engagement

Different individuals often come to vastly different conclusions about climate change in part because they hold different core values. **Values**—such as honesty, hard work, loyalty, privacy, patriotism, fairness, or interdependence—help people make judgments about whether or not climate change is a problem and if and how they should respond.⁷

Most of the time, people seek out information that supports their existing beliefs and values and reject information that contradicts the beliefs and values that are most important to them.8 For example, when someone who strongly values personal property rights hears that dunes that will protect the coast against sea level rise will obstruct her waterfront view, an understandable reaction is to dismiss or deny one of the primary factors that would justify the dunes (namely, sea level rise that is being exacerbated by climate change). Likewise, many Americans hold the values implied by the American Dream—such as opportunity, prosperity, and hard work—near and dear to their hearts. Environmental messages with themes that run contrary to these values—the need to sacrifice, reducing material consumption, and doing more with less—may thus be rejected.9

Climate communicators should appeal to values held by their target audience to make it easier for audience members to recognize climate change as a personally meaningful issue. For example, someone who values national security may be receptive to hearing about how clean energy can reduce dependence on foreign energy sources, thus improving national security. Someone who values prosperity might be motivated by a message that emphasizes how clean energy solutions can unlock new economic opportunities for American families. And information about strengthening community preparedness for future natural disasters may speak well to people who strongly value hard work and self-sufficiency. To learn more about how to identify the values held by your audience, see SIDEBAR 1: Getting to Know Your Audience.

Align Climate Messages with Your Audience's Worldviews

People's responses to climate change (and messages about it) are also powerfully influenced by their worldviews. **Worldviews** are sets of deeply held beliefs and attitudes about how the world works



and how people should relate to one another. When it comes to climate change, worldviews often act as filters that help people determine whether or not climate change poses a serious risk to society. By affecting our perceptions of risk, worldviews thus shape beliefs about whether and how to respond to climate change.

Let's look at a couple of relevant types of worldviews. The first one relates to a person's beliefs about whether the world should operate through a hierarchical structure (that is, whether people's or groups' ranks should determine their levels of authority) or through a more egalitarian process (a world in which status doesn't matter and all people are equal and treated accordingly). A second relevant worldview relates to how much or little someone believes individuals should be free to pursue their own interests rather than be constrained (to some extent) by considerations of the "greater good." Social scientists refer to the former view as individualism and the latter as communitarianism. These two sets of worldviews powerfully influence individuals' beliefs about climate change.

SIDEBAR

1

Getting to Know Your Audience

Although it is difficult for communicators to uncover *all* of an audience's preexisting worldviews, values, and identities, here are a few steps communicators can take to better understand their audiences.

Do your homework. Communicators should gather as much as information as possible about their audience before interacting with them. Communicators can learn about local concerns and issues by picking up a local newspaper, observing local billboards and ads, and spending time at local stores, restaurants, community centers, libraries, and parks. In addition, communicators can glean insights about broader social, cultural, and political trends and opinions by consulting polling organizations such as the Pew Research Center. If communicators are working with a specific organization, they can also consult the organization's mission statement, local news stories that feature that organization, and the organization's website and social media streams.

Ask questions. To gauge an audience's initial knowledge about climate change, communicators can pose the following sample questions at the beginning of a presentation:

- (1) Which of the following statements do you agree with?
 - a. Climate change is happening now and is caused mainly by human activities.
 - b. Climate change is happening now and is caused mainly by natural forces.
 - c. Climate change is *not* happening now.
 - d. No answer/don't know
- (2) Scientists use the term "greenhouse effect" to describe:
 - a. A hole in Earth's ozone layer, which allows more sunlight to get through
 - b. The heat-trapping properties of certain gases, such as carbon dioxide (CO₂)
 - c. The warming effect of pavement and cities
 - d. No answer/don't know
- (3) Do you think that changing weather patterns and an increase in extreme weather events such as storms, floods, and droughts in the United States are caused by climate change?
 - a. Yes
 - b. No
 - c. Maybe
 - d. No answer/don't know

Answers can be obtained by a quick show of hands.

Develop a dialogue with your audience. For the development of a larger, more comprehensive communication strategy, communicators can use a range of methods, from one-on-one interviews to focus groups and surveys, to determine what their audiences care about, what they already believe, whom they trust most, and so on. See the **FURTHER READINGS** section on Page 82 for more information on how to conduct effective surveys and focus groups.

For example, individuals who believe the world should operate on egalitarian and communitarian principles tend to perceive climate change as something that affects poorer populations or minorities more severely and that will lead to even greater inequality. This view leads such individuals to be generally supportive of broad action on climate change.

In contrast, individuals who believe in the benefits of a hierarchically structured world and who support strong individual rights (even at the expense of the group) are likely to be less supportive of climate action, especially when government-run policies or solutions are highlighted. This is because these individuals may perceive such proposed solutions to climate change as mere excuses for greater (and in their view unnecessary) government regulation and may be afraid that such policies would infringe on their freedoms and rights as citizens.

Communicators can boost engagement by tailoring their communication strategies to the worldviews of their audiences. For example, someone who holds an individualistic worldview and favors self-reliance might react positively to a message that focuses on the capacity to take action on one's own. In contrast, that same person may respond negatively if messages focus only on climate change solutions that require government-organized cooperative action or strict regulation, because these solutions are perceived to weaken the role of individual responsibility.

Understand How Identity Shapes Climate Engagement

An **identity** is a person's conception and expression of his or her self and the social groups he or she is part of. Everyone holds multiple identities. For example, someone might identify with a political party, be a member of a religious group, be a resi-

dent of a city and region, and be a parent or grand-parent. People's identities with certain groups play significant roles in shaping how they think, feel, and respond to climate change. People's occupational identities—such as being a business executive or a farmer—can also play a role in shaping the attitudes and beliefs they hold about climate change. Research suggests that how "top of mind" a certain identity (such as being a parent or a Republican) is in a given moment can play a significant role in shaping how a person responds to messages (and public polling questions) about climate change.¹⁰

Identity plays a particularly strong role in shaping how people respond to climate change when they have limited knowledge about the complex issue and when they have strongly held identities. ¹¹ For example, in the United States, climate change has become closely associated with political identity. ¹² According to the findings of a recent study, when Republicans are reminded that they are Republicans, they report even more skepticism about climate change. And when Democrats are reminded that they are Democrats, they report



SIDEBAR 2

Choosing the Right Messenger for Your Audience



No matter how carefully a communicator designs a message, even a perfectly crafted message is unlikely to succeed if it's delivered by a messenger the audience doesn't trust, admire, or respect.

An ideal messenger is someone whose identities, values, and group affiliations are similar to those of the audience; someone the audience trusts and respects; and someone who can identify and connect with the audience's everyday needs and concerns. Often, it just takes some time spent watching and listening to audience members to identify who they repeat, whose advice they share, who they follow and pay attention to, and thus who might be a good messenger. Those with additional time and resources may want to consider conducting focus groups, in-depth interviews, experiments, and surveys, which can also help identify the right messengers. (See the **FURTHER READINGS** section on Page 82 for resources on how to conduct focus groups and surveys.) CRED research suggests that local messengers (both individuals and institutions) may be more likely to get a response for calls to action on climate change than individuals from outside the community. People are more likely to take action when they feel a strong sense of affiliation with the individual or institution making the request.

Finding the right messenger is especially important because it can help people link new identities to climate change. With the desired identity activated in people's minds, a well-matched communicator can more easily speak to people's values and priorities and make a powerful connection with the audience. (Think of how Mothers Against Drunk Driving succeeds by having mothers talk directly to other mothers.) Keep in mind that messengers may need training in how to deliver messages to their social groups and networks.

even more conviction about the issue.13 This doesn't mean, however, that there aren't opportunities to help shift the association between particular identities and climate change. For example, Republican leaders such as Christie Todd Whitman, who led the EPA under President George W. Bush, have noted that many Republicans believe that climate change is real and human-caused, even though their party platform often indicates otherwise.14 Other conservative groups have started talking about climate change in terms of its connections to faith, health, the economy, and national security, a strategy that is likely to bolster support for action on the issue among conservatives (in part by redirecting the current relationship between conservative identity and climate change skepticism).15

Communicators should keep in mind that nearly any identity may have both productive and counterproductive implications for climate change engagement. For example, emphasizing someone's identity as a good provider for his or her family may seem like an ideal approach to engaging certain types of people on climate solutions. However, if not approached carefully, talking about this identity in the context of climate change may actually have the opposite effect, making people think about the need to protect their families at the expense of the larger community. Strategies emphasizing the identity of being a good provider for one's family will likely be most effective if they emphasize how taking action on climate can help families achieve other goals, such as keeping kids healthy and saving money on energy bills.16 It is also possible to create new, positive connections between specific identities and climate solutions. To read about a realworld example of how one initiative is working to link climate change to new identities, see SIDEBAR 3: Harnessing Identity to Bolster Engagement with Climate Change: The MomentUs Initiative.



When putting together a communication strategy, communicators should start by identifying core identities of their target audiences. Some of these identities may be obvious, but other identities may be more difficult to recognize. For example, it may be readily apparent that someone is a senior citizen but not immediately clear that he or she is interested in humanitarian work or is very religious. Communicators should then identify whether a certain identity is already linked to a particular stance on climate change and, if so, how linking climate change to that identity will affect people's support for or opposition to climate solutions. No matter what, climate communicators should help people identify how taking or supporting meaningful action on climate change aligns with the identities they hold.

Appeal to People's Desire to Be "Good People"

Tightly linked to people's values and core identities is their sense of what is morally good and what is morally required of "good people." People are highly

motivated to view themselves as good and moral. Identifying climate change as a "moral issue" may help people tap into these desires. 17 However, communicators should take care to communicate the moral significance of the issue using audience members' values, identities, and priorities rather than their own. Otherwise, a communicator's efforts can come across as moralizing, preaching, or finger wagging.

Climate communicators may also wish to appeal to the virtues (morally good traits and qualities) that people strive for in their personal and social lives. Previous communication efforts have placed little emphasis on virtues (for example, going above and beyond to help others prepare for extreme weather events). Yet emphasizing virtues may be highly effective in encouraging fundamental and long-term change in people's responses to climate change, in part because doing so can help people develop concrete projects that provide concrete personal results. In short, to encourage long-term engagement, communicators should develop messages that align with their audiences' moral values and that provide opportunities for people to put their virtues into practice. For more information on how to develop messages that resonate with your audience's moral values, see SIDEBAR 4: Understanding and Connecting with Moral Foundations.

Harnessing Identity to Bolster Engagement with Climate Change: the Momentus Initiative

One of the greatest challenges that climate communicators face is that climate change is so tightly linked to politics and political identity. But climate change doesn't have to just be about politics. Responding to climate change can also be about being a good citizen, living out one's faith, doing good business, staying healthy, or being an engaged teacher or student. This is a core motivating idea behind MomentUs, a new ecoAmerica initiative designed to catalyze a game-changing increase in the base of public support for climate solutions in the United States. MomentUs was conceived on the premise that Americans will act on climate change if they come to understand how it is relevant to the many identities they hold outside of the voting booth. MomentUs empowers leaders who interact with Americans where they work, live, play, pray, and learn with research-based guidance on climate communication to help facilitate this shift in understanding among the American public. Through peer-to-peer engagement, conferences, and training, MomentUs encourages leaders to harness the identities they share with their audiences to build trust, credibility, and consequently support for climate solutions. To learn more about MomentUs, visit momentus.org.

SIDEBAR 4

Understanding and Connecting with Moral Foundations

Researchers studying moral judgment have established six sets of *moral foundations* that drive people's understanding of what is "good" or "moral," as outlined in **TABLE 1**:

Moral Foundations and their Characteristic Emotions,

Virtues, and Examples. For example, the moral foundation known as "care/harm" encompasses kindness, gentleness, and nurturance, while the "fairness/cheating" foundation encompasses fairness, justice, and trustworthiness. Some moral foundations resonate more strongly with some audiences than with others.

For example, psychologists at the University of Virginia found that liberals showed greater endorsement and use of the care/harm and fairness/cheating moral foundations, whereas conservatives tended to use and endorse all moral foundations more equally.²⁰

In another study, researchers at the University of California-Berkeley found that environmental messages tend to emphasize care/harm, a moral foundation important to many liberals. This may explain why liberals are sometimes more receptive to environmental messages than conservatives. However, the researchers also found that *reframing* environmental issues in terms of sanctity/degradation increased conservatives' concern. This suggests that reframing the same issue using different moral foundations can have a significant impact on the diversity of individuals and groups who will show concern about it. For more information on framing, see SECTION 5: Connect Climate Change to Issues That Matter to Your Audience.

TABLE 1

Moral Foundations and their Characteristic Emotions, Virtues, and Examples

The table below lists six moral foundations along with the characteristic emotions, relevant virtues, and climate communication themes and concepts associated with each.²² Climate communicators can decide which climate communication themes and concepts to emphasize with an audience depending on the moral foundations they think the audience will resonate with most.

	Characteristic emotions	Relevant virtues	Examples of climate communication themes and concepts
Care/Harm	compassion for victim; anger at perpetrator	caring, kindness	keeping children safe from climate's health effects; "saving the environment;" protecting polar bears and other wildlife
Fairness/ Cheating	anger, gratitude, guilt	fairness, justice, trustworthiness	effect of climate change on farmers in developing nations; oil companies' pollution and profits
Loyalty/ Betrayal	group pride; rage at traitors	loyalty, patriotism, self-sacrifice	preserving America's natural wonders; being good stewards of American nature
Authority/ Subversion	respect, fear	obedience, deference	following the advice of or obeying respected professionals, business leaders, or the pope
Sanctity/ Degradation	disgust, adoration	temperance, chastity, piety, cleanliness	ensuring clean air and clean water
Liberty/ Oppression	joy, loathing	independence, respect for autonomy, rationality	self-sufficient forms of energy

Source: Adapted from Haidt, J. (2012). The righteous mind: Why good people are divided by politics and religion. New York: Pantheon.

TIPS Put Yourself in Your Audience's Shoes

Consider the following questions when thinking about audiences and the role that existing beliefs and attitudes play in shaping how they respond to climate change.

- Who is your target audience?
- What relevant beliefs does the target audience already hold? What do you know about audience members' core values and worldviews? How can you help people recognize where climate change solutions can line up with those values and worldviews? (See SIDEBAR 1: Getting to Know Your Audience, for tips on finding this information.)
- What identities do your audience members hold? Are they religious? Liberal? Conservative? Do they work on farms? On Wall Street? Are they single or married? Do they have children or grandchildren? Will reminding people of these identities make them more or less likely to want to positively engage with climate change?
- What virtues and moral values do your audience members find most important? How can you frame your message in a way that shows how doing something about climate change can help people put those virtues into practice?
- What moral foundations might be most important to your audience? (See TABLE 1: Moral Foundations and their Characteristic Emotions, Virtues, and Examples and SIDEBAR 4: Understanding and Connecting with Moral Foundations.) How can you show that climate change issues relate to those moral foundations?
- Who does your audience trust and respect? Can any of these individuals serve as messengers for a climate communication strategy? (See SIDEBAR 2: Choosing the Right Messenger for Your Audience.)

2 Channel the Power of Groups

"Well, if my church is getting involved..."

At their core, humans are social beings, and their identities and memberships in social groups and networks play a seminal role in shaping their attitudes and behaviors. This section explains how people behave and process information differently in groups, which groups are most likely to help catalyze climate engagement, and how communicators can harness groups and social networks to keep people engaged on climate change in the long run.

How People Think and Behave Differently in Groups

People often think and behave differently when they're physically part of a group or reminded of their membership in a group. When people make decisions or process information as part of a group, their goals may shift toward promoting outcomes that are good for the group rather than promoting outcomes that are good for only themselves as individuals. These effects are driven by a number of mechanisms unique to group settings, including an enhanced sense of affiliation and connection with other people, an increased tendency to follow the group's norms, a weakened focus on personal identities and goals, and the desire to avoid social ostracism and exclusion.



SIDEBAR 5

Talking about Climate Change in Group Settings

People process information about climate change differently when they engage with it in a group setting, such as a focus group or neighborhood meeting. In groups, people often consider a wider range of possible options and show deeper engagement with arguments and various courses of actions that are proposed. Australian researchers Anne Pisarski and Peta Ashworth have found that facilitated small-group discussions can produce positive changes in climate attitudes and support for policy solutions.²⁵ Their "Citizens' Round Tables" provide non-expert members of the public an opportunity to voice their own opinions, ask questions without fear of ridicule, and see themselves as engaged citizens trying to tackle this large problem.

As with other successful group-based strategies, Citizens' Round Tables start with an interactive discussion that provides an opportunity for group members to bond with one another and express their initial attitudes and beliefs. Only once people are comfortable and engaged do they receive a short, focused presentation from a climate scientist. Using multiple formats and media (video, PowerPoint, fact sheets), presenters give participants accurate information about various energy futures and their impacts on climate change. Finally, participants engage in a second discussion with each other and with the scientists in the room, so they can integrate and consider the information they have been presented. Although time-intensive, such focused, group-based approaches to climate change communication can be highly effective. Communicators may wish to keep in mind that **involving highly influential members of society, including policy makers and community leaders, may be an especially productive approach to promoting broader diffusion**.

Climate communicators can channel the influence of groups by helping people view their actions and responses to climate change as part of a larger group effort, whether that group is a neighborhood, a company, or a faith-based organization. Framing climate change as a group challenge is particularly important given the large-scale nature of the problem (which can activate feelings of inefficacy and despair if people focus solely on their own contributions).²³ Climate communicators may also wish to create opportunities to allow people in a community to discuss climate change and climate solutions in group settings. (See SIDEBAR 5: Talking about Climate Change in Group Settings.)

Mobilize Social Groups and Networks

One powerful way to keep people engaged in the long term is to weave climate change into the activities of existing social groups and networks, such as neighborhood associations, religious groups, clubs, parent-teacher associations, or company departments. People are more likely to become engaged on an issue when a group they are a part of—and that's important to them—cares about it. The most relevant groups are often relatively small and geographically local, such as a neighborhood or a group of work colleagues. Dispersed but highly interconnected groups (such as virtual, internet-based groups through

Facebook and other social media sites) may also prove fruitful for climate engagement.

Groups and social networks that are particularly powerful are those that hold strong, shared beliefs about questions of "right and wrong." These groups are often able to encourage members to follow group norms of behavior, meaning that a shift in thinking or acting among group leaders can have effects on many others. (For more information on norms, see SECTION 10: Make Behavior Change Easy.) Communicators can be particularly effective by identifying and working with such groups, as well as with those that are ready to take action on climate change but are not yet doing so. Providing climate communication and engagement resources to leaders within these groups can be an especially effective strategy for eventually activating the group's entire membership.²⁴

Getting New Constituencies Talking about Climate Change: The Climate Conversations Project

Congregations across Minnesota are holding small, peer-topeer conversations about climate change as part of a new initiative called the Climate Conversations Project.²⁶ The conversations, which are led by Minnesota Interfaith Power & Light with assistance from Climate Access and other researchers, are designed to increase engagement around climate change among those who aren't already talking about and acting on the issue. Facilitators pose guiding questions that help participants uncover why climate change is personally relevant, how it relates to what they already value, and what they can do to take action on the issue. The inspiration for the project came from the mar-

riage equality movement, which used similar conversations to catalyze changes in people's beliefs around marriage for gay couples.²⁷ Initiatives like these have shown that people are more likely to become engaged on an issue when it is brought onto their radar by a group to which they belong and that they deem important.



Group Affiliation and Cooperation

CRED researchers designed an experiment to measure the effects of social goals, in particular the effect of affiliation on cooperation. Students were split randomly into four-person groups (analogous to four large greenhouse gas emitters). The researchers created different levels of affiliation among group members (temporary, short-lived connections). Groups then played a game that rewarded those who chose to defect rather than cooperate. CRED researchers found the following: as affiliation increased, so did cooperation; affiliation made social goals (for instance, concern for others) a greater priority; and the added benefit of cooperation more than made up for the sacrifice (in this case, monetary sacrifice). Students reported that they felt good about cooperating. Communicators who want to promote cooperation should try to activate concern for others by combining social and economic appeals and by emphasizing an affiliation among group participants. This approach can be more effective than offering economic incentives alone.

A related study shows that when identification with one's group is very high, people are willing to overcompensate for defectors within their group (that is, group members who act selfishly and don't support the greater good of the group) at a personal cost and even when defectors end up doing better than they do. At least part of the motivation for the person overcompensating is a desire to be perceived as "ethical" and as a role model for the not-so-good group member. Tapping into group affiliation and identity not only can lead to greater engagement and cooperation among group members but can also be a powerful tool to help groups reach tipping points in behaviors even when some group members are defecting (not doing the right thing for climate change).²⁹

TIPS Channel the Power of Groups

Most Americans are part of at least one formal or informal social group, like a company department, faith or religious organization, parenting group, professional association, or athletic group. These groups can serve as powerful conduits for climate engagement. Consider the following questions regarding the role of identity and goals:

- What relevant social networks (parents of children in a particular school, for example) and groups (religious denominations or congregations, sports clubs, companies, the Rotary Club) is your audience already a part of?
- Who are the leaders of these groups? Would any of them be amenable to serving as a messenger for your climate communications strategy? (See SIDEBAR 2: Choosing the Right Messenger for Your Audience.)
- What values of these networks and groups align with climate solutions?
- Now can your audience's existing group identities and networks be leveraged to make climate change salient and personally relevant?
- How can you strengthen individuals' affiliations with each other and thus increase their likelihood of acting cooperatively?
- What opportunities can you create that will allow people in your audience or community to discuss climate change and to brainstorm possible solutions as a group? (See SIDEBAR 5: Talking about Climate Change in Group Settings.)

CRAFTING YOUR MESSAGE:

Solutions, Impacts, Framing, and Imagery

CRAFTING YOUR MESSAGE: SOLUTIONS, IMPACTS, FRAMING, AND IMAGERY

Starting with people and their values, worldviews, identities, and group memberships is a critical first step in effective climate change communication. But climate communicators also need to understand how to craft messages that incorporate both climate impacts and climate solutions and that show how climate change relates to other issues people care about. This part of the guide explains why it's essential to keep solutions and benefits front and center, provides tips about how to communicate about climate impacts in a way that both personalizes the issue and empowers people to act, describes how to link climate change to other issues audiences care about through framing, and overviews how to use imagery and storytelling to bolster climate engagement.

Solutions should be described in a way that identifies specific roles for individuals and local communities to play, either in the development or implementation of proposed strategies.

3 Emphasize Solutions and Benefits

"This is just so depressing."

Recent research indicates that a critical barrier to greater public engagement on climate change is the perception that the problem is simply too big to solve.³⁰ People realize that confronting climate change will require collective and political action, yet many have little faith in one another and even less in government to solve the problem.³¹ Not believing that climate change can be solved can paralyze people through apathy and hopelessness and eventually create a self-fulfilling prophecy. To avoid this, climate communicators should take care to put climate solutions and benefits of action front and center. This section describes how "solutions-first" messages can foster engagement, explains why communicators need to help their audiences feel like they can be part of the solution, and helps communicators identify the scale of solutions they should communicate.

Lead with Solutions to Boost Engagement

Climate communicators often assume that people have to be convinced that climate change is happening before they will support solutions or

take action. However, this is not the only way to approach the issue. In fact, leading with solutions, rather than the problem, often makes it easier for people to accept that climate change exists.³² This may be especially true when people hear about strategies to prevent or prepare for climate change that align with their values and worldviews.

Solutions imply action and opportunity. They also provide a goal to reach for, individually and collectively. When communicators help people envision solutions to climate change, they provide a positive vision of what the future could be like. This can help quell counterproductive feelings of hopelessness and dread. Images of possible new energy production mechanisms and systems, for example, can provide people with a buffer against the otherwise paralyzing negative emotions about climate.33 "Solutions-first" messages may also help promote positive emotional responses, including pride and hope, that can motivate action and engagement. It is important to identify solutions that match the level of action that the audience can take. One way to do this is to generate strategies and activities through a participatory process involving representatives of all relevant parties. The Red Cross Red Crescent Climate Centre has applied this approach in developing an early warning/early action system with residents along the Senegal River.34 Through participatory games, mapping exercises, and discussion, community members generated more than three hundred new ideas for possible actions to take prior to and during a flooding event.

Show Your Audience Members How They Can Become Part of the Solution

People are unlikely to take action when they don't believe an issue can be solved—either through their own or others' efforts. Successful communication must therefore build confidence that

climate change can be addressed. People's sense of personal and collective *efficacy*—the capacity and willingness to successfully confront the challenge—is part of what ultimately drives how they respond to the threat of climate change.³⁵

Generating positive emotional responses and a sense of efficacy requires that people believe two things about proposed solutions: first, that proposed actions, technologies, or policies can actually solve the problem; and second, that those solutions will actually be implemented. Equally important, solutions should be described in a way that identifies specific roles for individuals and local communities to play, either in the development or implementation of proposed strategies. For large-scale political solutions, this role may be as motivators of change, being part of an engaged citizenry, or taking political and civic action. For more local-scale solutions, the engagement may be more direct: from shifting consumption practices to working with local leaders to encouraging new business models to changing one's own behavior and encouraging one's friends and family to do the same.36

Another strategy for helping audience members understand how they can be a part of the solution is discussing the *behavioral wedge*. The "behavioral wedge" is a term coined by researchers who found that household behavior could make a substantial difference in reducing greenhouse gas emissions as part of a comprehensive climate action plan that includes a number of large-scale technological innovations and responsible policy making to decrease emissions to 80 percent below 1990 levels.³⁷ Adding a behavioral/personal action component to the wedge approach would mean that in the U.S. residential sector alone, emissions could be reduced in an amount equivalent to the total emissions of France. The majority of this potential comes from

the adoption of energy-efficient behavior and technologies at the household level. Emphasizing the scale of impact that personal choices can have may help inspire audiences to take action.

Highlight the Benefits of Taking Action

Climate change is not an isolated issue. The impacts of climate change extend to the economy, public health, agricultural systems, national security, and even psychological well-being. This also means that responding to climate change can bring benefits to other areas of society. For example, responding to climate change can bolster our health and well-being, strengthen community cohesion, and catalyze economic opportunities in the United States and across the world. Research indicates that emphasizing co-benefits, especially when they are immediate and personally relevant to audience members, may be an especially effective way to get more people on board with solutions.³⁸

Align Solutions with Your Audience's Values and Priorities

As discussed throughout this guide, people are more likely to respond positively to climate change communication efforts that speak directly to their values. This fact is especially true for communicating about solutions. When proposed solutions align with people's values and worldviews,



people are more likely to endorse both the solution and the existence of climate change.³⁹ However, the reverse is equally true: when there is a mismatch between the solution (such as greater regulation by federal government agencies) and people's values or worldviews (such as a strong focus on individualism rather than collectivism), people are likely to reject both the solution and the larger issue (even those who might otherwise believe climate change to be a problem). Communicators may also wish to consider using traditionally masculine cultural themes, such as boldness, scale, and dominance, when talking about climate solutions to align with the values and worldviews of, for instance, self-reliance, independence, or patriotism.⁴⁰

Communication efforts should thus:

- Help people identify how a proposed solution allows them to pursue the priorities and values that they already care about
- Link solutions to values that are widely shared (such as patriotism, independence, and freedom in the United States)
- Incorporate and account for values and identities in the design and implementation of climate solutions.⁴¹

Presenting solutions that align with people's values and goals is also likely to generate greater engagement because individuals, communities, businesses, and organizations see how these solutions will benefit them. This may be particularly true with local-scale or sector-specific solutions. For example, recent efforts to sequester carbon in grasslands and rangelands could motivate individuals and communities who might otherwise be skeptical of climate science and policy with the use of associated financial incentives. (For example, ranchers could be paid to manage their lands in ways that increase how

much carbon is sequestered in the ground.)⁴² Other research suggests that presenting wind and solar energy as opportunities to bolster the American manufacturing base and to lessen U.S. dependence on foreign oil, which are key priorities for some Americans, could be especially effective in motivating support among some conservatives.⁴³

Scale from Local to Global Solutions

Communicators should strive to highlight the personal and local aspects of climate change when possible, with regard to both climate impacts and climate solutions. Connecting local-scale solutions to local-scale impacts helps people see and recognize cause-and-effect relationships between climate actions and outcomes for themselves, something that is harder to communicate when talking about solutions to an issue perceived as far off in time and space. Ideally, proposed solutions are win-win: they both help combat climate change and address visible, well-known local issues or local climate impacts.

Solutions should also match the impact and scale of the issue: talking about hyperlocal solutions but framing climate change as a global phenomenon (or vice versa, focusing on local impacts but promoting only national or global policy responses) may backfire by confusing people or making them skeptical that the solutions and problem actually fit one another.

Put Technological Solutions in Context

Highlighting solutions to climate change is a powerful route to engaging people on the issue. However, not all solutions are created equal, and communicators need to be careful not to induce backfire effects by promoting solutions that are mismatched to the scale or time frame of the problem. Some proposed solutions (such as nuclear fusion) could actually

decrease motivation for individual-level action. This is particularly true of technological solutions, which can undermine engagement by promoting false beliefs of "technosalvation" or "solutionism" and can reduce motivation to take personal or collective responsibility. Solutions that are not plausible at the time of communication (such as immediate widespread adoption of distributed renewable energy systems) should be promoted along with, not as a replacement for, the individual- and local-scale solutions that will also need to take place. Communicators should also acknowledge that some technological solutions can have (or can be perceived as having) unintended dangerous side effects and should be mindful of people's possible fears associated with engineering innovations.

The following table provides examples of climate solutions for various sectors.

 TABLE

 2

Climate Solutions and Mechanisms to Facilitate Them

Sector	Suggested Climate Solutions and Mechanisms
Energy production	 increasing renewable heat and power (solar, wind, hydropower, geothermal, and bioenergy) reducing subsidies for fossil fuels taxing fossil fuels implementing incentives or requirements to source electricity from renewable/clean sources (such as the Renewable Portfolio Standard) providing subsidies for producers of renewable energy facilitating carbon dioxide capture and storage (CCS) implementing power plant emissions limits switching from coal to natural gas in the interim using nuclear power in the interim
Transportation	 using fuel-efficient vehicles, hybrid and electric vehicles, and cleaner diesel vehicles using biofuels using and improving public transportation using nonmotorized forms of transportation (walking and biking) improving and implementing fuel economy standards for vehicles changing transportation and land use planning to influence mobility needs taxing vehicle purchase, registration, and use pricing road usage and parking

Buildings and homes	 using more efficient lighting, such as CFLs and LEDs using daylight instead of artificial light using more efficient electrical appliances and heating and cooling devices improving insulation using solar heating and cooling using appliance standards and labeling that show energy usage encouraging consumers to use less energy during peak hours implementing building codes and certification using smart meters that provide feedback and control 	
Industry	 recovering heat and power from manufacturing processes recycling materials replacing materials with climate-friendly materials controlling emissions of all greenhouse gases that contribute to climate change (for example, methane and nitrous oxide) creating and using more efficient electrical equipment facilitating voluntary agreements with clear targets to reduce pollution implementing cap and trade systems (like the Regional Greenhouse Gas Initiative in the Northeast) 	
Food and agriculture	 improving crop and grazing land management to increase the amount of carbon soil storage using fertilizer more efficiently to reduce nitrous oxide irrigating crops more efficiently improving livestock and manure management to reduce emissions of methane improving energy efficiency in the agricultural sector providing incentives and regulation for improved land management 	
Forestry/ forests	 facilitating afforestation (planting trees where there didn't used to be trees) and reforestation (planting trees where trees have been cut down) using forestry products to create bioenergy to replace the use of coal and oil facilitating and improving land-use regulation facilitating and improving forest management and reducing deforestation 	
Waste	 composting organic materials such as food scraps recycling and reducing waste recovering methane pollution produced by landfills capturing energy produced during waste incineration controlling wastewater treatment facilitating regulations and incentives for better waste and wastewater management 	

Note: The guide authors do not endorse these solutions and mechanisms. Rather, they are suggestions for policies and actions that climate communicators may wish to highlight in their climate communication strategies.

Source: Adapted from Table SPM.4: "Selected Examples of Key Sectoral Mitigation/Adaptation Technologies, Policies and Measures, Constraints and Opportunities" in the Intergovernmental Panel on Climate Change's 2007 Synthesis Report. Available at: www.ipcc.ch/publications_and_data/ar4/syr/en/spms4.html#table-spm-5.



Helping people imagine a brighter future for their family and community without dangerous climate impacts should be a central goal for climate communicators. Doing so will boost perceptions of personal and collective efficacy and circumvent potential roadblocks to engagement and action, such as fatalism, apathy, doubt, and denial. Providing your audience with concrete, plausible solutions to climate change is one way to accomplish this goal.

Moreover, when people believe there are solutions available, they are more likely to perceive climate change as a problem worth addressing. Whatever solution your organization promotes (see TABLE 2: Climate Solutions and Mechanisms to Facilitate Them for ideas), communication efforts should emphasize the role that individuals and local communities have to play in making those possibilities a reality and the benefits that they will accrue as a result of responding to the issue. When developing solutions-based messaging, communicators should consider the following questions:

- Does your strategy highlight solutions to climate change or does it focus exclusively on making people understand the problem?
- Can you clearly communicate the personal benefits of the proposed solution? Do these benefits seem tangible and immediate?
- Are you framing solutions in a way that aligns with the values and identities held by your target audience? Are you communicating how a proposed solution allows your audience to pursue the goals and values they already care about?
- Do the solutions being proposed involve or require individual-level or community-level action? Does your communication make clear which type of action (if any) is required of the audience to whom you're communicating?
- Are you communicating solutions that are plausible at the time of communication?
- Are you being careful not to underpromote the role that individuals and communities need to play, even for large-scale technological solutions?
- Are you focusing on the local aspects of solutions whenever possible?

4 Bring Climate Impacts Close to Home

"But climate change isn't affecting me."

Over the past few years, the narrative about climate change impacts has shifted. Where communicators once focused on polar bears losing their habitat in the Arctic as a key impact of climate change, more communicators are now focusing on impacts that climate change-induced extreme weather will have around the United States. Despite such recent efforts to make climate impacts resonate better with audiences, many people continue to perceive climate change as a distant issue that won't affect them personally.45 This section describes how climate communicators can encourage people to respond to climate change by focusing on local impacts, highlighting personal experience, focusing on the "what" and not the "when," and pairing impacts with solutions.

Focus on Local Impacts

People have a hard time thinking about—or acting on—things and events that are perceived as far in the future, physically distant, happening to other people, or involving uncertainty. Psychologists refer to these as dimensions of **psychological distance**. ⁴⁶ Climate change is a prime example of a psychologically distant phenomenon. Thus our minds are not designed to immediately react to climate change, which can weaken motivation to take action.

To overcome these challenges, communicators can use vivid imagery and messages to help people identify the locally relevant, personally experi-



enced consequences and impacts that climate change is already causing. (For more on the use of imagery in climate change communication, see SECTION 6: Use Images and Stories to Make Climate Change Real.) For example, the concept of rising sea levels may feel distant or abstract to many people, even those who live on or near the coast. To make this impact more concrete, communicators can describe future water levels in terms of recent flood events that are vivid and easily imagined. Communicators might describe how climate change risks could put parts of a city that were flooded during a past storm underwater more frequently or even permanently. Climate communicators can

SIDEBAR 8

Making Climate Change Concrete through Experience, Real or Virtual

The most vivid way for people to learn about the impacts of climate change may simply be to experience them. Seeing water lapping at one's doorstep removes the psychological distance of flooding in every way: it is certain, it has been pulled out of the future and into the present, and it is physically close and personal. Some evidence suggests that communities that are already experiencing flooding may be better able to connect these events with climate change. Indeed, flood experience has been shown to increase concern about climate change and to reduce feelings of uncertainty.⁵⁷

However, not all communities experience hazardous events that connect easily back to climate change. Moreover, waiting for a natural hazard to strike is of course a costly way to bring climate change psychologically closer to the public. Personal experience with flood events is only one way to make climate change feel closer and more concrete. Other ways include asking people to detail the specific actions they would take in the event of a hazard, listing the individual effects the hazard is likely to have on their homes, facilitating participation in evacuation drills or mock emergency events, and encouraging people to update their disaster preparedness kits.

Many groups have made sea level rise psychologically closer to the public by creating "blue line" projects that pair scientists with artists to paint the height of future sea levels on waterfront buildings and infrastructure. Seeing a line of blue paint on telephone poles, mailboxes, and downtown buildings provides a very concrete image of what sea level rise will mean for individuals and communities. Besides increasing support for global efforts to reduce climate change, this type of awareness-raising project has the additional advantage of promoting local preparedness, such as improving building codes or even retreating from flood-prone areas. However, climate communicators should take care to acknowledge the emotional and psychological effects that result from experiencing climate change directly or virtually and should build people's confidence that they can effectively take action on the issue.⁵⁸

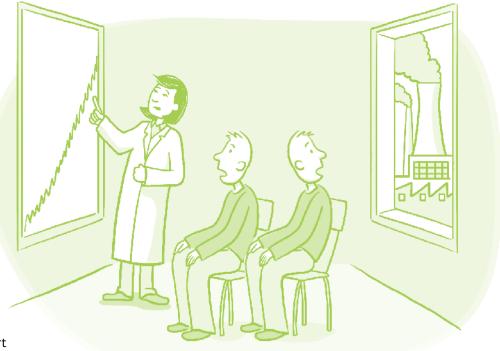
also use interactive tools and maps such as those created by Climate Central, which allow people to visualize how different degrees of sea level rise will affect their own neighborhoods.⁴⁹

Highlight Personal Experience

People's lives are filled with immediate and near-term concerns, most of which are perceived as more pressing than climate change. This is the case in part because people have a **finite pool**

of worry, meaning they are able to worry about only so much at any given point. Yet it turns out that many people, including most Americans, are already feeling the negative impacts of climate change, even if they don't associate those impacts with climate change.⁵⁰ Helping people identify the local and personally relevant impacts of climate change—including loss of property from intensified extreme weather events and the greater spread of infectious diseases—may go a long way in making the problem salient and urgent for more people.

In addition, highlighting people's personal experience with current, local impacts of climate change in general is likely to increase audiences' engagement with the issue more so than communicating additional abstract facts and figures. This is in part because direct experience with climate impacts affects people's perceptions of the risk of climate change and how worried they are about the issue. Researchers in the United Kingdom, for instance, have found that people who have experienced major flooding events report higher concern about climate



change and are more certain that it is happening.⁵¹ Other research has found that the effects of personal experience of climate impacts are particularly strong among individuals and communities that tend to be more skeptical of climate change.⁵²

Climate communicators should keep in mind, however, that there is a fine line between productively engaging people through their personal experiences with climate-related impacts and unintentionally leading people away from positive engagement with the issue. Making the issue "too real and too scary" repeatedly is a possibility and can lead to denial of the problem.

Climate communicators should also exercise caution in attributing specific extreme weather events or other environmental and societal changes to climate change. While scientists know that the frequency and/or severity of many extreme weather events—such as storms, droughts, floods, and extreme temperatures—are increasing with climate change, scientists are unable to attribute any one specific event to climate change.⁵³ One useful metaphor to

help explain this phenomenon is that of a baseball player using steroids. While no one can know whether any particular home run is directly attributable to a player's use of steroids, one can be reasonably sure that the likelihood of the baseball player hitting home runs is greater as a result of his use of steroids.

Pair Impacts with Solutions to Avoid Emotional Numbing

Communication strategies and messages that make climate change concrete and vivid without simultaneously building feelings of hope, pride, and efficacy are unlikely to be effective, as they are likely to lead to emotional overload and paralysis. If communication efforts repeatedly expose people to emotionally draining messages and images, audiences may eventually stop responding emotionally altogether, a phenomenon that psychologists call emotional numbing.54 One key to avoiding these effects is to tie concrete, personal climate impacts to immediate, local solutions already available to individuals and communities. Using the same overarching frame (for example, public health or clean energy jobs) when communicating challenges and potential solutions can be an especially effective way to make sure the audience both understands the issue and feels empowered to be part of the solution. For example, talking about negative economic impacts of extreme weather could be paired with highlighting opportunities for entire new job sectors in renewable energy to generate feelings of hope and efficacy. See SECTION 5: Connect Climate Change to Issues That Matter to Your Audience for more information about using frames effectively.

Focus on the "What," Not the "When"

One of the mistakes communicators often make is assuming that people will interpret and understand numerical and statistical information exactly as communicators intended. In reality, people often distort, misunderstand, or simply ignore such information, particularly information about mathematical probabilities. To overcome these obstacles, communicators should focus on the consequences of particular impacts or events (such as a drought or major flood) rather than on the probability or likelihood that such an impact will occur within a particular period of time (such as this hurricane season or next year). Similarly, common terms used by scientists to describe major events, such as "hundred-year flood," can make people think they are safer than they are in the few years immediately following such an event. Again, climate communicators should avoid terms like these and instead focus on describing what will happen the next time that impact occurs locally.

If communication efforts repeatedly expose people to emotionally draining messages and images, audiences may eventually stop responding emotionally altogether.

Be Sensitive to Recent Losses and "Near Misses"

Highlighting recent losses and major climaterelated events can help people understand why climate change is personally relevant and requires immediate action. Yet highlighting these types of events can also quickly backfire if people think that communicators are trying to exploit recent tragedies and fragile emotions to pursue their own ends. Communicators can avoid these negative effects by helping people move quickly from identifying local impacts to embracing local solutions, particularly those that have to do with preparedness. People will take risks more seriously-and be more likely to act—when they perceive the impacts of climate change as local and personal and when they understand concrete steps they can take to prepare for or prevent those impacts moving forward.

On the other hand, recent "near misses" (as occurred for many people in the New York City area with Hurricane Irene) can push people in the opposite direction. Near-miss events—when people are warned of an impending storm or other negative impact that ends up not happening—can decrease people's trust in communicators and scientists, increase resistance to paying up-front costs for preparedness, and make people generally complacent about future warnings. Specifically, when near misses are interpreted as disasters that did not occur (versus events that almost happened), people underestimate the danger of subsequent hazardous situations and make riskier decisions.55 When interacting with individuals or communities that have recently experienced near misses or false alarms, communicators should be careful to focus people on what they need to do to keep themselves safe when the next storm, drought, or other impact does hit, regardless of exactly when the negative event will happen.

SIDEBAR



The Psychological Impacts of Climate Change

When people think about climate change, they often think about the impacts it will have on the weather and the physical environment. This can make climate change seem distant and abstract. Yet climate change will also have significant impacts on our mental health. For example, as climate change progresses, experts expect heightened levels of stress, anxiety, depression, and post-traumatic stress disorder, as well as a loss of community identity and increases in interpersonal aggression. 59

Communicating about these more tangible impacts of climate change may help personalize the issue and motivate people to take action to prepare for and prevent these effects. As with any climate communication, communicators should take

As with any climate communication, communicators should take care to balance a focus on the psychological impacts of climate change with a focus on how individuals and communities can prepare for and prevent them.



Bring Climate Impacts Close to Home

For most people, climate change is perceived as a distant threat. Even when events made more severe by climate change—such as storm surges or extreme droughts—occur, many people may not readily connect them to human-induced climate change. Communicators should strive to highlight local-scale impacts that are already occurring—and that will occur in the future—as a result of climate change. However, it is important that communicators also explain the need for and build people's confidence in the possibility of preparedness and prevention responses by individuals and communities.⁵⁶

Consider the following questions as you are putting together your communication strategy about climate impacts:

- Are you helping people identify the locally relevant consequences and impacts that climate change is already causing?
- Are you pairing climate impacts with solutions to avoid emotional numbing and to bolster engagement?
- Are you being sensitive to people's recent losses when discussing local impacts and hazards from climate change?
- Are you focusing on the "what" rather than the "when" for disasters and avoiding terms like "hundred-year-flood"?
- Have members of your target audience recently experienced one or more near misses or false alarms involving major hazardous events? If so, how will you confront the challenges this can pose to future decision making?
- Does your strategy help people identify ways to prepare for future events and impacts?
- Are you employing strategies that focus on resilience and preparedness to help make climate change more concrete and to help guide people toward action?

5 Connect Climate Change to Issues That Matter to Your Audience

"I just don't get why this matters to me."

Effective climate change communication helps people make the connection between their personal concerns and climate change. To tell a compelling story, communicators need to make decisions about what information or perspectives to highlight through the process of framing. This section helps communicators understand how to find and use frames that highlight information that will be most meaningful for their audiences and will be most likely to generate meaningful engagement.

Connect Climate Change to Issues That Matter to Your Audience Using Content Frames

Climate communicators are more successful when they show how climate change connects to issues or concerns that their audiences care about. Content frames describe who, what, why, and how. Content frames might highlight, for example, public health implications of climate change, the relationship between climate change and national security, or how climate change (and climate solutions) affects personal health and family well-being. One frame that has received increasing attention is a human health frame, especially with regard to the Environmental Protection Agency's regulations for emissions from coal-fired power plants. To learn more about framing climate change in terms of human health, see SIDEBAR 10: Using a Public Health Frame to Talk about Climate Change. Unsurprisingly, different content frames speak to different audiences and motivations. (See SIDEBAR 11: Framing and the Politics of Carbon.)60

Provide a Coherent Narrative: Match Audience Priorities with Structure Frames

While content frames provide the outline of the narrative a communicator will develop about climate change, another type of frame can shape how particular aspects of the problem or solution are presented. Such frames, which usually have to do with subtle yet powerful changes in wording, are called **structure frames**.

Structure frames shape how an audience relates to a message by emphasizing "when," "where," and "how many." For example, communicators can frame climate change in terms of potential losses versus gains, local versus nonlocal impacts, the present versus the future, and preventing bad outcomes versus promoting positive outcomes.⁶¹ Impacts on nonhuman species, for instance, can be discussed in terms of "saving biodiversity" (gain frame) or "species extinction" (loss frame).

Researchers have identified a number of structure frames that play a strong role in affecting how people perceive climate change. Communicators



SIDEBAR 10

Using a Public Health Frame to Talk about Climate Change

Many Americans do not yet perceive climate change as a threat to human health.

Drawing attention to the connections between climate change and human health may be an effective method for elevating public concern about climate change in the United States. This is especially true for people and groups that have tradition-

ally been skeptical about the nega-



tive environmental effects of climate change.⁶⁶ By articulating the serious health consequences of climate change and fossil fuel burning, such as more severe and widespread asthma and allergies, more illness and death from extreme heat, and the increased spread of disease, communicators can help frame climate change as a concrete, personal concern for everyone. Health-based messages are often even more effective when they include real stories about people suffering from asthma or heat-related illnesses and when they include statistics from credible, nonpartisan sources like the American Lung Association.⁶⁷ Another best practice is to describe how climate change will impact the lives of the most vulnerable populations, like children and the elderly.⁶⁸

Framing solutions to climate change—such as advancing the clean energy economy—in terms of health benefits may also help increase engagement and support for action. The combustion of fossil fuels creates "dirty energy" and emits large amounts of health-damaging pollutants. In addition to advancing climate change, these emissions directly pollute the air and water that people rely on for good health. Highlighting the health impacts of such air pollution—and avoiding direct mentions of climate change—has been found to increase support for mitigation policies among political conservatives.⁶⁹

Communicators may also wish to emphasize the health benefits that come from taking steps to prepare for and help prevent climate change. These benefits include more bicycle- and pedestrian-friendly communities, healthier food, reduced motor vehicle-related injuries and deaths, cleaner air and water, increased physical activity, decreased obesity and reduced morbidity and mortality associated with it, increased social capital and well-being, and lower levels of depression.⁷⁰

should carefully consider each of the following frames and how an audience might respond to it. In some cases, research suggests a clear recommendation about which frame to use no matter what. In other cases, climate communicators need to determine which frame is likely to be most effective with their audiences on a case-by-case basis.

Loss versus Gain: Many environmental issues can be framed either positively or negatively, which can impact how an audience perceives and evalu-

ates them. For example, highlighting the potential for climate change to threaten our way of life evokes a negative, loss frame. In contrast, many preparation-oriented messages use a gain frame when they focus attention on benefits that come from building more resilient communities and infrastructure. The negative feelings associated with losing something (such as losing \$100) generally outweigh the positive feelings associated with gaining that same thing (such as winning \$100). When policies and outcomes

SIDEBAR 11

Framing and the Politics of Carbon

Although many economists and climate scientists agree that a carbon tax would be the most streamlined step the United States could take to reduce its contribution to climate change, support for a carbon tax among major politicians is fairly limited. At the same time, many businesses and individuals voluntarily purchase carbon offsets (or carbon credits), which promise to balance out the greenhouse gases produced by particular activities they are engaging in, such as flying across the country. How much of this support is a reflection of the framing power of the words "tax" and "offset"? CRED researchers polled a large national sample about a program that would raise the cost of certain products believed to contribute significantly to climate change (such as air travel and electricity) and use the money to fund alternative energy and carbon capture projects. The identical program was described as a carbon tax to half the respondents and as a carbon offset to the other half. This simple change in framing had a large impact on whether people said they would buy a product with an inclusive carbon fee. When considering a pair of products, 52 percent of respondents said they would choose the more expensive product when the cost increase was labeled a carbon offset, but only 39 percent said they would choose it when the cost increase was labeled a tax. Support for regulation to make the cost increase mandatory was greater when it was labeled an offset than when it was labeled a tax.

Strikingly, the framing effect interacted with respondents' political affiliations. More liberal individuals were equally likely to support the program regardless of the label used, but more conservative individuals strongly preferred the carbon offset to the carbon tax. A follow-up study revealed that the tax label triggered many negative thoughts and associations among more conservative individuals, which in turn led them to reject the carbon tax. These findings demonstrate that communicators should carefully consider the way in which carbon regulations are labeled or presented. Communicators may wish to use politically neutral terms when describing carbon regulations, such as the label "user fee," which makes the point that those who receive a benefit should pay for it.

are framed in terms of potential losses, people are usually willing to take bigger risks to avoid those negative outcomes.⁶² The reverse is also true: when policies and outcomes are framed in terms of potential gains, people become more risk averse, preferring "sure bets" or smaller, less risky choices. Communicators can use this knowledge when deciding whether to frame a message or decision as a loss or a gain, depending on whether the goal is for people to make a risky choice (investing in certain insurance policies) or a less risky choice (line drying clothes to save energy).

Present versus Future: People tend to perceive immediate threats as more relevant and of greater urgency than future problems. ⁶³ Because people discount the future (thinking it will be easier to solve future problems due to an [unrealistic] technological fix or an [imagined] greater availability of financial resources), communicators should generally try to highlight the impacts of climate change that are already being experienced in the present or are likely to occur in the very near future. This will create an urgency to act now. Similarly, people tend to think that it will be easier to part with money if necessary in the future, as demonstrated by research that shows that employees are often willing to commit next year's pay raise to a retirement plan. ⁶⁴ In terms of a climate preparedness or energy conservation program, participation may be greater if communicators



SIDEBAR 12

Making Clean Energy Attractive across Political Lines

One part of the solution to climate change is the widespread adoption of clean or renewable energy, such as solar power.

Energy campaigns typically focus on how solar technologies reduce emissions or utility bills. These "reduce" messages are likely to be effective in motivating liberals to invest in renewable energy, as they see themselves as personally responsible for reducing their energy use and emissions. However, this language may fail to engage more politically conservative individuals who do not share this sense of obligation. Dena Gromet and CRED researcher

Howard Kunreuther, both of the Wharton School at the University of Pennsylvania, have investigated how framing renewable energy as reducing negative aspects of energy use, as compared to increasing positive aspects of this use, interacts with political ideology to affect individuals' interest in adopting solar power.

In two studies of California homeowners, participants could choose to read about different home improvement options, one of which was installing solar panels on their homes.⁷¹ The researchers varied whether the solar option was described as reducing a negative aspect of energy use ("Want to reduce your use of fossil fuels? Get solar panels!") or as increasing a positive aspect ("Want to increase your use of renewable energy? Get solar panels!"). The reduce/increase framing interacted with political ideology to predict people's decisions about whether or not to learn more about solar. Liberals were more inclined than conservatives to choose to learn about solar when a "reduce" message was used, whereas the divergence between liberals and conservatives was lessened (or reversed) when an "increase" message was used. Additional questions revealed that "reduce" messages were more appealing to liberals because they communicated that individuals had a personal obligation to conserve energy, whereas "increase" messages conveyed greater personal benefit.

These findings demonstrate that **the emphasis on reducing a negative aspect of energy use, as compared to increasing a positive aspect, can dramatically affect individuals' interest in renewable energy**. This framing effect appears to be primarily driven by how messages resonate with individuals' political views and sense of personal responsibility for addressing energy issues.

The results highlight the importance of understanding how different framings resonate with individuals' political values, which can influence their energy choices. In addition, research suggests that highlighting benefits or gains from taking action may be an effective way to increase willingness to respond to climate change, regardless of an individual's political orientation.

¹ This research was conducted as part of the Sunshot Solar Energy Evolution and Diffusion Studies (SEEDS) program, Department of Energy.

ask people to sign up in advance to take a more cost-intensive action down the road, such as committing to weatherizing their homes the following year. It is important to note that some individuals may actually respond more positively to future-oriented information about climate change, in part because doing so can make the issue less overwhelming while giving people a sense that they can still do something.

Local versus Global: Climate change impacts and solutions can be framed as local (local extreme weather events; community-level preparedness efforts) or as distant (climate change as a global phenomenon; international agreements). In general, communicators should frame climate change as a local issue, both in terms of consequences and possible solutions. In part, this is because local impacts and solutions are more vivid and thus easier to think about for most people. Additionally, research has found that the more traditional approach of highlighting the global scale of the problem without also highlighting local impacts may actually increase political polarization, as such messages resonate well with liberals but poorly with conservatives. Thus communicators may wish to emphasize local impacts first, before scaling up to show how climate change is affecting other parts of the country and the world.



Your communication strategy should integrate frames that help audience members quickly identify why and how climate change is meaningful to them. To bolster audience engagement, use frames that speak to your audience's major concerns. Consider the following questions before determining which frames to use:

- What are your audience's major concerns and worries? Which content frames (such as a public health frame or a national security frame) would resonate most clearly with your audience?
- Now can you use structure frames to make the issue relevant and meaningful to your audience?
- > How can you incorporate a focus on present, local impacts into your communication strategy?
- Are there small changes you can make in how you describe climate impacts or climate solutions that would change how your audience reacts to your message?

Keep in mind that your answers to the questions in **SIDEBAR 1: Getting to Know Your Audience**, can also help you to determine the best form and content frames to use in your communication strategy.

6 Use Images and Stories to Make Climate Change Real

"Blah, blah, blah."

All too often, climate communicators rely on written communication and facts and figures to get their messages across. Images and storytelling, however, are critical tools for making climate impacts, solutions, and stories more real. This section describes how images can be used to underscore certain points, what types of images are most memorable, and why images of people and familiar things are usually more effective than scientific graphs. This section also provides tips on how communicators can employ storytelling to enhance their audiences' attention and engagement.

Use Images That Inspire and Empower

People think and feel using images. Images convey emotions and add emotional weight beyond what words can accomplish. Rather than directly telling the audience what to do or how to feel, images can let audiences create meaning for themselves. Although the use of images is not as well researched as other areas of climate change communication, a few studies have highlighted several important considerations that climate communicators can keep in mind when using images.

Climate change imagery often falls into one of two categories: images that increase the emotional impact or saliency of climate change, and images that increase self-efficacy and the feeling of personal agency. 73 Dramatic images that prompt fear (such as those of environmental refugees or "drowning" polar bears) or that depict climate impacts (such as aerial views of flooding) are good for attracting attention and giving climate change a sense of emotional importance. However, these types of images are less effective in the long-term

because they distance people from solutions and deeper engagement. On the other hand, images that promote self-efficacy (such as images of renewable energy or insulating one's home to reduce energy use) tend to be less salient (that is, they are less effective at grabbing an audience's attention). Communicators should take care to use both types of images, depending on whether they wish to attract audiences' attention or help empower audiences to act.



Climate communicators may also wish to employ cultural archetypes or icons to help audiences relate to climate change more effectively. For example, the quintessence of masculinity, as represented by construction workers, first responders, or cowboys, tends to align with values that are pervasive in American culture—boldness, scale, dominance, and progress—and thus may help engage new audiences on climate change. 74 Climate communicators should also take care to use clear, realistic images that closely match the narrative of accompanying text, which can enhance readers' understanding of climate change and its implications. 75

Show People, Not Pie Charts

In a series of experiments to find out what features make images more memorable, researchers discovered that **images of people or groups, faces, and common household items are among the most powerful.** ⁷⁶ Contrary to popular belief, aesthetically pleasing scenes like landscapes, architectural exteriors, wide-angle vistas, backgrounds, and natural scenes leave less of a mark. ⁷⁷

Researchers have also found that visualizations such as bar charts, pie charts, and scatter plots (which are frequently used to communicate climate change) are among the least memorable of all images. These kinds of images require prior knowledge and skill to read effectively and thus are appropriate only when designed and chosen with an audience in mind. 78 Unique visualization types, such as those using pictorial elements, repeated small multiples (such as stick figures to represent people), grids or matrices, trees and networks, or diagrams, are easier to remember than common graph types such as pie charts, scatter plots, bar graphs, and line graphs. 79 Moreover, the inclusion of objects, photographs, people, cartoons, and logos can help enhance memorability of visualizations used to communicate about climate change.

Use Storytelling to Strengthen Engagement

Stories are the single most powerful tool in a leader's toolkit.
-Howard Gardner, Harvard University

According to one recent poll, eight in ten Americans do not understand what it means to study something scientifically. ⁸⁰ As a result, science-and fact-based arguments about climate change are unlikely to resonate with the majority of the American public. Instead, stories are among the best ways to connect with core human values and social identities, build bonds between individuals and groups, and engage the public on climate change. This doesn't mean that facts cannot be persuasive; it's just that stories are more likely to make those facts more relevant. Stories about climate change can take a range of forms, including personal speeches, films, short stories, plays, or newspaper or magazine articles.

Stories influence people's beliefs because they shift the frames of reference for emotional and cognitive processes. ⁸¹ In addition, stories can enhance people's capacity for empathy. ⁸² As an alternative form of mental processing, both fictional and factual stories open people up

Stories are among the best ways to connect with core human values and social identities, build bonds between individuals and groups, and engage the public on climate change.

to new information, attitudes, intentions, beliefs, and behaviors. ⁸³ Stories can also focus on a long and glorious past as a motivator to care about and ensure a livable future. ⁸⁴

Climate communicators may wish to ask their audiences to tell their own stories about climate change impacts and solutions. Communicators can then share these stories with others and can create their own by identifying what drives them personally and by determining why climate change matters to others. For more resources on storytelling, see the FURTHER READINGS section on Page 82.





Use Images and Stories to Make Climate Change Real

Audiences bring different knowledge and experiences to their interactions with images—especially technical images like charts and graphs. Subject matter, composition, point of view, and visual style are just some of the ways that images communicate and frame communication, and connecting with an audience is just as important for images as it is for verbal communication.

Consider the following questions as you incorporate images and storytelling into your communication strategy:

- Do your images empower and inspire your audience?
- Do your images depict people, groups, faces, or common household items rather than landscapes and vistas?
- Are you using visualizations like bar charts, pie charts, and scatter plots sparingly and with your audience's previous knowledge and skills in mind?
- Are you using realistic images that closely match the narrative of accompanying text?
- Are you employing storytelling (both real and fictional) to help make climate change more vivid and to help people imagine possible courses of action?

Connecting on Climate: A Guide to Effective Climate Change Communication

OVERCOMING BARRIERS:

Science, Skepticism, and Uncertainty

OVERCOMING BARRIERS: SCIENCE, SKEPTICISM, AND UNCERTAINTY

Climate change is complicated. It involves scientific jargon, numbers that are hard to comprehend, and significant amounts of risks and uncertainty. The technical language used to describe climate change—terms like "anomaly" and "positive feedback"—can mean vastly different things to the general public than they do to scientists. Moreover, the term "global warming" has confused many people, who have come to understand climate change as a universal increase in temperatures rather than a global shift in weather patterns. While communicating about the science of climate change alone is often insufficient to catalyze engagement around climate change, communicators should still understand how to approach some of the basic issues surrounding science and risk communication (especially as they relate to climate change), uncertainty, and climate skepticism, which are explained in this part of the guide.

People update
their mental
models (usually
unconsciously)
by incorporating
new information,
correcting misinformation, and
making new
connections with
existing knowledge.



Make Climate Science Meaningful

"I have no idea what those numbers mean."

Scientists rely on quantification because numbers, even when uncertain, provide a consistent language for discussing the changes they are observing in our climate system. Yet for most members of the public, these types of statements are not meaningful. In part this is because most people are not familiar with or used to thinking in these terms. Similarly, without scientific training, it can be difficult for people to judge the relative importance, meaning, and quality of particular scientific facts or statements. The result is that numbers and statistics—on their own—do not provide an anchor to ground and generate an emotional response, which is crucial for engagement and action for many people. This section describes how people understand scientific phenomena like climate change, explains how to translate scientific and numerical information into familiar terms, and identifies which metaphors can help the public better understand climate change.

Uncover How Your Audience Understands Scientific Phenomena: The Role of Mental Models

Most Americans do not have a complete understanding of climate change and its associated risks. Yet most people have at least a bit of knowledge about climate change, which they will use to interpret new information they hear about it. People's understanding of climate change is often based on a mix of associations with the phrases "global warming" or "climate change," memories of related phenomena and past experiences, analogies they've heard from others, intuitive perceptions, and relevant yet incomplete sets of facts. These form the ingredients of a mental model.

Someone's mental model or **constructed concept** of climate change can answer some of the following questions: (1) What is climate change? (the issue and its causes); (2) If the climate changes, what might happen? (impacts); and (3) What can be done about climate change? (policy, individual action). People refer to mental models to judge the level of risk associated with a problem, its controllability, and its manageability. Mental models influence what people pay attention to, how they approach problems, and what actions they take.⁸⁶

While a person's mental model of climate change can be flawed or contain misconceptions, it is not fixed. People update their mental models (usually unconsciously) by incorporating new information, correcting misinformation, and making new connections with existing knowledge. This presents an enormous opportunity for communicators. For new



climate change insights to take hold, communicators can map the mental models that an audience already uses, create new models using facts and practices to refine or replace existing ones, and employ strategic messaging to correct wrong information and help people update their assumptions. (See SIDEBAR 13: A Mental Model Example: Using Images to Understand How People View the Stability of the Climate System.)

Sometimes people seek out or absorb only the information that matches their mental model, confirming what they already believe to be true. This can lead people to avoid, dismiss, or forget information that will require them to change their minds and possibly their behavior. This phenomenon, called **confirmation bias**, poses a potential stumbling block for those who try to communicate new information and options for behavioral change. **While confirmation**

bias is difficult to overcome, communicators can make audiences aware of the phenomenon. They can ask audiences to question themselves: "Could I possibly be wrong?" and "What would be the worst thing about being wrong?" Simply making people aware of this bias and encouraging them to have an open mind can be quite effective.

SIDEBAR 13

A Mental Model Example: Using Images to Understand How People View the Stability of the Climate System

Anthony Leiserowitz, director of the Yale Project on Climate Change Communication, has examined Americans' mental models about the stability of the climate system. 90 In nationally representative polls, Leiserowitz and his colleagues asked participants to indicate which one of five different pictures best represented their understanding of how sensitive the climate system is to global warming. The researchers then compared participants' mental models to their beliefs about the existence of climate change.

The results were striking: people's beliefs about the stability of the climate system strongly correlated with their beliefs about whether or not climate change is happening. Those who said they believed climate change was happening were much more likely to endorse *gradual*, *fragile*, *or threshold* models of the climate system. In contrast, those who said they were skeptical of climate change overwhelmingly chose either the *random or stable* pictures. These findings

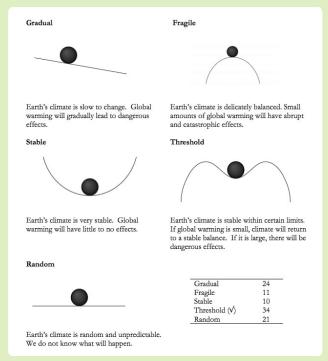


Figure 1: This image shows that people's beliefs about the stability of the climate system strongly correlate with their beliefs about whether or not climate change is happening. Image from Leiserowitz, A., Smith, N., & Marlon, J.R. (2010). *Americans' Knowledge of Climate Change*. Yale University. New Haven, CT: Yale Project on Climate Change Communication. www.environment.yale.edu/climate/files/ClimateChangeKnowledge2010.pdf.

point to the pervasive effects that mental models can have on people's beliefs about the role of human action in affecting the natural world. Providing audiences with a basic explanation of the stability of the climate system, in combination with other climate communication techniques discussed in this guide, may help improve people's understanding of our complex climate system.⁹¹

Communicate on a Human Scale

Often, the metrics and scales that scientists use to describe climate science are unfamiliar and unintuitive to most people. For example, people may think about the weight of a car when they hear a quantity measured in tons yet become confused when a volume of gas (such as CO₂) is described using the same metric, since our usual perception of gases is that they weigh nothing. When the scale or metric is confusing and doesn't translate into everyday experience, people have difficulty hearing or processing the information.



Figure 2: Visual representations of large numbers and unfamiliar concepts (such as tons of CO2) can be helpful to communicate information on a human scale. Image courtesy of Carbon Visuals (carbonvisuals.com) with funding from the Environmental Defense Fund.

SIDEBAR 14

Using Labels to Help Consumers Save Money and the Environment

The fuel economy of a vehicle can be expressed in several different ways. Fuel economy can be expressed as the amount of gas consumed, the cost in dollars to drive a certain distance, or the amount of carbon dioxide or greenhouse gases emitted. The U.S. Environmental Protection Agency and the National Highway Traffic Safety Administration recently overhauled the fuel-economy labels that appear on all new vehicles by adding additional fuel-efficiency "translations." The label still includes miles per gallon (MPG), but also includes an annual fuel cost estimate, gas consumption per



Figure 3: Studies show that consumers' fuel-efficiency decisions are strongly affected by the type and form of information provided on fuel-economy labels.

100 miles, and greenhouse gas and smog ratings. (See Figure 3, above.) With these new labels in mind, CRED researchers Adrian Camilleri and Richard Larrick conducted two studies to determine how changing metric and scale information on vehicle fuel-economy labels can help people make more informed choices. Across the two studies, Camilleri and Larrick found that consumers' fuel-efficiency decisions are strongly affected by the type and form of information provided: study participants chose fuel-efficient vehicles more often when fuel economy was expressed in terms of cost of gas over a long time-frame—100,000 miles (or roughly the life of a vehicle). This is an important finding, as current labels do not help people understand the long-term costs of owning less fuel-efficient cars or the savings realized by owning more fuel-efficient cars.

To avoid these potential pitfalls, communicators should translate unfamiliar or unintuitive statistics and numbers into relatable, easy-to-understand terms. CRED researchers (and others) have shown that using different metrics and scales to represent the same information can strongly influence people's preferences and behavior. For example, people prefer more fuel-efficient cars when information about fuel economy is presented in terms of: (1) the cost of gas rather than how much gas is consumed (different metrics); and (2) the cost savings over 100,000 miles of driving rather than over 100 or 15,000 miles (different scales).⁸⁷ This is because people quickly grasp that 100,000 miles is roughly the lifetime of a vehicle, making it easy to incorporate fuel-related costs into the up-front cost of purchasing a car.

It is also easier for people to understand numbers when the same piece of information is simultaneously presented in multiple formats.

SIDEBAR 15

Examples of Powerful Facts from Trusted Messengers

Research suggests that sticking to just one or two facts or figures, especially when they are attributed to trusted and reputable sources (especially those that don't seek profit or political gain), can be an especially effective way to bolster our understanding of climate change. Here are a few powerful facts about climate impacts and solutions that communicators can use to help build people's understanding of climate change and their support for solutions:

- According to the American Lung Association, the toxic chemicals in the air we breathe are affecting the health of nearly half of all Americans.⁹²
- According to the Department of Energy, solar energy is the most abundant energy resource on Earth. The solar energy that strikes Earth is equal to more than ten thousand times the world's total energy use.⁹³
- According to NASA, the ten warmest years on record were all after the year 2000.94
- According to the National Solar Jobs Census 2013, solar jobs in the United States are growing ten times faster than the national average.⁹⁵
- According to the Centers for Disease Control and Prevention (CDC), health impacts from climate change and ozone pollution will result in significant increases in acute respiratory symptoms, asthma, weather-related hospital admissions for children and the elderly, and premature deaths.⁹⁶
- According to an economic risk report jointly conducted by a leading research firm and the world's largest catastrophe-modeling company, if we continue on our current path, by 2050 between \$66 billion and \$106 billion worth of existing coastal property will likely be below sea level nationwide.⁹⁷

SIDEBAR 16

Using Metaphors to Help People Understand the Science of Climate Change

Metaphors, which help translate abstract concepts into familiar terms, are an especially effective tool for science communication. Metaphors are especially important when communicating about abstract issues like climate change because they help relate a complex issue to people's everyday life and personal experiences. Communicators should keep in mind, however, that not all metaphors are created equal—some can actually backfire by leading the audience away from productive engagement with the issue. For example, many medical metaphors about climate change ("Earth has a fever") are easy to grasp because people have lots of personal experience with fevers and illness, but they can also confuse people because they are related to concepts that don't fit the issue well.

Using a combination of methods, the FrameWorks Institute has identified the following metaphors that can help people better understand the causes of and solutions for climate change:

Regular versus Rampant Carbon Dioxide: This metaphor helps people understand why high levels of carbon dioxide are problematic. Some carbon dioxide (CO2) is needed for a lot of life processes. This is called regular CO2. Rampant CO2, on the other hand, occurs when we engage in actions like burning fossil fuels and driving cars, which put large amounts of CO2 into the atmosphere and oceans. This is called rampant CO2 because there is too much of it accumulating in the wrong places, causing problems for our climate. Regular CO2 will always be needed, but we need to start reducing rampant CO2.

The Ocean as the "Heart of the Climate": This metaphor helps people think about the role that oceans play in regulating the climate system. Much as the heart regulates the flow of blood throughout the body—controlling the circulation of blood and making sure the right amount gets to each part—the ocean sustains the climate system and keeps it in balance by controlling the circulation of heat and humidity. The ocean is the heart of Earth's circulatory system. It moves moisture and heat to the oceans, atmosphere, land, and other parts of the climate system.

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(See SIDEBAR 14: Using Labels to Help Consumers Save Money and the Environment.)⁸⁸ Additional research suggests that sticking to just one or two facts or figures, especially when they are attributed to trusted and reputable sources, can be an especially effective way to bolster people's understanding of climate change.⁸⁹ Visual representations of large numbers and unfamiliar concepts (such as tons of CO₂) can also be helpful.

Use Familiar Concepts to Help People Understand Science and Statistics

People interpret statistics and scientific facts by relating them to what they already know. Communicators should place statistical or scientific facts within a broader, familiar context so it is easy to make sense of that information and use it to make decisions. Communicators can also help people make explicit comparisons to familiar objects and concepts that

they encounter in the course of daily life (such as time or social interactions). For example, the difference between millions and billions of dollars lost to climate impacts is hard for people to grasp because both amounts sound so large. But comparing those losses to the (relatively small) amount of money being spent to combat climate change draws attention to the inequality between the huge scale of the problem and the insufficient scale of the current response.

SIDEBAR 17

Translation in Action

Take a look at the following statement: "In 2011, Americans experienced a record-breaking 14 weather and climate disasters that each caused between \$1 billion and \$10 billion in damages, in total costing approximately \$53 billion." ⁹⁹ This sort of statement is common in reporting on climate change. Yet on its own, this statement is unlikely to provoke a strong response or to motivate action, because \$53 billion means very little to people.

Now, compare the initial sentence with the following translation: "In 2011, Americans experienced record-breaking weather and climate disasters that cost our country approximately \$53 billion. That is more than eight times what our government spent on financing clean energy projects in the same year. We can either pay now or pay later to address climate change. It is our duty to responsibly and wisely manage our country's financial resources. An important way to do this is by investing in clean energy projects today that can benefit us all in the future." Notice how this translation incorporates an easily understood comparison (between money spent on cleanup efforts and money spent to avoid the problem in the first place) into a message that highlights widely shared core values (responsible management of shared resources; financial prudence) and promotes a particular solution (investments in clean energy). Remember: numbers and statistics can be powerful tools for communicators, but they should not be the centerpieces of the message. Instead, numbers should be used to support a well-framed, consistent core narrative about climate change, climate impacts, and climate solutions.



Make Climate Science Meaningful

In some situations, the communication of statistical and scientific data, findings, and facts is important or unavoidable. In these cases, communicators' aim should be to provide numerical information in a way that is readily usable and interpretable by their audiences. Consider the following questions before presenting numerical and scientific information:

- Have you identified what you can and will achieve by communicating numerical information, scientific findings, or facts? Are your expectations of the effects that such information will have on audiences supported by past research on and experience with climate change communication?
- What do you want your audience to do with the information you present? Are there ways to accomplish the same goals by communicating information besides scientific facts about the climate system, such as information about climate solutions or climate impacts?
- How familiar are people with the metrics and scales you are using? Could they be confused by an unfamiliar or nonstandard use of an otherwise familiar term (such as "tons")?
- If you are using numbers or statistics to highlight the scope or severity of the problem, are you successfully incorporating metaphors and real-life comparisons to help make those numbers meaningful for people?
- Are you providing enough context for people to understand the new information?
- Are you using numbers and facts sparingly and attributing the one or two facts and figures you do use to messengers or sources your audience knows and trusts?

SIDEBAR 18

How Time Horizons Affect Our Decisions around Climate Change

One thing that makes it particularly hard to capture the public's attention about climate change is the fact that many of the most serious impacts that must be prevented may not happen for quite a while. Future events are hard for people to care about because humans naturally discount future gains. Winning \$100 today feels great, but winning today and waiting one month for the payment feels much less good. When given the choice between \$100 today and \$120 one month from now, many people will take the smaller reward today rather than waiting a little longer for much more. That future \$120 is mentally discounted—enough to feel less valuable than \$100 now. 100 CRED researchers David

Hardisty and Elke Weber have found that the same attitude also influences people's decisions when it comes to protecting the environment.¹⁰¹

A similar effect happens when it comes to losses, such as incurring a loss now or in the future. When scientists tell the public that sea levels will rise by several feet in the coming century, people's natural tendency to discount, combined with a long time scale, can make the predicted rise seem inconsequential. Even with more easily imaginable outcomes such as economic losses of large magnitude, this discount effect is strong enough to make the costs of a \$300 million levy project (today) feel about the same as a \$1.3 billion flood-cleanup effort ten years later because people often delay large losses, even if delaying the action will result in higher costs than paying in the present. This may help explain why many people are not motivated to invest in flood-prevention efforts despite the fact that mitigation efforts cost much less than recovery on average. A contribution of \$1,000 to mitigation efforts is less than \$4,000 in recovery costs, but the \$4,000 may be discounted just enough to make it feel like less of a hit than the immediate \$1,000. Because of this, climate communicators may do better to place emphasis on the pure costs of cleanup and to de-emphasize the fact that cleanup will take place sometime in the future.

TABLE 3

Words with Different Meanings to Scientists and the General Public

The following table lists many words that scientists use to describe and talk about climate change, yet that mean different things to the general public, journalists, and policy makers. Make sure to avoid jargon and use words that truly convey what is meant to be communicated.

Scientific Word	Nonscientific Meaning	Better Language
enhance	improve	intensify, increase
uncertainty	not knowing	range
risk	low-probability event	probability
error	wrong or incorrect information	uncertainty associated with a measuring device or model
bias	unfair and deliberate distortion	offset from the observed value
positive trend	good trend	upward trend
theory	hunch, opinion, conjecture, speculation	physical understanding of how this works
hypothesis	conjecture	framework for physical understanding
sign	indication	positive/negative value, plus/minus sign
values	ethics, money	numbers, quantity
manipulation	exploitation	changes in experimental or model conditions to study the impact of those conditions
scheme	conspiracy	blueprint
anomaly	abnormal occurrence	deviation from a long-term average
mitigation	fixing something after it breaks	avoiding or preventing further climate change and global warming
adaptation	"going with the flow"; dealing with problems as they arise	increasing preparedness before impacts occur; prepar- ing for climate impacts that are already happening
geoengineering	Frankenstein-type messing with nature	deliberate alteration of natural Earth systems
environment		the air we breathe and the water we drink



"If the scientists aren't 100 percent sure, why should I listen to them?"

There's no escaping it: communicating on climate change involves talking about uncertainty. Uncertainty exists in part because climate science is complex and the climate system is even more so. While it may be tempting, communicators should not ignore the uncertainties that climate change presents, be they uncertainties associated with timing and severity of impacts or uncertainties related to the success or failure of mitigation and adaptation strategies or technologies. Communicators should be aware that even small levels of uncertainty are often used strategically to oppose climate action. This section explains how climate communicators should focus on what is known, describes which uncertainties matter and which ones don't, and explains how to help audiences become engaged on climate change, even when uncertainties do exist.

Uncertainty on its own is not necessarily a barrier to engagement or action.

Rather, it is the implied and perceived implications of uncertainties that can make engagement challenging.

The Role of Uncertainty in Climate Change Communication

At its core, human decision making deals with uncertainty. While people may be uncomfortable when confronted with uncertain situations or information, they are also experts at taking action under such conditions. Take the example of the daily weather forecast. Despite the fact that people tend to misinterpret probabilities and percentages, many people have little trouble translating a 60 percent chance of rain into concrete action (such as taking an umbrella). More importantly for communicators, most Americans now perceive and know that there are real scientific and political uncertainties surrounding climate change. As a result, communicators may need to recognize these uncertainties. In fact, research suggests that acknowledging uncertainty at the beginning of a climate communication message can increase people's willingness to engage with the issue. The question is how to engage with uncertainty more broadly in a way that helps people understand and respond to the issue rather than turns them away.

Uncertainty on its own is not necessarily a barrier to engagement or action. Rather, it is the implied and perceived implications of uncertainties that can make engagement challenging. If people believe that scientific or political uncertainty means that the problem is too difficult

to solve, they will be unlikely to support action. Conversely, if people are able to understand the ways in which uncertainty can provide opportunities for a new and better future, they are likely to embrace the issue and proposed solutions.

Ultimately, it will likely be people's experiences with emerging solutions and policies to address climate change that will narrow the gap between expert and public perceptions of the issue, rather than people's exposure to information about the uncertainties.¹⁰⁵

Focus on What Is Known

Communicators should generally aim to highlight the facts about climate change that are known with relative certainty. This is especially true of the fact that there is overwhelming consensus among climate experts regarding the basic facts of climate change. Despite this, many Americans



Figure 4: This image provides a clear visual example of the overwhelming scientific consensus on climate change. Image from Cook, J., & Lewandowsky, S. (2011). *The Debunking Handbook*. St. Lucia, Australia: University of Queensland.

SIDEBAR

African Farmers and Climate Information

Over the last decade, CRED researchers have been studying participatory processes in a variety of cases to understand how these can affect the use of climate information more broadly. In Uganda, discussion within farmers' groups facilitated the understanding of probabilistic seasonal rainfall forecasts by allowing members to pool their ideas and to plan appropriate responses. ¹¹³ This resulted in greater use of forecasts in agricultural decisions by group members, compared with farmers who did not participate in the group discussions. Farmers in Argentina also found value in group discussions of forecasts and other topics to improve their farming. Dairy farmers in the Dominican Republic used participatory meetings to explore the introduction of insurance mechanisms and were able to change the contracts offered to reflect their needs. **Participatory processes have an important impact on decision making and can be valuable for sharing information or preferences, particularly** in settings that have traditionally lacked equal access to information and that are often shaped by the strategic use of uncertainty. In Burkina Faso and Brazil, participation in water user committees has contributed to reducing conflicts over water allocation and enabling greater access to political processes or authorities. ¹¹⁴ In all of these cases, group context eased the problems commonly found in understanding and using uncertainty.

SIDEBAR 20

Better Safe Than Sorry: Invoking the Precautionary Principle

Uncertainty is often used as a justification for inaction or business-as-usual policies. Yet communicators can and should use uncertainty to encourage people to develop contingency plans and to adopt adaptive management strategies. Highlighting the concept of "better safe than sorry" (also known as the precautionary principle) can help individuals and communities reframe a potentially paralyzing uncertainty into justification for strong, protective action. Former governor of California Arnold Schwarzenegger referred to the precautionary principle when he said, "If ninety-eight doctors say my son is ill and needs medication and two say 'No, he doesn't, he's fine,' I will go with the ninety-eight. It's common sense—the same with climate change. We go with the majority...the key thing now is that since we know this industrial age has created it, let's get our act together and do everything we can to roll it back."

continue to perceive a lack of scientific consensus, which researchers have identified as a major barrier to greater public engagement with the issue. ¹⁰⁶ Research shows that short, simple statements are some of the most effective ways to increase public understanding about the scientific consensus on climate change. ¹⁰⁷ Using simple, audience-appropriate pie charts can also enhance understanding of the scientific consensus on climate change, especially among Republicans. ¹⁰⁸ Highlighting potential



"So yes, Dan and Kathy, as you can see it looks like it'll be up and down until 2109, but you're certainly going to want to think about abandoning the planet after that..."

solutions that involve relatively little uncertainty should also be a goal of climate communicators.

The 2014 National Climate Assessment and the Intergovernmental Panel on Climate Change's Fifth Assessment Report (AR5) provide detailed guidance about what is known with relative certainty and which prevention and preparedness approaches are viable as solutions pathways. ¹⁰⁹ See TABLE 2: Climate Solutions and Mechanisms to Facilitate Them for more information about solutions.

Uncover How Your Audience Responds to Uncertainty

Communicators should assume that every audience they interact with is uncomfortable with uncertainty. If communicators are presenting to a live audience, they can ask a few questions to test people's understanding of uncertainty by show of

hands. For example, communicators may ask a question like, "Does a 30 percent chance of rain tomorrow mean that it will rain in 30 percent of the area, that it will rain 30 percent of the time, or that it normally rains on 30 percent of days with these conditions?" Communicators may also wish to ask questions like, "Would you base any decisions on a 50/50 chance of something occurring?" and "How likely do you think it is that an earthquake will occur in New York City in the next twenty years?" Recognizing how an audience approaches probability, statistics, and uncertainty can help communicators tailor their communication strategies accordingly.

Determine Which Uncertainties Matter

It is important to recognize that there are multiple sources and types of uncertainty surrounding climate change. People do not respond to all of these

SIDEBAR

21

Helping People Imagine the Future

Research from various fields is converging on a key insight for climate communicators: helping people imagine a range of possible future scenarios can support engagement. In one recent study, researchers presented participants with one of three messages about future sea level rise:

- Scientists' best estimate is 3 feet of sea level rise by 2100.
- Scientists' best estimate is 3 feet of sea level rise by 2100, but it could be as much as 6 feet.
- Scientists' best estimate is 3 feet of sea level rise by 2100, but it could be as much as 6 feet or as little as 1 foot.

In all cases, estimates of sea level rise were accompanied with a projection of how many millions of Americans would be displaced from their homes and businesses by a given level of change. Strikingly, audiences' level of support for adaptation policies was strongest when they got the message with the full range of future impacts (best guess, worst case, best case). ¹¹¹ Moreover, people who received the third message also showed the biggest increases in trust in scientists, a critical predictor of belief about the reality and seriousness of climate change. ¹¹² **This and other research points to the importance of providing audiences with a range of "alternative futures," as doing so can both increase trust in communicators and make various trade-offs and decisions more concrete.**

uncertainties in the same way. For example, there is uncertainty about the severity and timing of future negative impacts from climate change (such as storms, droughts, or extreme temperatures), scientists are not sure just what volume of greenhouse gases can be emitted before the planet reaches a "tipping point," and there is always uncertainty regarding what exactly humans will decide to do about the problem (and when they'll take action).

Columbia University researchers Scott Barrett and Astrid Dannenberg have found that people working in groups find it very difficult to coordinate their actions to avoid bad outcomes (for example, incurring financial losses) when there is too much uncertainty about exactly how much up-front action the group must take to reduce the risk. When uncertainty around such "thresholds" is too high, people stop cooperating, leading to worse group outcomes. On the other hand, Barrett and Dannenberg have also found that groups are less strongly influenced by uncertainty regarding the severity of the impact, which is good news for climate communicators. 110

SIDEBAR 22

Strategies for Communicating Uncertainty

Practitioners can do a number of things to communicate uncertain information more effectively and meaningfully, including:

- Encourage group discussion about climate information. Work by CRED researchers in Africa and elsewhere has found that people are better able to use information involving probabilities and likelihoods to inform decision making when they process that information in a group setting rather than as individuals.¹¹⁵
- Communicate scientific information using multiple labels. People have an easier time understanding and using information when communicators use both numerical ("90 percent") and verbal ("very likely") labels and avoid negatively worded terms such as "unlikely." ¹¹⁶ Using only verbal labels, as is often the case both in technical (for example, the Intergovernmental Panel on Climate Change) and media discussions of climate change, leads to confusion and produces a gap between experts' understanding of uncertainty and the public's perceptions. ¹¹⁷
- Whenever possible, provide clear visualizations to show data and to illustrate what is known and what is less certain. For example, graphics that use icon-based representations can quickly and easily convey degrees of consensus, uncertainty, and relationships between variables.
- When referring to uncertain events such as future storms, focus on what will happen when the
 next climate change-related event occurs, not on the probability of it occurring this month or
 this year. Doing so will motivate people to consider all future possibilities and how they want to
 respond, despite uncertainty around the exact timing of events.



Acknowledge Uncertainty, but Show What You Know

Given that uncertainty will always be present in climate change, communicators need to find effective ways to confront uncertainties head-on. Although communicators may worry that talking openly about uncertainty will allow audiences to slip into wishful thinking about the severity of the problem, research on the communication of uncertainty tells a different story. A growing body of empirical evidence points to the benefits of highlighting certain types of uncertainty while guiding people toward factually correct explanations where they exist. When thinking about how to communicate uncertainty, consider the following questions:

- > What scientific uncertainties has your audience likely heard about?
- Are you using multiple presentation formats (for example, numerical, verbal, and visual) to communicate any given piece of scientific information?
- Are you using short, simple statements or pie charts to show that the overwhelming majority of scientists believe that climate change is real and human-caused?
- Now can you highlight the opportunities that uncertainty presents to shape the future?
- Are you providing enough context when communicating uncertainty to avoid causing feelings of hopelessness, despair, fatalism, and inefficacy?
- Are you using group discussion settings where possible to help your audience engage productively with the uncertainties that exist?
- Are you using the precautionary principle ("better safe than sorry") when appropriate?

9 Approach Skepticism Carefully

"But I heard..."

One of the biggest challenges for climate communicators is correcting misinformation about the causes and existence of climate change. Just as people's preexisting mental models must be taken into account when designing communication strategies, so too must communicators know how to respond to climate change skepticism and guide people toward personally meaningful and readily usable information. People are skeptical of climate change and the need for action for a variety of reasons. This section explains why some people are skeptical about climate change, describes how to distinguish between different types and sources of skepticism, and shows how to guide people toward solutions.

Why Do Some People Doubt Climate Change?

There are several types of climate change skepticism. Skepticism that stems from learning about the scientific uncertainties that truly exist in the context of the climate system is valid and an important part of the dialogue to address climate change. In contrast, skepticism that is the result of highly organized efforts by some individuals and organizations to intentionally mislead the public and policy makers (to derail efforts to confront climate change) does not play a productive role in shaping a collective response to climate change and must be addressed by communicators. In some cases, individuals' denial of climate change is also a result of more basic psychological processes that shape how people engage with information about climate change. These three main types of skepticism are described here in more detail:

Skepticism That's Part of the Scientific Process: Scientists use the scientific method to prove or disprove scientific theories and claims about how the world works. Such scientific skepticism is conducted in good faith and is a key component of the climate change research process because it allows scientists to talk about the uncertainties that still exist (for example, the exact timing or severity of future impacts) and ways to research them. Sometimes the public mistakenly takes scientific uncertainty to mean that the core principles of climate change are not settled or that no action can be taken to address it (neither of which is true). Communicators should reinforce that this type of good-faith skepticism is healthy and an important part of the scientific dialogue, at the

In some cases, individuals' denial of climate change is also a result of more basic psychological processes that shape how people engage with information about climate change.

same time reiterating that the core science about climate change is settled and agreed upon by the vast majority of climate scientists.

Skepticism Based on Misinformation: Particularly in the United States, some groups have worked to instill doubt and climate change denial among both high-level decision makers and the general public. This has been accomplished in part by producing and distributing incorrect information about the existence and causes of climate change, supporting and promoting scientists who deny observational data about the current climate system (such as global average temperatures), and undermining mainstream climate scientists' reputations. Some of this incorrect information has been passed along to the public through the media. This false information typically frames climate change as "uncertain" and uses the uncertainty to justify delays in action. The uncertainty is emphasized by questioning isolated pieces of evidence, emphasizing the need to delay action until the science is definitive, and stating that the fixes for climate change are expensive. Bringing awareness to these types of denial efforts and their characteristics can help audiences recognize when they are being exposed to good-faith skepticism or false information.

Skepticism Due to Underlying Psychological Processes:

Most people prefer to avoid negative emotions when possible. Yet the scope of climate change (and the messages climate communicators have often used) can easily lead people to feelings of sadness, fear, guilt, and hopelessness. This is particularly the case if people perceive themselves and their communities as unable to meaningfully confront the problem. One response is to avert these feelings altogether by denying the existence or downplaying the severity of climate change. Through a set of mostly unconscious processes that social scientists call *motivated reasoning*, many people perform



"mental acrobatics" to avoid believing that climate change is a problem or that it requires a large-scale response. Being skeptical about climate change is one way to avoid negative feelings about the issue as well as to justify inaction, and it is particularly likely to occur when proposed solutions (such as greater governmental regulation of the energy sector) are perceived as affronts to one's core identities, worldviews, and values.¹¹⁹

These mechanisms are not mutually exclusive. To some extent, they are all relevant because people have been exposed to information that highlights scientific uncertainties and disagreements among experts (real or not), as well as the cost and difficulty of responding to the issue.

Crucial to all discussions of climate change is therefore trust in scientists. Because most people are neither climate scientists nor highly science literate, people must rely on scientists and others for information about climate change. Thus beliefs about an abstract scientific issue such as climate change are influenced by the extent to which people trust scientists and science to accurately and

honestly report what's happening in the world. That said, climate scientists are generally a highly trusted source of information for Americans. 121 It is important for scientists to gain the trust of the audience when acting as climate communicators. One way to do this is by showing that they too are community members, with similar concerns and life challenges as audience members. If the communicator is a non-scientist, it is important for him or her to reinforce that information about the existence and nature of climate change comes from trusted science.

Identify Sources of Doubt

When communicators encounter skepticism, doubt, or outright denial, it is important that they identify the under-

lying sources and mechanisms at play. Someone

who questions climate change because he or she has been exposed to false information may need to be made aware that false information campaigns are going on and that they do not represent accurate science. In contrast, those who are skeptical about climate change because of deeper psychological processes inherent in ideology or worldview-driven motivated reasoning may need to be shown that there are solutions to the problem that are in fact in line with their deeply held convictions (see SECTION 3: Emphasize Solutions and Benefits)

before they can accept or respond to climate change. 122

The More Facts the Better? Not Quite

Communicators should take a multi-pronged approach to dealing with doubt and denial. The commonly held beliefs that "facts will save the day" and "the more facts people hear the better" are—as many scientists and advocates have discovered—simply not accurate. Similarly, the commonly used strategy of stating a myth (such as, "there has been no warming for the past ten years") and then refuting it with extensive evidence not only often fails to dislodge the myth but actually may reinforce it.

Climate communication researchers John Cook and Stephan Lewandowsky explain how this can happen via two effects, which they refer to as the familiarity effect and the overkill effect. The **familiarity effect** occurs when people hear a myth over and over again (often repeated by climate advocates in their attempts to discredit the myth), making it more familiar

SIDEBAR 23

"I Heard There's Been No Warming for Ten Years": Debunking Climate Myths

Climate change communicators often encounter the same few false claims and myths repeated over and over by climate deniers: "Climate has changed before," "There is no consensus," "It's natural," "Models are unreliable," "The temperature record is unreliable." Besides being incorrect and/or irrelevant, what these and other commonly used climate myths share is the ability to distract both honest communicators and uninformed audiences from grappling with the truly complex nature of the issue.

One claim that can be particularly confusing for audiences is the myth that there hasn't been any warming of the globe in the past ten years. This is a topic many scientists are currently studying because it involves complex research about short-term fluctuations in our climate system, but people who deny climate change often use this scientific dialogue as a blanket statement to "prove" that climate change is not real. When such claims are made (for example, in town hall meetings or other settings in which communicators can respond immediately), communicators should do the following:

- 1. State that the claim is a myth and therefore wrong, unequivocally, and explain in a short sentence why the talking point is false.
- 2. Provide some context. For example: "Organizations that deny climate change is happening cherry-pick the data and ignore information that doesn't fit their story."
- 3. State the core fact that you want to communicate, for example: "Climate change refers to long-term trends, and the data we have indicate an increase in global temperatures in recent decades, which is the short term."
- 4. Try to reinforce the core fact or takeaway with a little bit of additional detail and/or a clear graphic if possible, for example: "Using many different ways to track long-term trends, scientists have consistently found that Earth continues to warm." When possible, attribute the fact to a reputable source that the audience is likely to trust.
- 5. If appropriate, show people why responding to climate change makes sense, even if climate change were not human-caused. In other words, help the audience question why people would make a lose-lose wager when they can have a win-win by moving to clean energy sources that will have other positive effects in addition to climate change mitigation. For example, climate communicators may want to use a message such as, "We can gamble that our changing weather patterns are just a natural cycle that we can't do anything about. But why play Russian roulette with our kids' future when the alternative is to invest in new clean energy technologies like wind and solar power that will rebuild our manufacturing base, create jobs, and get our economy growing again?" 127

and thus easier to believe as truth. The **overkill effect** occurs when communicators try to provide too many counterarguments to refute a myth, making it harder for people to cognitively grasp the complex truth relative to the simplistic myth.¹²³

To avoid these negative outcomes, communicators should lead with the core concept they want people to grasp and use only a *few* of the clearest, most important facts, preferably from trusted and reputable sources. Contrary to some scientists' and communicators' beliefs about the public, people *are* often open to considering new evidence and information. However, this is more likely to happen and to be effective when messages:

- Contain one or two powerful facts or quotes from a trusted and credible source (see SIDEBAR 15: Examples of Powerful Facts from Trusted Messengers)
- Are presented in a compelling way (often using visualizations, pie charts, infographics, or animation)
- Start with the correct information and discuss the myth or misinformation only later on
- Connect the new fact directly to things people already care about (as discussed in SECTION 1: Put Yourself in Your Audience's Shoes and SECTION 5: Connect Climate Change to Issues That Matter to Your Audience)



- Avoid raising people's defenses, which happens
 when information contradicts worldviews and
 identities, causes negative emotions, or makes
 people feel that the problem is too big to solve
- Provide alternative explanations that fill in gaps in people's understanding when a belief is exposed as myth
- Announce to people in advance whenever false information is going to be discussed and debunked

Focus on Solutions, Not Just the Problem

Replacing myths and misinformation with evidencebased information and facts may help shift public opinion on climate change. Yet doing so is likely to be ineffective unless communicators also (1) address people's feelings that they are powerless to do anything about the issue and (2) acknowledge other underlying emotions about the issue.124 In fact, a sense of paralysis and inability to confront the issue may increase as people better understand and appreciate the scope of the problem (often as the result of communication efforts). 125 To avoid these problems, communicators should focus heavily on what can and already is being done to limit the impacts of climate change (for example, through climate solutions), both by individuals and collectively, as discussed in SECTION 3: Emphasize Solutions and Benefits. Strategies that fail to do so are likely to be counterproductive in the long term because they encourage people to avoid thinking and talking about the issue. 126



Approach Skepticism Carefully

Climate change is hard enough for most people to understand without the presence of misinformation about the issue. Consider the following questions when confronting myths, misinformation, and skepticism:

- > Have you identified the sources of doubt or types of skepticism expressed by your audience?
- When addressing a myth, have you included all three of the following components: core facts, explicit warnings, and alternative explanations?
- Do you know which myths or pieces of misinformation are important to address and which ones are less critical to accomplishing your communication and engagement goals?
- Are you focusing on solutions, not just the problem?
- Are you avoiding the tendency to lead with the myth rather than with new, personally relevant information?

TAKING IT TO THE NEXT LEVEL:

Creating the Conditions for Change

TAKING IT TO THE NEXT LEVEL: CREATING THE CONDITIONS FOR CHANGE

By now, communicators should have a solid understanding of how to craft climate change messages that will improve audiences' understanding of and engagement with the issue. For communicators who want to take it to the next level, however, this section provides information, tips, and recommendations about a related challenge: translating understanding and concern about the issue into actual action. This section outlines some of the primary tools that can help communicators create meaningful and lasting behavior change.

When people set specific goals for action, and when they make these goals public, they are more likely to follow through and take action.

10 Make Behavior Change Easy

"It's too hard to do anything about climate change."

The ultimate aim of many climate change communication efforts is to encourage decision making that will help prevent further climate change and help communities prepare for climate impacts. Such changes can be achieved through multiple routes, including increasing public support for new policies and regulation, directly persuading people to change their behavior, and changing the decision-making environment to make positive action easier and more automatic. Many climate change communicators focus on the first two approaches, but the third can also offer promising opportunities. This section reviews a variety of behavioral science strategies from a range of fields (such as behavioral economics and social psychology) that climate communicators and other individuals can use to enhance audience members' likelihood of making climate-friendly choices in their everyday lives, from household energy use to transportation decisions.

Enable People to Set Specific Targets for Their Behavior

The short- and long-term goals that people set for themselves shape the information they seek out and the behavior they engage in. When people set specific goals for action, *and* when they make these goals public, they are more likely to follow through and take action. Goal setting is often

used to encourage energy conservation, such as by giving households energy-savings targets to strive for. A goal can be set by an individual or by an external entity; research suggests that both can be effective in reducing energy use. Thus communicators should provide people with opportunities to publicly set targets for their behavior or publicly commit to following existing targets, whether around household energy use, food choices, or transportation choices.

Make Climate-Friendly Choices the Default Option

The *default effect* refers to people's tendency to stick with the option, choice, or behavior that is preselected for them or selected automatically. Defaults are omnipresent in modern life, which means there are many opportunities to promote positive behavior change by optimizing opt-in an opt-out choices. *Communicators can make climate-friendly behavior easier for people by*

presenting the climate-friendly option as the default. For example, when people are automatically enrolled in their electric utility's "green energy" program, they are more likely to stick with the cleaner energy source than if they have to actively opt in to the green program. When communicators are in a position to present people with information about various options (such as energy-saving activities or environmental policies), presenting more sustainable choices as the default can increase the likelihood that people will make the climate-friendly choice. For more information on using defaults to encourage climate-friendly behavior, see SIDEBAR 24: Encouraging Climate-Friendly Diets through Defaults.

Highlight the "Green Joneses"

Humans are highly social creatures, which is why shared identities and social goals can be such powerful sources of engagement, as discussed in SECTION 2: Channel the Power of Groups. Another

SIDEBAR 24

Encouraging Climate-Friendly Diets through Defaults

Small changes in people's eating habits can have a significant effect on greenhouse gas emissions. Replacing meat consumption with vegetarian options can reduce individuals' contribution to climate change. However, attempts to persuade people directly to eat less meat are often unsuccessful. Setting vegetarian meals as the default option, on the other hand, can be an effective way to shift behavior. Researchers did just this in a recent study. Working with the organizers of the Behavior, Energy and Climate Change conference, researcher Karen Ehrhardt-Martinez and her colleagues noticed that the default meal choice for conference participants had always been meat-based. Participants could order a vegetarian meal if they wanted to but had to make an extra effort to do so (namely, asking for a meat-free exception on the conference registration form). For the 2009 conference, Ehrhardt-Martinez simply changed the default to the vegetarian meal (and asked carnivores to indicate they preferred meat instead, by checking a box at the time of registration). With that simple flip, consumption of vegetarian meals went from the usual 20 percent to 80 percent, which reduced carbon emissions while maintaining participants' freedom to choose the meals they wanted. 136



by-product of humans' innate social tendencies is the influence of **social norms** on people's behavior. When people are made aware of what is customary behavior in a group, they often change their own behavior to match. Communicators can help facilitate behavior change by highlighting norms surrounding climate-friendly behavior, when they exist. The flip side is also true: communicators should be very careful not to play up negative social norms (for example, highlighting the large amounts of energy people are using), as doing so can actually backfire by making such behaviors seem normal and socially approved. The power of social norms to promote climate-friendly actions is described further in SIDEBAR 25: The Power of Social Norms: Opower and Energy Bills.

Give People Fewer Choices, Not More

Many of us are taught that the more choices people are provided, the better and the more motivated people will be. Yet research indicates that giving people more choices doesn't always lead to better outcomes. For example, in one study, grocery store shoppers visited a booth with either six jams or thirty jams on display. The results were striking. Shoppers were more likely to buy a jam when they were presented with six options rather than thirty. Similar results were found in a study of employees' decisions about whether to invest in 401(k) retirement savings plans. Participation in 401(k) plans dropped when employees were offered ten or more investment options compared to participation rates in plans offering a handful

of funds. Too much choice can be paralyzing. 131

This research suggests that communicators should limit the number of choices or options they give people to maximize the likelihood of follow-through. For example, a home energy-savings program might provide customers with just three tips for what they can do to save energy, rather than ten or twelve, to increase the chance that customers will actually act on these tips.

Incentivize Behavior with Appropriate Rewards

Providing incentives and rewards—financial rewards, social recognition, points, or something else—is another strategy communicators can use

to make behavior change easier. The key is finding the right type and magnitude of incentive for a given situation and behavior. For example, providing a financial incentive at the time a decision is made can be effective for encouraging long-term capital investments (such as purchasing energy-efficient appliances or weatherizing one's home), which often have large up-front costs and long payback periods. On the other hand, psychological research has found that monetary rewards can also have negative side effects by removing people's intrinsic motivation to act, which can decrease the likelihood of people continuing to engage in a desired behavior over time. 132

SIDEBAR 25

The Power of Social Norms: Opower and Energy Bills

Social psychologist Robert Cialdini's groundbreaking research into the power of social norms provides a powerful tool for encouraging positive behavior change. Inspired by Cialdini's work, the energy-efficiency software company Opower teamed up in 2007 with electrical utilities in the United States to provide customers with information about how their energy consumption compared to that of their neighbors. Using simple verbal and visual messages that revealed and reinforced neighborhood social norms surrounding electricity use, Opower and its partners were able to decrease energy usage between 1.5 and 3.5 percent on average. Now working with partners worldwide,

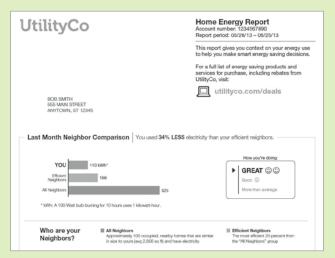


Figure 5: To yield energy-use reductions, Opower bills provide customers with information about how their energy consumption compares to that of their neighbors. Image courtesy of Opower.

Opower continues to successfully harness the power of social norms to bring about major reductions in residential energy consumption across the world. Communicators can use the work by Cialdini, Opower, and others as a model for creating norm-reinforcing messages that shift people in a positive direction on energy savings.

SIDEBAR 26

Helping People Understand Which Actions Have the Largest Impact

Research by CRED researcher Shazheen Attari finds that communicators have an important role to play in helping people identify the behaviors that will have the biggest impact in reducing climate change. In her research with American adults, Attari found a significant gap between people's beliefs about which energy-use behaviors have the biggest impact and the actual impact of those behaviors.¹³⁷ For example, people tend to underestimate how much energy could be saved by switching to more efficient appliances and overestimate how much



people are prone to the single-action bias (feeling that they have done their part by taking a single action to confront a problem), it is critical that climate communicators work to correct misconceptions about which actions have the biggest impact in reducing climate change.¹³⁸ For example, communicators may wish to provide audience members with a list of climate-friendly choices they can make in their everyday lives, ordered from largest to smallest impact.

One alternative to providing financial rewards is to provide social rewards in group or public settings. This can include giving points for taking positive steps (such as reducing office energy consumption), publicly recognizing individuals' good deeds, or providing encouragement to people who take leadership roles in promoting climate-friendly actions. Another form of social reward is "gamification," which involves using game mechanics (such as incorporating rewards) to motivate people to achieve their goals. Rewards can be given online or offline and can be as simple as the posting of an individual's photo or the announcement of names of people who have made a certain commitment. For example, when presenting to a school or community group, communicators might consider publicly sharing the names of people who have engaged in climate-friendly behaviors. This provides an immediate social incentive for action, as people are

often highly motivated to follow the behavior of their peers, especially those they know and trust.

Combining gamification with social media such as Facebook can provide additional opportunities for larger-scale sharing of one's actions and tracking progress, as well as inspiring others to join in. Mindbloom's Life Game is a good example of a game platform, combined with social media, that helps people "grow the life" they want.¹³³

In addition, research conducted by CRED shows that when people are publicly given rewards for a behavior, they become more motivated to contribute to the common good. To test the combined effect of monetary versus nonmonetary (social) rewards and providing feedback privately versus publicly, the researchers measured and rewarded employees for contributions to their companies' energy-conservation efforts. As expected, nonmonetary (social) rewards (such as telling people they did well or that they got a higher score than average) were more motivating than receiving money for the same behavior, and employees continued their energy-saving behavior even after the incentives ended. In addition, public feedback led to

more energy conservation than privately shared feedback. Most importantly, researchers saw the greatest reduction of energy consumption when social, nonmonetary rewards were combined with public announcements. Interestingly, financial rewards in combination with private feedback didn't work at all as a motivator to save energy. 134 Psychologically, social rewards and receiving public feedback spur social (and pro-environmental) behavior through the activation of social norms. Additionally, public feedback may also stimulate people to communicate about their scores and may lead to more social interaction about energy conservation.

The positive effects of social rewards and public feedback may even spill over into other parts of people's lives beyond the original behavior. When promoting positive engagement through group affiliation and social identities, communicators should include social rewards for cooperative behavior and should provide rewards in such a manner that everyone in the group is aware of them (for example, by using social media platforms to share people's successes widely and in real time).

SIDEBAR 27

Goal Setting in Action: Reducing Residential Water Use

To reduce water usage during summer months, residents of the Durham community in Ontario, Canada, were provided with water gauges and signs to be placed over outside water faucets. The signs reminded residents to water their lawns on specific calendar days based on their house numbers and to water their lawns only when it had not rained the previous week. Critically, residents were also asked to sign commitments—which made the goals that people had set for themselves concrete and public—that they would water their lawns only on designated days and limit their watering to 1 inch per week (72 percent of residents made these commitments). Watering in the community decreased by 54 percent during the campaign relative to rates prior to the campaign.¹³⁹

TIPS Make Behavior Change Easy

When communicators' aim is to shift individual-level behavior—whether the focus is on house-hold energy use or civic engagement—numerous strategies can be used to make behavior change more likely. Consider the following questions as you develop your strategy to encourage behavior change:

- What positive social norms can you highlight to encourage climate-friendly behavior?
- What opportunities exist to highlight the "green Joneses" to encourage other people to engage in climate-friendly behavior?
- Now can you publicly recognize individuals and groups for their climate-friendly choices?
- How can you minimize the number of choices offered to your audience to increase the likelihood that they will act?
- Are there obvious default settings that can be changed to promote climate-friendly decisions?
- What opportunities can you create for audience members to set specific targets or goals for their behavior?

CONNECTING ON CLIMATE Quick Reference

THE BASICS:PUTTING PEOPLE FIRST

Put Yourself in Your Audience's Shoes

- One of the most important things climate communicators need to understand is that climate communication is not a one-size-fits-all practice.
- People's differing values (such as freedom, prosperity, or equality), identities (such as being a mother, a Democrat, or a businessperson), worldviews (such as thinking the world should be egalitarian or hierarchical), and personal priorities (such as health and finance) all shape how they respond and react to messages about climate change.
- For example, someone who values prosperity might be receptive to a message about climate change that emphasizes how clean energy solutions can unlock new economic opportunities for American families. This same person, however, would likely be frustrated by a message that emphasizes the need for sacrifice.
- Tip: Identify the values, identities, worldviews, and personal priorities of your audience and craft communication strategies accordingly.
- **Tip:** Think about whom your audience trusts and respects and whether these people can serve as messengers.

2 Channel the Power of Groups

- One of the most effective ways to build long-term engagement around climate change is to harness the power of social groups and networks, large and small.
- Humans are highly social creatures. They look to their groups and networks—such as church groups, company departments, parent-teacher

- associations, and sports clubs—for informal social norms, customs, or standards.
- When people are physically part of a group or are reminded of their membership in one, they are more likely to promote outcomes that are good for the group.
- **Tip:** Weave climate change into the activities of social groups and networks, such as neighborhood associations, religious groups, clubs, or company divisions.
- **Tip:** Provide existing group leaders with climate change communication and engagement resources to activate the group's entire membership.

CRAFTING YOUR MESSAGE: SOLUTIONS, IMPACTS, FRAMING, AND IMAGERY

Emphasize Solutions and Benefits

- Research indicates that it can be more effective to start with solutions rather than first giving an overview of climate change itself. This is especially true when people hear about solutions that align with their values and worldviews.
- Solutions can help reorient people toward action and opportunity and can quell feelings of hopelessness and dread.
- People's sense of personal and collective efficacy—
 the capacity and willingness to successfully confront a challenge—is part of what drives how they
 respond to climate change.
- Tip: Talk about the roles that individuals, governments (local, regional, and national), businesses, and nonprofits can all play in addressing climate change.
- **Tip:** Describe solutions that match the decision-making authority and capacity of the audience and show people the role they can play as individuals (for example, talk

- about local impacts and local solutions, not national policy and local impacts).
- **Tip:** Highlight the personal and societal benefits that climate solutions will bring, such as improving health, jump-starting new economic opportunities, catalyzing technological innovation, and strengthening communities.

4

Bring Climate Impacts Close to Home

- People have a hard time thinking about or acting on events that are psychologically distant—events that are perceived as far in the future, physically distant, or happening to other people.
- The concept of the **finite pool of worry** explains that people are able to worry about only a certain number of things at a given point.
- People are much more likely to think of climate change as a relevant and urgent issue when they understand how climate change is personally affecting the lives of those immediately around them.
- Emotional numbing occurs when audiences stop responding emotionally to a message. This can happen with climate change if people are repeatedly exposed to emotionally draining messages and images.
- **Tip:** Use messages that help people identify the locally relevant, personally experienced consequences and impacts that climate change is already causing.
- **Tip:** To avoid emotional numbing when communicating about the personally relevant impacts of climate change, take care to also mention solutions and actions that people can take and to focus on what impacts will occur, rather than on the exact timeline of when they will occur.
- **Tip:** Be aware of losses that may have come about as a result of recent climate impacts and focus on preparedness for the next event, rather than on the timing of the next event.

5

Connect Climate to Issues That Matter to Your Audience

- Climate change is unique in that it affects almost everything, from our health to national security, the economy, transportation, and agriculture.
 Likewise, climate solutions offer the opportunity to transform almost every element of society.
- Communicators can help audiences make the connection between climate change and issues that climate change and climate solutions will affect through the use of message frames.
- Content frames describe the "who," "what," "why," and "how" of a climate change narrative and can be useful in connecting climate change to issues that matter to your audience. One common content frame is the public health implications of climate change.
- Structure frames emphasize "when," "where," and "how many" and can shape how an audience relates to a message. Popular structure frames include loss versus gain, present versus future, and local versus global.
- **Tip:** Choose content frames that connect to the audience's concerns and worries.
- **Tip:** Choose structure frames that make the issue relevant and meaningful to the audience.

6

Use Images and Stories to Make Climate Change Real

- Images and stories that inspire and empower audiences and that match the narrative and tone of accompanying text can improve people's understanding of climate change and bolster their willingness to engage.
- Technical images such as charts and graphs are appropriate only when designed and chosen with the audience's knowledge and skills in mind.

- Stories are among the best ways to connect with core human values and social identities and to build bonds between individuals and groups.
 They enhance people's capacity for empathy and shift frames of reference for emotional and cognitive processes.
- **Tip:** Images that depict people, groups, faces, or common household items are more effective and more powerful than landscapes and nature scenes.
- **Tip:** Storytelling can help make climate change more vivid and can help people imagine the future and solutions to climate change.

OVERCOMING BARRIERS: SCIENCE, SKEPTICISM, AND UNCERTAINTY

7 Make Climate Science Meaningful

- Most people have some understanding of climate change; they have a *mental model* of how the phenomenon works. A person's mental model of climate change can include ideas about causes, impacts, and what can be done about it.
- By understanding people's mental models, communicators can help people update their assumptions and correct misinformation.
- The **confirmation bias** makes people seek out information that matches their mental models, confirming what they already believe to be true.
- Most people are unfamiliar with the metrics and scales that scientists use to describe climate science. These measures are unintuitive to most people.
- **Tip:** Making audience members aware of the existence of confirmation bias and encouraging them to have an open mind can help them overcome it.

- **Tip:** Present the same piece of information in multiple formats to help people understand unfamiliar numbers, metrics, and scales.
- **Tip:** Pick just a few key facts about climate change to share with an audience and put those facts into a context that audience members will understand, rather than overwhelming them with too many facts.

8 Acknowledge Uncertainty, But Show What You Know

- No matter whom you communicate with, there will always be a few people who are uncertain about the causes of or solutions for climate change.
- Some aspects of climate change, such as the timing and extent of climate impacts and policy and technological solutions that will be available, are inherently uncertain.
- People who are skeptical about climate change often use uncertainty as an argument in favor of not taking action on the issue instead of embracing the opposite and equally plausible approach, the *precautionary principle* ("better safe than sorry").
- **Tip:** Acknowledge the fact that there is uncertainty around elements of climate science but emphasize that uncertainty doesn't mean we shouldn't act.
- **Tip:** Use short, simple statements to highlight what is known with great certainty about climate change—that it is happening and is caused by human activities.

9 Approach Skepticism Carefully

- There are several types of climate change skepticism.
- Skepticism that's part of the scientific process is a key component of the climate change research process because it allows scientists to talk about uncertainties that still exist.

- Skepticism based on misinformation is the result of groups that have worked to instill doubt and climate change denial among high-level decision makers and the general public.
- Skepticism due to unconscious, underlying psychological processes is called motivated reasoning. People perform mental acrobatics to avoid negative feelings, sometimes because these feelings threaten their deeply held values and beliefs.
- Countering skepticism with too many facts can backfire: hearing a myth about climate repeatedly makes it easier to believe (the familiarity effect); exposure to too many arguments refuting a myth (the overkill effect) makes it harder to grasp a complex truth.
- **Tip:** Identify the underlying source of skepticism at play within your audience and develop a response that matches the source.
- Tip: Lead with the core concept that you want the audience to grasp and use only a few of the clearest and most important facts.

TAKING IT TO THE NEXT LEVEL: CREATING THE CONDITIONS FOR CHANGE

10 Make Behavior Change Easy

- The short- and long-term goals that people set for themselves shape the information they seek out and the behavior they engage in. When people set specific goals for action and make these goals public, they are more likely to follow through and take action.
- When given a choice, people have a tendency to stick with the option or behavior that is preselected for them or selected automatically—the so-called default effect. Defaults are omnipresent in everyday

- life, which means there are many opportunities to promote positive behavior change by optimizing choice settings for social and environmental benefits.
- People often adjust or change their behavior to match the behavior customary of a certain group, because humans like to comply with the social norms that govern groups they affiliate with.
- Psychologically, social rewards and receiving public feedback can spur social (and pro-environmental) behavior through the activation of social norms.
- **Tip:** Presenting climate-friendly behavior as the default choice can encourage behaviors that are beneficial for the individual and the environment.
- **Tip:** Showcase positive actions that other people are taking to address climate change, especially when these people constitute a majority in a certain area or community.
- **Tip:** Highlighting climate-friendly social norms can help motivate people to undertake their own climate-friendly behavior.

FURTHER READINGS

This list is a brief selection of relevant further reading. For a more comprehensive and up-to-date list, please visit connectingonclimate.org.

Focus Group and Survey Resources

Conducting Focus Groups

The Wallace Foundation compiled this workbook to provide an overview of focus groups and information about how to conduct focus group research using internal resources. www.wallacefoundation.org/knowledge-center/after-school/collecting-and-using-data/Documents/Workbook-D-Focus-Groups.pdf

Toolkit for Conducting Focus Groups

The Work Group for Community Health and Development at the University of Kansas developed this resource to explain the fundamentals of surveys. Specifically, the resource describes how to prepare a survey, when surveys should be conducted, how to distribute them, and how to analyze and compile results. www.ctb.ku.edu/en/table-of-contents/assessment/assessing-community-needs-and-resources/conduct-focus-groups/main

Survey Fundamentals: A Guide to Designing and Implementing Surveys

This guide, produced by the University of Wisconsin, describes the underlying principles of good survey design and implementation in nontechnical terms. Simple explanations lead the reader through methodology and logistics decisions, writing effective questions, and drawing conclusions from data. www.oqi.wisc.edu/resourcelibrary/uploads/resources/Survey_Guide.pdf

Storytelling Resources

Seeing Is Believing: A Guide to Visual Storytelling Best Practices

This best practices guide from Resource Media provides research and tools on how to incorporate visual storytelling into communication to inspire and prompt individuals to take action or change behaviors. This guide explains why images matter more than ever and how practitioners can start incorporating this reality into an effective communication strategy. www.resource-media.org/visual-story-lab/report/

The Story Group Climate Change Videos

The Story Group is an independent, multimedia journalism company. The organization has developed a climate change video series based on the 2014 National Climate Assessment, which explains the science behind the issue and shows how climate change is affecting real people. www.thestorygroup.org/category/nationalclimateassessment/

"How to Tell a Great Story"

This blog post from the Harvard Business Review provides six do's and don'ts of effective storytelling and presents two case studies to help drive these principles home. www.blogs.hbr.org/2014/07/how-to-tell-a-great-story/

Additional Communication Resources

The Psychology of Climate Change Communication: A Guide for Scientists, Journalists, Educators, Political Aides, and the Interested Public

This 2009 guide, published by CRED, is a companion document to this guide. It synthesizes research from across the social sciences to explain the disparity between knowledge and action on climate change. It also includes tips for presentations, lists of effective words, highlights of successful strategies, and suggestions for better communication tools. www.guide.cred.columbia.edu/

Communicating on Climate: 13 Steps and Guiding Principles

This guide, produced by ecoAmerica in 2013, combines the latest research on climate communication with road-tested communication best practices in an easy-to-use, practically applicable guide. www.ecoamerica.org/research/#comm13steps

American Climate Values 2014: Psychographic and Demographic Insights

This report summarizes top-line findings from ecoAmerica's latest round of psychographic research, which uses a sophisticated methodology to glean insights on how to effectively engage mainstream Americans on climate solutions. www.ecoamerica.org/research/#ACV14

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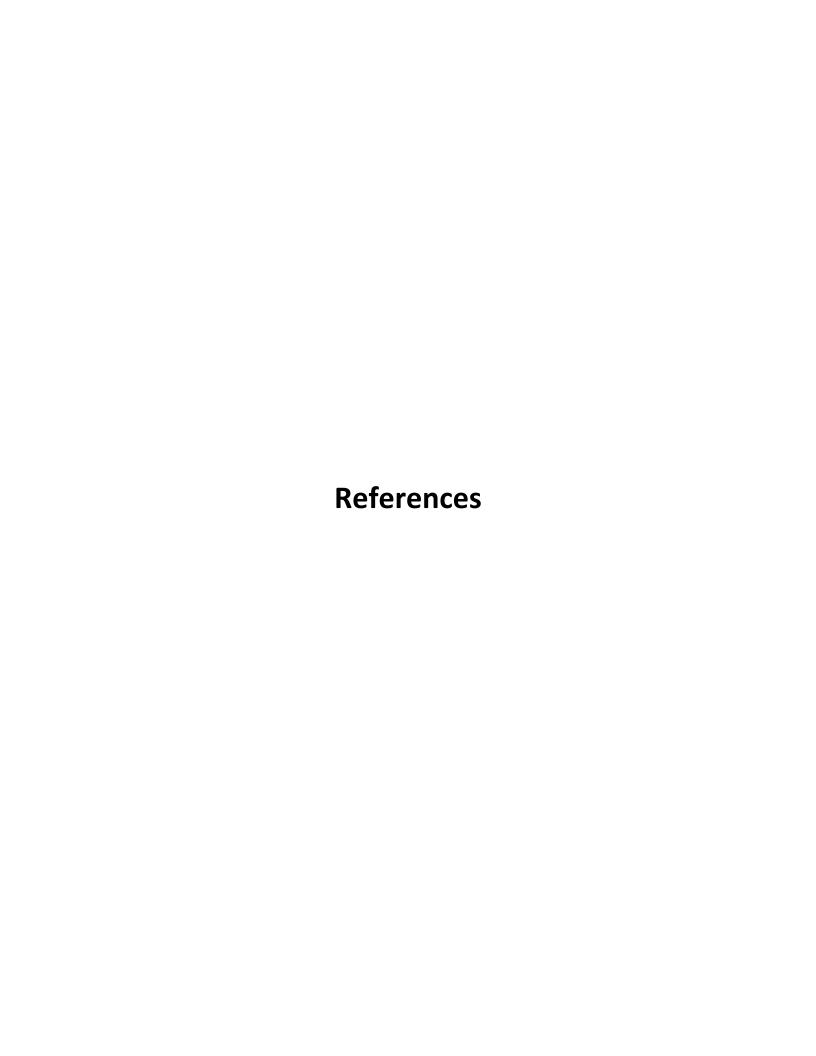


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