SCIENCE AND IMPACTS

CENTER FOR CLIMATE AND ENERGY SOLUTIONS

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The scientific evidence is unequivocal. The Earth is warming due to the dramatic increase of concentrations of heat-trapping gases in the atmosphere caused by human activities, especially the burning of fossil fuels. As more greenhouse gases are released into the atmosphere, the Earth will continue to warm in the decades and centuries ahead. The impacts of warming can already be observed throughout the United States, from rising sea levels to droughts, wildfires and extreme rainfall. Climate change is already affecting ecosystems, freshwater supplies, and public health around the world. Although some climate change in the coming decades is now unavoidable, much worse impacts can be avoided and our efforts to adapt made easier by substantially reducing the amount of heat-trapping gases released into the atmosphere. Preparing for the impacts that are unavoidable will make our economy, natural systems and society more resilient and minimize the greatest costs of climate change.

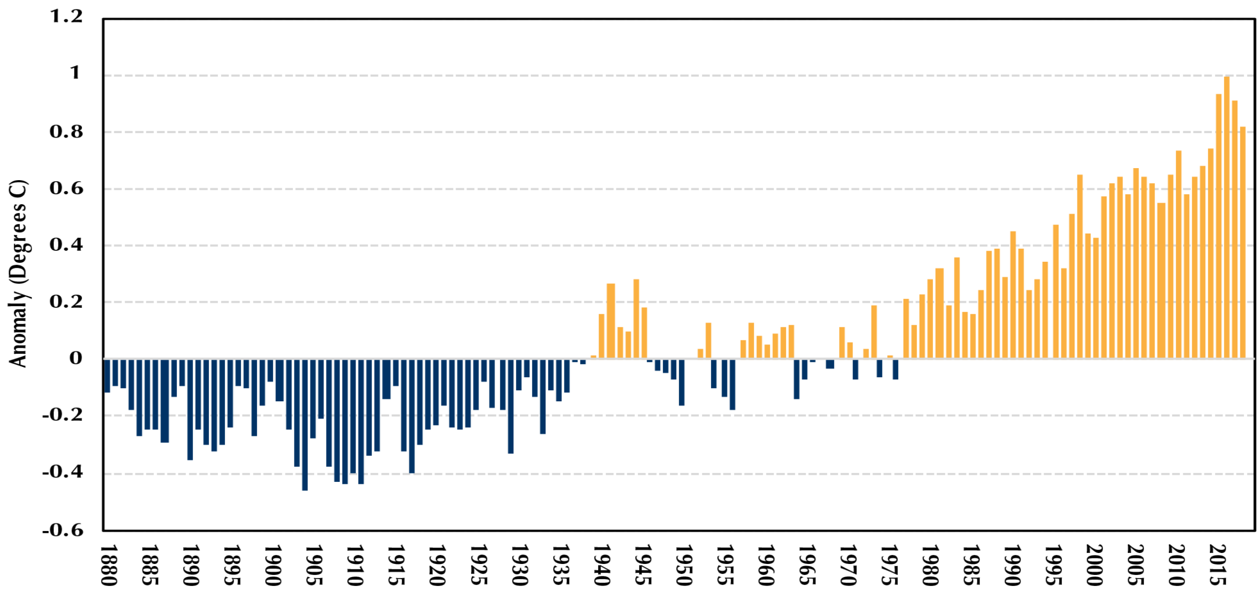
CLIMATE CHANGE SCIENCE: THE BASICS

The Fourth National Climate Assessment, published by the U.S. Global Change Research Program (USGCRP) in 2018, concluded, "*the evidence of human-caused climate change is overwhelming and continues to strengthen… the impacts of climate change are intensifying across the country, and … climate-related threats to Americans' physical, social, and economic well-being are rising.*"[1] This warning was reiterated in the International Panel on Climate Change's (IPCC) special report, "Global Warming of 1.5 degrees Celsius" which states, "*Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term changes in the climate system…*" In the following section, we summarize what is known about the science and risks facing our society and natural ecosystems.

GLOBAL TEMPERATURES: THE EARTH IS WARMING

Global average temperature data based on reliable thermometer measurements are available back to 1880. Based on this data, global average temperature rose by 1.8 degrees F from 1901 to 2016 (see **Figure 1**). Data from the U.S. National Centers for Environmental Information shows that the last five years have been the warmest since 1880: 2016 was the warmest on record, followed by

FIGURE 1: Global Temperature Anomalies from 1880–2018



The annual average temperatures for each year from 1880 to the present are compared to the 1901-2000 average temperature. In the mid-twentieth century we see a greater number of above average temperatures and that there were no average or cooler than average years after 1976.

Data: NOAA National Centers for Environmental Information, Climate at a Glance: Global Time Series, 2018.

2015, 2017, 2018 and 2014. Every person born after 1976 has lived their entire life in a world that is warmer than the 20th century average.[2] Data on extreme temperatures over the past century show similar trends of rising temperatures: cold waves have occurred less frequently over time, while heat waves have occurred more frequently.[3]

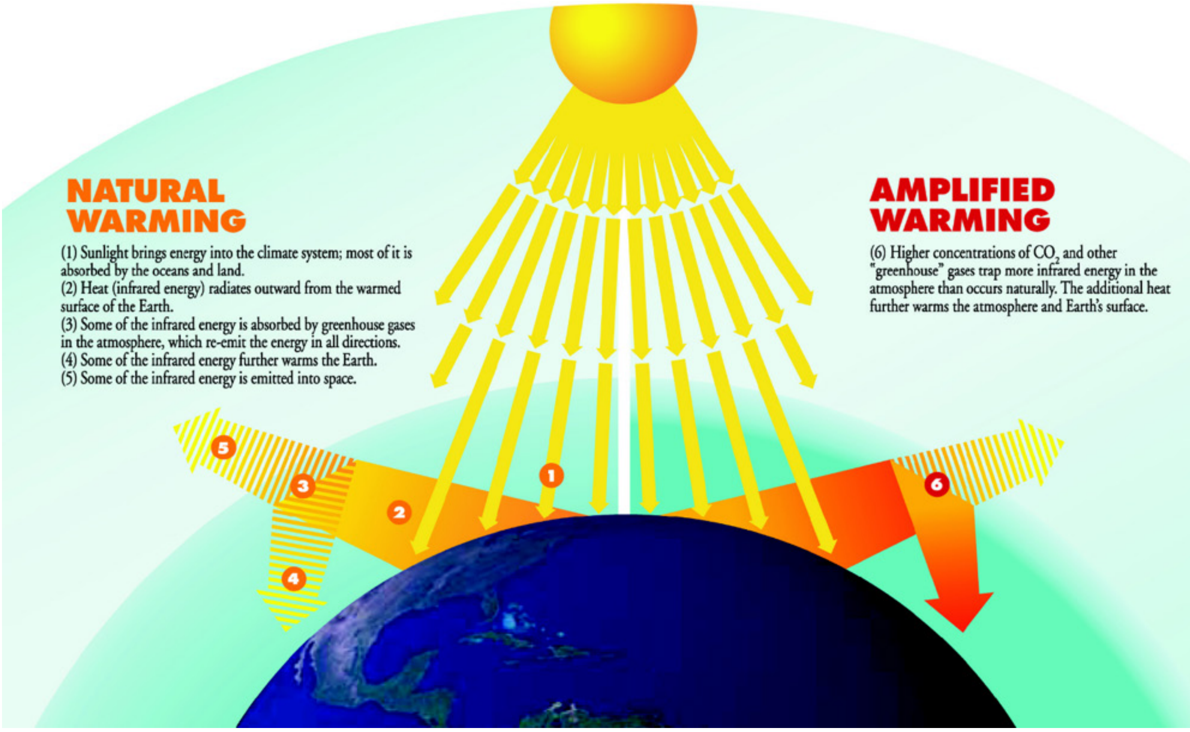
Warming has not been limited to the Earth's land surfaces. The oceans have a large capacity to absorb heat and only slowly interact with the atmosphere, creating a time lag in the climate system. Over the next several millennia, the heat already absorbed by the ocean will be released back to the atmosphere.[4] Estimates for the amount of climate change already "locked in" in the oceans from emissions before 2000 are about an additional 1 degree F of surface warming. This warming also has significant implications for ice sheets and glaciers at our northern extremes; a warmer ocean means more melting and rising sea levels.

GREENHOUSE GASES: NATURAL AND HUMAN-CAUSED

Although global temperatures have varied naturally over thousands of years, we know the rapid rise in global temperatures during recent decades is caused by human activities. Burning fossil fuels add carbon dioxide (CO_2) and other heat-trapping gases to the atmosphere.[5] This warming is the greenhouse effect, and the heat-trapping gases are known as greenhouse gases (see **Figure 2**). When sunlight reaches the Earth's surface, it can be reflected (especially by bright surfaces like snow) or absorbed (especially by dark surfaces like open water or pavement). Absorbed sunlight warms the surface and is released back into the atmosphere as heat. Greenhouse gases trap this heat in the atmosphere, warming the Earth's surface.

The greenhouse effect has warmed the Earth through the release of naturally occurring gases like CO_2, methane (CH_4), nitrous oxide (N_2O), and even water vapor. Without the natural greenhouse effect, the Earth's surface would be nearly 60 degrees F colder on average.[6] The additional greenhouse gases released by human

FIGURE 2: The Greenhouse Gas Effect



An illustration of the greenhouse effect. Visible sunlight passes through the atmosphere without being absorbed. Some of the sunlight striking the Earth is absorbed and converted to heat, which warms the surface. The surface emits heat to the atmosphere where some of it is absorbed by greenhouse gases and re-emitted toward the atmosphere. The presence of additional greenhouse gases causes an increase in the amount of heat that gets absorbed before escaping to space, thus enhancing the greenhouse effect and amplifying the warming of the Earth.

Source: Marian Koshland Science Museum of the National Academy of Sciences.

activities (or anthropogenic emissions) include those listed above as well as a number of fluorinated gases[7] released in industrial processes that are extremely powerful greenhouse gases. This causes our atmosphere to be warmer than it would be naturally. This human-magnified greenhouse effect is the "enhanced" or "amplified" greenhouse effect.

Multiple, independent lines of evidence clearly link human actions to increased greenhouse gas concentrations.[8] There is also strong evidence that this is the main reason that Earth has been warming in recent decades.

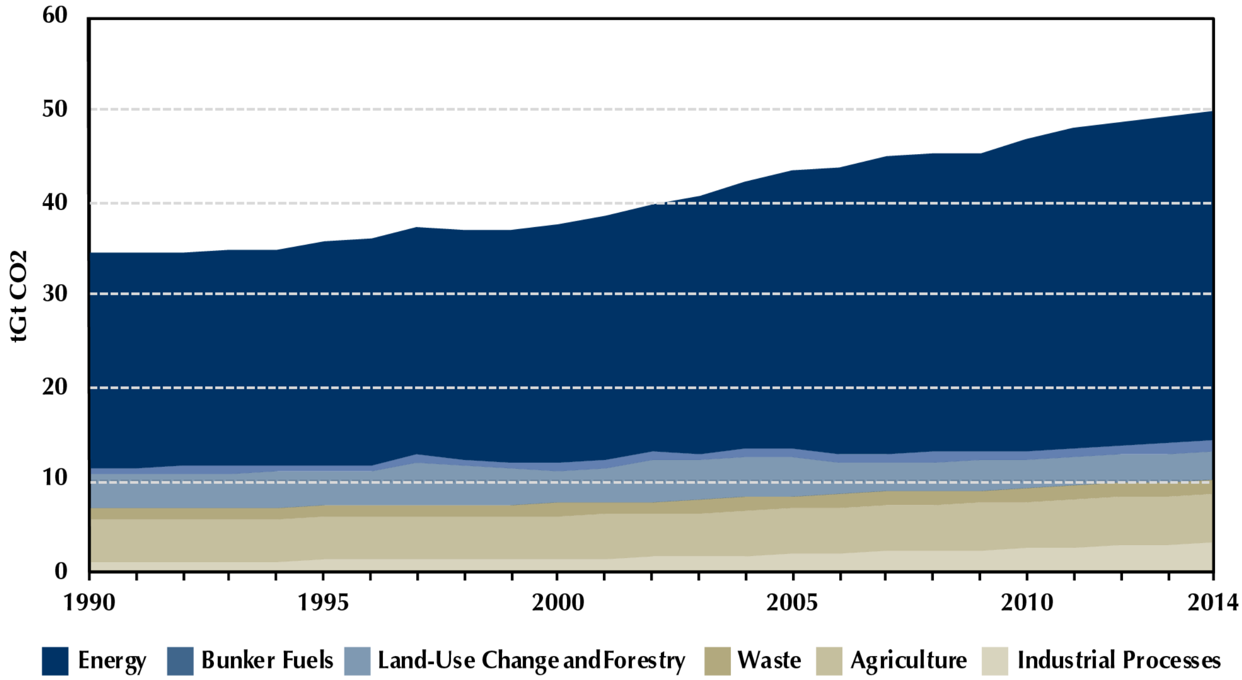
Greenhouse Gas Levels Rising

Since pre-industrial times, concentrations of CO_2 have increased by 46 percent, CH_4 by 157 percent, and N_2O by 22 percent.[9] The principal gas contributing to the enhanced greenhouse effect is CO_2. Between 1959 and 2017, the burning of fossil fuels accounted for about 82 percent of anthropogenic CO_2 emissions globally, which we know from organizations and research groups around the world tracking emissions sources through energy consumption data, economic modeling, and land use modeling.[10]

Scientists are also able to study the carbon molecules in the atmosphere to trace their source. Carbon molecules that come primarily from plants are variants of the carbon molecule. They are isotopes carbon-12 and carbon-13, while those from geological materials like coal, oil and natural gas are a different isotope (carbon-14). This process of isotopic fingerprinting helps scientists trace sources of carbon, and indicates that most of the additional CO_2 in the atmosphere is from fossil fuels.[11]

Most of the remaining emissions came from changes in the land surface, primarily deforestation. Trees, like all living organisms, are made mostly of carbon; when

FIGURE 3: Global Carbon Dioxide Emissions by Source



From 1990 to 2014 the emissions from energy grew by over 50 percent, the most of any sector, accounting for more than half of all emissions in this time. The other significant emissions are from the agriculture sector and land use change.

Data: CAIT Climate Data Explorer, World Resources Institute, 2017.

forests are cleared and/or burned, the carbon in the trees and soil is released as CO_2.

The current trajectory of rising greenhouse gas concentrations is pushing the climate into uncharted territory. The concentration of CO_2 in the atmosphere was measured as 409 ppm on January 1, 2019.[12] Scientists determined this is much higher than any other time in human existence using ice core samples from ancient glaciers to learn about the atmosphere and temperatures of the last 800,000 years. CO_2 data from these samples correlate closely with the ebb and flow of ice-age cycles and changes in global temperature (see Figure 3). Low CO_2 concentrations relate to colder periods and higher relate to warmer periods.

Looking Ahead

As greenhouse gases are released into the atmosphere, the amplified greenhouse effect strengthens. Continued greenhouse gas emissions could cause warming of 0.5 to 8.6 degrees F over the next century above the warming that has already occurred, depending on future emissions, the efforts that we make to limit them, and how the climate system responds.[13] This is a large range of uncertainty for future temperatures but even the lower end of the range is likely to have undesirable effects on society and nature.

Higher latitudes warm more quickly than lower latitudes, because of the angle of the sun. Therefore, regional temperature increases may be greater or less than global averages, depending on location. For example, the United States is projected to experience more warming than the global average, and the Arctic is expected to experience the most warming.[14]

Box 1: At Issue, 20th Century Temperature Trends

Scientists have noted a distinct pattern of warming during the twentieth century, with a large warming between 1910 and 1940, moderate cooling from 1940 to 1975, and a large warming again from 1975 to the present. The most likely reason for the cooling during the middle of the century is a surge in sun-blocking aerosols, or very fine particles, resulting from the largescale ramp-up of polluting industries after World War II.[50] Air pollution is linked to increased risks of heart disease, stroke, lung disease, asthma and more, and many ecological consequences requiring policy and technology interventions to curb those impacts.[51] Pollution controls helped reduce aerosols and fine particulates and GHG concentrations have grown to levels that now outweigh the cooling effects of the aerosols and particulates, leading to rapid warming. In the future, industrial emissions of aerosols are expected to further decrease as environmental regulations improve in developing countries, as they did in previous decades in more developed countries like the United States.[52]

CHANGING CLIMATE: THEORY TO REALITY

Although "climate change" and "global warming" are often used interchangeably, rising temperature is just one aspect of climate change. To understand why, it is important to distinguish between "weather" and "climate." The climate is the average weather over a long period of time. A simple way to think of this is: weather is what determines if you will use snow boots today; climate determines whether you own snow boots. When looking at climate change and its impacts, it is important to consider more than just global temperature trends. Changes in the climate other than average temperatures have more direct impacts on nature and society.

The Climate Science Special Report says, "climate change is transforming where and how we live and presents growing challenges to health and quality of life, the economy, and the natural systems that support us."[15] Sea level rise, the loss of sea ice, changes in weather patterns, more drought and heavy rainfall, and changes in river flows are among the documented changes in the United States threatening ecosystems and public health.

RECOGNIZING CLIMATE CHANGE IN WEATHER EVENTS

Scientific and computing advances since 2004 now allow scientists to detect how anthropogenic climate change affects the likelihood and magnitude of extreme weather events. This field of study is known as climate change attribution. Climate change attribution determines how greenhouse gases make certain kinds of extreme weather events more likely.

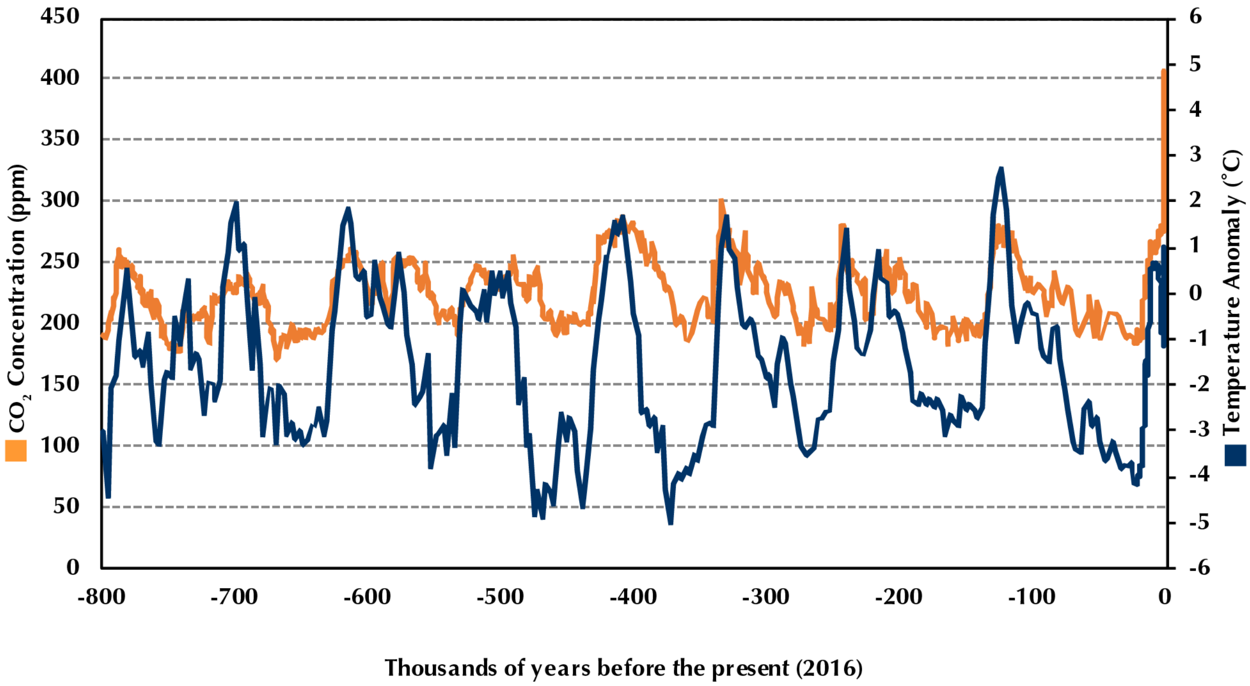
A special edition of the *Bulletin of the American Meteorological Society* has been produced annually since 2012, devoted solely to studies of climate change attribution. The 2017 edition passed a milestone when, for the first time, weather events were observed that could not have occurred without the warming effect of amplified greenhouse gases.[16] Those events included the record-breaking global average temperature in 2016, a heat wave in Asia, and a persistent area of warm ocean water off the coast of Alaska. That marine heat wave, known as "the Blob," damaged important West Coast and Alaska fisheries for crab and salmon, and harmed the food supply of sea lions and some seabirds.[17]

While not all attribution studies find a significant influence of climate change on weather events, many of the most severe weather events of recent years have been found to have been made more likely or stronger because of greenhouse gases. Attribution science is poised to become operational as several European meteorological organizations are preparing to start conducting attribution studies as a regular part of weather forecasting.[18] The increased use of this methodology will shed light on the extent to which climate change impacts are felt locally and day to day.

MORE EXTREME WEATHER

Extreme weather events have become more common in recent years, with more rainfall in heavy precipitation events and most states experiencing more heatwaves than they did in the mid-20th century. This trend will continue in the future. Climate change has a significant effect on local weather patterns and, in turn, these changes can have serious impacts throughout natural systems and society.

FIGURE 4: Global Temperature and CO_2 Concentration over 800,000 years



Global atmospheric CO_2 concentration (left axis) and global temperature anomaly (right axis) over the past 800,000 years as determined from Antarctic ice cores and direct atmospheric CO_2 measurements.

Data: U.S. EPA Climate Change Indicators, Atmospheric Concentrations of Greenhouse Gases, 2016.

Hotter Extremes

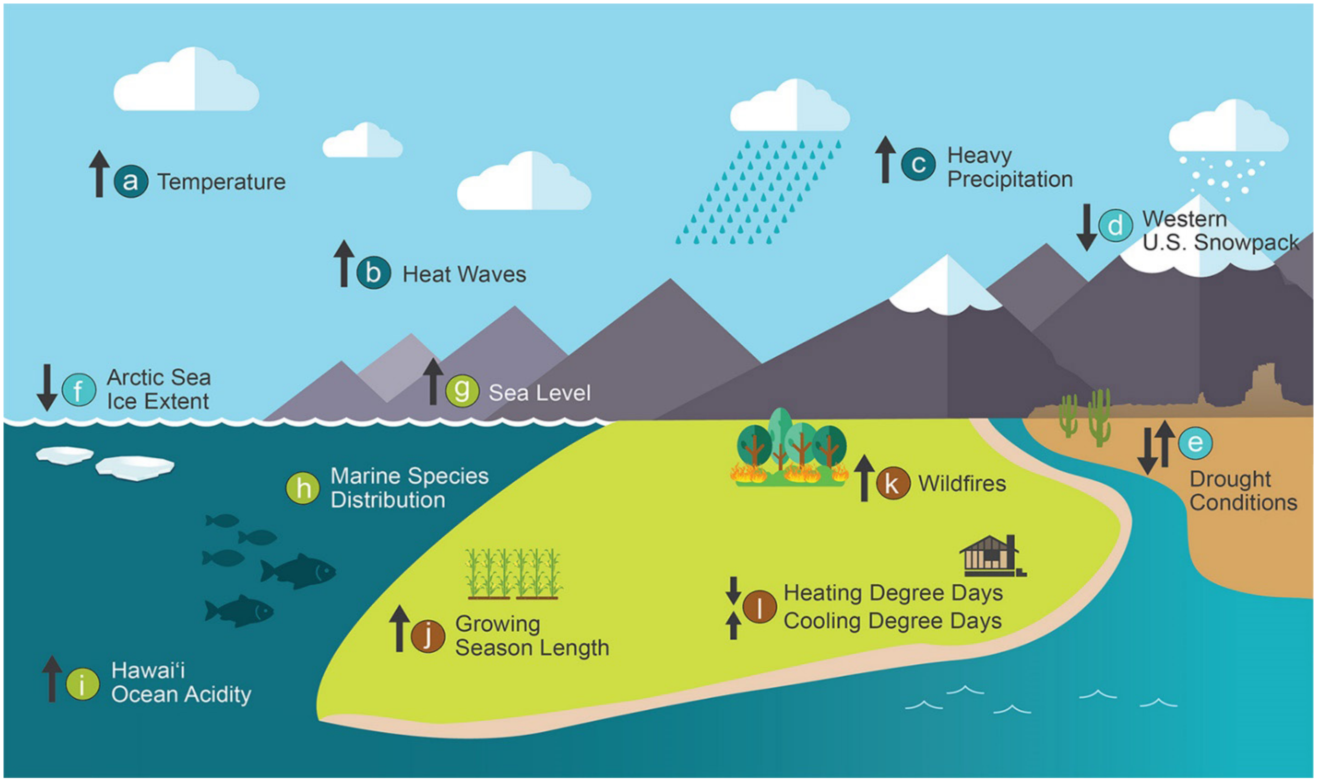
Average temperatures are rising, and extreme temperatures are rising even more, causing more frequent heat waves and hotter high temperature extremes. Heat waves are defined in different ways, but the U.S. Global Change Research Program defines them as periods of two or more consecutive days where the daily minimum temperature (adjusted for humidity) exceeds the 85th percentile of historical July and August temperatures in that location.[19] Another indicator that communities and regions are paying attention to is days over 90 of 95 degrees F. Record-high temperatures are being set more often than record low temperatures,[20] and those highs have considerable costs to public health, infrastructure, and local economies. For instance, Phoenix approached 120 degrees F in 2017, exceeding the safe operating limits for some airplanes and grounding flights in the city.

Wetter Extremes

Climate change will increase the frequency and duration of floods in most regions. The warming atmosphere holds more water, so more rain is falling in extreme events now compared to 50 years ago (see **Figure 4**). Cities across the country are experiencing 1,000-year rainfall events, totals that are so rare that they historically have had just a 0.1 percent chance of occurring each year. The Weather Channel tallied five such events in 2018, in the Carolinas, Wisconsin, Michigan, Colorado, and Virginia.[21] These extreme storms are no longer once a millennium, in fact, Ellicott City, Maryland, experienced two 1,000-year storms in two years. Hurricane Harvey was the third 500-year rainfall event affecting the Houston area[22], although NOAA has since revised its estimates for heavy rainfall frequency in Texas, recognizing that what is considered a rare storm has become up to 5 inches rainier than previously thought.[23]

Climate change can also be tied to increased precipi-

FIGURE 5: Climate change impacts across the United States



Scientists are able to identify and monitor the warming trend in our climate system using long-term observations of a number of indicators. This figure shows climate-relevant indicators of these changes. Arrows indicate directions of trends, drought has both up and down arrows because there are no definitive national trends.

Source: Fourth National Climate Assessment, USGCRP, 2018.

tation from winter storms. The frequency of extreme snowstorms in the eastern United States has increased over the past century, a trend that can be tied to warmer ocean surface temperatures in the Atlantic. It is also possible that higher temperatures in the Arctic and reduced sea ice could contribute to larger winter storms.[24] It is important to note that nationwide, a larger proportion of total precipitation is expected to fall as rainfall (and less precipitation will take the form of snow) as has been observed in the Pacific Northwest and parts of the Midwest.[25]

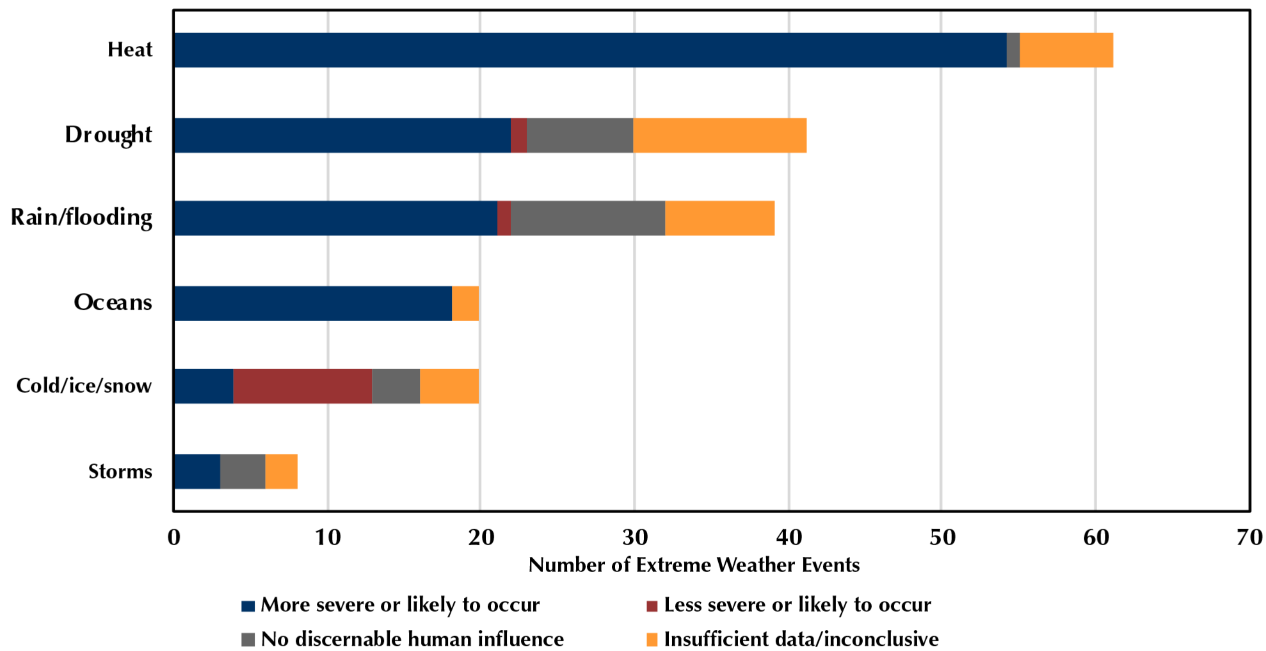
Stronger Hurricanes

Since hurricanes draw their strength from the heat in ocean surface waters, hurricanes have the potential to become more powerful as the water warms. A 2010 peer-reviewed assessment of the link between hurricanes and climate change concluded that high-resolution modeling projected substantial increases in the frequency of intense cyclones and 20 percent more rain falling in the core of storms.[26] Model experiments on Hurricanes Katrina, Irma, Maria and others concluded that anthropogenic climate change to date made the rainfall from those events 4–9 percent heavier than would have been otherwise but did not affect wind speeds.[27] The massive destruction caused by the hurricanes of 2017 provides a painful reminder of the vulnerability felt in both coastal as well as inland communities to these events.

Drought and Wildfire

Diminished water resources are expected in semi-arid regions, like the western United States, where water shortages already pose challenges. Areas affected by drought are also expected to increase. As the atmo-

FIGURE 6: Findings of Attribution Science Publications



Researchers have published more than 170 studies examining the role of human-induced climate change in 190 extreme weather events. This shows how these reports characterized the role of climate in each weather event studied.

Data: Nature, Vol. 560, 20-22, 2018.

sphere becomes warmer, soils dry out faster and there are seasonal shifts in precipitation.

The water supplies of hundreds of millions of people depend on the seasonal melting of mountain ice and snow. However, those supplies are now threatened by the increasing amount of seasonal melt from glaciers and snowpack, the increasing amount of precipitation that falls as rain instead of snow, and the altered timing of snowmelt. In the near term, the melting of mountain ice and snow may cause flooding; in the long term, the loss of these frozen water reserves will significantly reduce the water available for drinking, agriculture, and energy production.

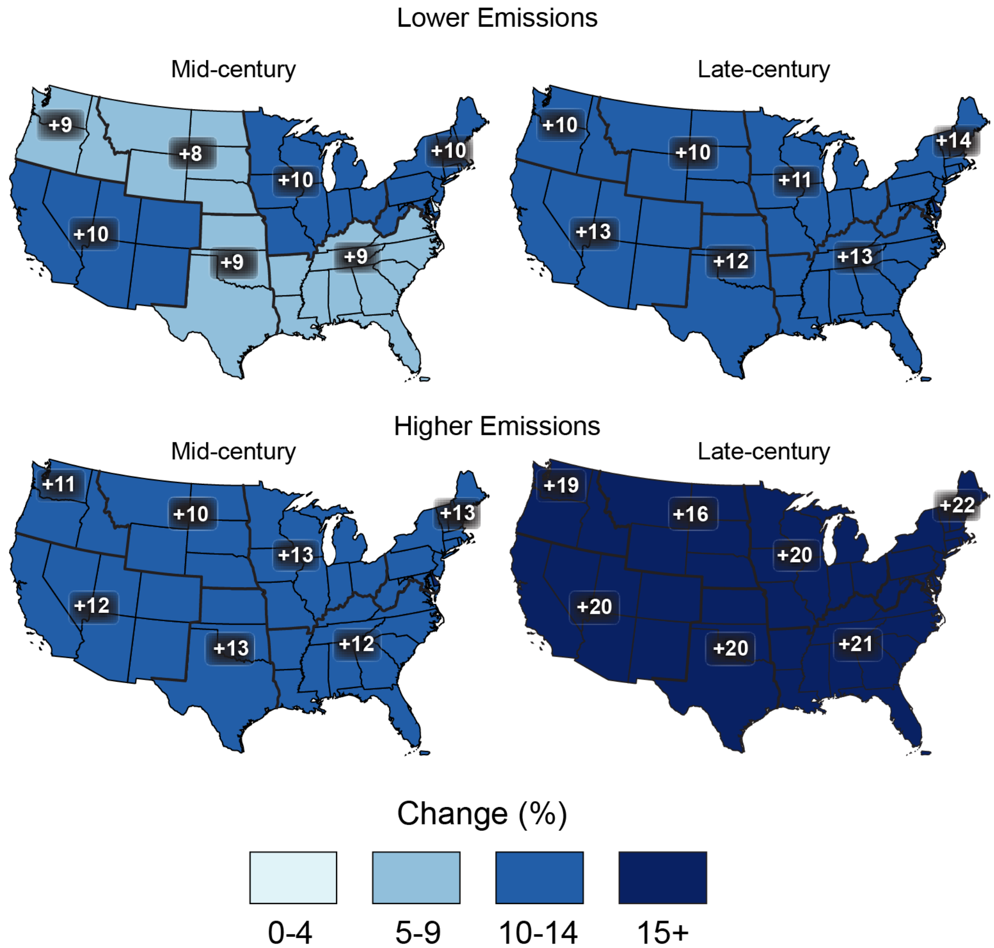
Climate change will affect the quality of drinking water and impact public health. As sea level rises, saltwater will infiltrate and contaminate coastal freshwater resources. Flooding and heavy rainfall may overwhelm local water infrastructure and increase the level of sediment and contaminants in the water supply. Increased rainfall could also wash more agricultural fertilizer and municipal sewage into coastal waters, increasing the risk of low-oxygen "dead zones" and harmful algal blooms in marine ecosystems, estuaries, and the Great Lakes.[28]

In much of the western United States, drier conditions and heat can also mean more wildfires. Fire-dependent and fire prone ecosystems are especially affected by climate change. Climate factors were found to be responsible for more than half the observed increase in western U.S. forest fuel aridity from 1979 to 2015 and doubled the forest fire area over the period 1984–2015.[29] Western states experienced a six-fold increase in the amount of land burned by wildfires from 1970 to 2000 because of earlier snowmelt and longer, drier, summers.[30]

THREATS TO ECOSYSTEMS

Climate change is threatening ecosystems around the world, affecting plants and animals on land, in oceans, and in freshwater lakes and rivers. Some ecosystems

FIGURE 7: Projected Change in Daily, 20-year Extreme Precipitation



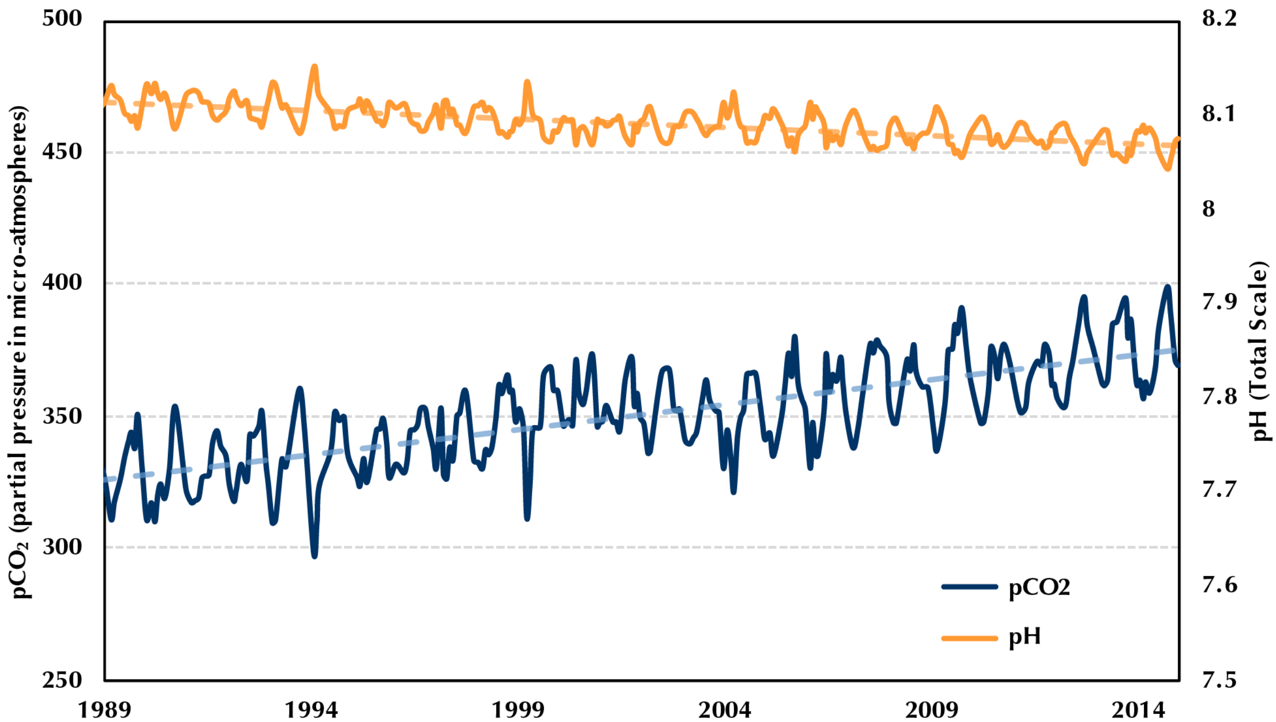
Projected change in extreme precipitation (defined in this graphic as storms with a 20-year return period or a 5 percent chance of that precipitation event occurring at any time). The change is percent increase over the current average precipitation amounts in events with this same likelihood. For instance, the mid-century, lower emissions map shows us that each region of the country can expect between 8 and 10 percent stronger storms. Estimates are for mid- (left maps) and late-21st century (right maps). Results are shown for a lower emissions scenario that assumes atmospheric CO2 levels remain below 550 ppm this century, and for a higher emissions scenario which assumes that greenhouse gas emissions continue to rise through the century to 936 ppm by the end of the century.

Source: Fourth National Climate Assessment, CICS-NC, NOAA NCEI, 2017.

are especially at risk, including the Arctic and sub-Arctic, which are sensitive to temperature and likely to experience the greatest amount of warming; tropical rainforests because they are sensitive to small changes in temperature and precipitation and coral reefs because they are sensitive to high water temperatures and ocean acidity, both of which are rising with atmospheric CO_2 levels.

Recent warming is already affecting ecosystems. Entire ecosystems are shifting toward the poles and to higher altitudes. This poses unique challenges to species that already live at the poles and mountain-dwelling

FIGURE 8: CO_2 Concentration and pH in Ocean Waters



The graph demonstrates the correlation between the increase of CO_2 in the water (pCO_2) and the decreasing pH in ocean water, indicating that the water is more acidic. Data collected in Hawaii.

Data: EPA Climate Change Indicators in the Unites States, 2016.

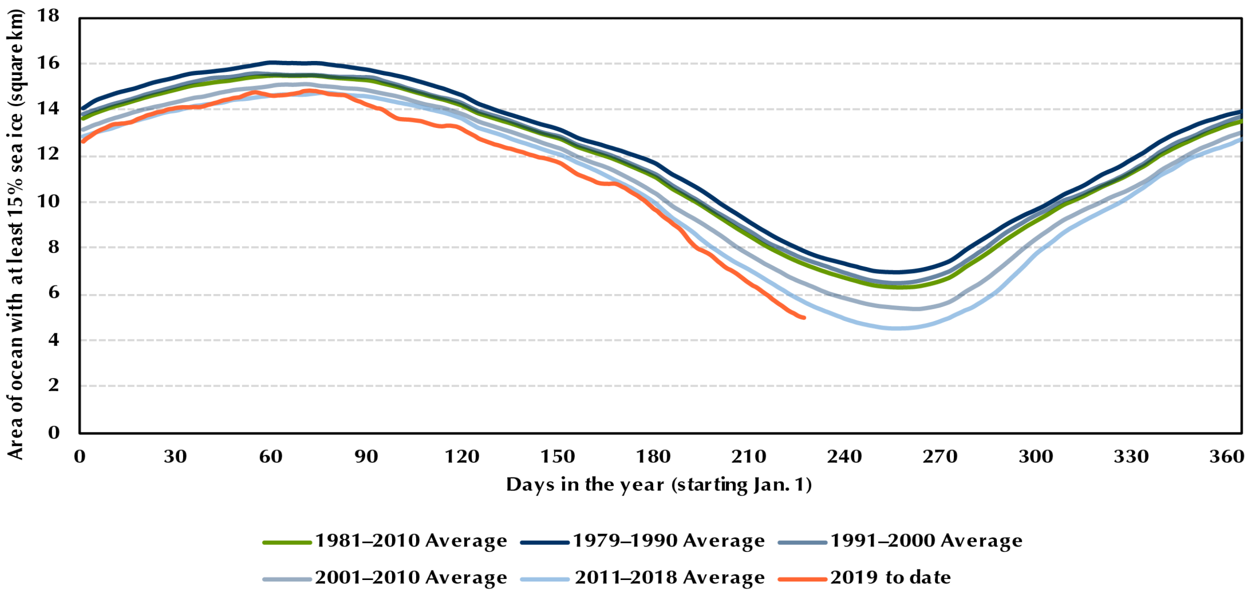
species already living at high altitudes. Spring events, like the budding of leaves and migration of birds, are occurring earlier in the year, causing some species to get out of sync with their food sources. As warming increases, species will start to lose suitable habitat and face increased risk of extinction. A meta-analysis of studies of climate change-induced extinctions estimates that unchecked climate change could cause 16 percent (or 1-in-6) of all species on Earth to die out.[31] Some groups are particularly sensitive to temperature. For example, with only 1.5 degrees C warming over pre-industrial levels, coral reefs are expected to decline by 70–90 percent from current levels. Two degrees C warming will cause losses to exceed 99 percent.[32]

OCEAN ACIDIFICATION

Some of the excess CO_2 in the atmosphere is absorbed by the ocean, warming the water, reducing its oxygen concentration, and making it more acidic.[33] Ocean acidification refers to the increase of carbonic acid in ocean water, measured using a pH value. Since the beginning of the industrial revolution, the level of ocean surface waters acidification has increased by 30 percent[34].

Ocean acidification affects organisms with shells, likely threatening the zooplankton that form the base of the ocean food web.[35] Ocean acidification will disrupt ocean ecosystems like coral reefs, where coral struggles to form shells from calcium carbonate due to increased acidity.[36] Coral reefs are a central component of the ecosystem, with over half a billion people relying on them for food, income and coastal protection.[37] Furthermore, the ocean's capacity to absorb CO_2 emissions becomes increasingly limited as the acidity level rises, which will further accentuate climate change.[38]

FIGURE 9: Arctic Sea Ice Extent



This graph of the area of ocean with at least 15 percent sea ice shows that the arctic sea ice extent has declined in the last four decades. The 2019 arctic sea ice extent is lower than all prior averages, pointing to this continued declining trend.

Data: National Snow and Ice Data Center, 2019.

SHRINKING ARCTIC SEA ICE

Arctic sea ice has seen dramatic declines in recent years, with the past 10 years having the smallest summertime extent on record, all occurring since 2007.[39] The importance of sea ice decline comes from the role it plays in both the global climate system and Arctic ecosystems. Snow and ice reflect sunlight very effectively, while open water tends to absorb it. As sea ice melts, the Earth's surface will reflect less light and absorb more. Consequently, the disappearance of Arctic ice will actually intensify climate change.[40]

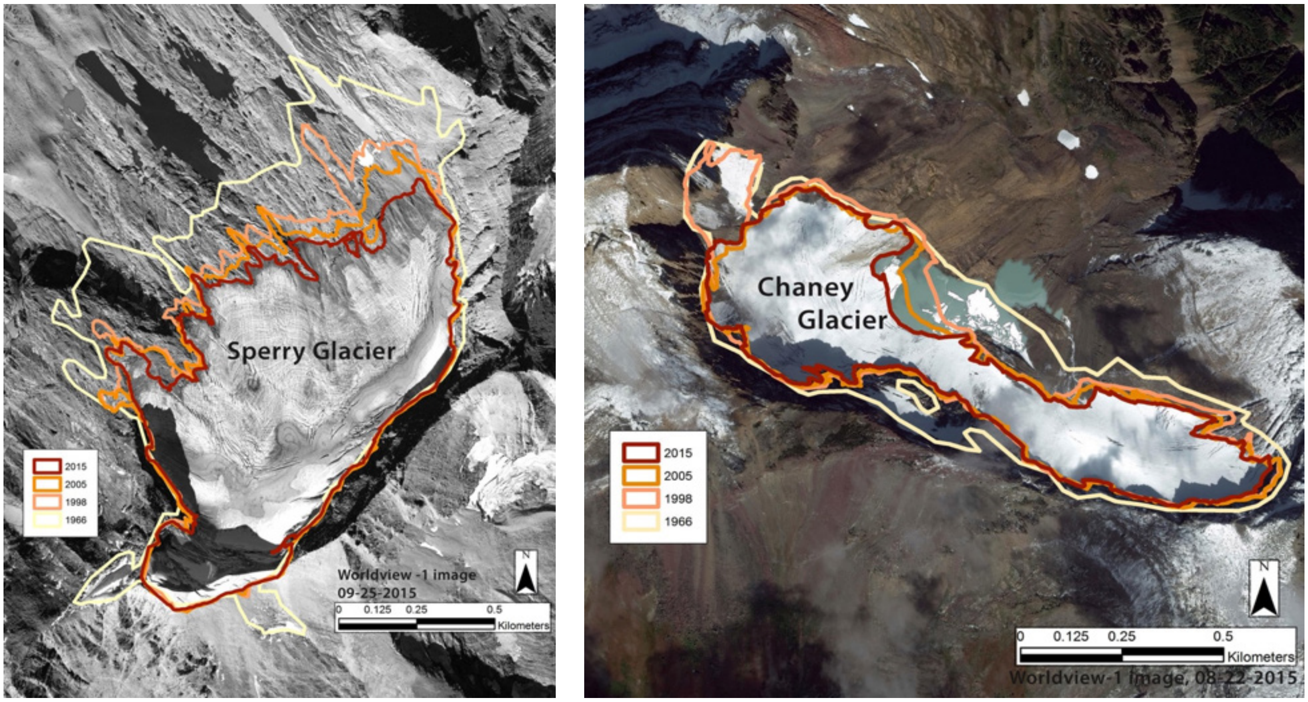
If warming continues, scientists are sure that the Arctic Ocean will become largely free of ice during the summer. Depending in part on the rate of future greenhouse gas emissions, the latest model projections indicate that the opening of the Arctic is likely to occur around 2040, but as early as 2032.[41] The opening of the Arctic has enormous implications, ranging from global climate disruption to national security issues to dramatic ecological shifts. The Arctic may seem far removed from our daily lives, but changes there are likely to have serious global implications.

LOSS OF GLACIERS, ICE SHEETS, AND SNOW PACK

Land-based snow and ice cover are declining because of climate change and contributing to sea level rise. Mountain glaciers at all latitudes are in retreat, from the Himalayas in Central Asia to the Andes in tropical South America to the Rockies and Sierras in the western United States. The U.S. Geological Survey published a time series analysis of the glacier margins of the glaciers in Glacier National Park from 1966 to 2016 and found that all glaciers have shrunk, with an average area reduction of 39 percent and up to 85 percent area reductions for some glaciers.[42]

The polar ice sheets of Greenland and Antarctica have both experienced net losses of ice in recent years, and the rate of ice loss is accelerating. Melting polar ice sheets add billions of tons of water to the oceans each year, contributing to sea level rise and potentially changes in ocean circulation. The current rate of ice loss is enough to raise sea levels by almost 6 inches by 2050 (melting of glaciers and other land ice combined with thermal expansion of ocean water would raise sea level even more).[43]

FIGURE 10: **Glacial Melt in United States National Parks.**



These images show the perimeter of Sperry and Chaney Glaciers, of Glacier National Park in 1966, 1998, 2005, and 2015 and demonstrate the retreat of the glaciers since 1966.

Source: USGS, 2015.

Climate scientists pay especially close attention to the West Antarctic Ice Sheet because it is increasingly instable due to climate change. Beyond a threshold amount of warming, a so-called tipping point, melting would become irreversible, and ongoing rapid sea level rise could then be unstoppable. A recent review of the literature on major polar ice sheet estimates that warming of 1.5 to 2 degrees C could trigger increased and irreversible melting of the Greenland and Antarctic ice sheets. Projections of the ice sheets' response to warming remain challenging because many of the processes involved remain poorly understood.[44]

RISING SEA LEVEL

Among the most serious and potentially catastrophic effects of climate change is sea level rise, which is caused by a combination of the "thermal expansion" of ocean water as it warms and the melting of land-based ice. Since 1900, global sea level has risen about 7 –8 inches.[45] To date, most climate-related sea level rise can be attributed to thermal expansion. Going forward, however, the largest potential source of sea level rise comes from melting land-based ice, which adds water to the oceans. By the end of the century, global sea level could be one to four feet higher than it is today, with some regions experiencing much higher sea level rise due to local circumstances (the large range of this estimate comes from uncertainties in how quickly polar ice sheets will melt in response to warming temperatures).[46]

Even small amounts of sea level rise will have severe impacts in many low-lying coastal communities throughout the world, especially when storm surges are added on top of sea level rise. Globally, high population densities along coastal areas, low elevations, and storm surge zones combine to make some countries especially vulnerable, such as Bangladesh, China, India, Indonesia, and the Philippines.[47] In the United States, about half of the population lives near the coast. The most vulnerable areas are the Mid-Atlantic and Gulf Coasts, especially the Mississippi Delta. Also at risk are low-lying areas and bays, such as North Carolina's Outer Banks, much of the Florida Coast, and California's San Francisco Bay and Sacramento/San Joaquin Delta. Sea level rise in these areas poses risks to critical ports that provide resources to the country, large population centers, highly-valued real estate and other coastal assets.

SOCIAL AND ECONOMIC EFFECTS

These changes in the climate are already having far-reaching impacts to human health, quality of life, economy and the natural systems that support us. Climate change is expected to affect public health directl—from heat waves, floods, and storms—and indirectly, from higher temperatures and wildfire causing poor air quality, the spread of infectious diseases, reducing the availability and quality of food and water, and possible mental health consequences.

Climate impacts, especially health impacts, are not felt equally across the United States. Climate will affect low-income, communities of color, children and the elderly the most. Indigenous groups can be uniquely and disproportionately affected by climate impacts because of reliance on lands, waters and natural resources for cultural and subsistence purposes. Native American communities in Alaska and Ile de Jean Charles in Louisiana are some of the first in the country to face the challenge of relocating from highly vulnerable areas.

Climate change also has broad economic consequences, from damaged infrastructure to disrupted energy distribution to reduced labor productivity. The Government Accountability Office found that in the decade from 2007 to 2017, climate change has already cost the federal government more than $350 billion, and end of century damages could amount to up to 5.6 percent of GDP in the end of the century.[48] The damages and lives at stake show the importance for companies, individuals and governments to act now to reduce emissions and prepare for the climate impacts already observed and that are ahead.

HOW SCIENCE INFORMS CLIMATE ACTION

The Earth's climate of the last 10,000 years was stable because emissions of naturally-occurring greenhouse gases were in balance with naturally-occurring ways to remove greenhouse gases from the atmosphere, known as sinks. A key indicator for future stable climate regimes is the global average temperature compared to pre-historic levels. The Paris Agreement, the preeminent international agreement on climate change, states that countries will work to "[hold] the increase in the global average temperature to well below 2 degrees C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 degrees C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change."

Much research done since the Paris Agreement was signed in 2015 has focused on technological and other changes needed to meet these stabilization goals. In particular, the 2018 IPCC report examined pathways that would result in stabilization at 1.5 degrees C above pre-industrial temperature. All the pathways included historically unprecedented changes in the way societies across the globe get and use energy, goods, and food.[49] The 2018 report also found that the 1.5 degrees C stabilization target would significantly lower the risks of climate change impacts to society and natural systems.

It is still possible—and necessary—to reduce the magnitude of future climate change. However, climate change is already underway and dangerous. To respond to these current impacts and prepare for a different future climate, adaptation must occur at the individual, business, community, state and national level. It must include structural resilience strategies to fortify buildings, shorelines and infrastructure as well as non-structural strategies to better prepare people and governments to withstand and efficiently build back from climate-related trends and disasters.

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ENDNOTES

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