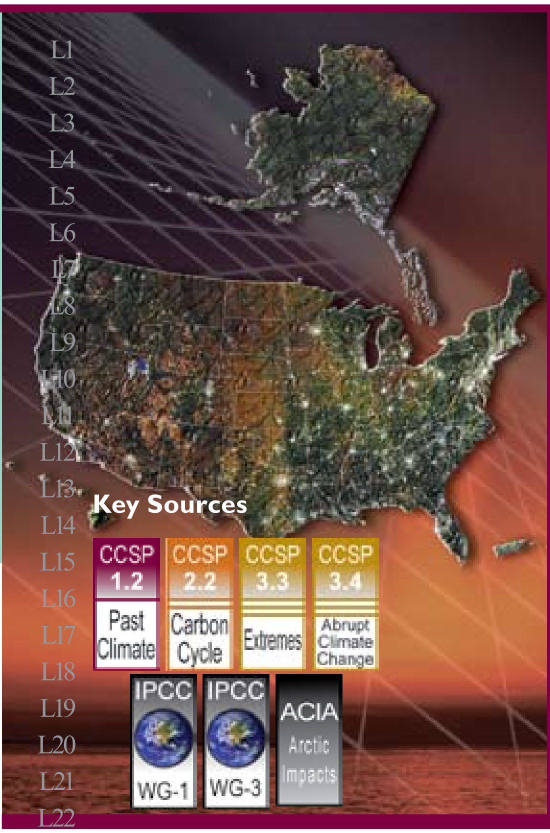
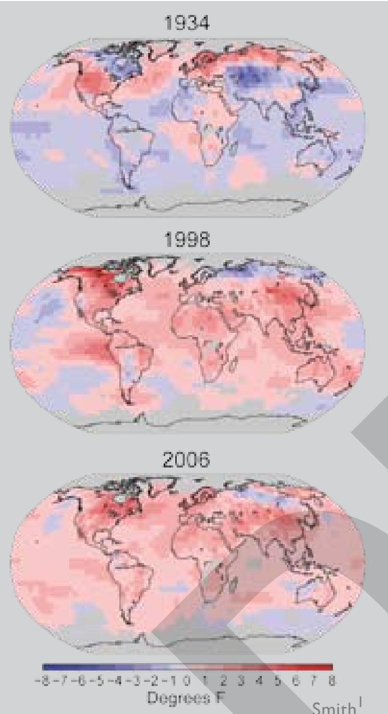


National Climate Change

Key Messages:

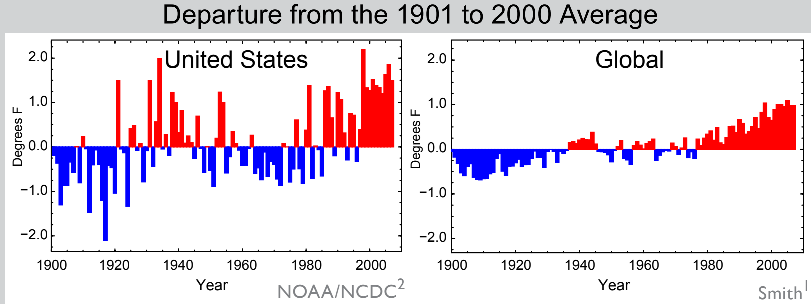
- The average U.S. temperature has risen more than 2°F over the past 50 years and will rise more; how much more depends primarily on the amount of heat-trapping gases emitted globally.
- Precipitation has increased an average of about 5 percent over the past 50 years. Shifting patterns have generally made wet areas wetter, while dry areas have become drier. This is projected to continue.
- The heaviest downpours have increased approximately 20 percent on average in the past century, and this is projected to continue, with the strongest increases in the wettest places.
- Many types of extreme weather events, in addition to heavy downpours, have become more frequent and intense during the past 40 to 50 years.
- The destructive energy of Atlantic hurricanes has increased in recent decades and is projected to increase further in this century.
- In the eastern Pacific, the strongest hurricanes have become stronger since the 1980s even while the total number of storms has decreased.
- Sea level has risen 2 to 5 inches during the past 50 years along many U.S. coasts, and is projected to rise more in the future.
- For cold-season storms outside the tropics, storm tracks are shifting northward and the strongest storms are projected to become stronger.
- Arctic sea ice is declining rapidly and this is projected to continue.

Like the rest of the world, the United States has been warming significantly over the past 50 years in response to the build up of heat-trapping gases. When looking at national climate, however, it is important to recognize that climate responds to local and regional, as well as global factors. Therefore national climate varies more than global climate, which tends to be stabilized by the moderating influence of the oceans. While various parts of the world have had particularly hot or cold periods earlier in the historical record, these periods have not been global in scale, whereas the warming of recent decades has been truly global—hence the term *global* warming. It is also important to recognize, that at both the global and national scale, year-to-year fluctuations in natural weather and climate patterns can produce a string of years that don't follow the long-term trend. Thus, each year will not necessarily be warmer than every year before it.



The maps show annual temperature difference from the 1961-1990 average for the 3 years that were the hottest on record in the United States: 1998, 1934 and 2006. Red areas were warmer than average, blue were cooler than average. The 1930s were very warm in much of the United States, but they were not unusually warm globally. On the other hand, the warmth of recent decades has been global in extent.

Annual Average Temperature
Departure from the 1901 to 2000 Average



The graphs show annual average temperature differences from the 1901-2000 average for the United States (left) and for the globe (right). Each year's average temperature is one bar, with blue bars representing years cooler than the long-term average and red bars representing years warmer than that average. As the graphs illustrate, national temperatures vary much more than global temperatures.

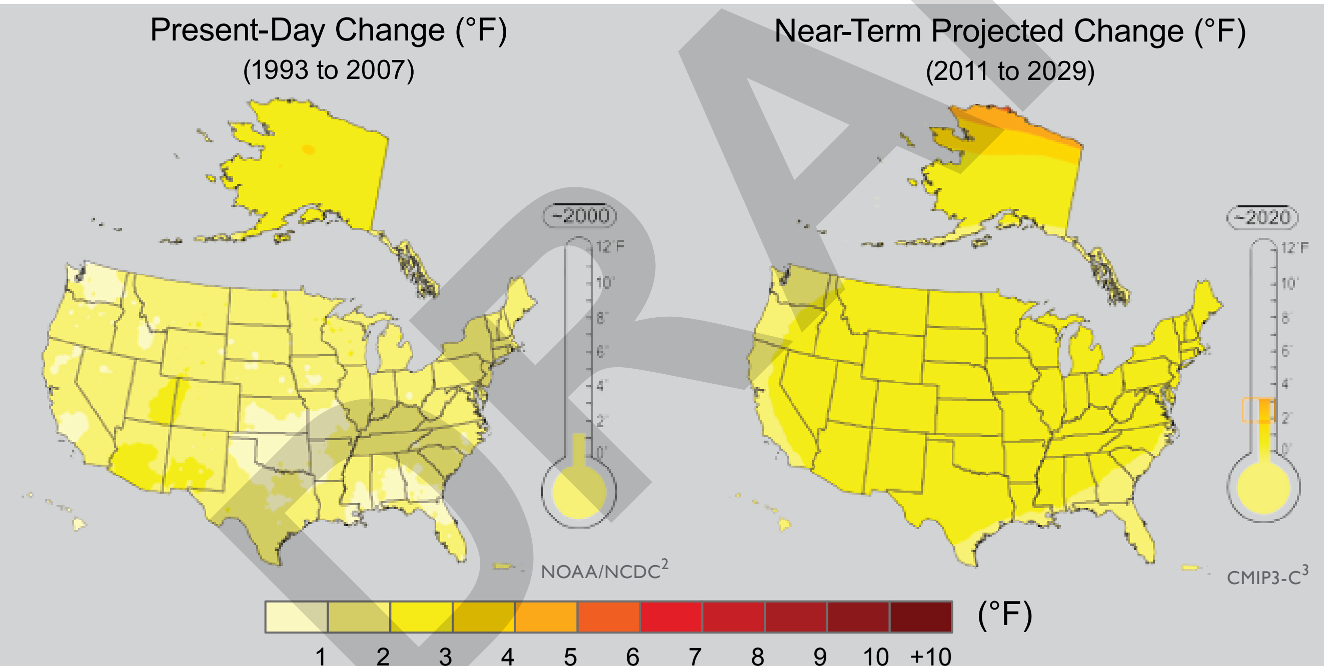
The average U.S. temperature has risen more than 2°F over the past 50 years and will rise more; how much more depends primarily on the amount of heat-trapping gases emitted globally[4].

The series of maps and thermometers on these two pages shows the magnitude of the observed and projected changes in annual average temperature. The map for the period around 2000 shows that most areas of the United States have warmed 1 to 2°F compared to the 1960s and 1970s. Although not reflected in these maps of annual average temperature, this warming has generally resulted in longer warm seasons and shorter, less intense cold seasons.

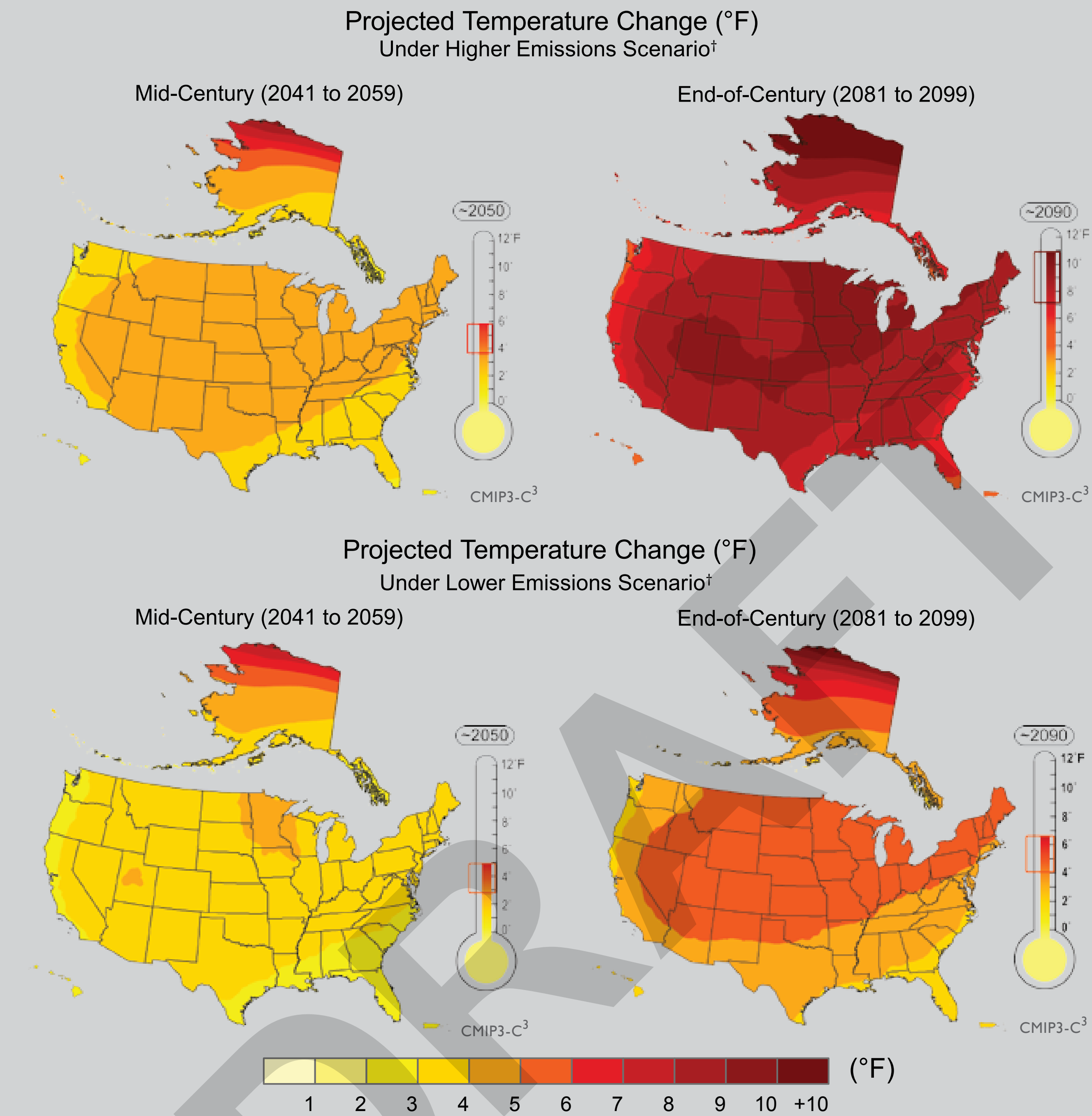
The remaining maps show projected warming over the course of this century under a lower emissions- and a higher emissions scenario† (see *Global Climate Change* section, page 24). Temperatures will continue to rise throughout the century under both emissions scenarios†, although higher emissions result in more warming by the middle of the century and significantly more by the end of the century.

Temperature increases in the next couple of decades will be primarily determined by past emissions of heat-trapping gases. As a result, there is little difference in projected temperature between the higher and lower emissions scenarios† in the near-term (around 2020), so only a single map is shown for this timeframe. Increases after the next couple of decades will be primarily determined by future emissions[5]. This is clearly evident in greater projected warming in the higher emissions scenario† by the middle (around 2050) and end of this century (around 2090).

The average warming for the country as a whole is shown on the thermometers adjacent to each map. By the end of the century, the average U.S. temperature is projected to increase by approximately 7 to 11°F under the higher emissions scenario† and by approximately 4 to 6.5°F under the lower emissions scenario†.



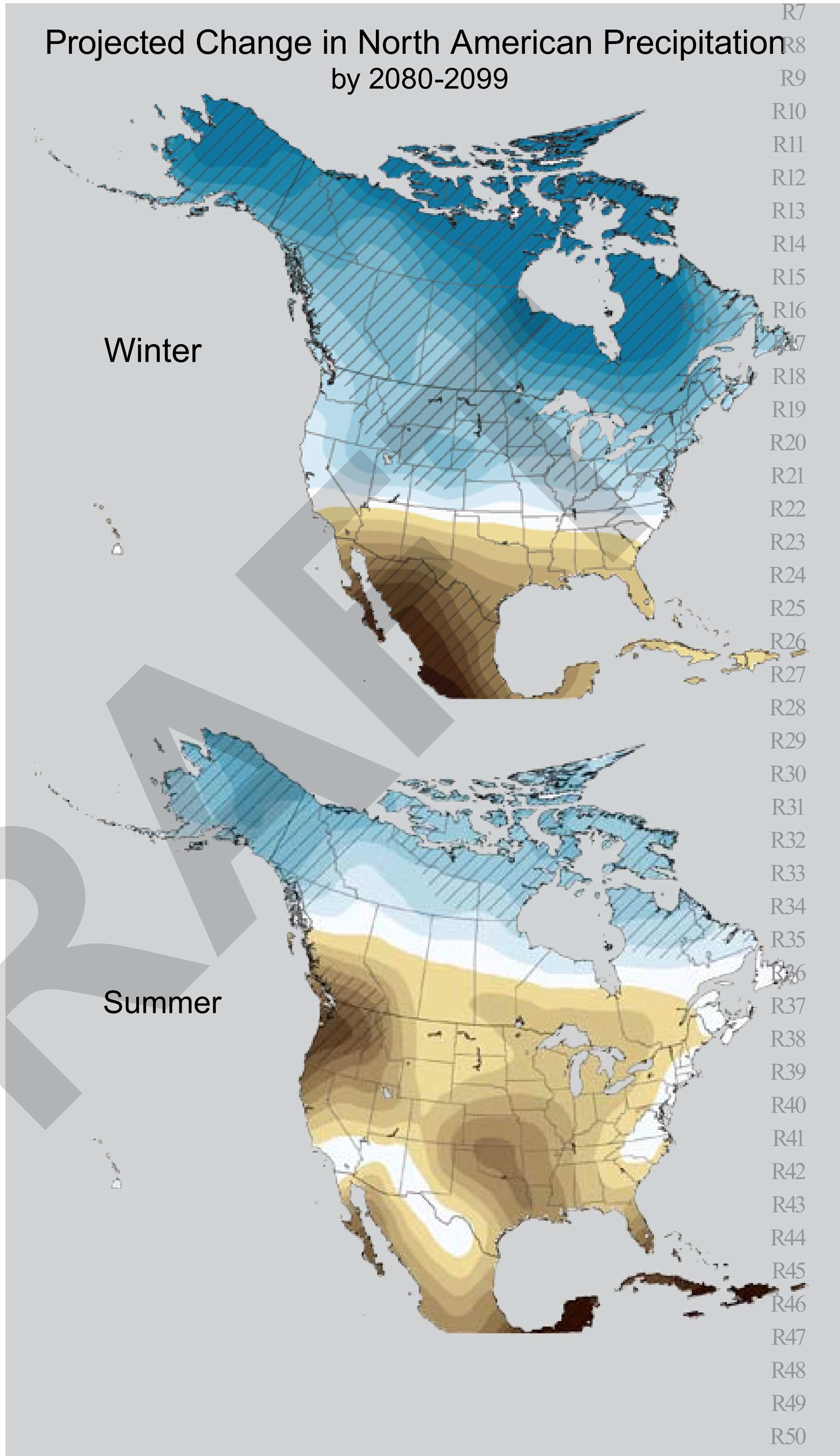
The maps and thermometers on this page and the next page show temperature differences from conditions as they existed from 1961 to 1979. Comparisons to this period are made because the influence on climate from increasing greenhouse gas emissions has been greatest during the past five decades. The present day map is based on observed temperatures from 1993 to 2007. Projected temperatures are based on 16 climate models for the periods 2011 to 2029, 2041 to 2059, and 2081 to 2099. The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible. The mid-century and end-of-century maps show projections for both the higher and lower emission scenarios†. The projection for the near-term is the average of the higher and lower emission scenarios† because there is little difference in that timeframe.



The maps on this page and the previous page are based on projections of future temperature by 16 of the Coupled Model Intercomparison Project Three (CMIP3) climate models using two emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC), *Special Report on Emission Scenarios* (SRES)[6]. The "lower" scenario here is IPCC SRES B1, while the "higher" is A2†. The brackets on the thermometers represent the likely range of model projections, though lower or higher outcomes are possible. Additional information on these scenarios is in the previous section, *Global Climate Change*. These maps, and others in this report, show projections at regional and even local scales, using well-established downscaling techniques[7].

Precipitation has increased an average of about 5 percent over the past 50 years. Shifting patterns have generally made wet areas wetter, while dry areas have become drier. This is projected to continue.

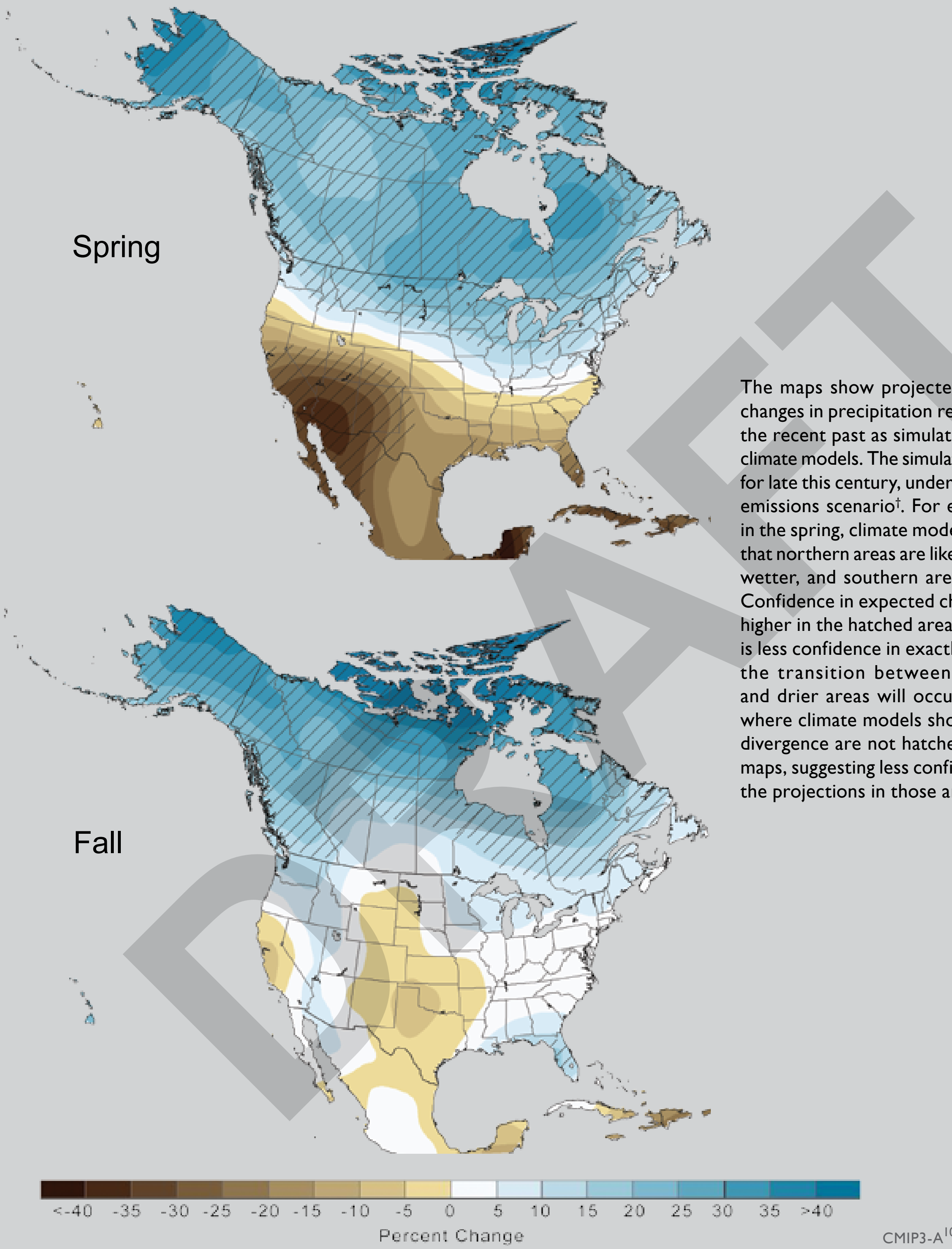
While precipitation over the United States as a whole has increased, there have been important regional differences[8]. Wetter areas, such as the Northeast, have generally become wetter, while drier areas, such as the Southwest, have generally become drier. This fits the pattern projected to occur due to global warming[4]. There have also been seasonal differences, with some seasons showing large increases or decreases in various regions.



Future changes in total precipitation due to human-induced warming are more difficult to project than changes in temperature. It is virtually certain that in some seasons, some areas will experience an increase in precipitation, other areas will experience a decrease, and others will see little discernible change. The difficulty arises in predicting the extent of those areas and the amount of change. Model projections of future precipitation generally suggest continuations of observed patterns, with northern areas becoming wetter, and southern areas, particularly in the West, becoming drier[4].

Confidence in projected changes is higher for winter and spring than for summer and fall. In winter and spring, northern areas are expected to receive significantly more precipitation than they do now, because the interaction of warm and moist air coming from the south with colder air from the north will occur farther north than it did on average in the last century. The more northward incursions of warmer and moister air masses are expected to be particularly noticeable in northern regions that will change from very cold and dry atmospheric conditions to warmer but moister conditions[9]. Alaska, the Great Plains, upper Midwest, and Northeast are beginning to experience such changes for at least part of the year, with the likelihood of these changes increasing over time.

In some northern areas, warmer conditions will result in more precipitation falling as rain and less as snow. In addition, potential water resource benefits from increasing precipitation could be countered by the competing influences of increasing evaporation and runoff. In southern areas, significant reductions in precipitation are expected in winter and spring as the sub-tropical dry belt expands[4]. This is particularly pronounced in the Southwest, where it will have serious ramifications for water resources.



The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century, under a higher emissions scenario†. For example, in the spring, climate models agree that northern areas are likely to get wetter, and southern areas drier. Confidence in expected changes is higher in the hatched areas. There is less confidence in exactly where the transition between wetter and drier areas will occur. Areas where climate models show some divergence are not hatched in the maps, suggesting less confidence in the projections in those areas.

The heaviest downpours have increased approximately 20 percent on average in the past century, and this is projected to continue, with the strongest increases in the wettest places.

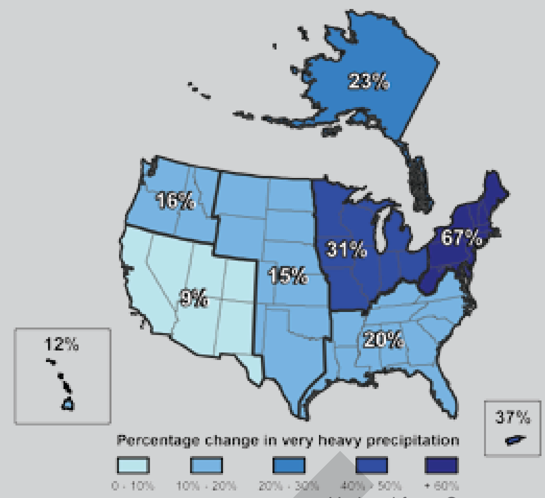
One of the clearest precipitation trends in the United States is the increasing frequency and intensity of heavy downpours. This increase was responsible for most of the observed increase in overall precipitation during the last 50 years. In fact, there has been little change or a decrease in the frequency of light and moderate precipitation during the past 30 years, while heavy precipitation has increased. In addition, while total average precipitation over the nation as a whole increased by about 7 percent over the past century, the amount of precipitation falling in the heaviest 1 percent of rain events increased nearly 20 percent[11].

During the past 50 years, the greatest increases in heavy precipitation occurred in the Northeast, Midwest, and Great Plains. There have also been increases in heavy downpours in the other regions of the continental United States, as well as Alaska, Hawaii, and Puerto Rico[11].

Climate models project continued increases in the heaviest downpours during this century, while the lightest precipitation is projected to decrease. Heavy downpours that are now 1-in-20-year occurrences are projected to occur about every 4 to 15 years by the end of this century, depending on location, and the intensity of heavy downpours also is expected to increase. The 1-in-20-year heavy downpour is expected to be between 10 and 25 percent heavier by the end of the century than it is now[11].

Changes in extreme weather and climate events are among the most serious challenges to our nation in coping with a changing climate.

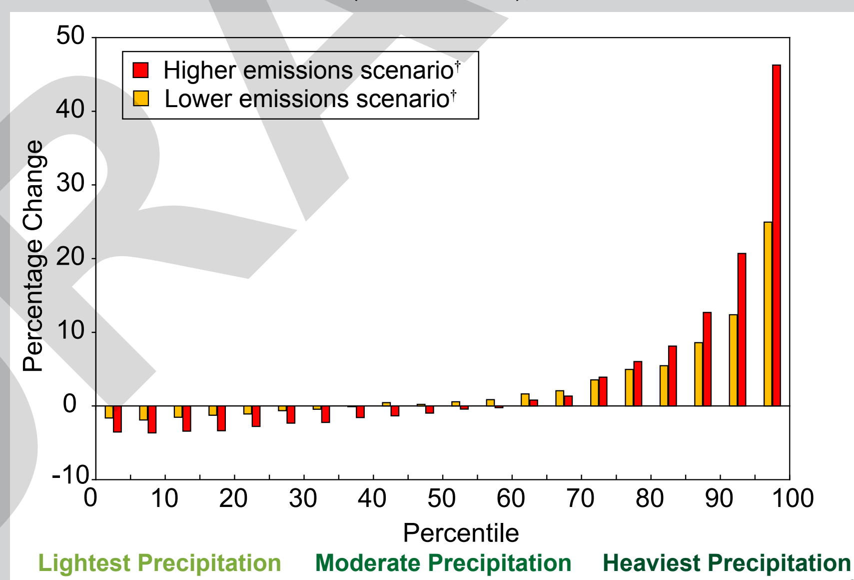
Increases in Very Heavy Precipitation
(1958 to 2007)



Updated from Groisman *et al.*[12]

The map shows the percentage increases in very heavy precipitation (defined as the heaviest 1 percent of all events) from 1958 to 2007 for each region, compared to a baseline period of 1961-1990. The clearest trends toward more very heavy precipitation are evident at the national scale, and in the Northeast and Midwest.

Projected Change in Precipitation Intensity
(2080 to 2099)



CCSP SAP 3.3[9]

The figure shows projected changes from the 1990-1999 average to the 2090-2098 average in the intensity of precipitation in North America displayed in 5 percent increments from the lightest drizzles to the heaviest downpours. As shown here, the lightest precipitation is projected to decrease, while the heaviest will increase, continuing the observed trend. The higher emission scenario† yields larger changes. Projections based on the models used in the IPCC 2007 Fourth Assessment report.

Many types of extreme weather events, in addition to heavy downpours, have become more frequent and intense during the past 40 to 50 years.

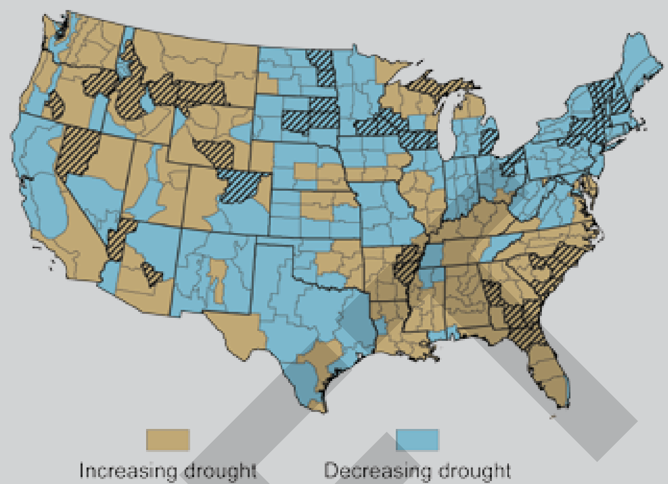
Many extremes and their associated impacts are now changing. For example, in recent decades most of North America has been experiencing more unusually hot days and nights, fewer unusually cold days and nights, and fewer frost days. Droughts are becoming more severe in some regions. The power and frequency of Atlantic hurricanes have increased substantially in recent decades, though North American mainland land-falling hurricanes do not appear to have increased over the past century. Outside the tropics, storm tracks are shifting northward and the strongest storms are becoming even stronger. These trends are projected to continue throughout this century[9,11,13].

Drought

Like precipitation, trends in drought have strong regional variations. In much of the Southeast and large parts of the West, the frequency of drought has increased coincident with rising temperatures over the past 50 years. As precipitation has increased, other regions, such as the Midwest and Great Plains, have seen a reduction in drought frequency.

Although there has been an overall increase in precipitation and no clear trend in drought for the nation as a whole, increasing temperatures have made naturally occurring droughts more severe and widespread than they would have otherwise been. Without the observed increase in precipitation, higher temperatures would have led to an increase in the area of the contiguous United States in severe to extreme drought, with some estimates of a 30 percent increase[11].

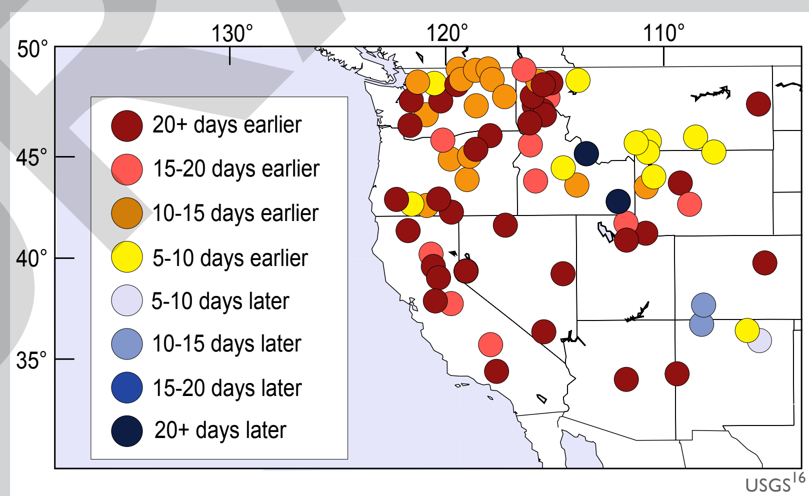
Observed Drought Trends 1958 to 2007



Trends in end-of-summer drought as measured by the Palmer Drought Severity Index from 1958 through 2007 in each of 344 U.S. climate divisions. Divisions with hatching indicates significant trends. Values are averaged in climate divisions of each U.S. state by averaging the corresponding station observations within each climate division[15].

Rising temperatures have also led to earlier melting of the snowpack in the western United States[14]. Because snowpack runoff is critical to the water resources in the western United States, changes in the timing and amount of runoff can exacerbate problems with already limited water supplies in the region.

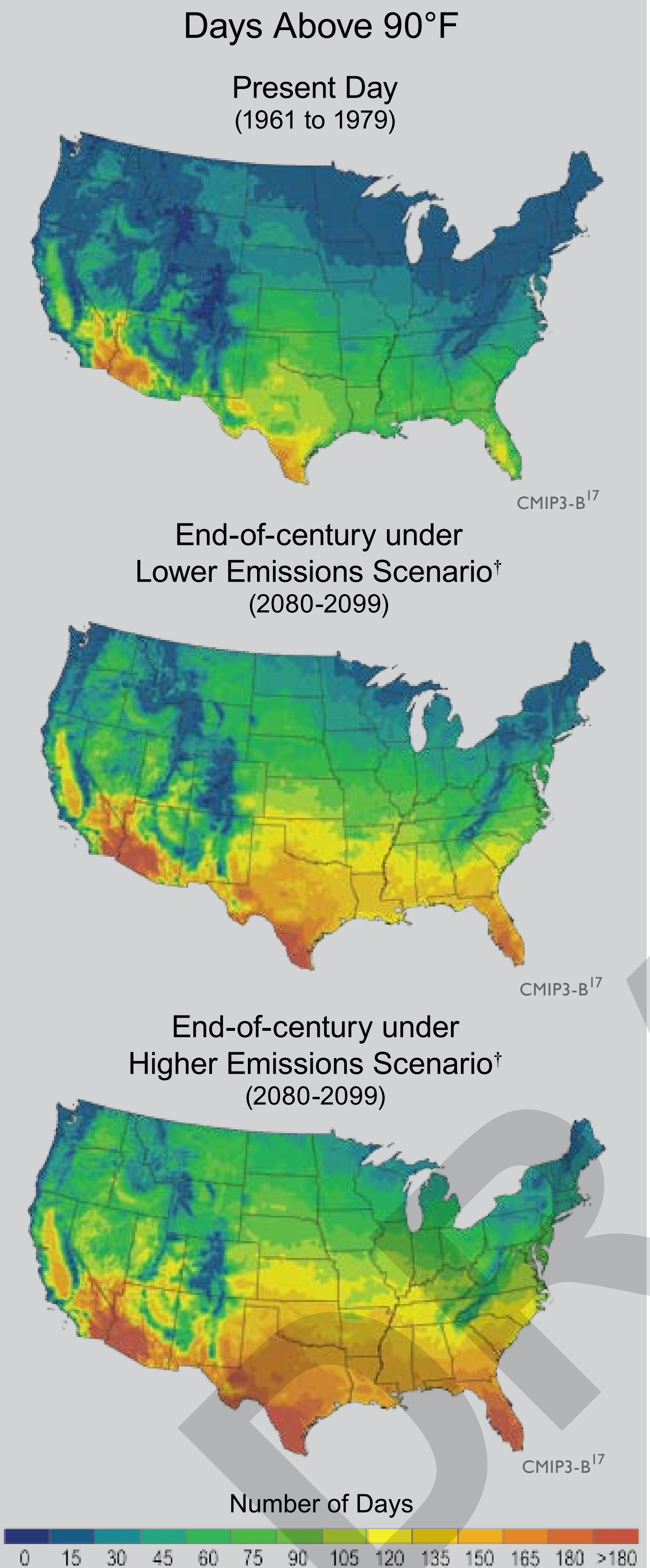
Observed Spring Snowmelt Dates



Date of onset of spring runoff pulse. Large dark red circles indicate significant trends toward onsets more than 20 days earlier. Lighter circles indicate less advance of the onset. Blue circles indicate later onset. The changes depend on a number of factors in addition to temperature, including altitude and timing of snowfall.

Heat Waves

A heat wave is a period of several days to weeks of abnormally hot weather, often with high humidity. During the 1930s, there was a high frequency of heat waves due to high daytime temperatures resulting in large part from an extended multi-year period of intense drought. By contrast, in the past 3 to 4 decades, there has been an increasing trend in high-humidity heat

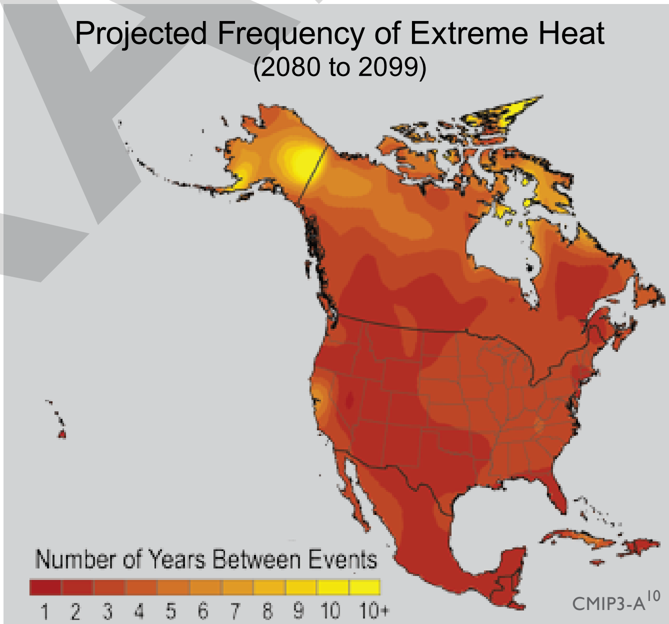


The average number of days when the maximum temperature exceeded 90°F from 1961 to 1979 (top) and the projected number of days above 90°F by the 2080s and 2090s for lower emissions (middle) and higher emissions (bottom)†. Much of the southern United States is projected to have more than twice as many days above 90°F by the end of this century.

waves, which are characterized by persistence of extremely high nighttime temperature[11].

As average temperatures continue to rise throughout this century, the frequency of cold extremes will decrease and the frequency and intensity of high temperature extremes will increase[9]. The number of days with high temperatures above 90°F is projected to increase throughout the country as illustrated in the map to the left. Parts of the South that currently have about 60 days per year with temperatures over 90°F are projected to experience 150 or more days a year above 90°F by the end of this century, under a higher emissions scenario†. There is higher confidence in the regional patterns than in results for any specific location (see *Recommendations for Future Work* section).

With rising high temperatures, extreme heat waves that we currently consider rare will occur more frequently in the future. Recent studies using an ensemble of models show that events that occur once every 20 years will occur about every other year in much of the country by the end of this century. A day so hot that it occurs once every 20 years at the end of the century will be approximately 10°F hotter than a day that is rare at present[9].



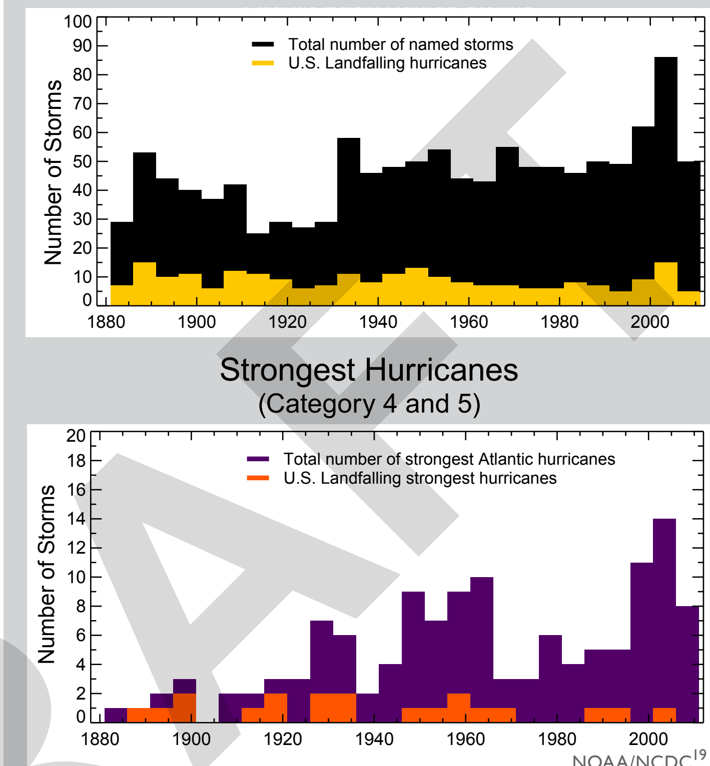
Simulations for 2080 to 2099 indicate how currently rare extremes (a 1-in-20-year event) are projected to become more commonplace. A day so hot that it is currently experienced once every 20 years would occur every other year or more by the end of the century under the higher emissions scenario†.

The destructive energy of Atlantic hurricanes has increased in recent decades and is projected to increase further in this century.

Of all the world's tropical storm and hurricane basins, the North Atlantic has been the most thoroughly monitored and studied. The advent of routine aircraft monitoring in the 1940s and the use of satellite observations since the 1960s have greatly aided monitoring of tropical storms and hurricanes. In addition, observations of tropical storm and hurricane strength made from island and mainland weather stations and from ships at sea began in the 1800s and continue today. Because of new and evolving observing techniques and technologies, scientists pay careful attention to ensuring consistency in tropical storm and hurricane records from the earliest manual observations to today's automated measurements. This is accomplished through collection, analysis, and cross-referencing of data from numerous sources and, where necessary, the application of adjustment techniques to account for differences in observing and reporting methodologies through time. Nevertheless, data uncertainty is larger in the early part of the record. Confidence in the tropical storm and hurricane record is greatest from 1900 to the present[11].

The total number of hurricanes and strongest hurricanes (Category 4 and 5) observed from 1851 through 2007 shows multi-decade periods of above average activity in the 1800s, the mid 1900s, and since 1995. Considering the more reliable period of data (since 1900), there is a significant upward trend in both the number of hurricanes and the number of strongest hurricanes. In contrast, there is no trend in the number of landfalling hurricanes on the East and Gulf coasts.

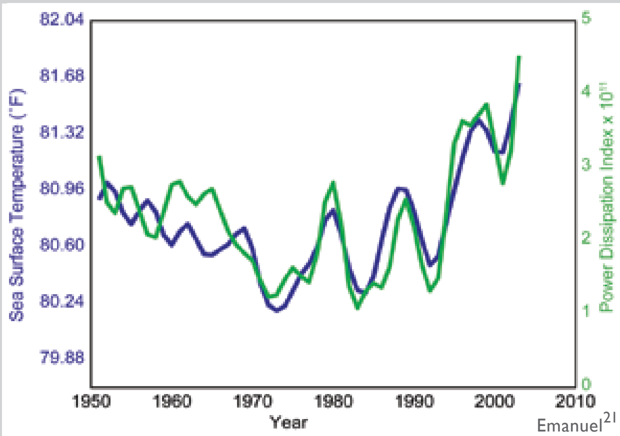
Tropical storms and hurricanes develop and gain strength over warm ocean waters. As oceans warm, they provide a source of energy for hurricane growth. During the past 30 years, annual sea surface temperatures in the main Atlantic hurricane development region increased nearly 2ºF. This warming coincided with an increase in the destructive energy (a combination of intensity, duration, and frequency) of Atlantic tropical storms and hurricanes. The strongest hurricanes (Category 4 and 5) have, in particular, increased in intensity[11]. The graph on the next page shows the strong correlation between hurricane power and sea surface temperature in the Atlantic and the overall increase in both during the past 30 years. Recently, however, new evidence has emerged for other temperature related linkages that can help explain the increase in Atlantic hurricane activity. This includes the contrast in sea surface temperature between the main hurricane development region and the broader tropical ocean[18]. There is a possibility that other causes



Top: Total numbers of North Atlantic named storms (tropical storms and hurricanes) (black) and total U.S. landfalling hurricanes (yellow) in five-year periods based on annual data from 1881 to 2008. The total number of named storms have been adjusted to account for missing storms in the era before satellites (prior to 1965). The last 5-year period is standardized to a comparable 5-year period assuming the level of activity from 2006 to 2008 persists through 2010. **Bottom:** Total numbers of strongest (Category 4 and 5) North Atlantic basin hurricanes (purple) and strongest U.S. landfalling hurricanes (orange) in 5-year periods based on annual data from 1881 to 2008. The number of strongest hurricanes have not been adjusted owing to the fact that storms of this strength are unlikely to be missing in the observational record of the pre-satellite era.

The total number of hurricanes in the Atlantic, particularly the strongest ones, has increased during the past century. However, there has been little change in the total number of landfalling hurricanes, in part because a variety of factors affect the number of hurricanes making landfall. These include atmospheric stability, wind shear, and ocean heat content. This highlights the importance of understanding the broader changes occurring throughout the Atlantic Basin beyond the storms making landfall along the U.S. coast.

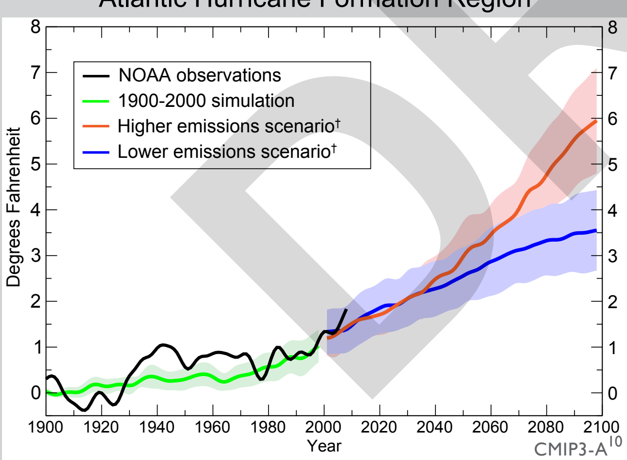
Observed Relationship Between Sea Surface Temperatures and Hurricane Power in the North Atlantic Ocean



Observed sea surface temperature (blue) and the Power Dissipation Index (green), which combines frequency, intensity and duration for North Atlantic hurricanes. Hurricane rainfall and wind speeds are likely to increase in response to human-caused warming. Analyses of model simulations suggest that for each 1.8°F increase in tropical sea surface temperatures, rainfall rates will increase by 6 to 18 percent.

beyond the absolute rise in ocean temperature might be involved in the increasing trends in Atlantic hurricane activity (as defined by the Power Dissipation Index, which combines hurricane frequency, intensity, and duration). This highlights the finding that more intense hurricanes are linked to sea surface temperatures, a critical factor for intense hurricanes. In addition, other factors have been shown to influence hurricane activity, such as wind shear and atmospheric stability. For these and other reasons, a confident assessment requires further study[11].

Observed and Projected Sea Surface Temperature Change
Atlantic Hurricane Formation Region



Observed (purple) and projected temperatures (blue = lower scenario; red = higher scenario) in the Atlantic hurricane formation region. Increased intensity of hurricanes is linked to rising sea surface temperatures in the region of the ocean where hurricanes form.

Evidence of increasing hurricane strength in the Atlantic and other oceans with linkages to rising sea surface temperatures is also supported by satellite records dating back to 1981. An increase in the maximum wind speeds of the strongest hurricanes has been documented and linked to increasing sea surface temperatures. These results include an estimated 14.5 (± 9.4) mile per hour increase in the wind speed of the strongest hurricanes for each 1.8°F increase in sea surface temperature[20]. Using other sources of hurricane data, a near doubling in the frequency of the strongest hurricanes (Category 4 and 5) has been observed globally in the past few decades[8].

Projections that sea surface temperatures in the main Atlantic hurricane development region will increase at even faster rates during the second half of this century under higher emissions scenarios† highlight the need to better understand the relationship between increasing temperatures and hurricane intensity. As ocean temperatures continue to increase in the future, it is likely that hurricane rainfall and wind speeds, will increase in response to human-caused warming[9]. Analyses of model simulations suggest that for each 1.8°F increase in tropical sea surface temperatures, core rainfall rates will increase by 6 to 18 percent and the surface wind speeds of the strongest hurricanes will increase by about 1 to 8 percent[13]. Storm surge levels and hurricane damages are likely to increase because of increasing hurricane intensity coupled with sea-level rise, which is a virtually certain outcome of the warming global climate[9].

In the eastern Pacific, the strongest hurricanes have become stronger since the 1980s even while the total number of storms has decreased.

Although on average more hurricanes form in the eastern Pacific than the Atlantic each year, cool ocean waters along the U.S. west coast and atmospheric steering patterns help protect the contiguous U.S. from landfalls. Threats to the Hawaiian

Islands are greater but landfalling storms are rare in comparison to those of the U.S. East and Gulf coasts. Nevertheless, changes in hurricane intensity and frequency could influence the impact of landfalling Pacific hurricanes in the future.

The total number of tropical storms and hurricanes in the eastern Pacific on seasonal to multi-decade time periods is generally opposite to that observed in the Atlantic. For example, during El Niño events it is common for hurricanes in the Atlantic to be suppressed while the eastern Pacific is more active. This reflects the large-scale atmospheric circulation patterns that extend across both the Atlantic and the Pacific oceans[22,23].

Within the past three decades the total number of tropical storms and hurricanes and their destructive energy have decreased in the eastern Pacific[9,23]. However, satellite observations have shown that like the Atlantic, the strongest hurricanes (the top 5 percent), have gotten stronger since the early 1980s[24,25]. As ocean temperatures rise, the strongest hurricanes are likely to increase in both the eastern Pacific and the Atlantic[9].

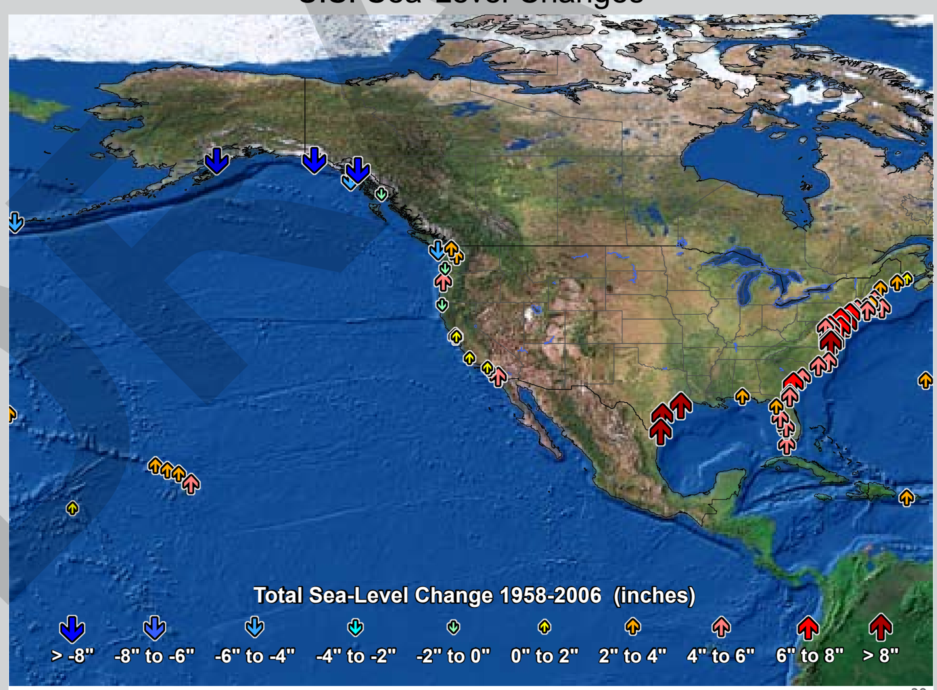
Sea level has risen 2 to 5 inches during the past 50 years along many U.S. coasts, and is projected to rise more in the future.

During the past 50 years, sea level has risen 2 to 5 inches along many coastal areas of the United States and more than 8 inches in some locations. This rise was due to the warming-induced expansion of the oceans, accelerated melting of most of the world's glaciers and ice caps, and loss of ice on the Greenland and Antarctic ice sheets[19]. There is strong evidence that global sea-level is currently rising at an increased rate[26,27]. A warming global climate will cause further sea-level rise over this century and beyond[5,28].

The amount of relative sea-level rise experienced along different parts of the U.S. coast depends on the changes in elevation of the land that occur as a result of subsidence (sinking) or uplift (rising), as well as increases in global sea level due to warming. In addition, atmospheric and oceanic circulation, which will be affected by climate change, will influence regional sea level.

Human induced sea-level rise is occurring globally. The majority of the Atlantic Coast and Gulf of Mexico Coast has experienced significantly higher rates of relative sea-level rise than the global average during the last 50 years, with the local differences mainly due to land subsidence[29]. Portions of the Pacific Northwest and Alaska coast have, on the other hand, experienced slightly falling sea level as a result of long-term uplift as a consequence of glacier melting and other geological processes. Regional variations in relative sea-level rise are expected in the future. For example, assuming these historical geological forces continue, a 2-foot rise in global sea level (which is within the range of recent estimates) by the end of this century would result in a relative sea-level rise of 2.3 feet at New York City, 2.9 feet at Hampton Roads, Virginia, 3.5 feet at Galveston, Texas, and 1 foot at Neah Bay in Washington state[30].

U.S. Sea-Level Changes



Updated from Zervas[29]

Observed changes in relative sea level from 1958 to 2007 for locations on the U.S. coast. Some areas along the Atlantic and Gulf coasts saw increases greater than 8 inches over the past 50 years.

For cold-season storms outside the tropics, storm tracks are shifting northward and the strongest storms are projected to become stronger.

Large-scale storm systems outside the tropics are the dominant weather phenomenon during the cold season in the United States. Although the analysis of these storms is complicated by a relatively short length of most observational records and by the highly variable nature of strong storms outside the tropics, some clear patterns have emerged[11].

A northward shift in storm tracks has occurred over the last 50 years as evidenced by a decrease in the frequency of storms outside the tropics in mid-latitude areas of the Northern Hemisphere, while high-latitude activity has increased. There is also evidence of an increase in the intensity of extra-tropical storms in both the mid- and high-latitude areas of the Northern Hemisphere, but there is greater confidence in the increases occurring in high latitudes[11]. This northward shift is projected to continue through this century, and strong cold season storms are likely to become stronger and more frequent, with greater wind speeds and more extreme wave heights[9].

Snowstorms

The northward shift in storm tracks is reflected in regional changes in the frequency of snow-storms. The South and lower Midwest saw reduced snowstorm frequency during the last century. In contrast, the Northeast and upper Midwest saw increases in snowstorms, although considerable decade-to-decade variations were present in all regions, influenced, for example, by the frequency of El Niño events[11].

There is also evidence of an increase in lake-effect snowfall along and near the southern and eastern shores of the Great Lakes since 1950[11]. Lake-effect snow is produced by the strong flow of cold air (15 to 32ºF) across large areas of ice-free water. As the climate has warmed, ice coverage on the Great Lakes has fallen. The maximum seasonal coverage of Great Lakes ice decreased at a rate of −8.4 per-cent per decade from 1973 through 2008, amount-ing to a roughly 30 percent decrease in ice coverage (see *Midwest* region). This has created conditions

Areas in New York State east of Lake Ontario received over 10 feet of lake effect snow during a 10-day period in early February 2007.

conducive to greater evaporation of moisture and thus heavier snowstorms. Among recent extreme lake-effect snow events was a February 2007 10-day storm total of almost 12 feet of snow in western New York State. Climate models suggest that lake-effect snowfalls are likely to increase over the next few decades. In the longer term, lake-effect snows are likely to decrease as temperatures continue to rise, with the precipitation falling as rain[31,32].

Tornadoes and severe thunderstorms

Reports of severe weather including tornadoes and severe thunderstorms have increased during the past 50 years. However, the increase is widely believed to be due to improvements in monitoring technologies such as Doppler radars, changes in population, and increasing public awareness. When adjusted to account for these factors, there is no clear trend in the frequency or strength of torna-does since the 1950s[11].

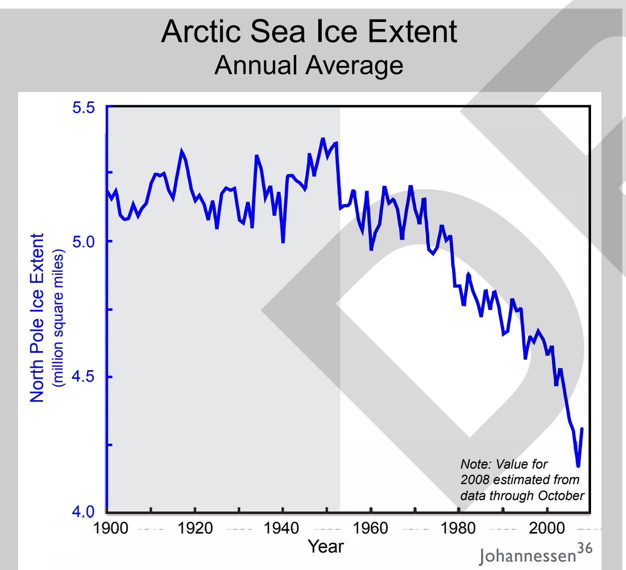
Severe thunderstorm reports in the United States have increased exponentially since the mid-1950s. The distribution by intensity for the strongest 10 percent of hail and wind reports is little changed, providing no evidence of an increase in the severity of events[11]. Climate models project future increases in the frequency of environmental conditions favorable to severe thunderstorms. But the inabil-ity to adequately model the small-scale conditions involved in thunderstorm development remains a limiting factor in projecting the future character of severe thunderstorms and other small-scale weather phenomena[9].

Arctic sea ice is declining rapidly and this is projected to continue.

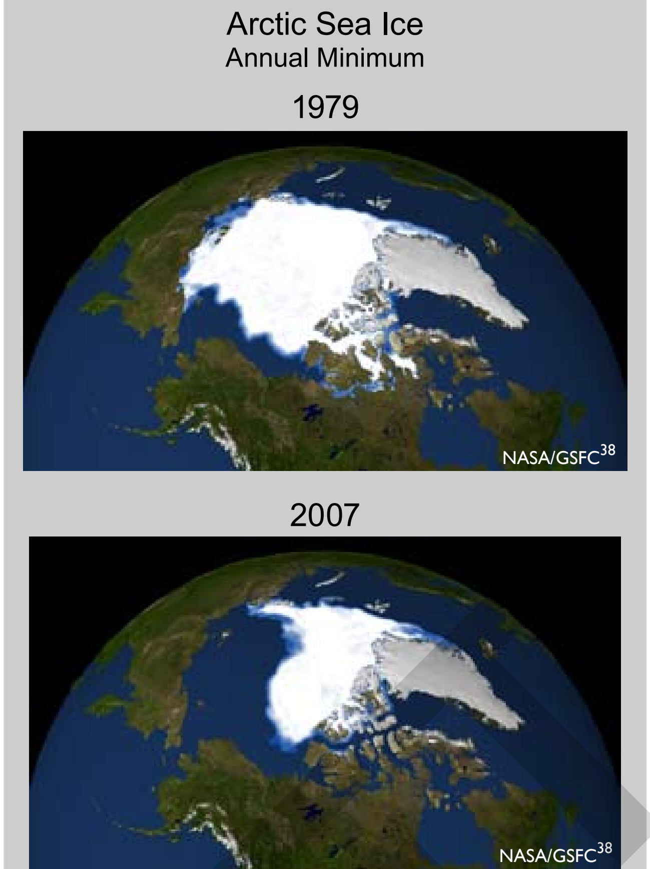
Sea ice is a very important part of the climate system. In addition to direct impacts on coastal areas of Alaska, it more broadly affects surface reflectivity, ocean currents, cloudiness, humidity, and the exchange of heat and moisture at the ocean's surface. Open ocean water is darker in color than sea ice, which causes it to absorb more of the Sun's heat, which increases the warming of the water even more[14,33].

The most complete record of sea ice is provided by satellite observations of sea ice extent since the 1970s. Prior to that, aircraft, ship, and coastal observations in the Arctic make it possible to extend the record of Northern Hemisphere sea ice extent back to at least 1900, although there is a lower level of confidence in the data prior to 1953[14].

While Arctic sea ice extent was little changed during the pre-satellite record, it has fallen at a rate of 3 to 4 percent per decade since 1979. End-of-summer Arctic sea ice has fallen at an even faster rate of more than 11 percent per decade in that time. Year-to-year changes in sea ice extent and record low values are influenced by natural variations in atmospheric pressure and wind patterns[34]. However, clear linkages between rising greenhouse gas concentrations and declines in arctic sea ice



Observations of annual average Arctic sea ice extent for the period 1900 to 2008. The gray shading indicates less confidence in the data before 1953. The slight upturn at the end of the record is the estimated data for 2008.



Arctic sea ice reaches its annual minimum in September. The satellite images above show September Arctic sea ice in 1979, the first year these date were available, and 2007.

have been identified in the climate record as far back as the early 1990s[35]. The extreme loss in Arctic sea ice that occurred in 2007 would not have been possible without the long-term reductions that have coincided with a sustained increase in the atmospheric concentration of carbon dioxide and the rapid rise in global temperatures that have occurred since the mid-1970s[36]. Although the 2007 record low was not eclipsed in 2008, the 2008 sea ice extent is well below the long-term average, reflecting a continuation of the long-term decline in Arctic sea ice. In addition, the total volume of Arctic sea ice in 2008 was a record low because of the greater quantity of thin first-year ice.

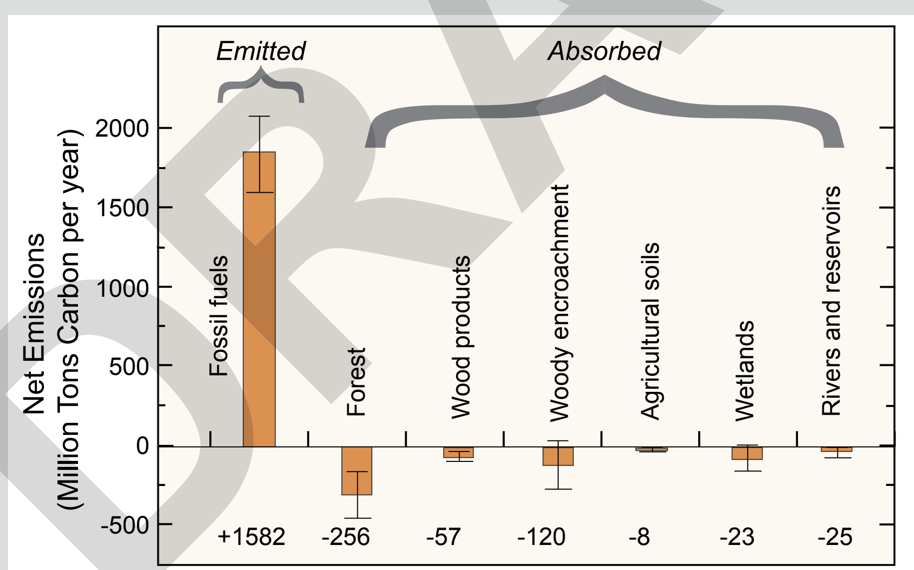
It is expected that declines in Arctic sea ice will continue in the coming decades with year-to-year fluctuations influenced by natural atmospheric variability. The overall rate of decline will be influenced mainly by the rate at which carbon dioxide and other greenhouse gas concentrations increase[37].

Emissions of Heat-Trapping Gases by the United States

Since the industrial revolution, the United States has been the world's largest emitter of heat-trapping gases. Although China has recently surpassed the United States in current total annual emissions, per capita emissions remain much higher in the United States. Carbon dioxide, the most important of the heat-trapping gases produced directly by human activities, is a cumulative problem because it has a long atmospheric lifetime. Roughly one-third of the carbon dioxide released from fossil fuel burning remains in the atmosphere after 100 years, and roughly one-fifth of it remains after 1,000 years[3]. As a result, the United States is responsible for about 28 percent of the human-induced heat-trapping gases in the atmosphere today[8].

U.S. carbon dioxide emissions grew dramatically over the past century. These emissions come almost entirely from burning fossil fuels. These sources of carbon dioxide are one side of the equation and on the other side are "sinks" that take up carbon dioxide. The growth of trees and other plants is an important natural carbon sink. In recent years, it is estimated that about 20 percent of U.S. carbon dioxide emissions have been offset by U.S. forest growth (see figure below)[39].

The amount of carbon released and taken up by natural sources varies considerably from year to year depending on climatic and other conditions. For example, fires release carbon dioxide, so years with many large fires result in more carbon release and less uptake as natural sinks (the vegetation) are lost. Similarly, the trees destroyed by intense storms or droughts release carbon dioxide as they decompose, and the loss results in reduced strength of natural sinks until regrowth is well underway. For example, Hurricane Katrina killed or severely damaged over 320 million large trees. As these trees decompose over the next few years, they will release an amount of carbon dioxide equivalent to that taken up by all U.S. forests in a year[9]. The net change in carbon storage in the long run will depend on how much is taken up by the regrowth as well as how much was released by the original disturbance.



CCSP SAP 2.2[39]

Carbon dioxide emissions and uptake in millions of tons of carbon per year in 2003. The bar marked "Emitted" indicates the amount of carbon as carbon dioxide added to the atmosphere from U.S. emissions. The bars marked "Absorbed" indicate amounts of carbon as carbon dioxide removed from the atmosphere. The thin lines on each bar indicate estimates of uncertainty.