SECTION 4

How Are Global and National Climate Projected to Change?

Greenhouse gas emissions are projected to increase global and national average temperatures, precipitation, sea level, and ocean acidity. More extreme heat and heavy rainfall events are also likely. The amount of change that actually occurs will depend on the amount of future greenhouse gas emissions and will vary by location. The most recent projections for 21st century climate change (IPCC 2013) [1] align with and confirm earlier projections (e.g., IPCC 2007), [2] although new estimates indicate faster rates of sea level rise during this century and in the centuries to come.

1. **Significant warming is projected for the 21st century as a result of greenhouse gases emitted from human activities.[1]** The amount of warming that occurs from about mid-century onward depends on the amount of greenhouse gases emitted in the coming decades. Natural variability is expected to remain an important feature of global and regional climate, at times amplifying and at other times counteracting the long-term trends caused by rising greenhouse gas emissions.

    - *Continued rise in global temperatures.* Warming is projected to continue throughout the 21st century. Higher emissions of greenhouse gases will result in greater warming (Figure 4-1; Table 4-1). Projected warming for 2081-2100 (relative to 1986-2005) ranges from +1.8°F (range: +0.5°F to +3.1°F) for a scenario that assumes aggressive reductions in greenhouse gas emissions to +6.7°F (range: +4.7°F to +8.6°F) for a high "business as usual" emissions scenario.[A][B] Heat waves are projected to continue to become more prevalent and cold snaps less frequent.[1]

    - *Ocean warming.* The oceans will continue to warm, and heat will penetrate from the surface to the deep ocean. Projected warming in the top 330 feet of the ocean is +1.1°F to +3.6°F for 2081-2100 relative to 1986-2005.[1]

    - *Past emissions have committed the climate to ongoing changes, regardless of future emissions.* Current and past greenhouse gas emissions have already caused warming that will continue into the 21st century and persist for several centuries or longer.[3] To keep global temperature increases between +0.5 and +3.1°F (by 2081-2100 relative to 1986-2005), net greenhouse gas emissions would have to be reduced by about 50% by 2050 (relative to 1990 emissions), and to near or below zero in the final decades of the 21st century.[4]

[A] Greenhouse gas scenarios were developed by climate modeling centers for use in modeling global and regional climate impacts. These are described in the text as follows: "very low" refers to the RCP 2.6 scenario; "low" refers to RCP 4.5 or SRES B1; "medium" refers to RCP 6.0 or SRES A1B; and "high" refers to RCP 8.5, SRES A2, or SRES A1FI – descriptors are based on cumulative emissions by 2100 for each scenario. See Section 3 for more details.

[B] The RCP 2.6 (very low) and RCP 8.5 (high) scenarios.

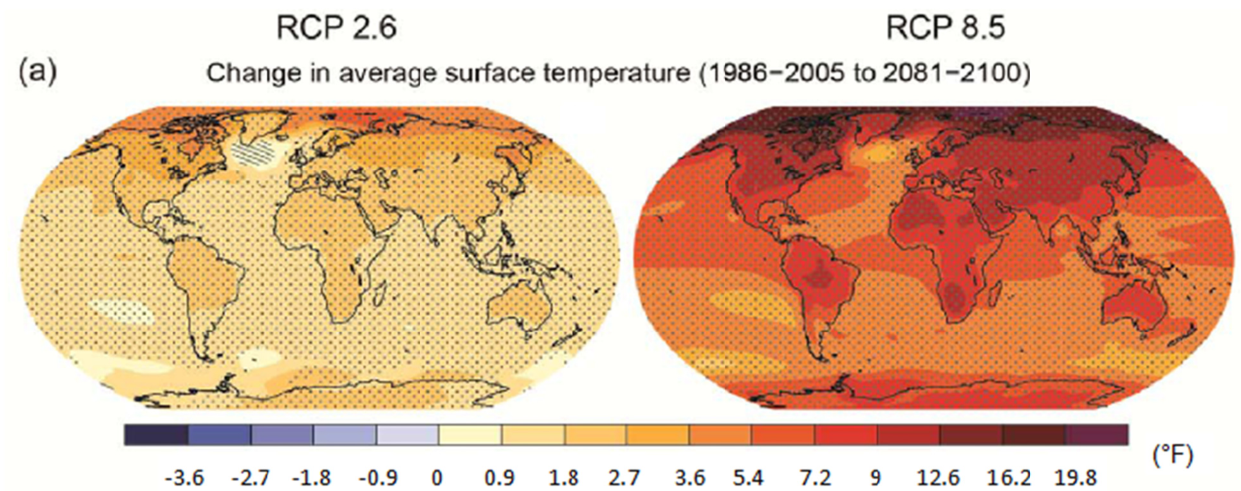

Figure 4-1. All scenarios project warming for the 21st century**.** Projected changes in annual average air temperature at the Earth's surface for 2081-2100 (relative to 1986-2005) for a very low (RCP2.6) and high (RCP8.5) greenhouse gas scenario, from an average of global climate models. Stippling indicates regions where at least 90% of models agree on the direction of change. *Figure and caption adapted from IPCC 2013, Figure SPM.8.[1]*

2. **Global warming will be accompanied by changes in precipitation, continued decreases in glaciers and ice sheets, continued sea level rise, and increasing ocean acidity.**

    - *Modest increases in global average precipitation.* Changes in precipitation will vary by location and are less certain than those in temperature. Overall, global average precipitation is projected to increase modestly, by +0.6 to +1.6% per °F for most greenhouse gas scenarios.[C][4] In general, historically dry regions and seasons are expected to get drier and historically wet regions and seasons are expected to get wetter. Heavy rainfall events are projected to become more intense over most mid-latitude land areas, including much of the continental U.S.

    - *Declining ice, snow, and glaciers.* Arctic sea ice, Northern Hemisphere spring snow cover, and the vast majority of glaciers will continue to shrink with warming. Many models project that the Arctic could be nearly ice free in September by mid-century, if greenhouse gas emissions continue to rise significantly.[1]

    - *Continued rise in sea level.* Global mean sea level is projected to rise by +11 to +38 inches by the end of the 21st century (2100, relative to 1986-2005), according to the IPCC,[D][1] and +20 to +55 inches (relative to the year 2000), according to a National

[C] Specifically, for the RCP 4.5, 6.0, and 8.5 greenhouse gas scenarios

[D] Sea level rise projections vary depending on the greenhouse gas emissions scenarios used. The average and associated ranges reported in Church et al. 2013 are +17 in. (range: 11-24 in.) for the very low (RCP 2.6) greenhouse gas scenario to +29 in. (range: 21-38 in.) for the high (RCP 8.5) greenhouse gas scenario.

Research Council report.[E][5] In all scenarios, 21st century global sea level is projected to rise faster than it has in recent decades (1971-2010).[4] Sea level rise will continue to rise for several centuries after 2100 as the ocean and ice sheets continue to respond to changes in global temperatures.[3][4]

- *Ocean acidification.* The acidity of the ocean is projected to increase by +38 to +109%[F][1] by 2100 relative to 1986-2005 (or increase roughly +150 to +200% relative to pre-industrial levels)[6] as global oceans continue to absorb carbon dioxide from the atmosphere.

3. **The most recent projections for 21st century climate change (IPCC 2013)[1] align with and confirm earlier projections (e.g., IPCC 2007),[2] although new estimates indicate faster rates of sea level rise during this century and in the centuries to come.**

- *Close agreement in many areas.* Projected changes in temperature, precipitation, snow cover, and ocean acidification closely match the projections from 2007. Differences in warming projections are largely a result of differences between among greenhouse gas scenarios.

- *Exploring the consequences of aggressive greenhouse gas reductions.* The 2013 IPCC report includes a greenhouse gas scenario that requires aggressive reductions in global carbon dioxide emissions, and therefore indicates a lower amount of warming than for the low end of the scenarios used in the 2007 report, which assumed no greenhouse gas reduction efforts.

- *Higher sea level rise projections.* The updated sea level rise projections are about +40% higher, in large part because the new report includes projected changes in ice sheet flow, which were omitted in the 2007 IPCC report.

- *New findings about Greenland.* The Greenland ice sheet may be more easily destabilized by warming than previously thought. Studies indicate that the threshold for initiating a near-complete loss of Greenland ice is a global warming of +2°F to +7°F relative to pre-industrial, well within the projected warming for 2100. This would result in a sea level rise of more than 20 feet over the next one thousand years or more.[4]

- *Antarctic ice sheet stability.* The stability of large Antarctic marine ice sheets in a warmer climate is uncertain; their breakup could also lead to several additional feet of sea level rise, though probably not in this century.

E The IPCC projections are lower than those from the National Research Council (NRC 2012),[5] especially at the high end of the range. The two studies employed different analytical approaches and different assumptions about future greenhouse gas emissions.

F Although the acidity of the ocean is projected to increase, the ocean itself is not expected to become acidic (i.e., drop below pH 7.0). Ocean pH has decreased from 8.2 to 8.1 (a 26% increase in hydrogen ion concentration, which is what determines the acidity of a fluid) and is projected to fall to 7.8-7.9 by 2100. The term “ocean acidification” refers to this shift in pH towards the acidic end of the pH scale.

4. The United States is also projected to experience warming, modest changes in precipitation, and continued sea level rise.

- *Warming.* Continued warming of +3°F to +11°F by the end of this century (2070-2099), relative to recent decades (1971-1999; Figure 4-2).[G][7][8]

- *Variable changes in precipitation.* Precipitation changes will vary by location and season. Winter and spring precipitation are expected to increase in the northern U.S. while summer precipitation is projected to decrease throughout the U.S.[7]

- *More extreme events.* Heavy rains and heat waves will continue to become more frequent.[7] Climate models currently project increases in the frequency and intensity of the strongest Atlantic hurricanes, although there is large uncertainty about these conclusions given the numerous factors that influence the formation of hurricanes.[7]

- *Continued rise in sea level.* Averaged over the U.S., sea level is projected to rise in response to global sea level rise.[7] Locally, sea level rise will vary from place to place due to differences in the rate of vertical land movement, ocean currents, and other factors.

- *Impacts on human and natural systems.* Projected changes in U.S. climate are expected to: increase damage to infrastructure as a result of higher storm surge, increased flooding, and extreme heat events; increase the likelihood of water shortages and competition for water among agricultural, municipal, and environmental uses; and reduce the capacity of ecosystems to moderate the consequences of disturbances such as droughts, floods, and severe storms, among other impacts. Impacts on U.S. agriculture are expected to become more problematic after mid-century as temperature increases and precipitation extremes are further intensified.[9]

For more details on projected global and national changes in climate, see Table 4-1.

[G] U.S. temperature projections from the 2007 IPCC report[2] differ somewhat from the projections presented in IPCC 2013[1] because of the different greenhouse gas scenarios (see Section 3 of this report) and historical base periods used (1971-99 vs. 1986-2005).

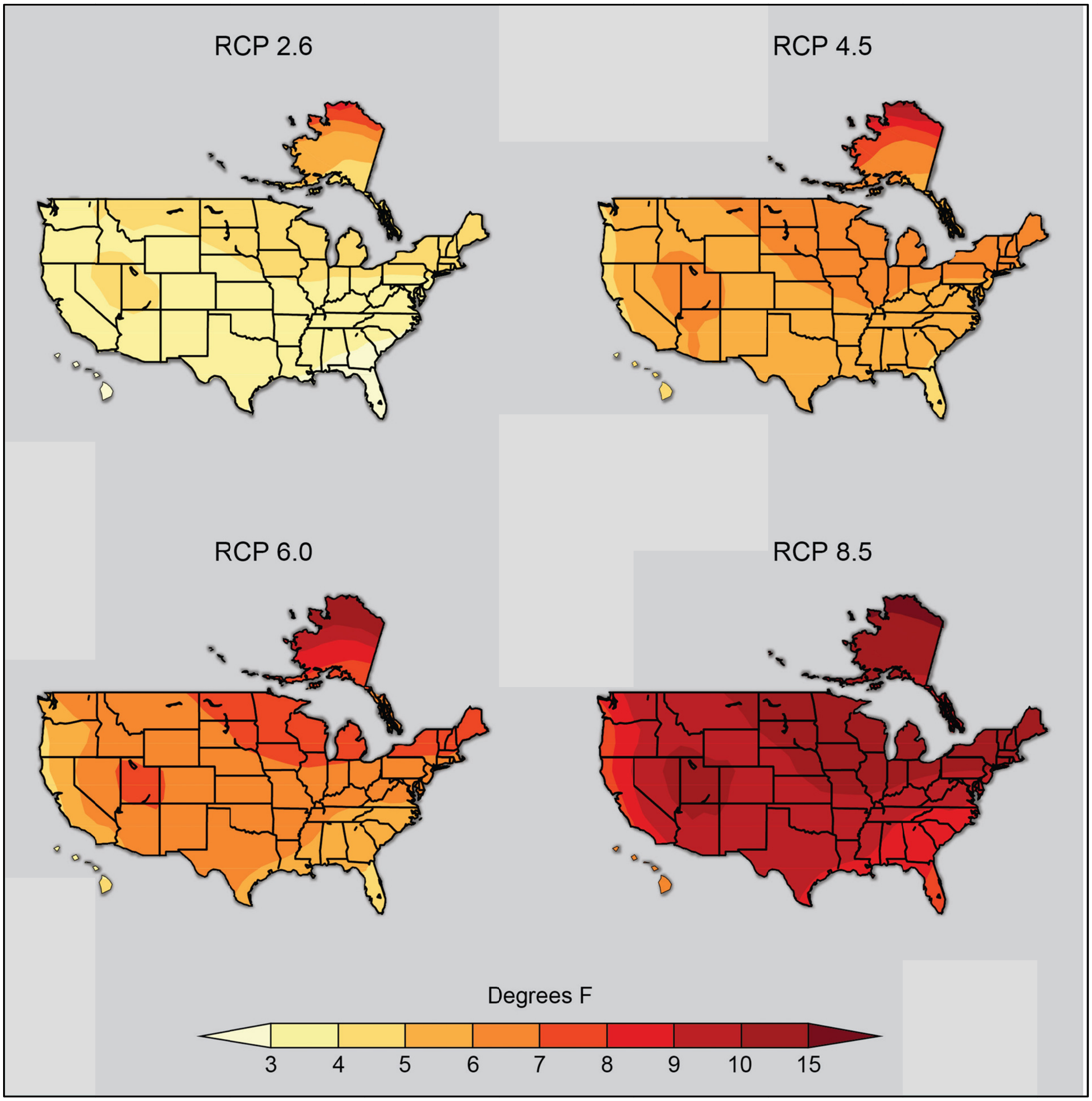

Figure 4-2. All scenarios project warming for the U.S.; the amount of warming depends on the amount of greenhouse gases emitted in the coming decades. Projected changes in annual average air temperature for the U.S. at the Earth's surface for the later part of this century (2071-2099) relative to 1971-2000 for the four greenhouse gas scenarios used to project global changes in IPCC 2013. RCP 2.6 (top left) is a very low greenhouse gas scenario that assumes rapid reductions in emissions – about a 50% cut from 1990 levels by 2050. RCP 8.5 (bottom right) is a high scenario that assumes continued increases in greenhouse gas emissions until the end of the 21st century. Also shown are temperature changes (°F) for a low scenario (RCP 4.5, top right) and a medium scenario (RCP 6.0, bottom left). For more details on greenhouse gas scenarios, see Section 3 of this report. *Figure and caption adapted from Walsh et al., (in press).*[7]

Table 4-1. Projected changes in global and national climate.

Variable and Region	***Projected Long-term Change***
Temperature	
Global	Warming ▪ Warming projected for *all* greenhouse gas scenarios; amount of warming depends on the amount of greenhouse gases emitted. ▪ Projected change for 2081-2100 relative to 1986-2005: Very low emissions (RCP 2.6): +1.8°F (range: 0.5°F to 3.1°F) High emissions (RCP 8.5): +6.7°F (range: 4.7°F to 8.6°F)[1] ▪ Spatial pattern of warming varies. More warming is projected over land than over oceans, and the Arctic is projected to warm more rapidly than the global average.
U.S.	Warming ▪ Warming is projected for all scenarios for the end of the century (2070-2099, relative to 1971-1999): Low emissions (B1): +3 to +6°F High emissions (A2): +5 to +11°F[8] ▪ Spatial pattern of warming varies. In the continental U.S., the inland West and upper Midwest are projected to warm more rapidly than the coasts.[7]
Extremes	Increasing extreme heat events and decreasing extreme cold events globally and nationally. ▪ Projected change for the U.S. for the 2050s (2041-2070, relative to 1980-2000), under a high emissions scenario (A2): o Increase in number days above 95°F. Greatest increases occur in the southern U.S. and the Midwest.[4] o Decrease in number of days below 10°F. Greatest decreases occur in the interior West, upper Midwest, and Northeast.[4]
Precipitation	
Global	Decreases in annual precipitation at mid-latitudes and in the subtropics, increases at high-latitudes and parts of the tropics.
U.S.	Changes vary by season, location, and time period. ▪ Projected changes for mid-century (2041-2070; relative to 1971-2000) under a high emissions scenario (A2):[4] o Increasing winter precipitation in most of the U.S., including much of the Northwest. o Increasing spring/fall precipitation in most of the U.S., except the Southwest, where decreases are projected. o Decreasing summer precipitation in the Northwest and Southwest, and parts of the Midwest and East.

Variable and Region	***Projected Long-term Change***
Heavy Precipitation	Increasing, but varies by location. ▪ Globally, more frequent and more intense extreme precipitation events expected by the end of this century over most of the mid-latitude land areas and wet tropical regions. ▪ Within the U.S., heavy rainfall events projected to become more frequent. Greatest increases expected in Alaska, the Northeast, and the Northwest.[4]
Snow and Ice	
Glaciers	Continued losses, on average, globally and nationally. Global average projections for 2081-2100, relative to 1986-2005: Very low emissions (RCP 2.6): −15 to −55% decline High emissions (RCP 8.5): −35 to −85% decline[1]
Arctic Sea Ice	Decreasing ▪ Projected decline in total area covered by Arctic sea ice for 2081-2100 relative to 1986-2005 (range from RCP 2.6 to RCP 8.5): February*:* −8 to −34% September*:* −43 to −94%[1]
Northern Hemisphere Snow Cover	Decreasing ▪ Projected change in spring (March-April) snow extent for 2081-2100 (relative to 1986-2005) from a very low (RCP 2.6) to a high (RCP 8.5) greenhouse gas scenario: −7 to −25%[1]
Oceans	
Ocean Temperature	Warming ▪ Projected warming greatest near the surface and generally decreasing with depth. Projected change for 2081-2100 relative to 1986-2005: Top 330 ft (RCP 2.6 to RCP 8.5): +1.1 to +3.6°F Top 3,300 ft (RCP 2.6 to RCP 8.5): +0.5 to +1.1°F[1]
Global Sea Level	Rising globally and nationally, on average, although rate and direction of change will vary by location. ▪ Projections of global average sea level:[D] *IPCC (2081-2100 relative to 1986-2005):* Very low emissions (RCP 2.6): +17 in. (range: +11 to +24 in.) High emissions (RCP 8.5): +29 in. (range: +21 to +38 in.) [1] *National Research Council (2100 relative to 2000):* Range from low (B1) to high (A1FI) emissions scenario: +20 to +56 in.[5] ▪ No projected range specific to the U.S. as a whole (projections are for specific regions within the U.S.)

Variable and Region	*Projected Long-term Change*
Ocean Acidification	Global ocean acidity is projected to increase by 2100 for all scenarios (relative to 1986-2005).[1] Low emissions (RCP 4.5): +38 to +41% *(decrease in pH: 0.14-0.15)* High emissions (RCP 8.5): +100 to +109% *(decrease in pH: 0.30-0.32)*

[1] (IPCC) Intergovernmental Panel on Climate Change. 2013. *Working Group 1, Summary for Policymakers.* Available at: http://www.climatechange2013.org/images/uploads/WGIAR5-SPM_Approved27Sep2013.pdf

[2] (IPCC) Intergovernmental Panel on Climate Change. 2007. *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[3] Solomon, S. et al., 2009. Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Sciences*, 106(6), 1704-1709.

[4] (IPCC) Intergovernmental Panel on Climate Change. 2013. *Climate Change 2013: The Physical Science Basis: Technical Summary*, available at: http://www.ipcc.ch/report/ar5/wg1/#.UluMuxCz4zo

[5] (NRC) National Research Council. 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. Washington, DC: The National Academies Press, 2012.

[6] Feely, R.A. et al., 2009. Ocean acidification: Present conditions and future changes in a high-CO2 world. *Oceanography* 22(4):36–47, http://dx.doi.org/10.5670/oceanog.2009.95.

[7] Walsh, J., D. Wuebbles, et al. (in press). Our Changing Climate. Chapter 2 in the draft 2014 U.S. National Climate Assessment, http://ncadac.globalchange.gov/.

[8] Kunkel et al. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 9. *Climate of the Contiguous United States,* NOAA Technical Report NESDIS 142-9, NOAA National Environmental Satellite, Data, and Information Service, Washington, D.C.

[9] (NCADAC) National Climate Assessment and Development Advisory Committee. 2014. U.S. National Climate Assessment, http://ncadac.globalchange.gov/.