Appendix C: Regional Climate Change Summaries

Projections of future climate change can be made with increased confidence at the regional level as climate modeling and downscaling capabilities continue to improve. However, changes in precipitation are more difficult to project than changes in temperature. Confidence in projected changes is also higher for the winter and spring seasons than for the summer and fall. Furthermore, average temperature changes are not as important as the projected increases of the minimum and maximum temperature. All regions will continue to experience considerable decadal variation due to events such as El Niño.

With these points in mind, this appendix summarizes regional, climate-related changes that have been observed over the twentieth century or are projected to occur at some time during or by the end of the twenty-first century. These results have been excerpted from the U.S. Global Change Research Program's *Global Climate Change Impacts in the United States*, (Karl et al. 2009), unless otherwise indicated.

Northeast (Maine to Virginia)

The following changes in climatic conditions have been observed in the Northeast:

- Since 1970, the average air temperature has increased by 2°F; the rise in temperature during the winter was 4°F.
- Days with temperatures over 90°F have become more frequent.
- An increasing trend in precipitation has been observed throughout much of the year and, most notably, over the last 50 years, the number of days with very heavy precipitation has increased.
- Winter precipitation has come more typically as rain rather than as snow, leading to reduced snowpack.
- Winter ice is disappearing earlier from lakes and rivers, and river flows are peaking earlier in the spring as the snow melts.
- Average sea surface temperature levels have been increasing in the North Atlantic.
- In the mid-Atlantic region from New York to North Carolina, rates of relative sea level rise ranged between 2.4 and 4.4 mm/year (~.094 and .173 in) or about .3 m (~11.8 in) over the twentieth century (CCSP 2009c); low-lying topography and a high storm frequency make this area particularly vulnerable.

The following climate-related changes are projected for the Northeast:

- Air temperature will rise an additional 2.5 to 4°F in winter and 1.5 to 3.5°F in summer over the next several decades.
- Under a higher emissions scenario, by late this century:
  - The summer heat would occur three weeks earlier and end three weeks later and the average number of days above 100°F for certain cities would increase,
  - Short-term droughts are projected to occur as frequently as once each summer in the Catskill and Adirondack Mountains and across the New England states, and
  - Winters will be shorter with fewer cold days, more precipitation, and a reduced snow season.
- Severe flooding due to sea level rise and heavy downpours is likely to occur more frequently.

- The densely populated coasts of the Northeast face substantial increases in the extent and frequency of storm surge, coastal flooding, erosion, property damage, and loss of wetlands.
- As the average temperatures of the ocean continue to increase, the center of lobster fisheries is projected to continue its northward shift and the cod fishery on Georges Bank is likely to be diminished.

Southeast (includes Gulf of Mexico States)

The following changes in climatic conditions and impacts have been observed in the Southeast:

- Since 1970, the annual average temperature has risen about 2°F, with the greatest change occurring during the winter.
- The number of freezing days has declined by four to seven days per year for most of the region since the mid-1970s.
- Since 1901, there has been a 30 percent increase in precipitation during the fall (except in southern Florida). Summer and winter precipitation declined.
- There has been an increase in heavy downpours in many parts of the region.
- The percentage of the region experiencing moderate to severe drought increased over the past three decades.
- Barrier islands are losing land at an increasing rate, reducing their protective function.
- The destructive potential of Atlantic hurricanes has increased since 1970, correlated with an increase in sea surface temperature. A similar relationship with the frequency of landfalling hurricanes has not been established.
- An increase in average summer wave heights along the U.S. Atlantic coastline since 1975 has been attributed to a progressive increase in hurricane power.

The following climate-related changes are projected for the Southeast:

- Quality of life will be affected by increasing heat stress, water scarcity, and severe weather events.
- Warming in all seasons will continue and the rate of warming will increase through the end of the century.
- The greatest increases in temperature are expected in the summer, and the number of very hot days will increase at a greater rate than the average temperature.
- Average temperatures are projected to rise from between 4.5°F to about 9°F by the 2080s, depending upon the degree to which emissions are controlled.
- Higher temperatures will lead to an increased frequency, intensity, and duration of drought across the region.
- An increase in average sea level of up to two feet or more and the likelihood of increased hurricane intensity and associated storm surge are likely to be among the most costly consequences of climate change for this region.
- The intensity of Atlantic hurricanes is likely to increase this century with higher peak wind speeds, rainfall intensity, and storm surge. Increased intensity will further affect low-lying coastal ecosystems and coastal communities along the Gulf and South Atlantic coastal margin; increase inland and coastal flooding, coastal erosion rates, wind damage to coastal forests, and wetland loss; and exacerbate the risk to people, personal property, and public infrastructure.
- More frequent storm surge flooding and permanent inundation of coastal ecosystems and communities is likely in some low-lying areas, particularly along the central Gulf Coast where the land surface is sinking.
- The salinity of estuaries, coastal wetlands, tidal rivers, and shallow aquifers is likely to increase.

- Ecological thresholds are expected to be crossed throughout the region, causing major disruptions to ecosystems and to the benefits they provide to people.
- Decreased water availability due to increased temperature and longer periods of time between rainfall events, in addition to an increase in demand, is very likely to affect the region's economy as well as its natural systems.

Midwest (Great Lakes)

The following changes in climatic conditions have been observed in the Midwest in recent decades:

- Average temperatures have increased, particularly during the winter.
- Precipitation in summer and winter has been above average for the last three decades, the wettest period in a century.
- Heavy downpours are twice as frequent as they were a century ago, and two record-breaking floods occurred in the past 15 years.
- There has been a decrease in lake ice throughout the region and in the Great Lakes.

The following climate-related changes are projected for the Midwest:

- Heat waves are expected to be more frequent, severe, and longer lasting.
- Precipitation is expected to increase in winter and spring and to become more intense throughout the year, leading to more pronounced flooding/runoff conditions.
- The likelihood of drought will increase in the summer, with water levels declining in rivers, streams, and wetlands.
- Great Lake levels are expected to fall no more than a foot under a lower emissions scenario and between one and two feet under a higher emissions scenario. The greater the temperature rise, the higher the likelihood of a larger decrease in lake levels. There are also potential impacts on beaches, coastal ecosystems, dredging requirements, infrastructure, and shipping.
- Stratification of lake waters will occur earlier and for longer periods during the summer, increasing the risk of oxygen-poor or oxygen-free dead zones that kill fish and other living things.
- Aquatic ecosystem disruptions are likely to be compounded by invasions by non-native species. Native species are expected to decline.

Southwest

The following changes in climatic conditions have been observed in the Southwest:

- The average temperature in the Southwest has increased about 1.5°F compared to a 1960-1979 baseline period.
- As of 2009, much of the region remained in a drought that began around 1999; the most severe western drought in the last 110 years, which has been exacerbated by record warming.
- Precipitation generally decreased during the summer and fall in the Southwest, while winter and spring have had increases in precipitation.

The following climate-related changes are projected for the Southwest:

- By 2100, the average annual temperature is expected to rise from about 4 to 10°F above the 1960–1979 baseline period; summer temperature increases are expected to be greater than the annual average increase in some areas.
- There is an increased probability of drought.
- Increased flood risk in the Southwest is likely to result from a combination of decreased snow cover on the lower slopes of high mountains and an increased fraction of winter precipitation falling as rain and therefore running off more rapidly. The increase in rain on snow events will also result in rapid runoff and flooding.
- Changes in the timing and amount of river flow during the winter and spring in the Sacramento-San Joaquin River Delta is expected to double the risk of flooding by mid-century and increase it by a factor of eight by 2100.

- There is presently no consensus on how the region's summer monsoon (rainy season) might change in the future.
- Limitations imposed on water supply by projected temperature increases are likely to be made worse by substantial reductions in rain and snowfall in the spring months, when precipitation is most needed to fill reservoirs to meet summer demand.

Northwest

The following changes in climatic and related conditions have been observed in the Northwest:

- The region experienced an average temperature increase of 1.5°F over the last century, with some areas having an average increase of up to 4°F.
- Higher cool season temperatures have resulted in more precipitation falling as rain rather than snow and leading to an earlier snowmelt.
- The April 1 snowpack has declined substantially throughout the region. The average decline in the Cascade Mountains was about 25 percent over the past 40 to 70 years, with most of this due to the 2.5°F increase in cool season temperatures over that period.
- The timing of the peak spring runoff has been shifting over the past 50 years with the peak of spring runoff shifting from a few days earlier in some places to as much as 25 to 30 days earlier in others.
- A low oxygen dead zone off the coast of Washington and Oregon is believed to be driven by climate change.
- Ocean acidification is occurring along the Northwest coast.

The following climate-related changes are projected for the Northwest:

- Temperatures are projected to increase another 3 to 10°F by 2100.
- Increases in winter precipitation and decreases in summer precipitation are projected, though these projections are less certain than those for temperature.
- Heavier winter rainfall suggests an increase in saturated soils and, therefore, an increased number of landslides on coastal bluffs, which will be especially problematic in areas where there has been intensive development on unstable slopes. Sea level rise will exacerbate these conditions.
- Further declines in the region's snowpack are expected, with variations due to latitude, elevation, and proximity to the coast. A decline in the April 1 snowpack in the Cascades of 40 percent is projected by the 2040s.
- The trend in the earlier timing of the peak spring runoff is projected to continue, with shifts anticipated of 20 to 40 days. However, major shifts in the timing of runoff are not expected in areas dominated by rain instead of snow.
- Extreme high and low streamflows are also projected to change. Increased winter rainfall is expected to lead to more flooding in some areas, and low flows in the late summer are projected to decrease further.
- Sea level rise along vulnerable coastlines will result in increased erosion and the loss of land. Some areas in the Northwest are experiencing falling sea levels due to uplift. A mid-range estimate of 13 inches by 2100 has been made for the Puget Sound basin.
- Salmon and other coldwater species will experience additional stresses as a result of rising water temperatures and declining summer streamflows.

Alaska

The following changes in climatic conditions and impacts have been observed in Alaska:

- Higher temperatures are contributing to earlier spring snowmelt, reduced sea ice, widespread glacier retreat, and permafrost warming.
- Between 1970 and 2000, the snow-free season increased by approximately 10 days across Alaska, primarily due to earlier snowmelt in the spring.

- Increased evaporation, combined with thawing of permafrost, has resulted in declines in the area of closed-basin lakes over the past 50 years.
- Increasing storm activity in autumn in recent years has delayed or prevented barge operations that supply coastal communities with fuel.
- High-wind events have become more frequent along the western and northern coasts. The same regions are experiencing increasingly long sea-ice-free seasons and hence longer periods during which coastal areas are especially vulnerable to wind and wave damage.
- Coastal erosion is causing the shorelines of some areas to retreat at average rates of tens of feet per year. The ground beneath several native communities is literally crumbling into the sea.
- The rate of erosion along Alaska's northeastern coastline has doubled over the past 50 years.
- The Bering Sea pollock fishery has experienced major declines in recent years.

The following climate-related changes are projected for Alaska:

- Average annual temperatures in Alaska are projected to rise about 3.5 to 7°F by the middle of this century and 5 to 13°F by the end of the century.
- Higher temperatures are expected to continue to reduce Arctic sea ice coverage, which will increase coastal erosion and flooding associated with coastal storms and alter the timing and location of plankton blooms, which is expected to drive major shifts of marine species.
- Storm activity is expected to increase in the Bering Sea. An increase in the frequency and/or intensity of Arctic Ocean storms is also expected.
- Increases in evaporation due to higher air temperatures are expected to lead to drier conditions overall and an increased likelihood of summer drought.
- Marine ecosystems will experience continued perturbations, including northward shifts, with consequences for the commercial fishery and for the food supplies of indigenous populations.

Islands

While changes in temperature and sea level have been observed for several decades, the following climate-related changes are projected for the Pacific and Caribbean islands:

- Air and ocean surface temperature are expected to increase.
- The number of heavy rain events is very likely to increase.
- In the Pacific islands, the rainy season may shift from winter to summer.
- In the Caribbean, total annual precipitation will decline, particularly under higher emissions scenarios.
- Hurricane (typhoon) wind speeds and rainfall rates are likely to increase with continued warming.
- Islands and other low-lying coastal areas will be at increased risk from coastal inundation due to sea level rise and storm surge, with major implications for coastal communities, infrastructure, natural habitats, and resources.
- The availability of freshwater is likely to be reduced, with significant implications for island communities, economies, and resources.