SECTION 2

How Is Pacific Northwest Climate Changing?

The Pacific Northwest is experiencing a suite of long-term changes that are consistent with those observed globally as a result of human-caused climate change. These include increasing temperatures, a longer frost-free season, decreased glacial area and spring snowpack, earlier peak streamflows in many rivers and rising sea level at most locations. Natural variability can result in short-term trends that are opposite those expected from climate change, as evidenced by recent regional cooling and increases in spring snowpack. Recent studies have investigated trends in greater detail, and clarified the role of variability, in particular regarding changes in extremes, sea level rise, ocean acidification, and snow.

1. Washington and the Pacific Northwest have experienced long-term warming, a lengthening of the frost-free season, and more frequent nighttime heat waves.[1]

- *Increasing temperatures.* The Pacific Northwest warmed about +1.3°F between 1895 and 2011, with statistically-significant warming occurring in all seasons except for spring.[A][1][2] This trend is robust: similar 20th century trends are obtained using different analytical approaches.[3] All but five of the years from 1980 to 2011 were warmer than the 1901-1960 average (Figure 2-1, Table 2-1).[1]

- *Frost-free season.* The frost-free season (and the associated growing season) has lengthened by 35 days (±6 days) from 1895 to 2011.[2]

- *Heat waves.* Nighttime heat events have become more frequent west of the Cascade Mountains in Oregon and Washington (1901-2009).[4] For the Pacific Northwest as a whole there has been no significant trend in daytime heat events or cold events for 1895-2011.

- *Short-term trends.* The Pacific Northwest's highly variable climate often results in short-term cooling trends, as well as warming trends larger than the long-term average (Figure 2-1). The cooling observed from about 2000 to 2011, for example, is similar to cooling observed at other times in the 20th century, despite overall long-term warming.

- *Challenges in assessing trends.* Estimates of temperature changes over time can be affected by changes in the location and number of measurements made and in the instruments used to make the measurements. The temperature datasets reported here include corrections for these factors,[5] and there is no published evidence that these issues affect long-term regional trends in temperature.[6]

[A] In this section, trends are only reported if they are statistically significant at the 90% level or more.

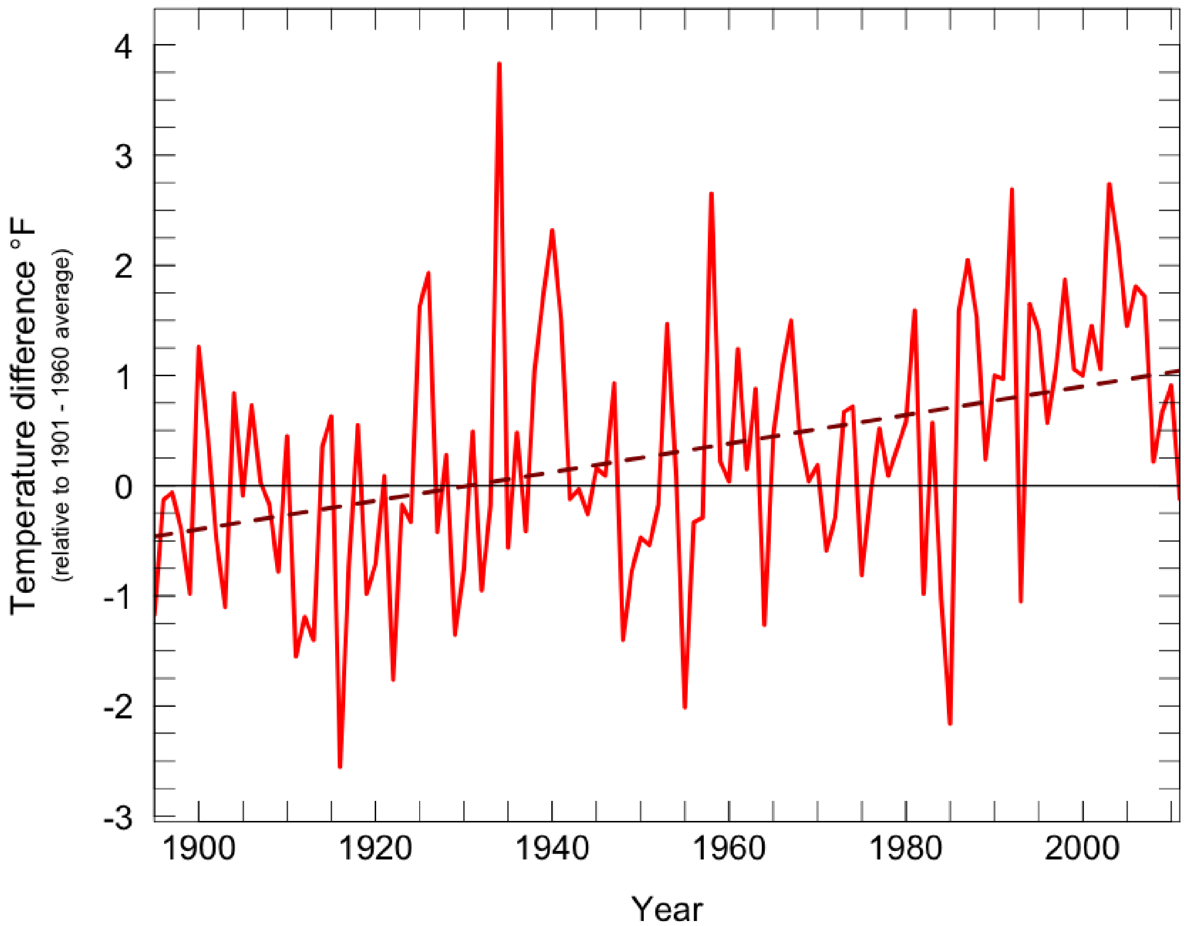

Figure 2-1. Rising temperatures in the Pacific Northwest. Average annual temperature (red line) shown relative to the 1901–1960 average (indicated by the solid horizontal line). The dashed line is the fitted trend, indicating the +0.13°F/decade warming for 1895-2011. *Data source: Kunkel et al. 2013.*[2]

2. **Sea level is rising along some parts of the Washington coastline and falling in others due to the combination of global sea level rise and local vertical land movement.**

- *Local sea level rise.* Although on average sea level is rising in the region, local sea level change is modulated by vertical land motion, in response to tectonics and other processes. Current observations of local sea level changes range from a decline along the northwest Olympic peninsula, a region experiencing uplift, to sea level rise in parts of the Puget Sound and the outer coast where land is subsiding.[7][8]

- *Year-to-year variability.* Local sea level is affected by shorter-term variations in addition to long-term changes in sea level associated with global warming. For example, El Niño conditions can temporarily increase regional sea level up to about a foot during winter months.[9][10]

3. There has been no discernible long-term trend in Pacific Northwest precipitation.

- *Annual precipitation.* There is no statistically-significant trend towards wetter *or* drier conditions in Pacific Northwest precipitation for the period 1895-2011.[2]

- *Year-to-year variability.* Natural variability has a large influence on regional precipitation, causing ongoing fluctuations between wet years and dry years and wet decades and dry decades.

- *Heavy downpours.* Trends in heavy precipitation events are ambiguous for the Pacific Northwest. Most studies find modest increasing trends, but most are not statistically-significant, and results depend on the dates and methods of the analysis.[2][11][12][13]

4. Long-term changes in snow, ice and streamflows reflect the influence of warming.

- *Spring snowpack.* Spring snowpack fluctuates substantially from year-to-year, but declined overall in the Washington Cascades from the mid-20th century to 2006.[14][15] This trend is due primarily to increasing regional temperature and reflects the influence of both climate variability and climate change.[16][17] Natural variability can dominate over shorter time scales, resulting (for example) in an increase in spring snow accumulation in recent decades.[14]

- *Glaciers.* About two-thirds of the glaciated area in the lower 48 states (174 out of 266 sq. miles) is in Washington.[18] Although there are some exceptions, most Washington glaciers are in decline. Declines range from a 7% loss of average glacier area in the North Cascades (1958-1998)[19] to a 49% decline in average area on Mt. Adams (1904-2006).[20]

- *Streamflow timing.* The spring peak in streamflow is occurring earlier in the year for many snowmelt-influenced rivers in the Pacific Northwest (observed over the period 1948-2002) as a result of decreased snow accumulation and earlier spring melt.[21]

5. The coastal ocean is acidifying, but ocean temperatures show no strong trends.

- *Ocean acidification*. The chemistry of the ocean along the Washington coast has changed due to the absorption of excess CO_2 from the atmosphere. Local conditions are also affected by variations and trends in upwelling of deeper Pacific Ocean water that is low in pH and high in nutrients, deliveries of nutrients and organic carbon from land, and absorption of other important acidifying atmospheric gases. Conditions vary by location and from season to season, but appear to have already reached levels that can affect some species.[B][8][22]

[B] 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.

- *Coastal ocean temperature.* The long-term trend in coastal ocean temperatures has been small compared to the considerable variations in ocean temperatures that occur from season-to-season, year-to-year, and decade-to-decade. These variations result from both local effects, such as winds and upwelling, to remote effects, such as El Niño. No warming has been detected for the general region of the Pacific Ocean offshore of North America,[23] but warming has been detected for the Strait of Georgia[C] and off the west coast of Vancouver Island.[24]

For more details on observed changes in Pacific Northwest climate, see Table 2-1.

Additional Resources

The following tools and resources are suggested in addition to the reports and papers cited in this document.

- Trends in temperature, precipitation, and snowpack for individual weather stations across the Pacific Northwest: http://www.climate.washington.edu/trendanalysis/
- Trends in temperature and precipitation for Washington state and specific regions within the state: http://charts.srcc.lsu.edu/trends/
- Centralized resource for observed climate in the Western U.S.: http://www.wrcc.dri.edu/

[C] The Strait of Georgia is located north of the Puget Sound, between Vancouver Island and British Columbia.

Table 2-1. Observed trends in Pacific Northwest climate.

Variable	*Observed Change* [A]
Temperature	
Annual	Warming: +0.13°F/decade (1895-2011)[1][2]
Seasonal	Warming in most seasons *Winter* Warming: +0.20°F/decade (1895-2011)[2] *Spring* No significant trend (1895 – 2011)[2] *Summer* Warming: +0.12°F/decade (1895–2011)[2] *Fall* Warming: +0.10°F/decade (1895–2011)[2]
Extremes	Statistically-significant increase in nighttime heat events west of the Cascade Mountains in Oregon and Washington (1901-2009).[4] No significant trends in daytime heat events or cold events (1895-2011).[2]
Freeze-free Season	Lengthening: +3 days/decade (1895–2011)[D][2]
Precipitation	
Annual	No significant trend (1895–2011)[1][2]
Extremes	Ambiguous: Studies find different trends depending on the dates and methods of the analysis[2][11][12][13]
Hydrology	
Snowpack	Long-term declines, recent increases. ▪ Washington Cascades snowpack decreased by about −25% between the mid-20th century and 2006, with a range of −15 to −35% depending on the starting date of the trend analysis (which ranged from about 1930 to 1970)[14][15] ▪ Snowpack in recent decades (1976–2007) has increased but the change is not statistically significant and most likely the result of natural variability.[14]
Glaciers	Declining overall ▪ North Cascades: −7% decline in glacier area (1958-1998)[19] ▪ Mt. Rainier: −14% decline in glacier volume (1970-2007)[25] ▪ Mt. Adams: −49% decline in glacier area (1904-2006)[20] ▪ Olympic Mountains: No published studies on long-term trends.
Annual Streamflow Volume	Declining in some locations Trends in annual streamflow are relatively small in comparison to year-to-year variability. A study of 43 streamflow gauges in the Pacific Northwest found declining trends (1948-2006), ranging from no change to −20% for individual locations.[26]

[D] Number of days between the last freeze of spring and first freeze of fall.

Variable	Observed Change [A]
Timing of Peak Streamflow	Shifting earlier, depending on location ▪ Spring peak streamflow in the Pacific Northwest has shifted earlier in snowmelt-influenced rivers – the shift ranges from no change to about 20 days earlier (1948-2002).[21]
Coastal Ocean	
Ocean Temperature	Varies with location ▪ Over the larger region offshore of North America: no significant warming in ocean surface temperatures (1900-2008)[23] ▪ In the Strait of Georgia and West of Vancouver Island: significant warming observed. Average for top 330 ft: +0.4°F/decade (1970-2005)[24]
Ocean Acidification	Acidifying ▪ Ocean waters on the outer coast of Washington and the Puget Sound have become about +10 to +40% more acidic since 1800 (decline in pH of −0.05 to −0.15).[27]
Sea Level Change	Mostly rising; varies with location ▪ Friday Harbor, WA: +0.4 in./decade (1934-2008) ▪ Neah Bay, WA: −0.7 in./decade (1934-2008) ▪ Seattle, WA: +0.8 in./decade (1900-2008) ▪ Astoria, OR: −0.1 in./decade (1925-2008)[28]

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