Chapter 2: Climate Change in Oregon

Summary

Oregon's climate has already warmed considerably, and the cause is most likely rising greenhouse gases. Future warming depends on how much global greenhouse gas emissions rise. Under continued increasing greenhouse gas emissions, Oregon's climate is expected to warm on average 3–7°F by the 2050s and 5–11°F on average by the 2080s. However, under scenarios that level off greenhouse gas emission by mid-century, Oregon's climate is expected to warm 2–5°F by the 2050s and 2–7°F by the 2080s. Annual precipitation is projected to increase slightly, although climate scientists have less confidence in precipitation projections than temperature projections. Summers are expected to warm more than the annual average and are likely to become drier. Extreme heat and extreme precipitation events are expected to become more frequent. In many respects, 2015 was a notable year in its record warmth and snowpack drought that resembles what climate model projections indicate would be normal conditions by middle of this century.

Introduction

Warming, already apparent in Oregon, is likely due to rising greenhouse gas concentrations caused by human activities. Future warming depends on how much global greenhouse has emissions rise. Under scenarios aligned with the Paris agreement of 2015 (and Oregon's own greenhouse gas emissions goals), it may be possible to limit warming to just another 1–3°F. Under continued increasing greenhouse gas emission, however, Oregon's climate is expected to continue to warm throughout this century and beyond. In general, Oregon can expect warmer temperatures year round with greater warming during the summer. A modest increase in annual precipitation is expected along with precipitation decreases in summer and increases during winter, spring, and fall. Precipitation projections are more uncertain than temperature projections.

Future climate projections in this chapter and most impacts analyses in subsequent chapters are based on the latest global climate models from the 5th Coupled Model Intercomparison Project (CMIP5) (Taylor *et al.*, 2012) forced with future emissions pathways called representative concentration pathways (RCPs) (van Vuuren *et al.*, 2011) (fig. 2.1). Under the very low emissions pathway (RCP 2.6), it could be possible to limit global warming to 2°C in line with the 2015 Paris agreement (UNFCCC, 2015), but net global emissions would need to be negative by 2100. The two most commonly cited future emissions pathways are the low emissions pathway (RCP 4.5), representing a moderate effort to reduce global greenhouse gas emissions which peak near mid-century then decline, and a high emissions pathway (RCP 8.5), representing a business-as-usual continuation of emissions throughout the 21st century. The previous generation of global climate models and emissions scenarios (SRES) is occasionally used in recent literature cited in this report. In addition, some recent economic analyses have taken advantage of a coordinated policy scenario framework using a reference scenario (REF) greater than RCP 8.5 and two mitigation policy scenarios (POL), one equivalent to RCP 4.5 and the other between RCP 4.5 and RCP 2.6 (Paltsev *et al.*, 2013). Table 2.1 gives a comparison between the SRES and RCP and REF/POL emissions pathways.

Figure 2.1 The representative concentration pathways (RCPs) are numbered according to the change in radiative forcing (from +2.6 to +8.5 watts per square meter) that results by 2100. This figure shows annual carbon emissions (top) and carbon dioxide equivalent levels in the atmosphere (bottom). (Figure source: Walsh *et al.*, 2014)

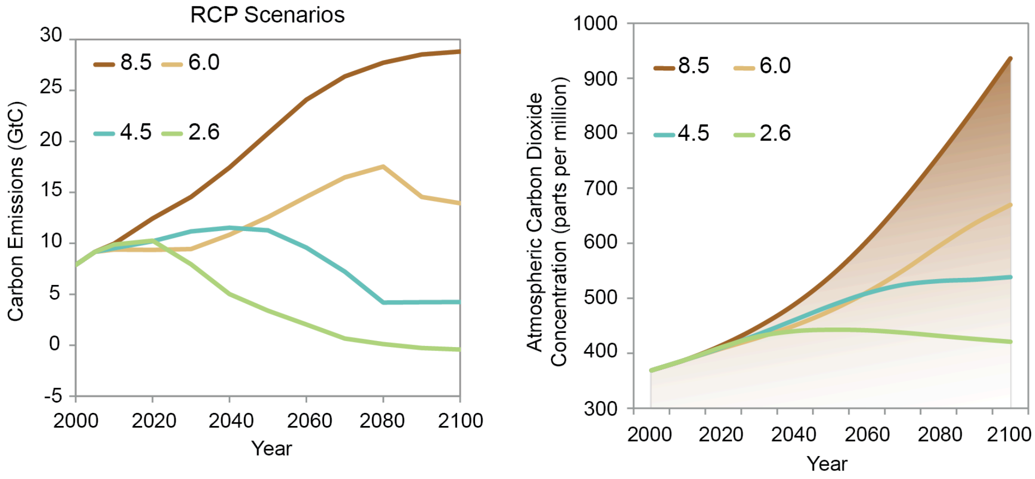


Table 2.1. Descriptors for emissions scenarios used in this report.

Descriptor	Scenario
Very Low	RCP 2.6, POL 3.7
Low	RCP 4.5, SRES B1, POL 4.5
Medium	RCP 6.0, SRES A1B
Medium High	SRES A2
High	RCP 8.5, SRES A1FI
Very High	REF 10

Sources of Variability

Year-to-year variability in Oregon's climate is influenced by the El Niño–Southern Oscillation (ENSO)— linked to variations in the atmosphere and ocean in the tropical Pacific Ocean—and other patterns of North Pacific variability (Abatzoglou *et al.*, 2014a; Halpert and Ropelewski, 1992; Newman *et al.*, 2016). The warm ENSO phase—El Niño—tilts the odds for a warmer, drier than normal winter in Washington whereas the cool phase—La Niña—makes a colder, wetter than normal winter more likely; the opposite is true for California. However, not every El Niño is alike, nor is its impact on Oregon's climate. In particular, in some El Niño years Oregon's winter climate is a little warmer and drier than usual like Washington's, in other El Niño years it's in the normal range, and occasionally southern Oregon is wetter than usual along with California. There is some evidence suggesting that the way it goes may depend upon the characteristics of El Niño itself—that is, upon where along the equator the sea surface temperatures are farthest from normal (Capotondi *et al.*, 2015; Yu *et al.*, 2012). However, the number of events of each type may be too small to draw robust conclusions.

Under a warmer climate, future changes in ENSO activity are uncertain as some models project ENSO amplitude to increase and others project it to decrease. The response of ENSO in CMIP5 climate models to global warming depends on the pattern of sea surface warming in the Tropical Pacific (Zheng *et al.*, 2016). Models with greater warming in the eastern Tropical Pacific, similar to the pattern during El Niño events, displayed an increase in ENSO amplitude in the future (Zheng *et al.*, 2016). Greater warming of the eastern tropical Pacific in a suite of climate models results in increases in the occurrence of extreme El Niño events (Cai *et al.*, 2014), which also contributes to greater occurrence of subsequent extreme La Niña events (Cai *et al.*, 2015). Furthermore, one study has shown that ENSO's remote connections between tropical Pacific sea surface temperature patterns and West Coast rainfall may intensify (Zhou *et al.*, 2014).

The dominant pattern of sea surface temperature in the North Pacific Ocean—the so-called Pacific Decadal Oscillation (PDO)—has been an important research topic for both scientists and resource managers alike. A consensus following the last 15 years of research has emerged that the PDO is not a single, independent phenomenon, but rather a combination of different processes including ENSO (Newman *et al.*, 2016). How the PDO might change under a warmer climate remains unclear; however, one study using a single climate model shows PDO amplitude weakening and the time scale shortening under a warmer climate (Zhang and Delworth, 2016).

Mean Temperature

Oregon's mean temperature warmed by 2.2°F per century during 1895–2015 (fig. 2.2). In fact, 2015 was the warmest year on record in Oregon (NOAA, 2016). The Pacific Northwest (Washington, Oregon, Idaho, and western Montana) warmed by about 1.1°F to 1.5°F between 1901 and 2012 largely due to increases in greenhouse gas concentrations (Abatzoglou *et al.*, 2014a). Other sources of regional climate variability cannot account for the observed long-term upward trend (Abatzoglou *et al.*, 2014b; Johnstone and Mantua, 2014). Warming in the Pacific Northwest has accelerated: trends in recent decades from the 1970s onward are larger than trends over the last century (Abatzoglou *et al.*, 2014a).

Going forward, Oregon's mean annual temperature is projected to increase by 2.1°–10.7°F by the 2080s (2070–2099 average) compared to the historical baseline (1970–1999 average) (fig. 2.2; table 2.2). The range in future temperature projections reflects the different climate model responses across both the low and high emissions pathways. Under the low emissions pathway (RCP 4.5), mean annual temperature in Oregon is projected to increase on average 3.6°F with a range of 1.8°–5.4°F by the 2050s and 4.6°F on average with a range of 2.1°–6.7°F by the 2080s (table 2). Under the high emissions pathway (RCP 8.5), annual temperature increases are higher: 5.0°F (2.9°–6.9°F) by the 2050s and 8.2°F (4.8°–10.7°F) by the 2080s. Summers are projected to warm more than other seasons (table 2.2), with average warming of 10.2°F (6.5°–13.9°F) by the 2080s under the high emissions pathway (RCP 8.5).

Figure 2.2 Projected changes in Oregon's mean annual temperature (top), winter (bottom left), and summer (bottom right) temperature from the baseline 1970–1999 under a low (RCP 4.5) and a high (RCP 8.5) future emissions pathway. The thicker solid lines depict the mean annual temperature of 35 climate models while the shading depicts the minimum and maximum annual temperatures from the 35 models. The mean, minimum, and maximum have been smoothed to emphasize long-term (greater than year-to-year) variability. Orange shading indicates where RCP 4.5 and RCP 8.5 overlap. Temperature observations using NCEI data for Oregon is shown by the thin black line (Figure source: David Rupp; data source: Rupp *et al.*, 2016)

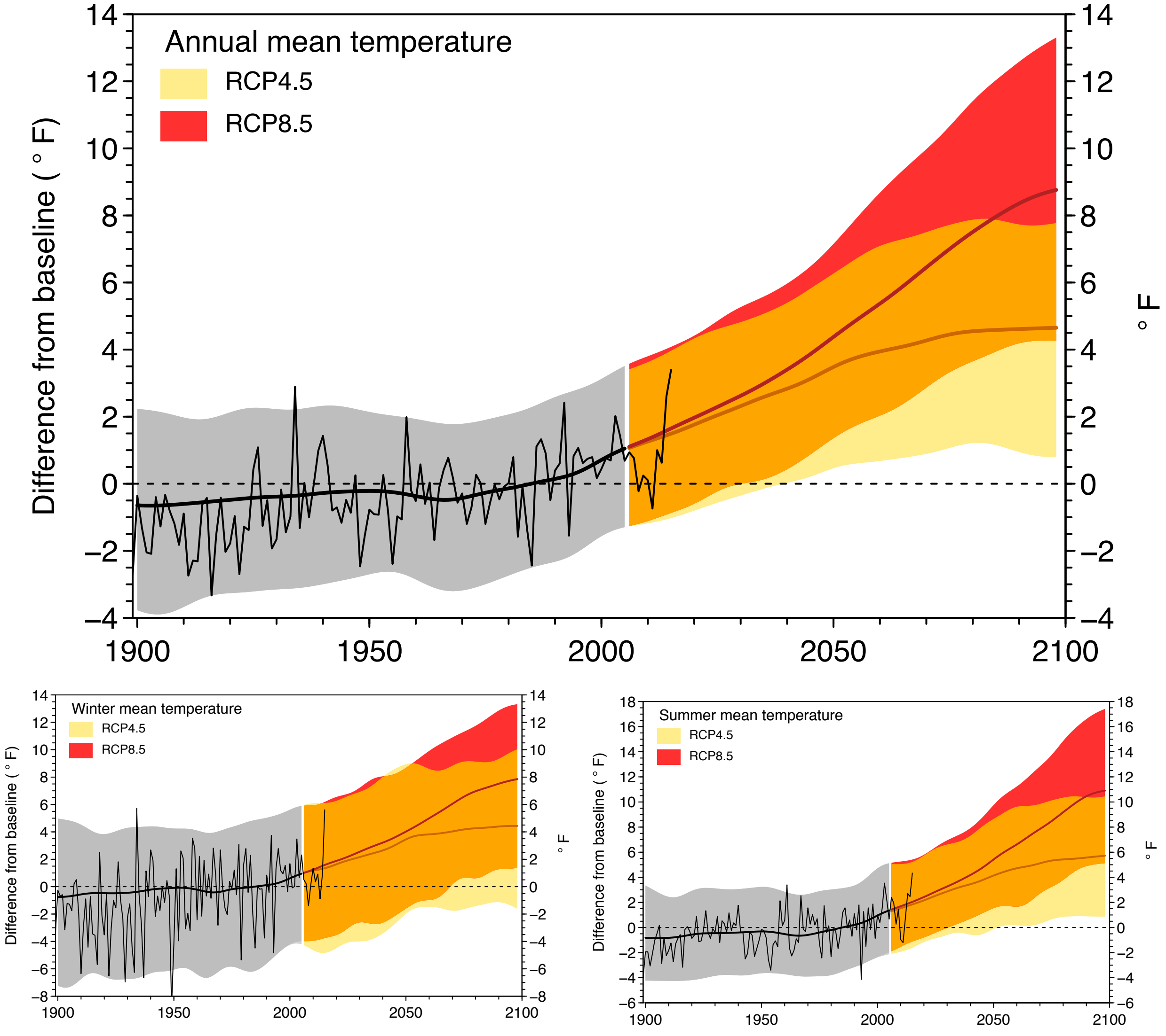


Table 2.2 Projected future changes in Oregon's mean annual and seasonal temperature (°F) from the historical baseline (1970–1999) for mid- and late-21st century under a low (RCP 4.5) and a high (RCP 8.5) future emissions pathway. Given are the average changes (bolded) from 35 global climate models and the 5th to 95th percentile range across the 35 models. (Data source: Rupp *et al.*, 2016)

	2050s		**2080s**	
	Low	High	Low	High
Annual	**3.6°F** (1.8, 5.4)	**5.0°F** (2.9, 6.9)	**4.6°F** (2.1, 6.7)	**8.2°F** (4.8, 10.7)
Winter (DJF)	**3.3°F** (1.6, 5.1)	**4.5°F** (2.4, 6.5)	**4.2°F** (1.8, 6.5)	**7.4°F** (4.2, 9.8)
Spring (MAM)	**3.1°F** (1.4, 5.0)	**4.1°F** (2.0, 5.9)	**3.8°F** (1.7, 6.0)	**6.7°F** (3.8, 9.2)
Summer (JJA)	**4.5°F** (2.2, 6.8)	**6.3°F** (3.6, 8.9)	**5.5°F** (2.7, 8.3)	**10.2°F** (6.5, 13.9)
Fall (SON)	**3.7°F** (1.5, 5.4)	**5.2°F** (2.6, 7.0)	**4.7°F** (2.0, 6.9)	**8.6°F** (4.6, 11.4)

Extreme Temperature

During 1920–2012, trends in the magnitude of the hottest day of the year varied across Oregon; some sites had warming and others cooling trends (Abatzoglou *et al.*, 2014a). Cooling trends were observed because many of the hottest day records were set in the 1930s during widespread drought (Abatzoglou and Barbero, 2014). However, warming trends were apparent in the coldest night of the year at all sites across Oregon and were quite large, exceeding 1.8°F per decade during 1970–2012 (Abatzoglou *et al.*, 2014a). During 1930–2010, many stations in the Pacific Northwest experienced increasing trends in extreme heat events defined by minimum temperature thresholds (Oswald and Rood, 2014), consistent with previous findings (Mote *et al.*, 2013).

In the future, extreme heat events are expected to increase in frequency, duration, and intensity due to warming temperatures. In fact, the hottest days in summer are projected to warm by 1°–2°F more than the change in mean summer temperature over the Pacific Northwest by late-century under the high emissions pathway (RCP 8.5) (Rupp, 2014). However, synoptic conditions that drive extreme heat events in the Pacific Northwest, such as upper-level ridges—or large areas of high atmospheric pressure—and strong offshore flow, are projected to weaken (Brewer and Mass, 2016a). Most CMIP5 climate models suggest reductions in ridging over the eastern Pacific during summer (Brewer and Mass, 2016b) leading to a weakening of the strong offshore flow events that result in heat waves for western Oregon and Washington by late-century under the high emissions pathway (RCP 8.5) (Brewer and Mass, 2016a). Increased frequency of ridging, however, is projected by most models for inland of the coast, which could enhance near-surface warming events in the western United States (Brewer and Mass, 2016b). These results suggest that increases in extreme heat events are likely to be greater for eastern Oregon than for western Oregon (Brewer and Mass, 2016a).

Precipitation

During 1895–2015, annual precipitation totals averaged over the state of Oregon ranged from 22” in 1930 to about 49” in 1996 with hardly a trend—0.73” increase per century—in annual totals (NOAA, 2016). Likewise, averaged over the Pacific Northwest, there was no significant trend in annual precipitation from 1901–2012, although a positive trend was noted for spring. Interannual-to-decadal variability dominated any long-term signal in precipitation (Abatzoglou *et al.*, 2014a).

Future precipitation trends are expected to continue to be dominated by large natural variability (fig. 2.3). Still, annual precipitation in Oregon is projected to increase on average by 1.9% by the 2050s, and 3.4% by the 2080s under the low emissions pathway (RCP 4.5). Under the high emissions pathway, increases in annual precipitation are a bit larger for each time period: 2.7%, and 6.3%, respectively. However, the range of responses from individual global climate models surrounds zero (table 2.3). Larger changes are projected for seasonal precipitation. Oregon’s already dry summers are projected to become drier while winter, spring, and fall are projected to become wetter, albeit some models project increases and others project decreases in each season (table 2.3). Climate models that are better at simulating historical climate in the Pacific Northwest (Rupp *et al.*, 2013) project a larger increase in precipitation during October–January than climate models with less skill (Rupp *et al.*, 2016). However, climate models’ representation of changes in Northern Hemisphere winds under global warming may be overestimated, on average, suggesting that future winter wetting along the West Coast may actually be less than the average of the wetting projected by CMIP5 models (Simpson *et al.*, 2015).

Figure 2.3 Projected changes in Oregon’s annual total precipitation (top), winter (bottom left), and summer (bottom right) precipitation from the baseline 1970–1999 under a low (RCP 4.5) and a high (RCP 8.5) future emissions pathway. The thicker solid lines depict the mean annual precipitation of 35 climate models while the shading depicts the minimum and maximum annual precipitation from the 35 models. The mean, minimum, and maximum have been smoothed to emphasize long-term (greater than year-to-year) variability. Medium blue shading indicates where RCP 4.5 and RCP 8.5 overlap. Precipitation observations using NCEI data for Oregon is shown by the think black line. (Figure source: David Rupp; data source: Rupp *et al.*, 2016)

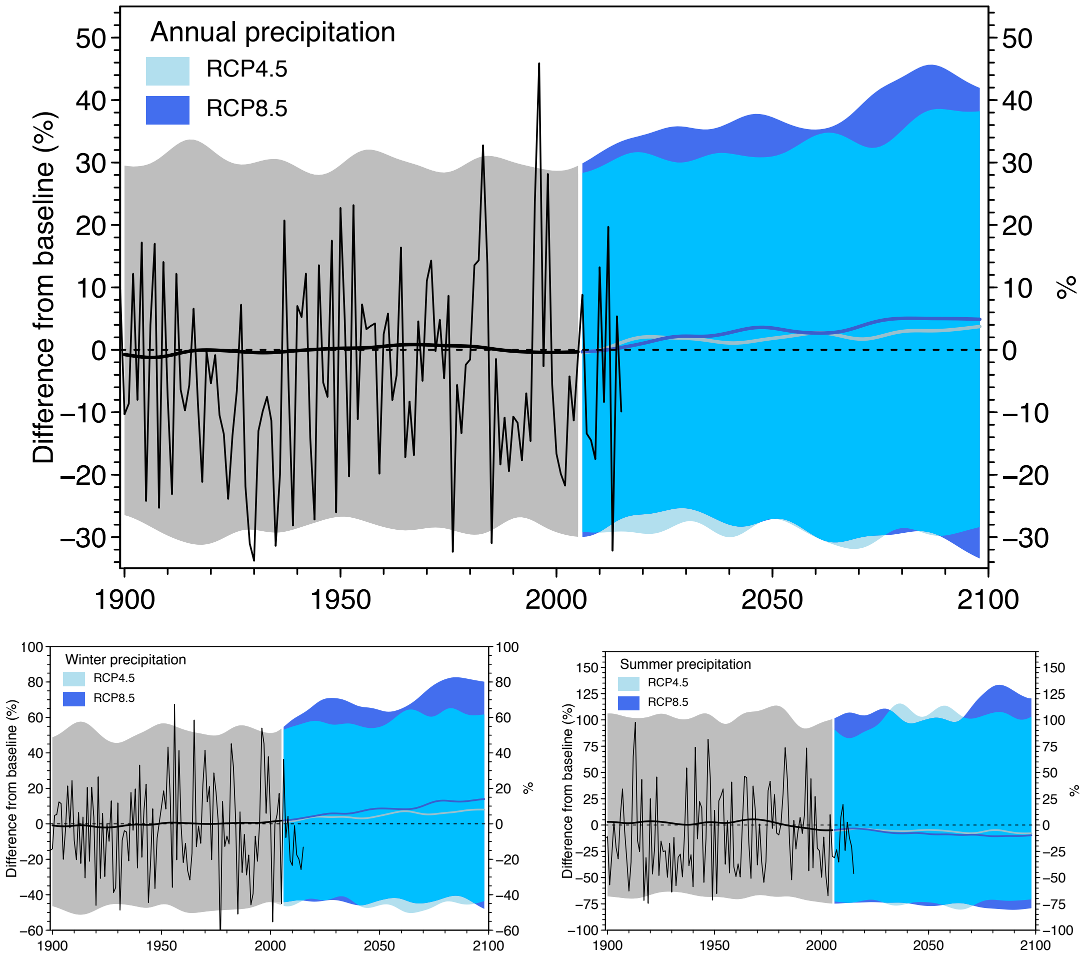


Table 2.3 Projected future relative changes in Oregon's total annual and seasonal precipitation (%) from the historical baseline (1970–1999) for mid- and late-21st century under a low (RCP 4.5) and a high (RCP 8.5) future emissions pathway. Given are the average changes (bolded) from 35 global climate models and the 5th to 95th percentile range across the 35 models. (Data source: Rupp *et al.*, 2016)

	2050s		**2080s**	
	Low	High	Low	High
Annual	**1.9%** (−4.9, 9.0)	**2.7%** (−6.0, 11.4)	**3.4%** (−5.6, 15.3)	**6.3%** (−5.2, 19.9)
Winter (DJF)	**4.9%** (−6.4, 16.5)	**7.9%** (−4.7, 24.3)	**7.3%** (−6.3, 19.9)	**14.5%** (−2.8, 37.1)
Spring (MAM)	**1.9%** (−8.9, 12.1)	**2.7%** (−7.2, 17.4)	**3.4%** (−7.7, 14.9)	**3.6%** (−9.4, 15.6)
Summer (JJA)	**−6.3%** (−28.5, 16.1)	**−8.7%** (−33.1, 22.5)	**−4.6%** (−24.2, 22.3)	**−7.7%** (−38.7, 33.5)
Fall (SON)	**0.5%** (−17.0, 14.4)	**−0.8%** (−17.1, 14.9)	**1.5%** (−15.0, 18.1)	**1.9%** (−17.2, 24.2)

Extreme Precipitation

Extreme precipitation events in the Pacific Northwest are governed both by atmospheric circulation and by how it interacts with complex topography (Parker and Abatzoglou, 2016). Atmospheric rivers—long, narrow swaths of warm, moist air that carry large amounts of water vapor from the tropics to mid-latitudes—generally result in coherent extreme precipitation events west of the Cascade Range, while closed low pressure systems often lead to isolated precipitation extremes east of the Cascade Range (Parker and Abatzoglou, 2016). Detection of past trends in extreme precipitation events across Oregon and the Pacific Northwest has depended on the location, time frame, and metric considered; some areas have seen increases and others decreases (Mote *et al.*, 2013). Two recent papers evaluating past extreme precipitation events over the Pacific Northwest using different metrics and time periods concluded that the frequency of extreme precipitation events did not change substantially (Hoerling *et al.*, 2016; Janssen *et al.*, 2014).

In the future, however, extreme precipitation events are expected to become slightly more frequent or intense in the Pacific Northwest. Under the high emissions pathway (RCP 8.5), both global and regional climate modeling project increases in the frequency of 2-day duration events with a 5-year return interval—that is, such events that have a 20% chance of occurring in a given year—on the order of a few more days per year by the end of the 21st century over the Pacific Northwest (Janssen *et al.*, 2014; Wang and Kotamarthi, 2015). Under a high emissions pathway (RCP 8.5), the amount of precipitation falling on extreme precipitation days is projected to increase by 15%–39% along the West Coast compared with an 11%–18% increase in winter mean precipitation (Warner *et al.*, 2015). Multiple regional climate modeling simulations over the Willamette River Basin, however, project only a slight increase in the magnitudes of the 2-year and 25-year extreme daily precipitation event by mid-century under a medium-high (SRES A2) emissions pathway (Halmstad *et al.*, 2013).

Box 2.1: The 2015 snow drought as a glimpse into Oregon's future

In 2015, Oregon was the warmest it has ever been since record keeping began in 1895 (NOAA, 2017). Precipitation during the winter of that year was near normal, but winter temperatures that were 5–6°F above average caused the precipitation that did fall to fall as rain instead of snow, reducing mountain snowpack accumulation (Mote *et al.*, 2016). This resulted in record low snowpack across the state, earning official drought declarations for 25 of Oregon's 36 counties (fig. 2.4).

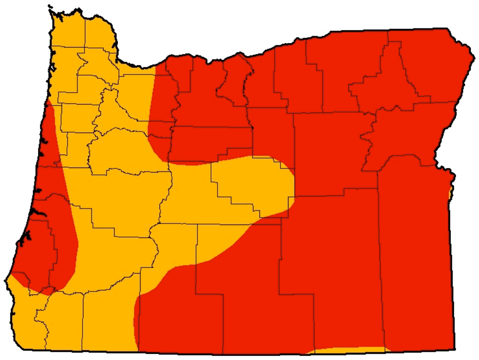


Figure 2.4. US Drought Monitor for August 25, 2015. All of Oregon was in severe (orange) or extreme (red) drought. Map courtesy of NDMC-UNL.

Drought impacts across Oregon were widespread and diverse:

- Farmers in eastern Oregon's Treasure Valley received a third of their normal irrigation water because the Owyhee reservoir received inadequate supply for the third year in a row (Stevenson, 2016).
- The 2015 fire season was the most severe in the Pacific Northwest's recorded history with more than $560 million in fire suppression costs (Sexton *et al.*, 2016).
- After not opening at all in 2014, Mount Ashland Ski Area had to make snow in order to open in 2015 (Stevenson, 2016).
- Detroit Lake saw a 26% decrease in visitation due to low water levels and unusable boat ramps (Wisler, 2016).
- People near the Upper Klamath Lake were warned not to touch the water as algal blooms that thrived in the low flows and warm waters produced extremely high toxin levels (Marris, 2015).
- More than half of the spring spawning salmon in the Columbia River perished, likely due to a disease that thrived in the unusually warm waters (Fears, 2015).
- In Washington, the 2015 snow drought resulted in crop losses amounting to an estimated $212.4 million for wheat, $86.5 million for apples, $13.9 million for raspberries, and $10.6 million for blueberries (McLain and Hancock, 2015). Similar analysis is not available for Oregon.

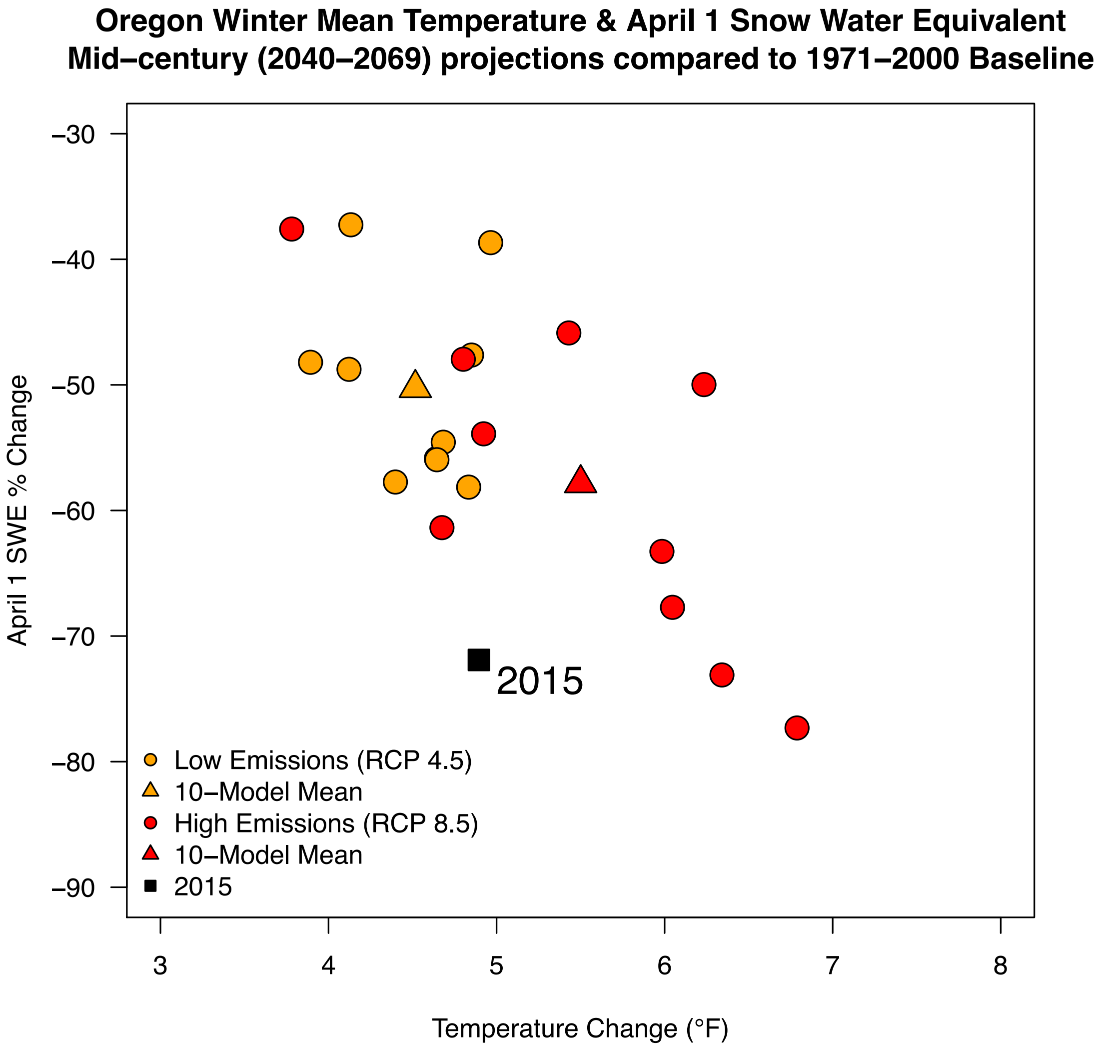
The West Coast–wide drought developed alongside a naturally-driven large, persistent high-pressure ridge (Wise, 2016). However, anthropogenic warming exacerbated the drought, particularly in Oregon and Washington (Mote *et al.*, 2016; Williams *et al.*, 2015). The 2015 snow drought in Oregon and Washington was also influenced to a larger degree by the persistent warm sea surface temperatures off the Pacific Northwest's coast (Mote *et al.*, 2016).

This mass of warm water off the coast—coined "the Blob"—began off the coast of southeast Alaska in fall of 2013 and, being maintained by the persistent high-pressure ridge, spread toward the West Coast in spring of 2014 and persisted through 2015 (Bond *et al.*, 2015). This was the largest ever recorded multi-year marine heat wave in the northeast Pacific (Di Lorenzo and Mantua, 2016). Remote connections between tropical Pacific and northeast Pacific sea surface temperatures during the weak El Niño of 2014–

15, and strong El Niño of 2015–16 helped this "blob" persist (Di Lorenzo and Mantua, 2016; Hu *et al.*, 2016).

Oregon's temperatures, precipitation, and snowpack in 2015 are illustrative of conditions that, according to climate model projections, may be considered "normal" by mid-century (fig. 2.5). With continued warming, this type of drought in which snowpack is low, but precipitation is near normal, should be expected more often in the future. In fact, for each 1.8°F of warming, peak snow water equivalent in the Cascade Range can be expected to decline 22%–30% (Cooper *et al.*, 2016). The 2015 drought in Oregon provided a salient test on the capacity of existing systems to tolerate such drought and gave insights into potential future adaptation priorities.

Figure 2.5 Projected future changes in winter (DJF) mean temperature and April 1 snow water equivalent (SWE) averaged over Oregon for mid-century (2040–2069) compared to the 1971–2000 historical baseline. The departure of year 2015 from the 1971–2000 baseline is noted. (Figure source: Meghan Dalton; data source: Mote *et al.* 2016, updated Livneh *et al.*, 2015, and http://climate.nkn.uidaho.edu/IntegratedScenarios/)



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