Future Climate Change Projections Oregon Mid-Coast Region

July 2019

Prepared by the Oregon Climate Change Research Institute

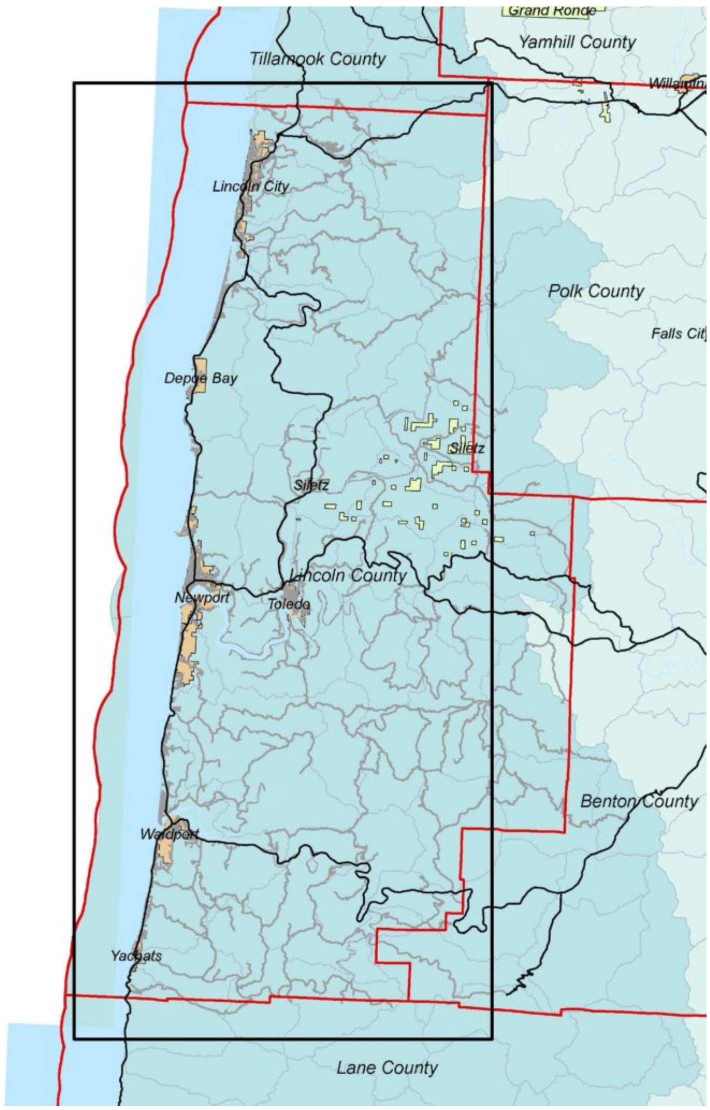

Photo: Mid-Coast Water Planning Partnership, http://midcoastwaterpartners.com/water-on-the-mid-coast/

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Future Climate Change Projections: Oregon Mid-Coast Region

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July 2019

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Introduction

Industrialization has given rise to increasing amounts of greenhouse gas emissions worldwide, which is causing the Earth's climate to warm (IPCC, 2013). The effects of which are already apparent here in Oregon (Dalton *et al.*, 2017; Mote *et al.*, 2019). Climate change, including changes in temperature, precipitation, hydrology, sea level, and coastal ocean conditions, is expected to affect the Oregon Mid-Coast region. This report describes projected future climate conditions for the Mid-Coast in terms of temperature, precipitation, snowpack, floods, droughts, wildfire, sea level, and coastal ocean conditions.

Projections in this report are derived from ten or more global climate models (GCM) and multiple scenarios of future global greenhouse gas emissions. Future climate projections have been "downscaled"—that is, made locally relevant—and summaries of projected changes in the climate are presented for a mid-21st century period—the "2050s"—and a late-21st century period—the "2080s"—compared to a historical baseline.

Global Climate Models

Global climate models are sophisticated computer models of the Earth's atmosphere, water, and land and how these components interact over time and space according to the fundamental laws of physics (Figure 1). GCMs are the most sophisticated tools for understanding the climate system, but while highly complex and built on solid physical principles, they are still simplifications of the actual climate system. There are several ways to implement such simplifications into a GCM, which results in each one giving a slightly different answer. As such, it is best practice to use at least ten GCMs and look at the average and range of projections across all of them.

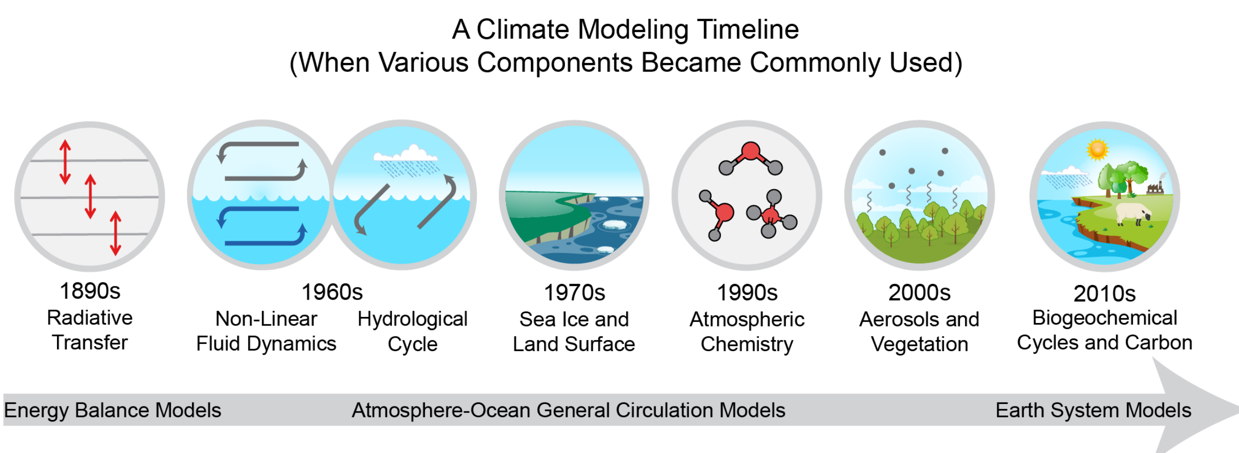

Figure 1 As scientific understanding of climate has evolved over the last 120 years, increasing amounts of physics, chemistry, and biology have been incorporated into calculations and, eventually, models. This figure shows when various processes and components of the climate system became regularly included in scientific understanding of global climate calculations and, over the second half of the century as computing resources became available, formalized in global climate models. (Source: science2017.globalchange.gov)

Greenhouse Gas Emissions

When used to project future climate, scientist give the GCMs information about the quantity of greenhouse gases that the world would emit, then the GCMs run simulations of what would happen to the air, water, and land over the next century. Since the precise amount of greenhouse gases the world will emit over the next century is unknown, scientists use several scenarios of different amounts of greenhouse gas emissions based on plausible societal trajectories. The higher global emissions are, the greater the increase in global temperature is expected. This report uses emission scenarios from the current suite of emissions scenarios called Representative Concentration Pathways (RCP) (Figure 2). Specifically, this report considers a lower emissions scenario (RCP 4.5) and higher emissions scenario (RCP 8.5) based on available data and relevant published literature. The lower emissions scenario represents modest efforts to cut global greenhouse gas emissions by mid-21st century whereas the higher emissions scenario represents a "business-as-usual" scenario with greenhouse gas emissions continuing to increase throughout the 21st century.

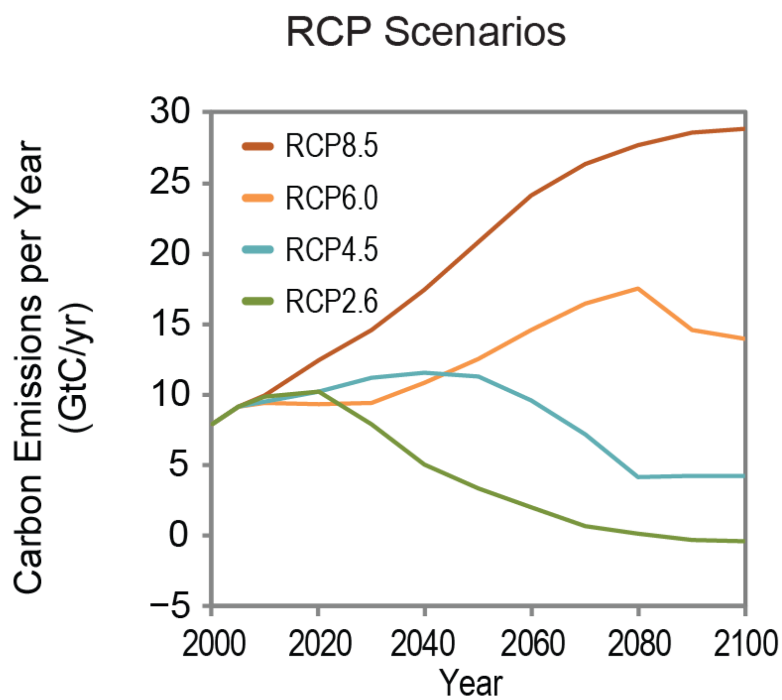

Figure 2 Scenarios of future atmospheric carbon dioxide emissions for the current suite of emissions scenarios (RCPs). (Source: science2017.globalchange.gov)

Downscaling

Global climate models simulate the climate across adjacent grid boxes the size of about 60 by 60 miles. To make this coarse resolution information locally relevant, global climate model outputs have been combined with historical observations to translate large-scale patterns into high-resolution projections. This process is called statistical downscaling. This report makes use of the future climate projections that have been statistically downscaled to a resolution with grid boxes the size of about 2.5 by 2.5 miles (Abatzoglou and Brown, 2012).

Future Time Periods

When analyzing global climate model projections of future climate, it is best practice to compare the average across at least a 30-year period in the future to an average historical baseline across at least 30 years. In this report, the historical baseline is 1971–2000 and the future time periods are the "2050s" (2040–2069 average) and the "2080s" (2070–2099 average), unless otherwise noted.

Read more about emissions scenarios, global climate models, downscaling, and uncertainty in the Climate Science Special Report, Volume 1 of the Fourth National Climate Assessment (https://science2017.globalchange.gov).

Temperature

Oregon's average temperature warmed at a rate of 2.2°F per century during 1895–2015. Average temperature is expected to continue warming during the 21st century under scenarios of continued global greenhouse gas emissions; the rate of warming depends on the particular emissions scenario (Dalton *et al.*, 2017). By the "2050s" compared to the 1970–1999 historical baseline, Oregon's average temperature is projected to increase by 3.6 °F with a range of 1.8°–5.4°F under a lower emissions scenario (RCP 4.5) and by 5.0°F with a range of 2.9°F–6.9°F under a higher emissions scenario (RCP 8.5) (Dalton *et al.*, 2017). Furthermore, summers are projected to warm more than other seasons (Dalton *et al.*, 2017).

Average temperature in Newport, Oregon is projected to increase 4.5 °F on average by the 2050s and 6.8 °F on average by the 2080s compared to the historical baseline under the higher emissions scenario (RCP 8.5) (Figure 3). While there is a range of responses from individual models, all models project warming. These projections for Newport are representative of the entire Mid-Coast region.

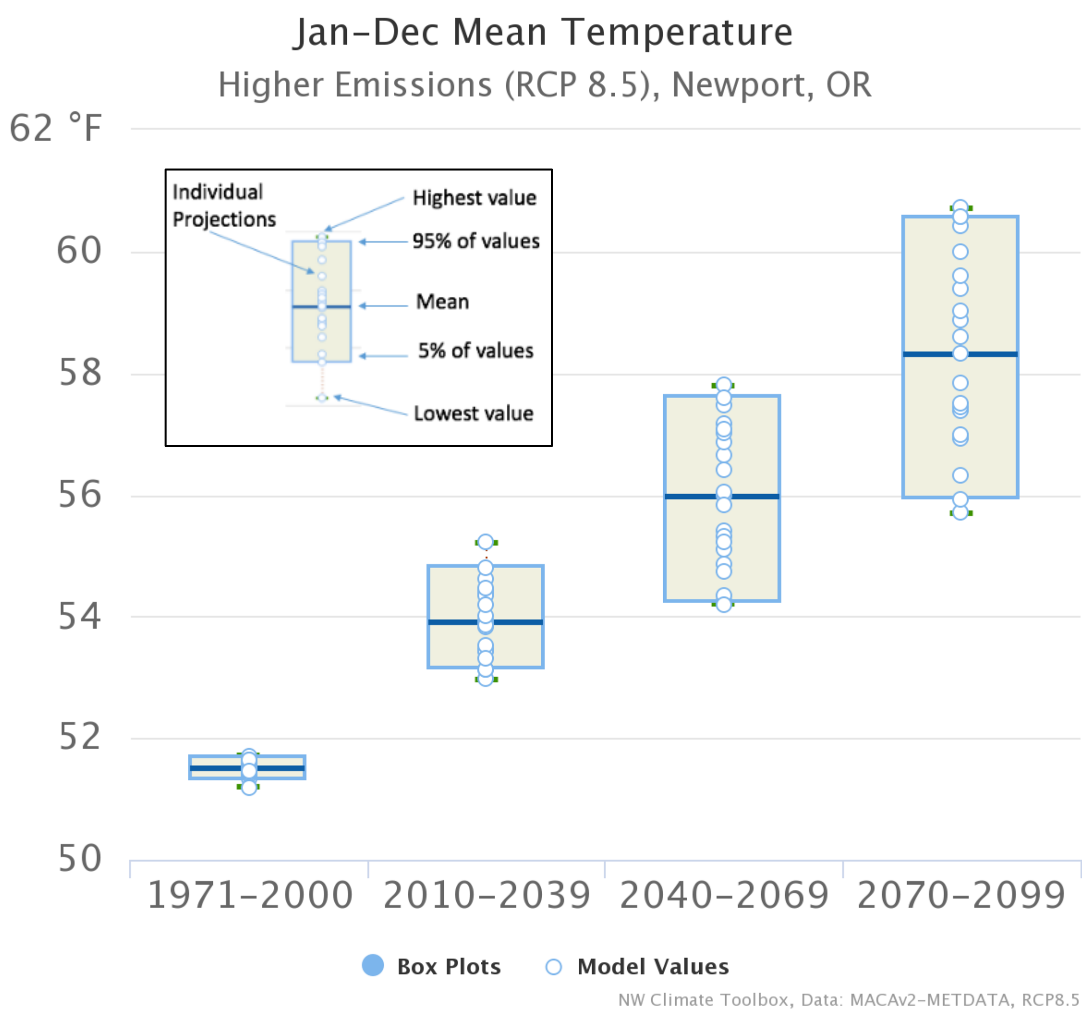

Figure 3 Simulated historical (1971–2000) and projected 2020s (2010–2039), 2050s (2040–2069), and 2080s (2070–2099) annual average temperature for Newport, Oregon under a higher emissions scenario (RCP 8.5) based on 20 global climate models. (Source: Northwest Climate Toolbox, Future Climate Tool, https://climatetoolbox.org/tool/future-climate)

Precipitation

In Oregon, observed precipitation is characterized by high year-to-year variability and future precipitation trends are expected to continue to be dominated by this large natural variability. On average, summers in Oregon are projected to become drier and other seasons to become wetter resulting in a slight increase in annual precipitation by the 2050s and 2080s. However, some models project increases and others decreases in each season and annually (Dalton *et al.*, 2017).

Annual precipitation in Oregon is projected to increase on average by 1.9% by the 2050s, and 3.4% by the 2080s under the lower emissions pathway (RCP 4.5). Under the higher emissions pathway (RCP 8.5), increases in annual precipitation are a bit larger for each time period: 2.7%, and 6.3%, respectively (Dalton *et al.*, 2017). Summer precipitation in Oregon is projected to decline on average by 8.7% and 7.7% by the 2050s and 2080s under the higher emissions scenario while winter precipitation is projected to increase on average by 7.9% and 14.5%, respectively.

In Newport, Oregon annual precipitation is projected to increase 1.5% on average by the 2050s and 4.2% on average by the 2080s compared to the historical baseline under the higher emissions scenario (RCP 8.5), although some models project decreases (Figure 4). Summer precipitation in Newport is projected to decline on average by 16.2% by the 2050s and by 18% by the 2080s under the higher emissions scenario while winter precipitation is projected to increase on average by 6.9% and 12.4%, respectively (Figure 5). While precipitation amount varies along the coast, the projected percent change at Newport is representative of the projected changes within the Mid-Coast region. With warming temperatures, precipitation will fall increasingly as rain, and snow on the coast will become increasingly rare.

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 (Parker and Abatzoglou, 2016).[1]

Observed trends in the frequency of extreme precipitation events across Oregon have depended on the location, time frame, and metric considered, but overall the frequency has not changed substantially. As the atmosphere warms, it is able to hold more water vapor that is available for precipitation. As a result, the frequency and intensity of extreme precipitation events are expected to increase slightly in the future (Dalton *et al.*, 2017). Atmospheric river events are generally expected to become more frequent and intense under future climate change conditions (Kossin *et al.*, 2017).

[1] Verbatim from the Third Oregon Climate Assessment Report (Dalton *et al.*, 2017)

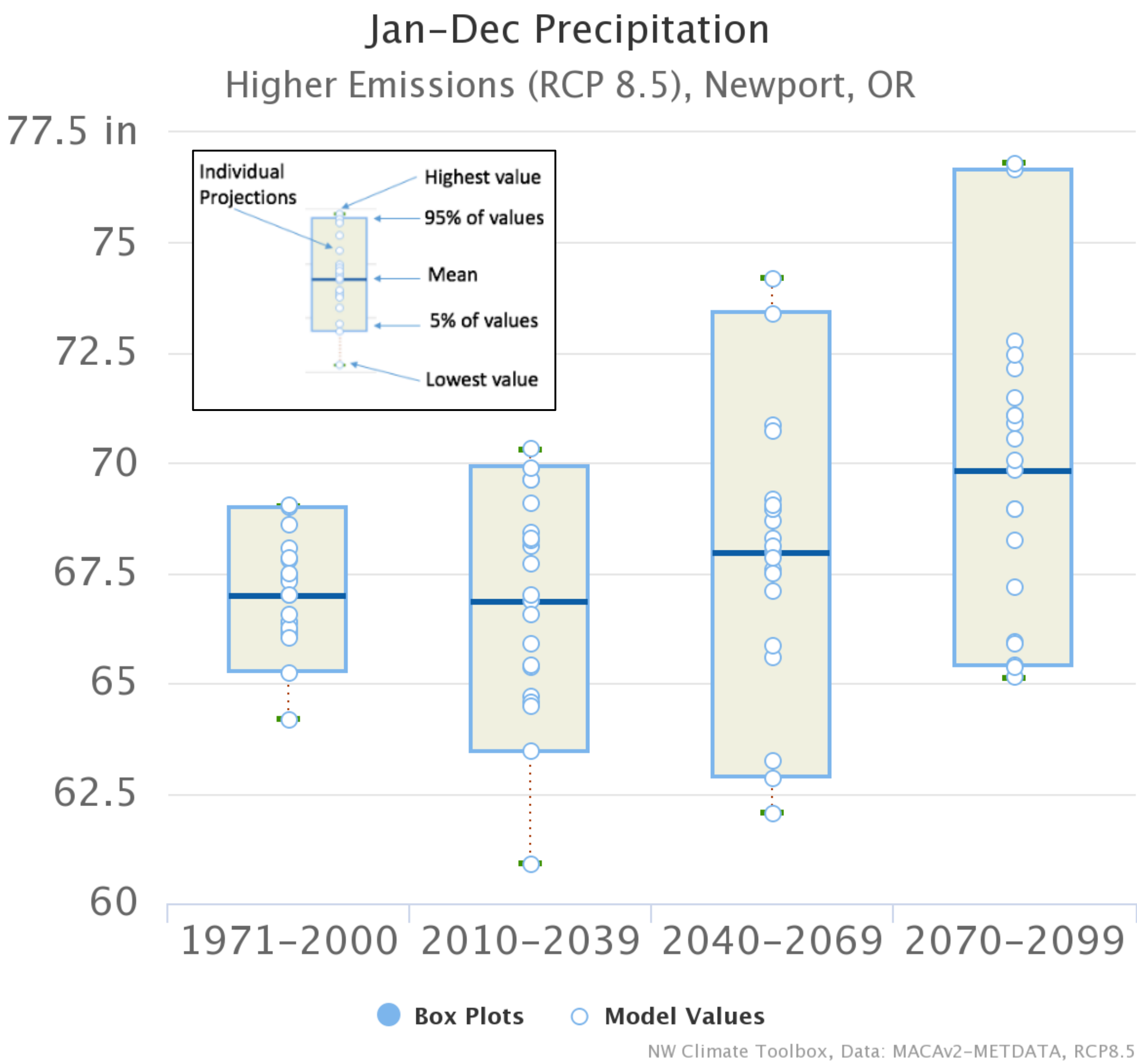

Figure 4 Simulated historical (1971–2000) and projected 2020s (2010–2039), 2050s (2040–2069), and 2080s (2070–2099) annual precipitation for Newport, Oregon under a higher emissions scenario (RCP 8.5) based on 20 global climate models. (Source: Northwest Climate Toolbox, Future Climate Tool, https://climatetoolbox.org/tool/future-climate)

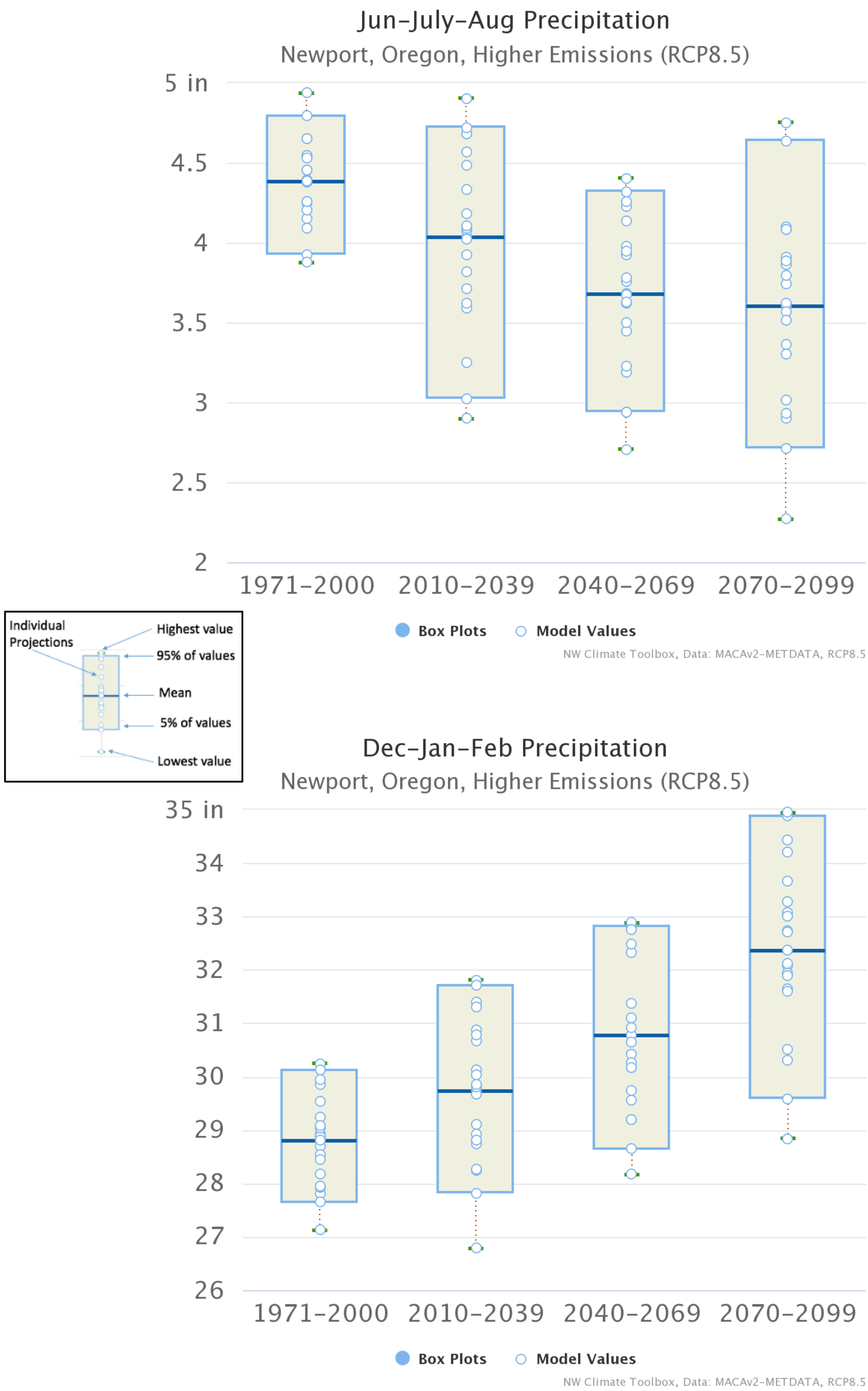

Figure 5 Simulated historical (1971–2000) and projected 2020s (2010–2039), 2050s (2040–2069), and 2080s (2070–2099) summer (top) and winter (bottom) precipitation for Newport, Oregon under a higher emissions scenario (RCP 8.5) based on 20 global climate models. (Source: Northwest Climate Toolbox, Future Climate Tool, https://climatetoolbox.org/tool/future-climate)

Floods

Future streamflow magnitude and timing for much of the Pacific Northwest is projected to shift toward higher winter runoff, lower summer and fall runoff, and an earlier peak runoff, particularly in snow-dominated regions (Raymondi *et al.*, 2013; Naz *et al.*, 2016)[2]. These changes are expected to result from warmer temperatures causing precipitation to fall more as rain and less as snow, in turn causing snow to melt earlier in the spring; and in combination with increasing winter precipitation and decreasing summer precipitation (Dalton *et al.*, 2017).

Streamflow in rain-dominant watersheds reflects the seasonal pattern of precipitation, with peak flows occurring during the winter and low flows occurring during the summer.[3] Coastal rain-dominated watersheds, like those in the Mid-Coast region, have received very little attention in the published literature in regards to how streamflow is expected to change under future climate. A recent study on coastal watersheds in the Western US featuring the Siletz River shows projected increases in streamflow during winter (November–March) relative to historic streamflow for the Siletz River (Burke and Ficklin, 2017) (Figure 6). By the late-21st century compared to the historical baseline, winter streamflow is projected to increase by about 18% on average, though projected changes were only statistically significant for the months of November, December, and March (Burke and Ficklin, 2017). This projected increase in peak winter flows in the Siletz River, although small percentage-wise, could increase the risk of flooding, yet that is dependent on the timing and amount of precipitation.

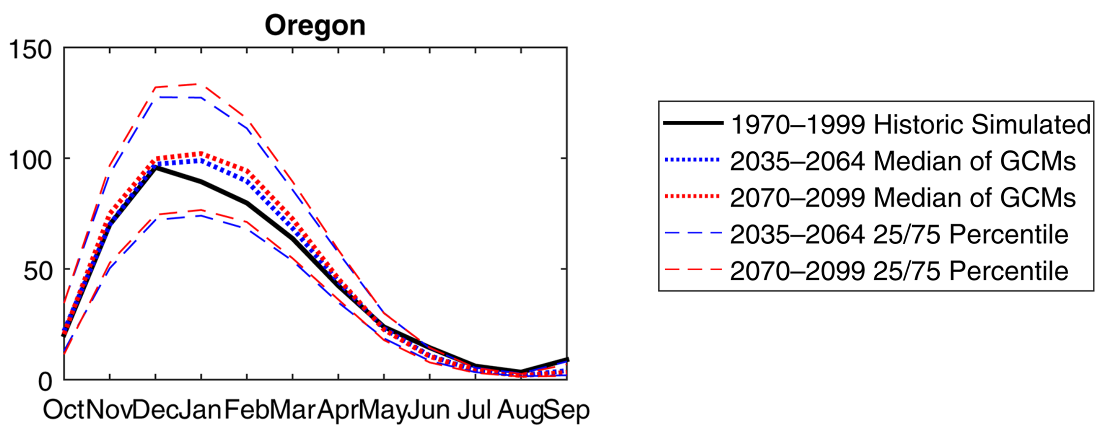

Figure 6 Median, 25th percentile, and 75th percentile streamflow based on RCP 8.5 for historic (1970–1999), mid-21st century (2035–2065), and late-21st century (2070–2099) periods. The 25th and 75th percentile range for both projected periods encompass the range of the historical data. Source: Burke and Ficklin, 2017.

Across the western US, the 100-year and 25-year peak flow magnitude is projected to increase at a majority of streamflow sites by the 2070–2099 period compared to the 1971–2000 historical baseline under the higher emissions scenario (RCP 8.5) (Maurer *et al.*, 2018). Table 1 summarizes these projections for the Siletz River.

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[2] Verbatim from the Third Oregon Climate Assessment Report (Dalton *et al.*, 2017)

[3] Verbatim from the Third Oregon Climate Assessment Report (Dalton *et al.*, 2017)

Table 1 Percent change in the 100-year and 25-year recurrence interval flows for the Siletz River between 2070–2099 and 1971–2000 and the return period in 2070–2099 of the flow with a magnitude equal to that of the 100-year and 25-year flow as determined fro 1971–2000. (Source: Maurer et al., 2018, personal communication)

Return Period (Probability in a given year)	Percent Change in N-Year Peak Flow 2070–2099 vs. 1971–2000	Return Period of N-Year Peak Flow (2070–2099)
25-Year (4%)	15.86% (p-val=0.064)	12.8-Year (7.8%)
100-Year (1%)	18.55% (p-val=0.055)	36.47-Year (2.7%)

Drought

Across the western US, mountain snowpack is projected to decline leading to reduced summer soil moisture in mountainous environments (Gergel *et al.*, 2017). Coastal Oregon is also projected to experience a decrease in summer soil moisture, but to a lesser degree than the Oregon Cascades (Figure 7). Climate change is expected to result in lower summer streamflows in snow-dominated basins across the Pacific Northwest as snowpack melts off earlier due to warmer temperatures and summer precipitation decreases (Dalton *et al.*, 2017; Mote *et al.*, 2019).

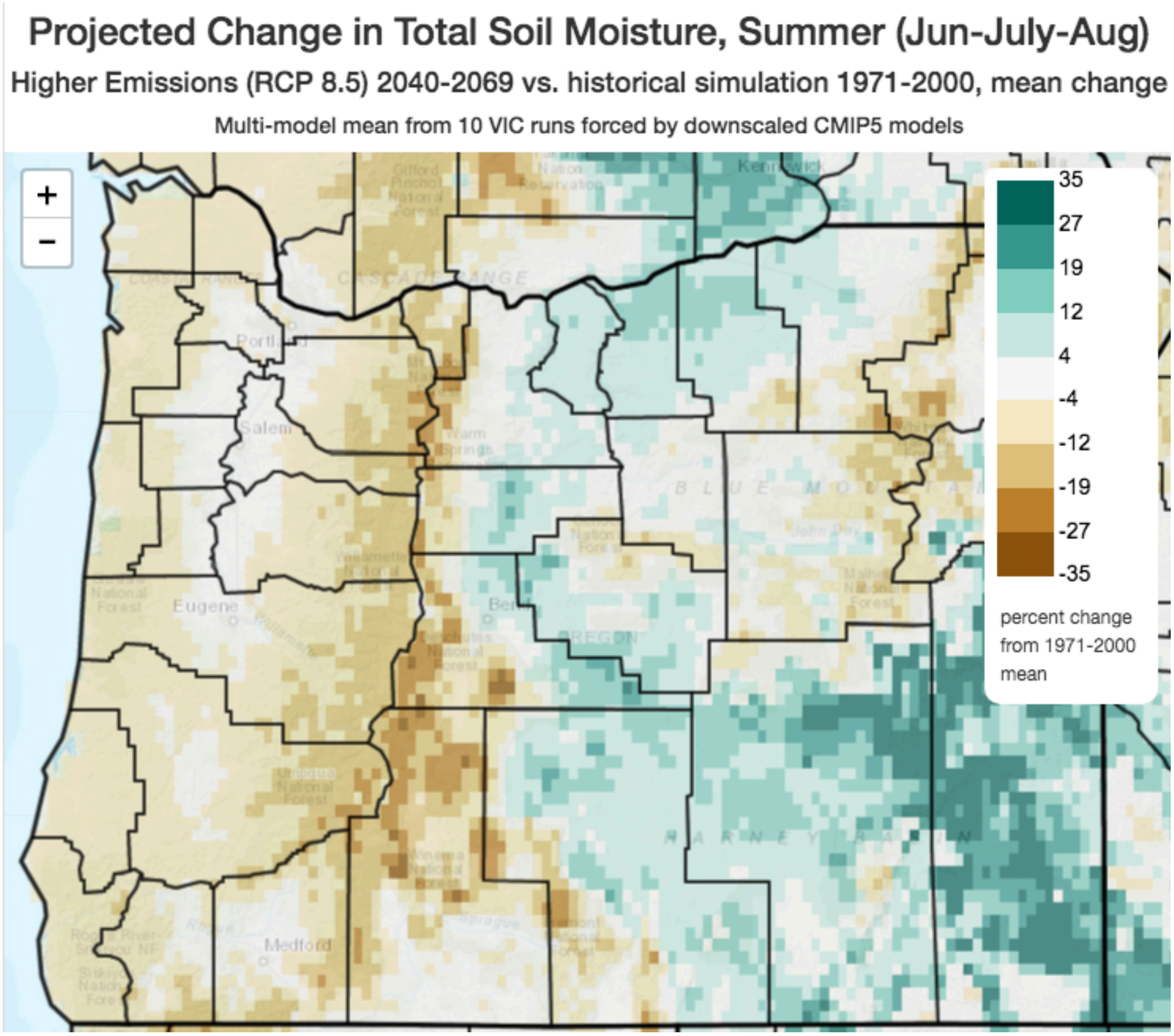

Figure 7 Projected change in total soil moisture for summer for Oregon for 10 climate models using the Variable Infiltration Capacity (VIC) model. Source: Northwest Climate Toolbox, climatetoolbox.org.

The Mid-Coast region is a rain-dominated system, meaning the drivers of drought and water scarcity are different than across much of the western US, where mountain snowpack contributes to streamflow (Dalton *et al.*, 2017; Mote *et al.*, 2019). As with the rest of the Pacific Northwest, the Mid-Coast region typically experiences wet winters and dry summers (Figure 8). This seasonal cycle of precipitation means that severe drought is rare in the rainy winters on the mid-Oregon coast, but the region is prone to periods of summertime water scarcity, especially when precipitation is lower than average in the shoulder seasons (e.g., spring, fall). This is exacerbated by the lack of natural storage (e.g., snowpack) and built storage (e.g., reservoirs).

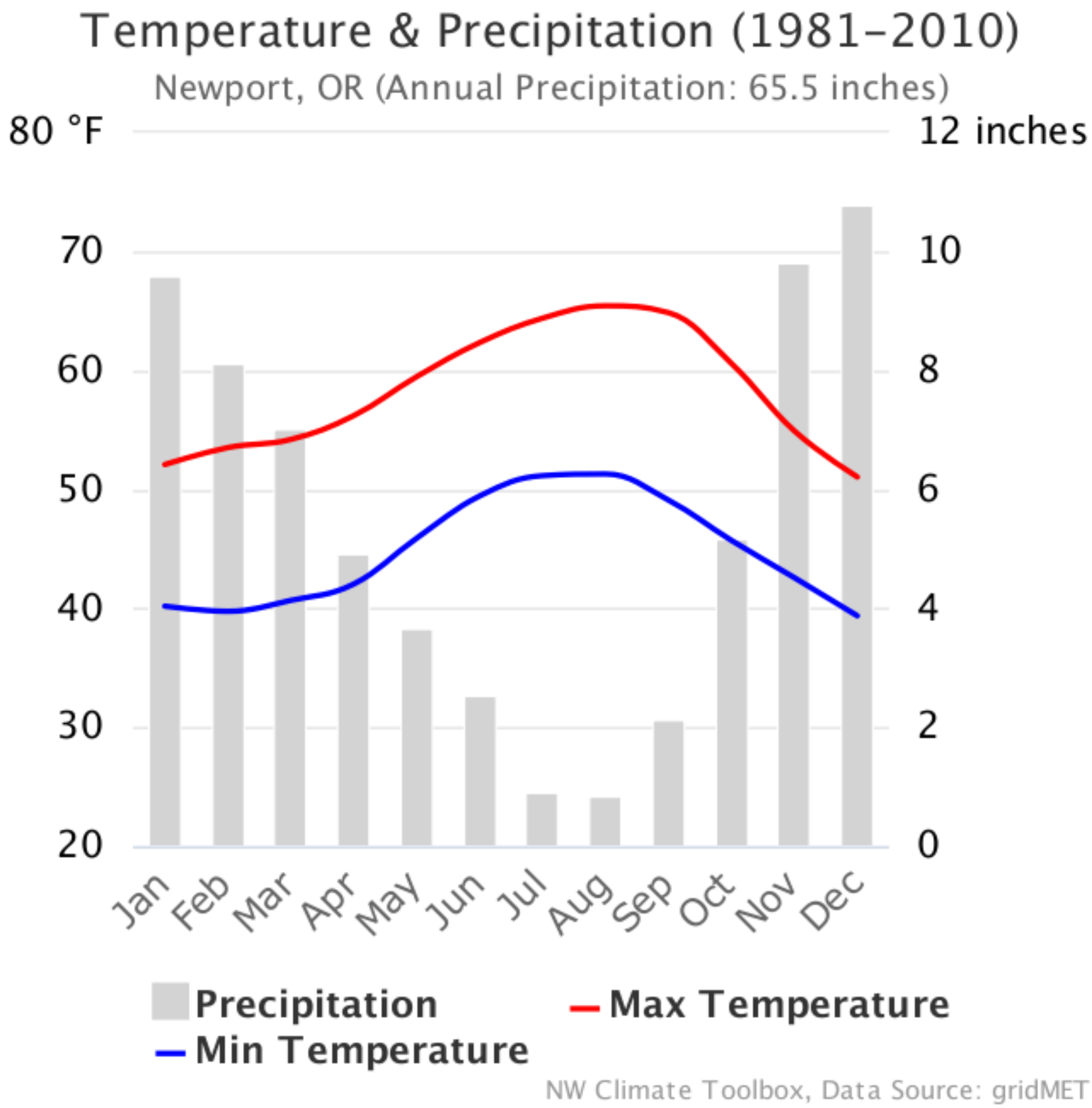

Figure 8 Graph of temperature and precipitation for 1981-2010 climate normal for Newport, OR (Source: Northwest Climate Toolbox, climatetoolbox.org)

In the Siletz River, historically low flows occurred in two of the last four years (2015 and 2018), owing to a combination of lower than normal spring and summer precipitation in each of those years (Figure 9). In August 2018, Governor Kate Brown declared a Drought Emergency in Lincoln County due to low streamflows and hot, dry conditions.[4]

[4] Exec. Order. No. 18–19, Office of the Governor State of Oregon (August 14, 2018), https://www.oregon.gov/gov/Documents/executive_orders/eo_18-19.pdf.

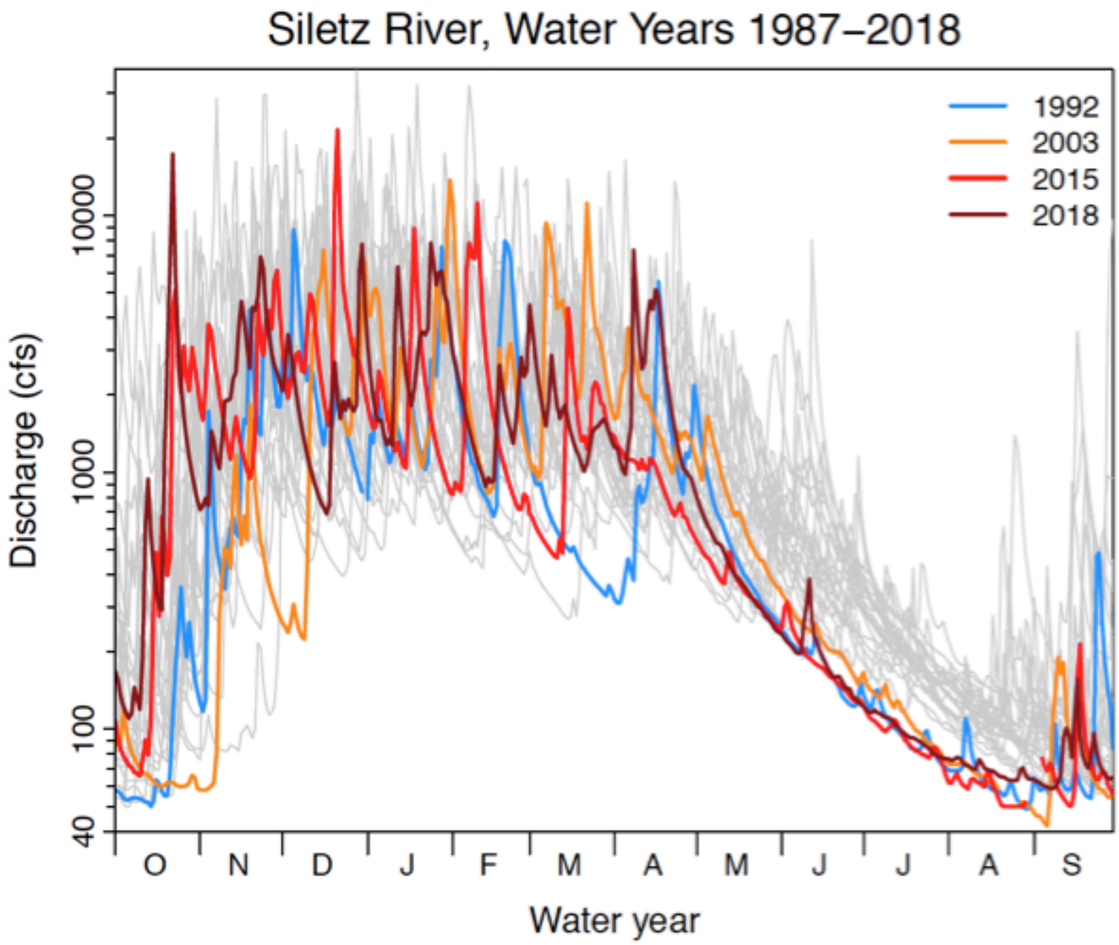

Figure 9 Historical monthly averaged streamflow (cfs) by water year for 1987–2018. The traces for the four years with the lowest summer flows are illustrated in color. Source: David Rupp, Oregon Climate Change Research Institute.

Additionally, warmer than normal summer temperatures can increase water demand, particularly in the agricultural sector arising from increased evapotranspiration (Lall *et al.*, 2018). In Newport, the four low-flow years (1992, 2003, 2015, 2018) all had warm, dry summers, as illustrated by their clustering in the warm, dry sector of Figure 10. These four years also correspond to significant drought years in the Pacific Northwest.

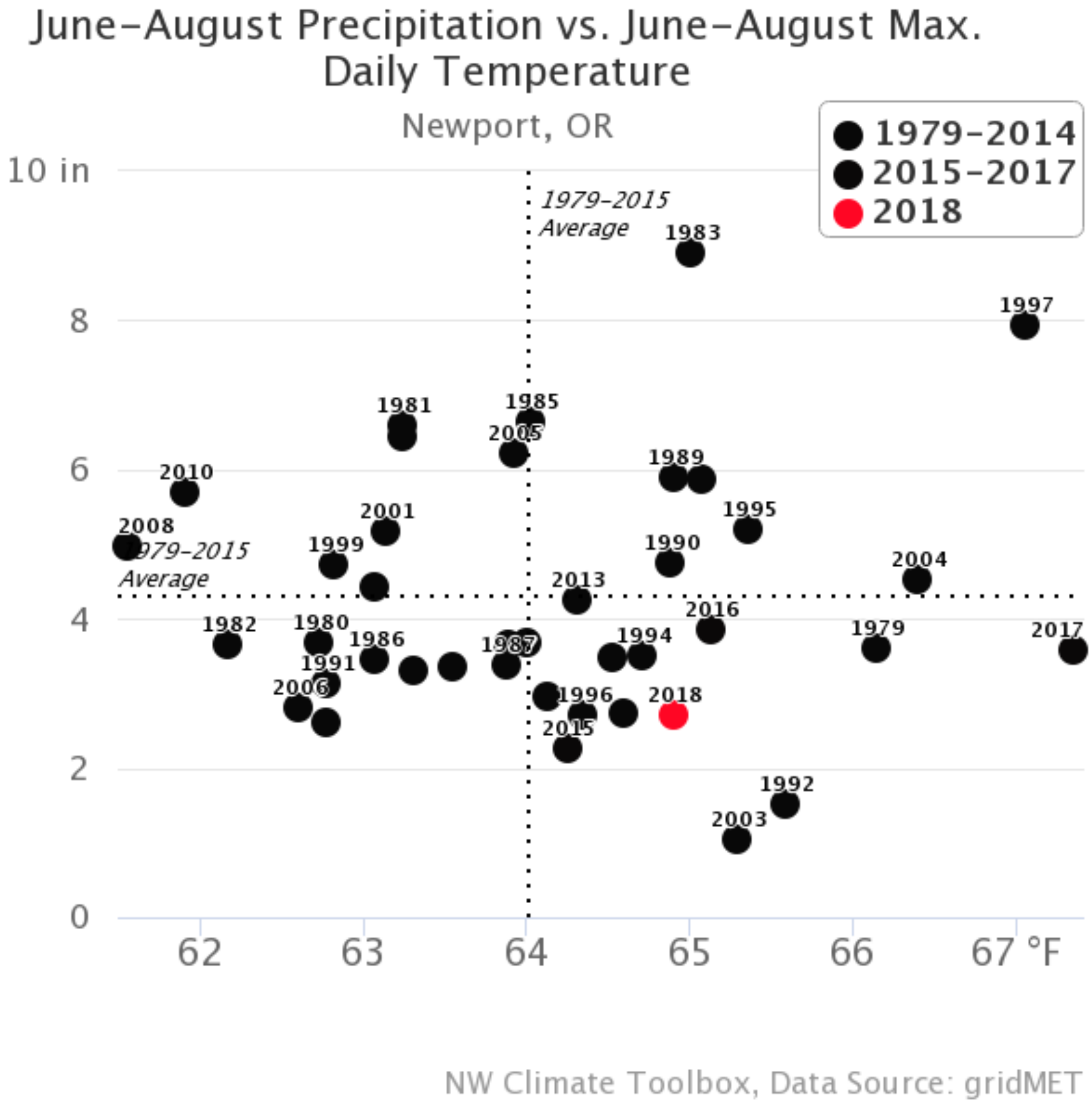

Figure 10 Historical temperature and precipitation for summer for Newport, OR displayed by year. The year 2018 is indicated in red. The lower right quadrant is warm and dry. Source: Northwest Climate Toolbox, climatetoolbox.org.

Hydrologic model projections from the Integrated Scenarios of the Future Northwest Environment project (https://climate.northwestknowledge.net/IntegratedScenarios/) available in summary form on the Northwest Climate Toolbox (https://climatetoolbox.org/) show a decrease in spring (March–May) runoff for the mid-Oregon Coast and a 4–12% decrease by mid-century (2040–2069) versus the historical baseline (1971–2000) in summer (June–August) under a higher emissions scenario (RCP 8.5) (Figure 11). Oregon coastal basins have received relatively little attention in the published literature with regards to changes to streamflow in a warming climate. A recent study on coastal watersheds in the Western US featuring the Siletz River shows shifts toward slightly greater streamflow in winter by the mid-21st century, with little change in the summer (Burke and Ficklin, 2017).

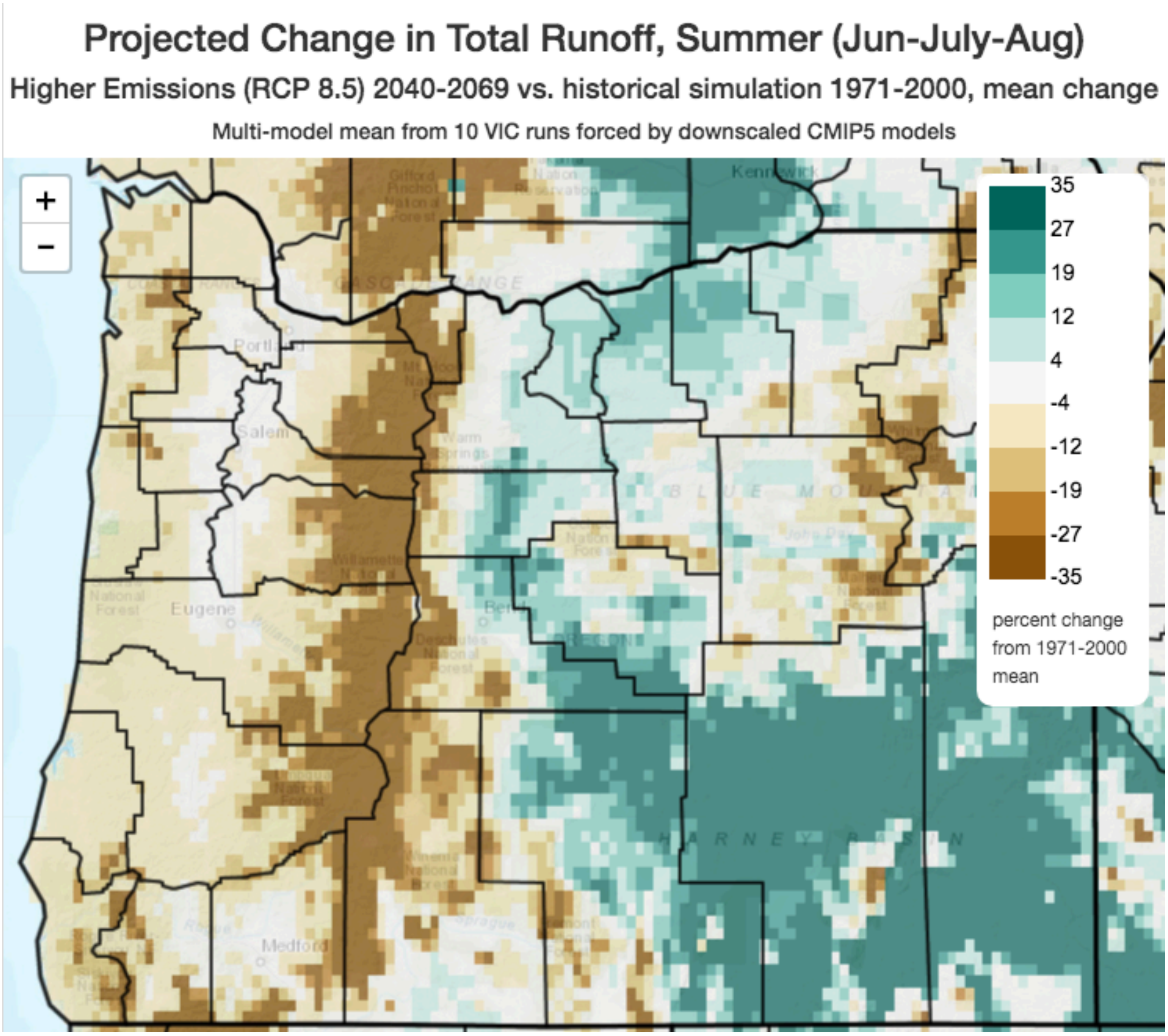

Figure 11 Projected change in total runoff for summer for Oregon for 10 climate models using the Variable Infiltration Capacity (VIC) model. Source: Northwest Climate Toolbox, climatetoolbox.org.

On the nearby north coast of Oregon (Tillamook County), previous analysis (Sharp *et al.*, 2013) shows a projected shift in the seasonality of precipitation to wetter winters and drier summers through the 21st century. Total annual precipitation is projected to remain within 1–2% of the historical average, but summers are projected to be drier across the entire region by mid-21st century (Dalton *et al.*, 2017; Mote *et al.*, 2019). However, averages across the annual and seasonal timescales may be less important than the year-to-year variability when it comes to drought in the Mid-Coast region, exemplified by the very dry and warm years 2015 and 2018. There is a projected increase in variability for spring and summer precipitation and temperature in the Columbia River Basin, but it has not been analyzed for the Oregon coast (Rupp *et al.*, 2017).

Wildfire

Over the last several decades, warmer and drier conditions during the summer months have contributed to an increase in fuel aridity and enabled more frequent large fires, an increase in the total area burned, and a longer fire season across the western United States, particularly in forested ecosystems (Dennison *et al.*, 2014; Jolly *et al.*, 2015; Westerling, 2016; Williams and Abatzoglou, 2016). The lengthening of the fire season is largely due to declining mountain snowpack and earlier spring snowmelt (Westerling, 2016). Recent wildfire activity in forested ecosystems is partially attributed to human-caused climate change: during the period 1984–2015, about half of the observed increase in fuel aridity and 4.2 million hectares (or more than 16,000 square miles) of burned area in the western United States were due to human-caused climate change (Abatzoglou and Williams, 2016). Under future climate change, wildfire frequency and area burned are expected to continue increasing in the Pacific Northwest (Barbero *et al.*, 2015; Sheehan *et al.*, 2015),[5] even in the climatologically wet areas in western Oregon (Mote *et al.*, 2019).

As a proxy for wildfire risk, this report considers a fire danger index called 100-hour fuel moisture (FM100), which is a measure of the amount of moisture in dead vegetation in the 1–3 inch diameter class available to a fire. It is expressed as a percent of the dry weight of that specific fuel. FM100 is a common index used by the Northwest Interagency Coordination Center to predict fire danger. A majority of climate models project that FM100 would decline across Oregon by the 2050s under the higher (RCP 8.5) emissions scenario (Gergel *et al.*, 2017). This drying of vegetation would lead to greater wildfire risk, especially when coupled with projected decreases in summer soil moisture as is projected for the Mid-Coast region. This report defines a "very high" fire danger day to be a day in which FM100 is lower (i.e., drier) than the historical baseline 10th percentile value. By definition, the historical baseline has 36.5 "very high" fire danger days annually. Future wildfire risk is expressed as the average annual number of "very high" fire danger days for two future periods under a higher emissions scenario (RCP 8.5) compared with the historical baseline (Figure 12).

The average annual number of "very high" fire danger days in Newport, Oregon is expected to increase from 36.5 days in 1971–2000 to 50.8 days (with a range of 33.2 days to 84.2 days) by the "2050s" under the higher emissions scenario (RCP 8.5) (Figure 12). This represents a percentage increase of about 39% with a range of -9% to 131%. Note that four models project slight decreases by the 2050s.

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[5] Verbatim from the Third Oregon Climate Assessment Report (Dalton *et al.*, 2017)

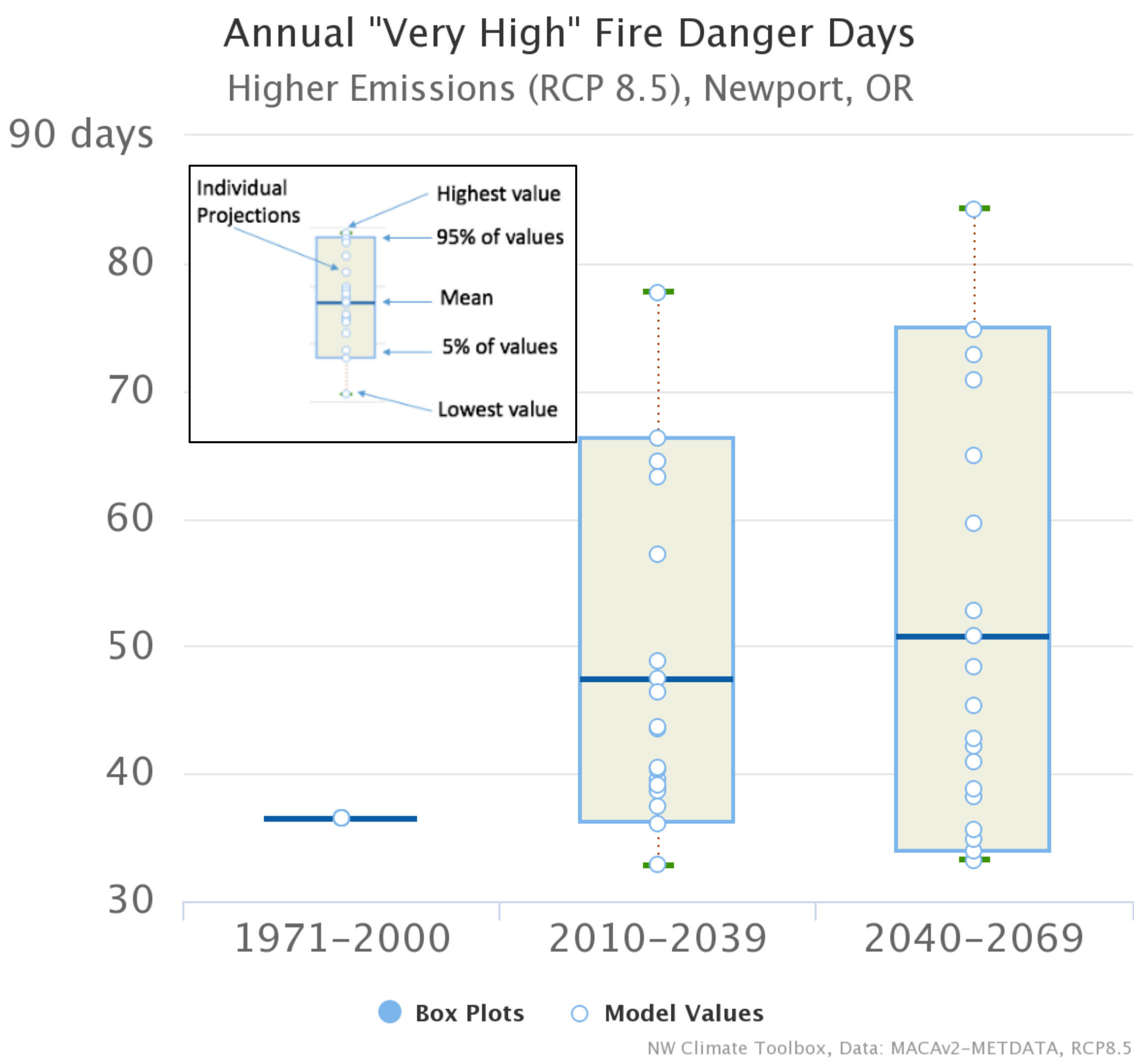

Figure 12 Simulated historical (1971–2000) and projected 2020s (2010–2039) and 2050s (2040–2069) frequencies of very high fire danger days for Newport, Oregon under a higher emissions scenario (RCP 8.5) based on 18 global climate models. (Source: Northwest Climate Toolbox, Future Climate Tool, https://climatetoolbox.org/tool/future-climate)

Sea Level Rise

Changes in global sea levels occur due to ocean thermal expansion, glacier and ice sheet mass loss, and land water storage. Regional and local sea levels on the Pacific Northwest's coast are governed by the global mean sea level, but also by natural variability (El Niño–Southern Oscillation affects ocean currents and wind fields), by vertical land motions from subducting ocean plates, and by post-glacial isostatic adjustment (Reeder *et al.*, 2013).[6]

Global average sea level has risen by about 7–8 inches (about 16–21 cm) since 1900, with almost half this rise occurring since 1993 as oceans have warmed and land-based ice has melted. Relative to the year 2000, sea level is very likely to rise 1 to 4 feet (0.3 to 1.3 m) by the end of the 21st century. Emerging science regarding Antarctic ice sheet stability suggests that, for higher scenarios, a rise exceeding 8 feet (2.4 m) by 2100 is physically possible, although the probability of such an extreme outcome cannot currently be assessed[7] (Hayhoe *et al.*, 2018).

A crucial point about both Greenland and Antarctica is that even after global temperatures are stabilized, melting will continue until a new equilibrium is reached. In the case of Greenland, there is growing concern that any warming beyond 1.5-2°C could lead to the irreversible melting of the entire ice sheet: once the melting reduces the altitude enough, the ice sheet cannot accumulate enough new snow in winter to offset the melting in summer. In the case of Antarctica, recent research by Oregon scientists (Clark *et al.*, 2018) shows that the equilibration to a new climate would take thousands of years. Their analysis suggests that stabilizing global climate at 2°C above preindustrial would limit sea level rise to less than 3.3 ft (1m) by 2300, but even so, it could reach 9m by the year 9000. Higher emissions scenarios could lead to increases in global mean sea level of almost 10m by the year 2500 and over 50m by the year 9000. The authors note that the policy consequences of limiting emissions now will last for millennia.[8]

Local sea level at Newport, OR[9] has risen about four inches during 1967–2013 and is projected to rise by 1.7 to 5.7 feet by 2100 (*Coastal Risks for Lincoln County, OR*, 2019) based on the Intermediate-Low and Intermediate-High global sea level scenarios used in the 2018 U.S. National Climate Assessment (Sweet *et al.*, 2017). This range of sea level rise scenarios is similar to the *very likely* range projected for the higher emissions scenario, RCP8.5, by 2100 (Figure 13). Table 2 shows the median projected local sea level rise at Newport, OR for each scenario and decade from 2030 to 2100 relative to the 1992 mean high tide line.

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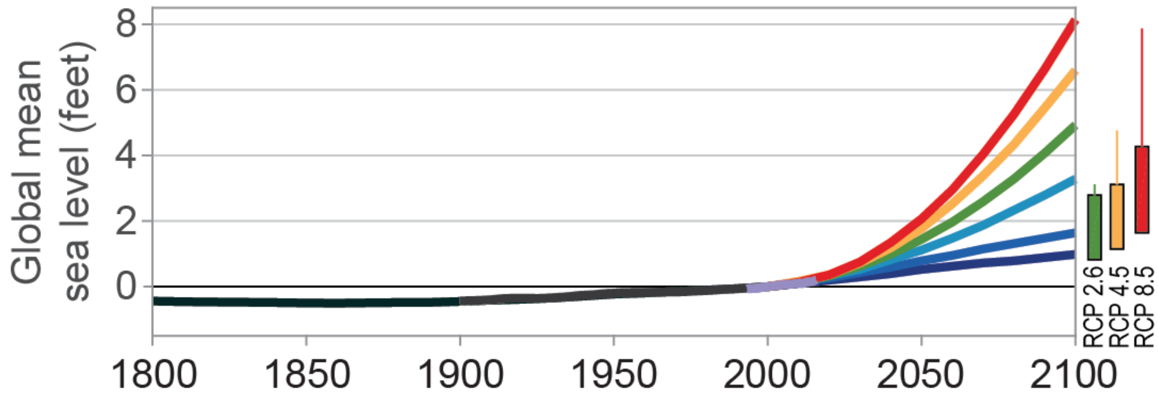
[6] Verbatim from the Third Oregon Climate Assessment Report (Dalton *et al.*, 2017)

[7] Verbatim from the Fourth National Climate Assessment Report (Hayhoe *et al.*, 2018)

[8] Verbatim from the Fourth Oregon Climate Assessment Report (Mote *et al.*, 2019)

[9] NOAA water level station at South Beach–Yaquina River



Scenario	RCP2.6	RCP4.5	RCP8.5
Low (1 ft)	94%	98%	100%
Intermediate-Low (1.6 ft)	49%	73%	96%
Intermediate (3.3 ft)	2%	3%	17%
Intermediate-High (4.9 ft)	0.4%	0.5%	1.3%
High (6.6 ft)	0.1%	0.1%	0.3%
Extreme (8.2 ft)	0.05%	0.05%	0.1%

Figure 13 (Top) Global mean sea level rise from 1800 to 2100 based on tide gauge-based reconstruction (black), satellite-based reconstruction (purple), and six future scenarios (navy blue, royal blue, cyan, green, orange, red) used in the Fourth National Climate Assessment (NCA4). The *very likely* ranges in 2100 for different RCPs (colored boxes), and lines augmenting the very likely ranges by accounting for various estimates of Antarctic contributions. (Bottom) Probability of exceeding each NCA4 global mean sea level scenario in 2100 under three RCPs. New evidence regarding the Antarctic ice sheet, if sustained, may significantly increase the probability of the intermediate-high, high, and extreme scenarios, particularly under the higher emissions scenario (RCP8.5), but these results have not yet been incorporated into a probabilistic analysis (Source: Sweet et al., 2017, https://science2017.globalchange.gov/chapter/12/)

Table 2 Median local sea level projections for Newport, OR (NOAA water level station at South Beach) based on scenarios used in the 2018 U.S. National Climate Assessment. Sea level rise is feet above a 1992 baseline. (Source: Climate Central Surging Seas Risk Finder, https://riskfinder.climatecentral.org/county/lincoln-county.or.us?comparisonType=place&forecastName=Basic&forecastType=NOAA2017_extreme_p50&level=4&unit=ft&zillowPlaceType=postal-code)

Scenario	2030	2040	2050	2060	2070	2080	2090	2100
L	0.4	0.5	0.6	0.8	0.9	1.0	1.1	1.2
I-L	0.5	0.6	0.8	1.0	1.2	1.3	1.5	1.7
I	0.6	0.9	1.2	1.6	2.0	2.4	2.9	3.5
I-H	0.9	1.3	1.8	2.4	3.0	3.8	4.7	5.7
H	1.1	1.7	2.5	3.4	4.3	5.5	6.8	8.4
E	1.3	2.0	2.9	4.1	5.3	6.8	8.4	10.3

Tall waves, intense storms, and ENSO events can combine with sea level rise to produce coastal erosion and inundation hazards (Reeder *et al.*, 2013).[10] The projected increase in local sea levels along the Oregon coast raises the starting point for storm surges and high tides making coastal floods more severe and more frequent (*Coastal Risks for Lincoln County, OR*, 2019).

Assuming the Intermediate-Low to Intermediate-High sea level scenarios for Newport, OR (Table 2), the multi-year likelihood of a 4-foot flood event—water reaching four feet above mean high tide—ranges from 45%–83% by the 2030s, 93%–100% by the 2050s, and 100% by 2100 (*Coastal Risks for Lincoln County, OR*, 2019). Table 3 shows the multi-year risk of flooding above 4 feet above mean high tide, that is, the risk of at least one such flood from 2016 through each year, for each sea level rise scenario. For historical perspective, the highest observed flood in the area between 1967 and 2013 was 3.9 feet above mean high tide and the statistical 1-in-100 year flood height is 3.9 feet (*Coastal Risks for Lincoln County, OR*, 2019).

These projections represent a real, eventual future flood risk for people and assets within the 4-foot flood area (Figure 14). According to Climate Central's Surging Seas Risk Finder, 406 people and $63 million in property value are in areas of Lincoln County that are within 4 feet above mean high tide and not potentially protected by levees or other features (Figure 15) (*Coastal Risks for Lincoln County, OR*, 2019).

Table 3 Risk (% Likelihood) of at least one flood exceeding 4 feet above mean high tide between 2016 through each year shown based on median local sea level projections for Newport, OR (Table 2). (Source: Climate Central Surging Seas Risk Finder, https://riskfinder.climatecentral.org/county/lincoln-county.or.us?comparisonType=place&forecastType=NOAA2017_intlo_p50&level=4&unit=ft&zillowPlaceType=postal-code)

Scenario	2030	2040	2050	2060	2070	2080	2090	2100
L	35%	59%	80%	94%	99%	100%	100%	100%
I-L	45%	74%	93%	99%	100%	100%	100%	100%
I	60%	91%	100%	100%	100%	100%	100%	100%
I-H	83%	100%	100%	100%	100%	100%	100%	100%
H	96%	100%	100%	100%	100%	100%	100%	100%
E	99%	100%	100%	100%	100%	100%	100%	100%

[10] Verbatim from the Third Oregon Climate Assessment Report (Dalton *et al.*, 2017)

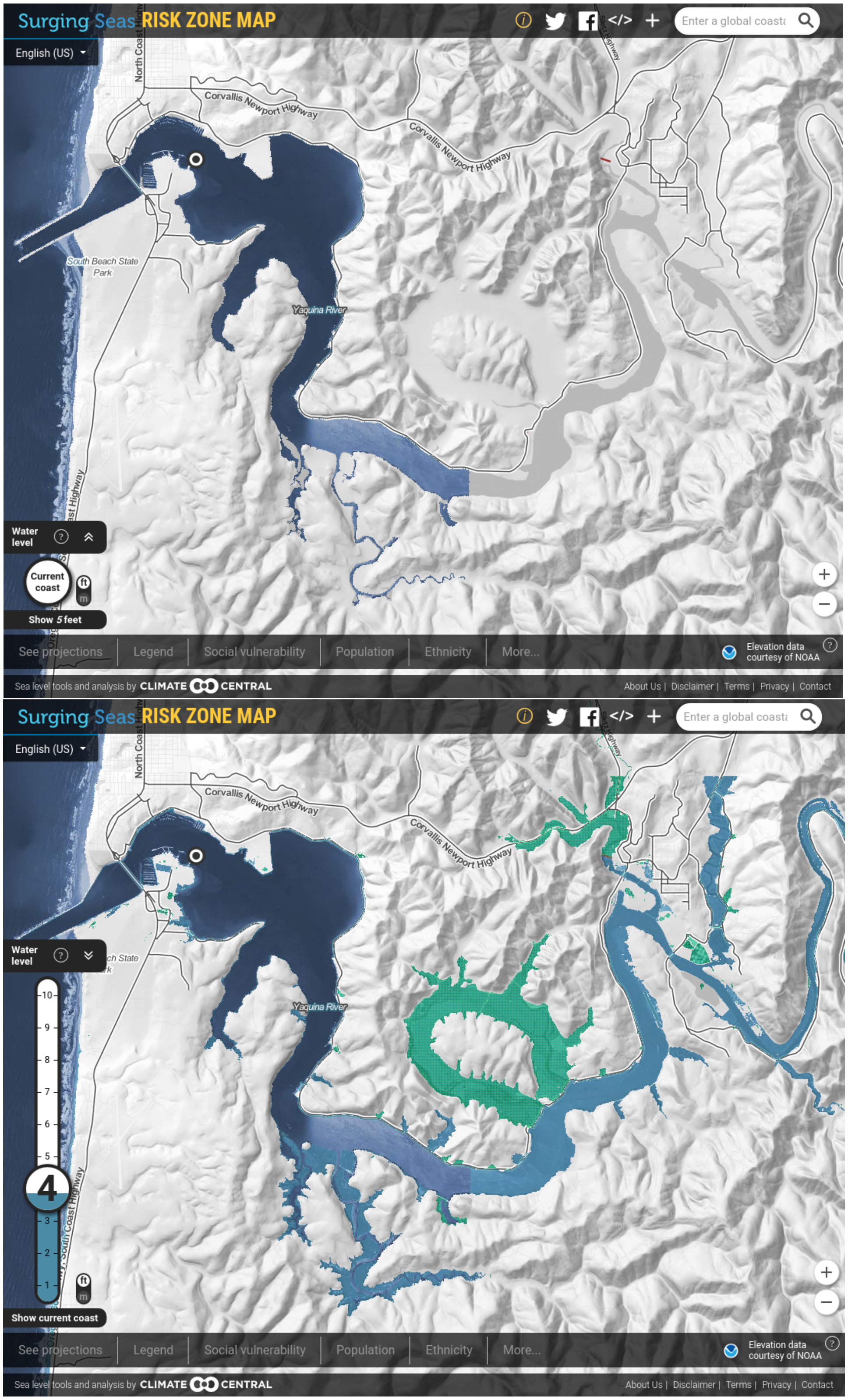


Figure 14 Climate Central's Surging Seas Coastal Risk Zone Map showing Newport, OR area's current coastline (top) and 4-foot water level. Light blue is below water level, green is below water level but isolated by levees or natural barriers, red lines depict levees. (Source: Climate Central Surging Seas, sealevel.climatecentral.org)

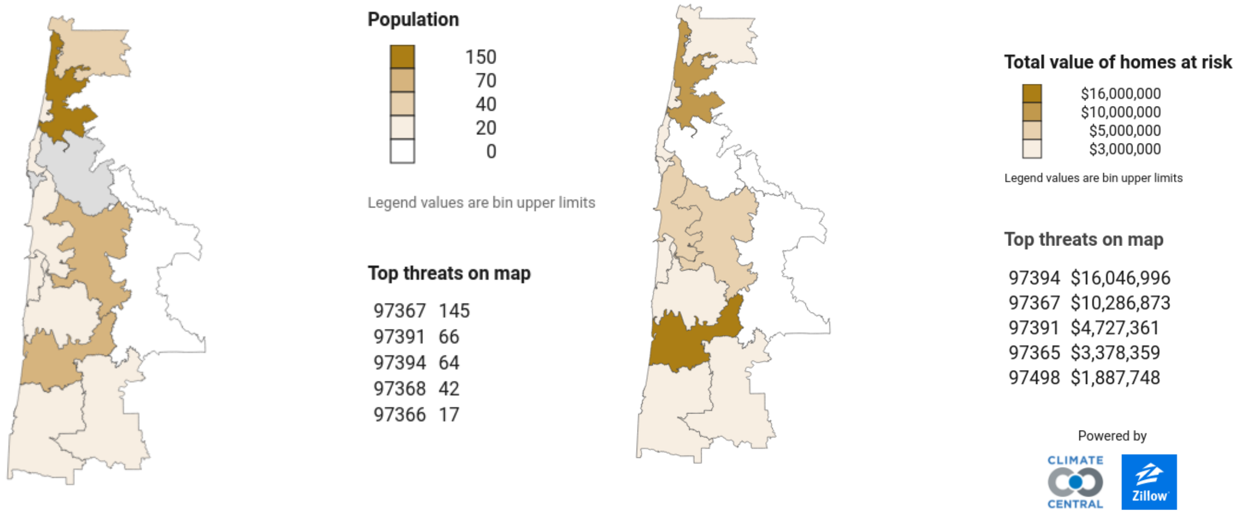


Figure 15 (Left) Total population below 4 feet in Lincoln County by zip code. Values exclude sub-4 foot areas potentially protected by levees or other features. (Right) Total home value at risk of yearly coastal flooding by 2050 by Lincoln County zip code. (Source: Climate Central Risk Finder, 2019. http://www.riskfinder.org/)

Sea level rise is also likely to alter the location and spatial extent of tidal wetlands. Some tidal wetlands may remain in place if the rate of accretion keeps pace with sea level rise, otherwise wetlands will need to migrate upslope if possible (Brophy *et al.*, 2017). Figure 16 shows the potential future extent of tidal wetlands and areas likely to be lost with sea level rise of 4.7 feet.

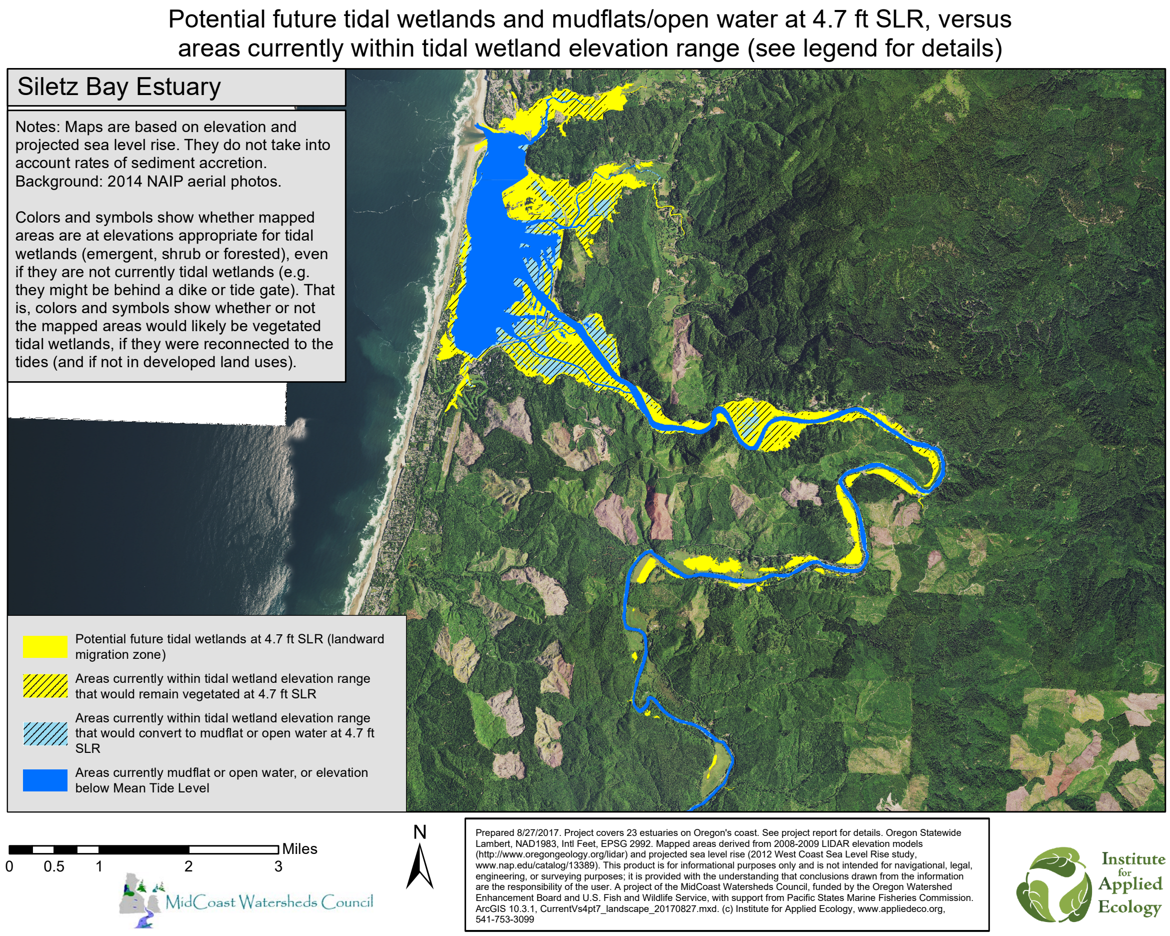


Figure 16 Potential tidal wetlands and mudflats/open water at 4.7 feet sea level rise, versus areas currently within tidal wetland elevation range. Source: Brophy et al., 2017.

Ocean Acidification

The world's ocean have absorbed 29% of all carbon dioxide (CO^2) emitted to the atmosphere since the beginning of the Industrial Revolution (Jewett and Romanou, 2017). Absorption of this CO^2 has led to increased ocean acidity, a fundamental shift in ocean chemistry that is a growing concern for coastal ecosystems and the people that depend on them. The West Coast Ocean Acidification and Hypoxia Science Panel recently issued a scientific consensus report on the state of ocean acidification and hypoxia along the West Coast and recommended actions for managing and reducing their effects (Chan *et al.*, 2016). Ocean acidification and hypoxia tend to co- occur, as they are both driven by increased atmospheric CO^2 levels and local nutrient and organic carbon inputs, and together they comprise a challenge that can be managed synergistically (Chan *et al.*, 2016).

Ocean acidification (OA) is often expressed in terms of a decrease in pH or increase in acidity. OA also reduces the concentration of carbonate ions, which impairs the ability of calcifying organisms, such as oysters and crabs, to build shells. By 21st century's end assuming the current rate of global CO^2 emissions, the surface ocean's average acidity is expected to double (Chan *et al.*, 2016). But although it negatively affects some physiological processes, pH may not be the most useful number by which to monitor the biological effects of OA, particularly on calcifying organisms (Waldbusser *et al.*, 2015; Chan *et al.*, 2016). Furthermore, biologically-relevant thresholds of mineral carbonate saturation state are expected to be crossed much sooner than pH thresholds for some organisms (Waldbusser *et al.*, 2015). Even before it declines enough to corrode calcium carbonate shells, a lowered carbonate saturation state can "make it more difficult and energetically costly for larval bivalves to build shells" (Waldbusser *et al.*, 2015). Reductions in calcifying organisms at the base of the marine food web could have cascading effects on higher trophic marine fish, birds, mammals, and the people who rely on this resource. In a simple projection of ocean water saturation state changes, the mean annual surface seawater aragonite saturation state off the Oregon coast is projected to reach a threshold known to disrupt calcification and development in larval bivalves by the 2030s (Ekstrom *et al.*, 2015). However, the West Coast has already reached a threshold and negative impacts are already evident, such as dissolved shells in pteropod populations (Feely *et al.*, 2016) and impaired oyster hatchery operations (Barton *et al.*, 2012). Furthermore, 60% of the dissolved inorganic carbon in surface waters off Oregon's coast in 2013 is attributed to increasing greenhouse gas concentrations (Feely *et al.*, 2016).

Hypoxia—low oxygen levels—tend to accompany high ocean acidity, and the combined effects can be worse than the effects either of hypoxia or acidification independently (Chan *et al.*, 2016). Hypoxic waters along the West Coast have expanded upward into shallower depths and are already affecting marine ecosystems (Somero *et al.*, 2016). Natural climate variability exercises strong control on dissolved oceanic oxygen levels, but detection of a deoxygenation trend beyond natural variability may be possible by the 2030s and 2040s in the north Pacific Ocean and along the US West Coast according to earth system modeling results (Long *et al.*, 2016).

The West Coast of North America is one of the first places in the world to experience severe environmental, ecological, and economic consequences of OA and hypoxia largely due to the naturally occurring CO^2-enriched, low-oxygen deep water that wells up along the continental shelf of the West Coast (Chan *et al.*, 2016). How the region manages these ongoing changes will likely influence management choices of other coastal regions of the world. OA is a global problem, and reducing global levels of CO^2 emissions will be the most effective strategy to lessen the effect of OA (Chan *et al.*, 2016). However, better management of local nutrient and organic matter inputs to the coastal environment can lessen exposure to OA where those local stressors are having impacts. Furthermore, managing ecosystems to increase resilience—the ability to withstand impacts—to OA represent an important path for local adaptation actions. Time is of the essence because delayed action will reduce management options in the future and more greatly diminish ecosystem services (Chan *et al.*, 2016). [11]

The Natural Resource Defense Council has mapped ocean acidification hot spots, including contributions to coastal acidification from rivers as well as estuary eutrophication scores. Figure 17 shows a summary of these factors for the Mid-Coast region. Coastal waters off the Mid-Coast are projected to reach chronically stressful water conditions (in terms of aragonite saturation state) by 2050. The Yaquina Bay and Alsea River estuaries rank moderately low in the estuary eutrophication score indicating a relatively smaller contribution to local coastal acidification conditions. However, upstream the Alsea River is ranked Medium for its riverine contribution to coastal acidification, which means that it scored in the middle 20% of US coastal rivers in a metric combining annual discharge with aragonite saturation state (high annual discharge and low aragonite saturation state constitute the highest amplification of coastal acidification). The Siletz River and Estuary have not been assessed.

[11] Verbatim from the Third Oregon Climate Assessment Report (Dalton *et al.*, 2017)

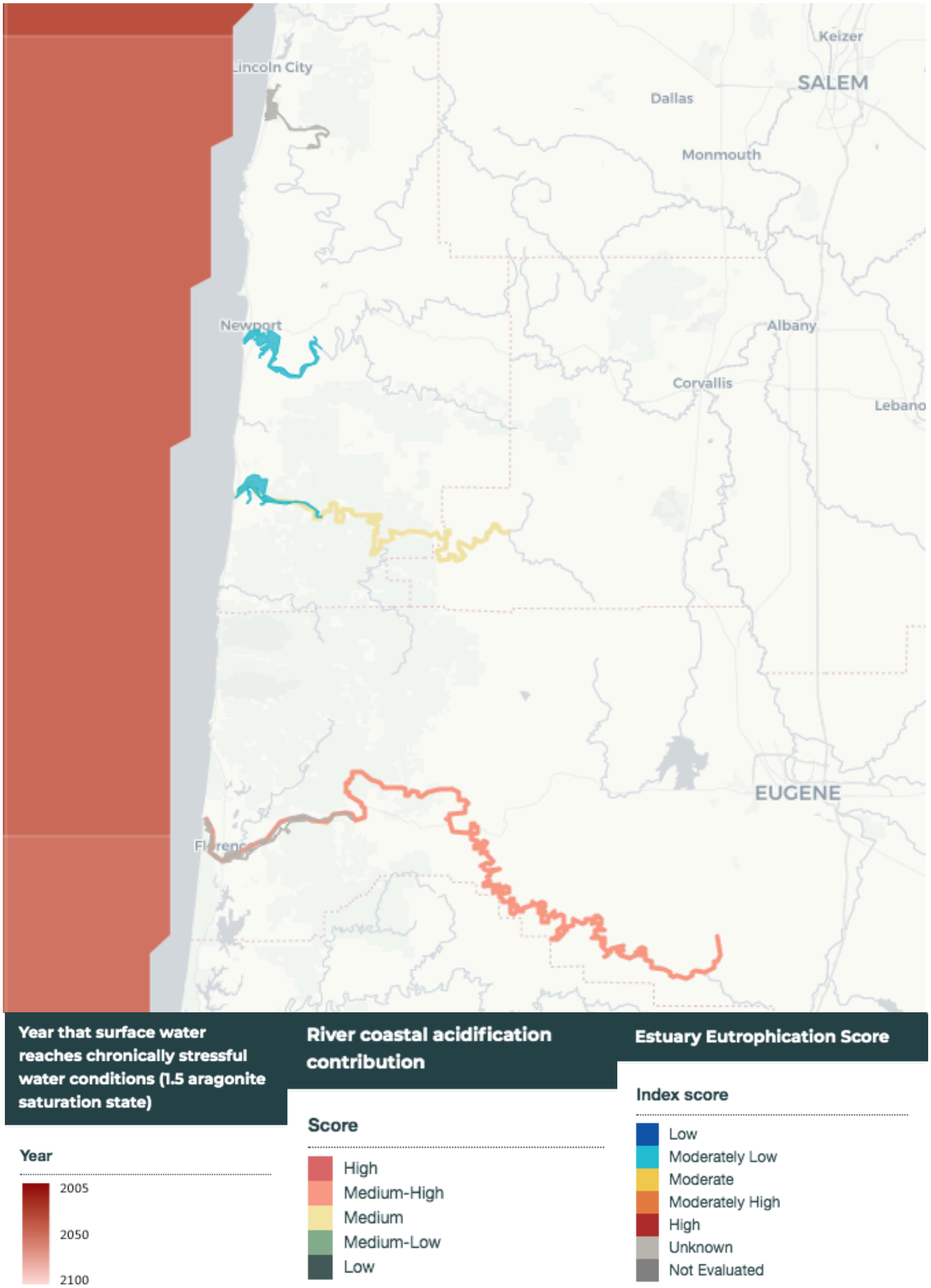


Figure 17 Factors of Coastal & Ocean Acidification for the Mid-Coast region. Source: Natural Resource Defense Council, https://www.nrdc.org/resources/ocean-acidification-hotspots.

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