

Water and Climate in the Pacific Northwest

INSTITUTE FOR WATER AND WATERSHEDS • OREGON CLIMATE CHANGE RESEARCH INSTITUTE • 8/2012

Water and climate in Oregon and Washington (hereby the Pacific Northwest, or PNW) are inextricably linked. Here, we explore how climate has changed and is projected to change during the 21st century, and the implications for water in the PNW and greater western United States.



How does climate vary over the Pacific Northwest landscape?

In the water cycle, surface water is both the accumulation from runoff from precipitation and groundwater. Precipitation can contribute to surface water immediately, either in the form of rain, or delayed, in the form of snowmelt-driven runoff. The seasonality of precipitation dictates the need for water storage in the form of snowpack in the PNW; most of the precipitation falls between October and March. Historically, mountain snowpack has served as natural storage for summertime water supply in much of the Pacific Northwest. In the future, as winter temperatures warm, mountain snowpacks will continue to diminish and summer water supply will likely decline.

Precipitation varies both spatially, or, across the landscape, and temporally (through time). Mountain ranges play an important role in where precipitation falls in the PNW. The highest annual precipitation amounts are found on the windward, or,

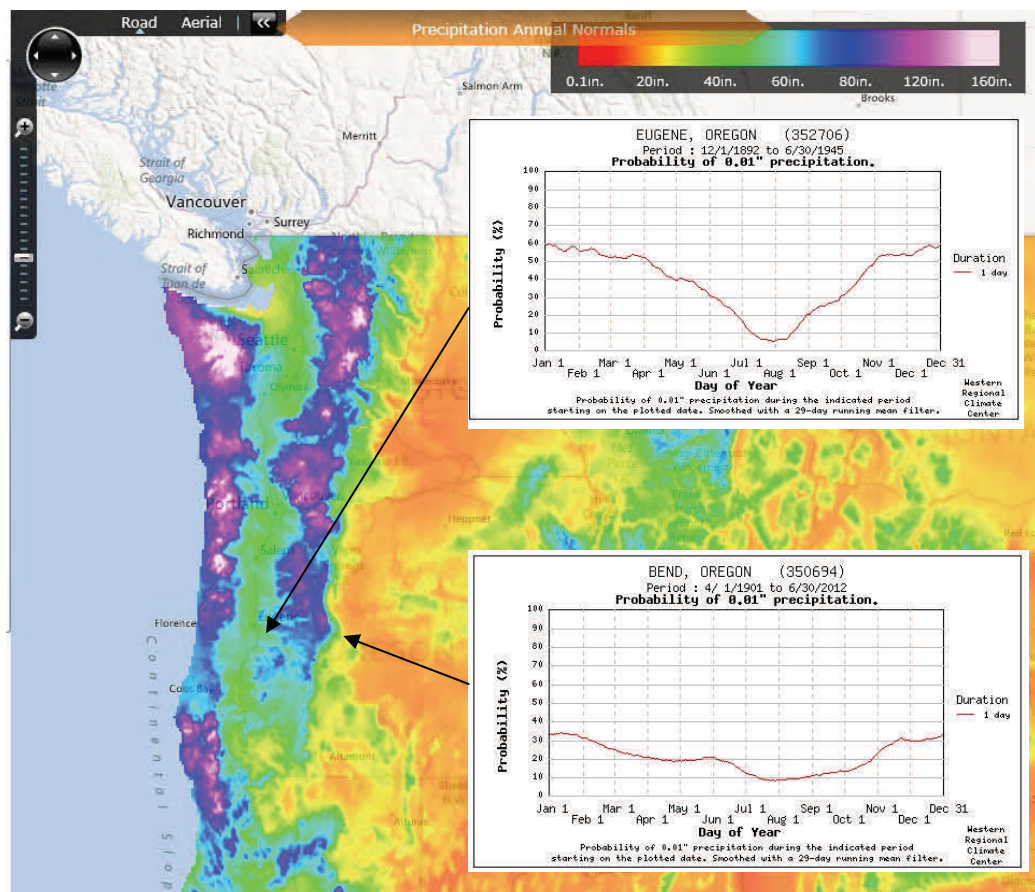


Figure 1. PRISM data mapped on 21st century climate services tool for Oregon and Washington. PRISM data (PRISM Climate Group, www.prism.oregonstate.edu, 21st Century Climate Services developed by Alex Wiggins of Oregon State University for OCS and funded by Microsoft Research, Bend and Eugene probability of at least 0.01" of precipitation in a 1-day period from Western Regional Climate Center).

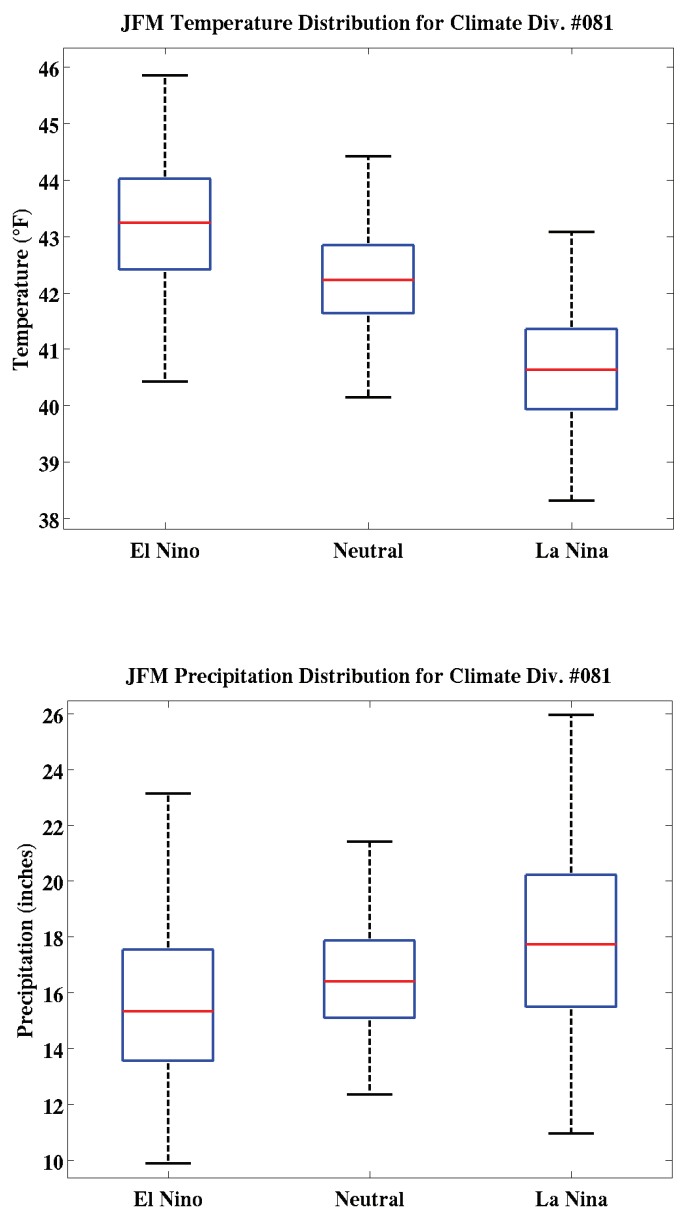


Figure 2. Shows temperature and precipitation distribution for interior Western Oregon for the months of January, February and March. The red line shows the mean, the blue box indicates the 33% and 66% values, and the end bars show the range from low to high for each mode of ENSO: El Niño, neutral (no signal detected in SST in ENSO area), and La Niña. In this part of Oregon, the temperature signal is a little more pronounced than the precipitation signal. The mid-range (33-66%) is different in temperature between El Niño and La Niña events, but there is overlap in the upper and lower ranges. In precipitation, the range from low to high precipitation in El Niño and La Niña events is greater than temperature, with overlap in the mid-range (33-66%) in warm, neutral, and cool phase conditions.

upslope side of the ocean-adjacent mountain ranges. Parts of the Coast Range in Oregon and the Olympic Mountains in Washington can see around 200 inches per year of precipitation on average.

The Pacific Northwest is billed as an excessively rainy place, but in reality, it does not live up to its wet reputation in the regions two largest cities: Seattle, WA and Portland, OR. Both cities both receive less precipitation annually (on average less than 40" per year), than New York City or Miami. This reputation isn't rooted in the amount of precipitation, but the number of days with rain. This rainy moniker is unfairly assigned to the entire Pacific Northwest, when the inland areas east of the Cascades are actually quite arid. This is because the Cascade Mountains of Oregon and Washington also create a rain shadow effect, keeping the inland areas mostly dry year-round.

The Cascades rain shadow can be described as such: ocean-influenced moist air masses are forced to rise when they meet the tall mountains. The rising air cools, condenses, and the moisture falls as precipitation. On the leeward (dry) side of the mountain, the now dry air warms and sinks. This is why Eugene, OR is rainier than Bend, OR, which is located directly over the mountains to the east. The Oregon Coast Range and Olympic Mountains of Washington produces a smaller, and somewhat less significant rain shadow; part of the reason that Newport, OR is wetter than Corvallis, OR, directly to its east.

General atmospheric circulation tends to dictate the timing of precipitation. The Aleutian Low is a semi-permanent atmospheric feature found in the general vicinity of the Aleutian Islands during the winter. Cyclonic flow tends to bring the flow and direct the general stormtrack over the Pacific Northwest. In the summer, the low shifts north and an opposite, anticyclonic ridging pattern tends to set up over the Northwest, keeping summers dry and

warm. Rain that does fall in the summer tends to be the result of small-scale convective events. Convective events usually bring short-lived bursts of heavy rainfall, and sometimes hail. These events are more typical east of the Cascades, where warm air required for ascent (a key element of thunderstorm development) is more free to mix with cold air aloft, triggering these events.

We've covered where and when precipitation tends to fall, and when, but temperature also plays a crucial role in water and climate in the Northwest. Proximity to the ocean also keeps temperatures mild in the winter; water doesn't cool as quickly as land. Winter, as we mentioned before, is the time of year when most of the precipitation falls in the Northwest. These mild temperatures are close enough to the freezing point ($0^{\circ}\text{C}/32^{\circ}\text{F}$), especially in the lower-mid elevations, that often a few degrees difference will spell the difference between rain and snow.

Modes of climate variability affect Pacific Northwest weather and climate on an interannual basis, namely the El Niño Southern Oscillation (ENSO), which is marked by an area in the equatorial Pacific Ocean. This area is where coupled sea surface temperature and atmospheric variations drive the overall global atmospheric circulation pattern. The warm phase of ENSO, is known as El Niño; the cool phase, La Niña. In the Pacific Northwest, especially the western portion of the region, the phase tends to affect seasonal temperature and precipitation. El Niño tends to split the jet stream, often bringing warmer air to Oregon and Washington and wetter weather to California. La Niña tends to position the northern storm track directly over the Pacific Northwest, bringing greater odds of cooler, wetter winters.

What are the overall trends in climate? How is human-caused climate change affecting the Pacific Northwest? What does climate change mean for water resources?

Human activity is primarily responsible for the observed 1.5°F increase in 20th century annual averaged temperatures in the Pacific Northwest, though a formal detection and attribution study has not been performed for this region. Trends in annual averaged precipitation have been more ambiguous, with some USHCN stations showing a wetter trend and some a drier trend. Winter temperatures have warmed in the Pacific Northwest over the last 110 years. Figure 3 shows United States Historical Climatology Network (USHCN sites over Washington, Oregon, Idaho. A red dot indicates a warming trend; a blue dot indicates cooling. The size on the dot is related to the magnitude of the trend per decade, a larger dot means a larger decadal trend.

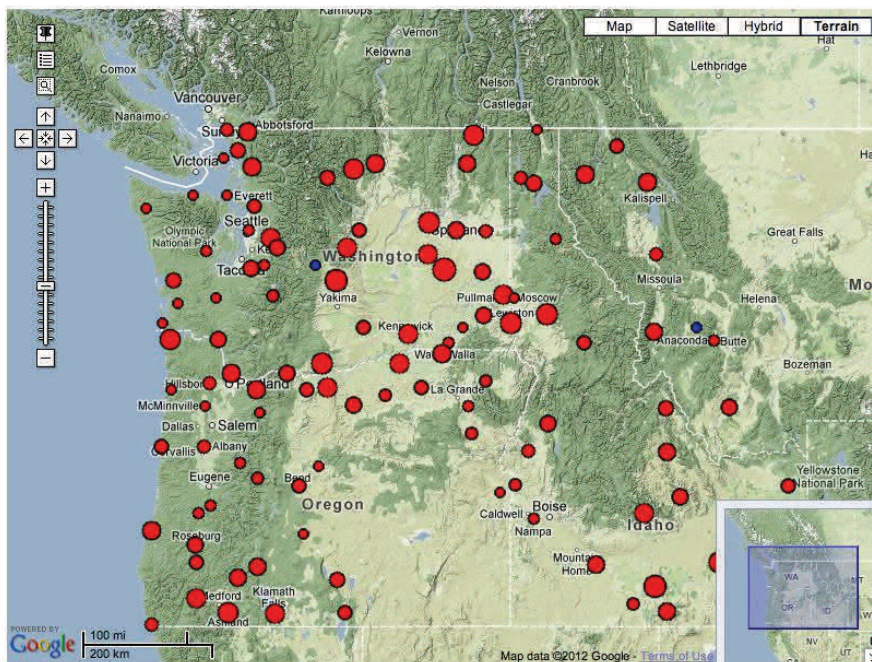
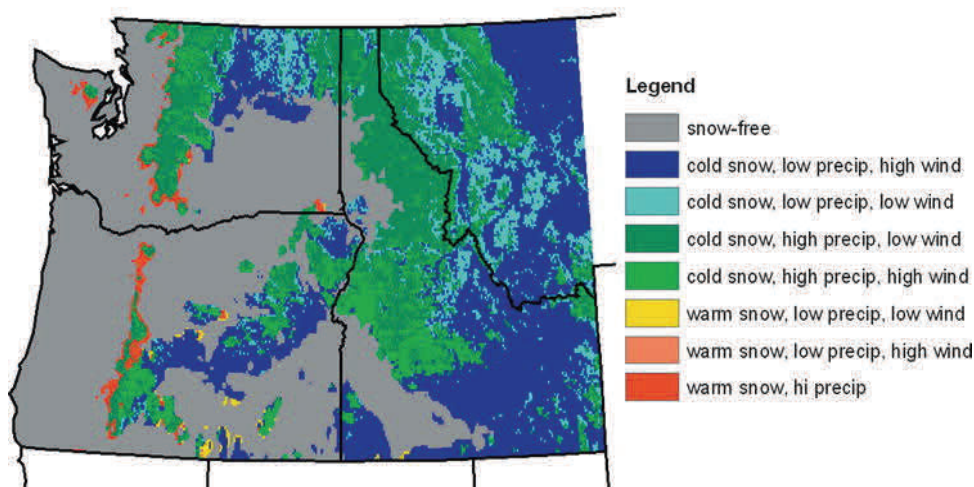


Figure 3. USHCN station trends in winter temperature for the Pacific Northwest. Office of the Washington State Climatologist, www.climate.washington.edu/trendanalysis

Historically, mountain snowpack has served as natural storage for summertime water supply in much of the Pacific Northwest. Increasing winter temperatures have left mountain snowpack, particularly lower-mid elevation snowpack vulnerable. In snowmelt-dominated basins in the Western U.S., there has been a shift in the timing of streamflow to earlier in spring, primarily driven by an increase in winter and spring temperatures. Formal detection and attribution studies show that human influence is responsible for 60% of the climate-related trends in historical streamflow and snowpack in the western U.S. from 1950-1999.

Snow Classification



Nolin and Daly (2006) mapped at-risk snow in the PNW using a rain-snow classification of 0°C (32°F). Areas shaded in orange/red are considered to be warm snow and at high risk (figure 4). They found that the Cascade and Olympic Mountain snowpacks were considered to be at highest risk, covering an area of about 9200 km², and could present adverse impacts not only for summer water supply, but to low elevation ski areas.

Figure 4. At-risk snow mapped across the Pacific Northwest (Figure from Nolin and Daly, 2006)

streams; some streams will peak earlier in the year, as shown at the Willamette River at Newberg, OR in Figure 5. Global climate models also suggest that a decrease in summer precipitation is also likely in the future, which means the small amount of precipitation that the state receives in the summer will be even less in the future.

A viable water supply is needed for irrigation, residential and commercial water use, fish propagation and survival and overall ecosystem health. With a (1.8 °F) 1°C rise in temperature, the amount and seasonality of water supply is projected to shift with seasonal changes in temperature and precipitation. It is important to note that not all past trends in streamflow can be attributed to global climate change; there is some interannual variability at play. Recent low flow years, particularly 2001 and 2005, stemmed from low winter precipitation. Snowmelt-related hydrologic variables already show a decline in basins with a snowmelt influence - earlier peak flow, lower summer flow, lower spring snowpack.

Earlier spring snowmelt will shift the timing of peak flows in

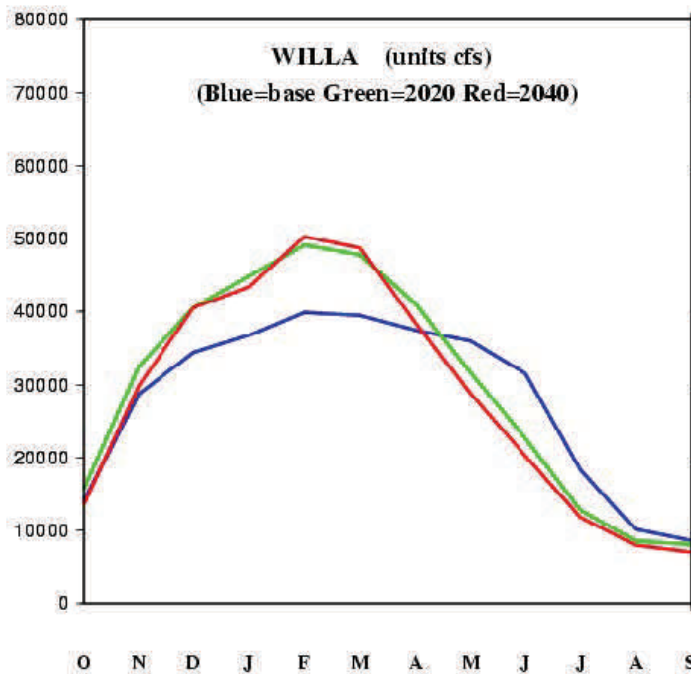


Figure 5. Infiltration Capacity (VIC) model as a part of University of Washington 2860 Project (Hamlet et al. 2010)

Cascade mountain snowpacks are projected to be less than half of what they are today by mid-century with lower elevation snowpacks being the most vulnerable. Through the end of the 21st century, April 1 snow water equivalent is projected to decrease in the Willamette River Basin in two emissions scenarios using an ensemble of GCMs from the Coupled Model Intercomparison Project 3 (CMIP3) experiment. There are two emissions scenarios: a1b (carbon intensive) or b1 (more renewables, less carbon intensive). Water demands are projected to increase throughout the 21st century, particularly in urban areas, adding an additional stress to water availability. Some climate change scenarios for the U.S. Pacific Northwest using global general circulation models (GCM) suggest a temperature-induced shift from snow to rain and earlier snow-melt⁵. Similarly, in the Colorado River Basin, future projections in changes in runoff using a more topographically-complex regional climate model (RCM) are dominated by a combination of winter snow cover change, increase in spring temperature and decrease in summer precipitation.

Other factors such as increased demand will pose an additional stressor to water availability. Water demands are projected to increase throughout the 21st century, particularly in urban areas. Part of the increased demand will likely be due to summer temperatures, and some of the demand can be attributed to overall population growth of the state. Data from Portland Water Bureau shows that there is a relationship between annual average water consumption and annual average temperature. While demand during winter months is expected to remain constant, research on urban water demand suggests that temperature is the most influential climate variable on water consumption, particularly among single family residential households. These impacts are also evident at multiple scales, including the household, neighborhood, and region.

Water quality is also likely to be impacted with rising air temperature and seasonal shifts in flow availability. Water temperatures are expected to rise as air temperature increases in the 21st century, particularly in urban streams where natural riparian vegetation is typically lacking. A decline in summer stream flow will exacerbate water temperature increases, because the low volume of water will absorb the sun's rays more than during times with larger instream flows. However, an increase in air temperature alone does not lead to major changes in stream temperature. Changes in riparian vegetation (either land use changes or climate-related) will influence streamflow and water temperature. Changes in water temperature can have significant implications for stream ecology and salmon habitat. Smaller streams in transient rain-snow basins and in eastern Oregon will be the most vulnerable to increasing summer air temperature and diminished low flows. There is little research on long term trends in water temperature in undisturbed watersheds; sites with long term data are rare. Sediment and phosphorus loads, which are a detriment to water quality, are expected to increase in winter as winter flow is projected to rise. It will be important for water resource managers statewide to include considerations for climate change in future planning.

Simulating future climate.

General circulation models/global climate models (GCMs) are numerical representations of the very complex climate system, including processes in the atmosphere, ocean, cryosphere and land surface. Many models are coupled with an ocean model to better understand the relationship between ocean and atmosphere. We use climate models to better understand how the climate may respond to increasing greenhouse gas emissions.

Climate modeling can be considered similar to a science experiment performed in a laboratory. GCMs are state-of-the-art powerful tools for recreating the earth in a laboratory, or more specifically, a supercomputer. GCMs are subject to rigorous testing, and are run for the 20th century with natural (chiefly volcanic and solar activity) and human forcings (anthropogenic greenhouse gases) and compared against observations to test how well the model can recreate past climate. GCMs are the most powerful tool available for simulating future climate, but the sheer size and computational power required for these to run means that they must do so at a coarse resolution, both horizontally (on the landscape) and vertically (in atmosphere). GCM outputs are used in the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (AR). IPCCAR5 is due out in 2013; the last Assessment Report was released in 2007. GCM outputs are often used in seeing how future climate may impact other sectors such as water. Future climate is fed into hydrologic, social, or land-use models, among others.

The latest group of GCM experiments for AR5, the Coupled Model Intercomparison Project 5 (CMIP5): A freely available state-of-the-art multimodel dataset. An integrated set of experiments that offer a perspective on simulated climate change and variability. Hundreds of model simulations of the 21st century are available.

Resolution continues to get better with each set of GCM runs, but GCMs excel at understanding global and large-scale climate change as opposed to smaller-scale, regional change. GCMs can tell the location of the Pacific Northwest on the globe and that there is land bordering an ocean. The coarse resolution of GCMs are unable to capture PNW topography, which plays an important role in PNW climate. To make GCM outputs usable at regional scales, climate scientists use a technique called downscaling. Downscaling attempts to take the large GCM scale and bring them to resolution that is usable for decision-makers and resource managers, who are often operating on a watershed or state scale, and not a global scale. There are two methods of downscaling.

- Statistical downscaling: Uses empirical relationships between large scale global climate model output and local conditions to produce data at a local scale
- Dynamical downscaling: Uses mechanistic models run at high resolution to produce local data.

Greenhouse gas emissions scenarios, or simply emissions scenarios are used as inputs to climate models. The new Intergovernmental Panel on Climate Change (IPCC) AR5 scenarios are now emissions trajectories. These new trajectories, called Representative Concentration Pathway (RCP), are followed by a number indicating the radiative forcing (in watts per square meter) or how much heating they would produce. Higher radiative forcing = more warming.

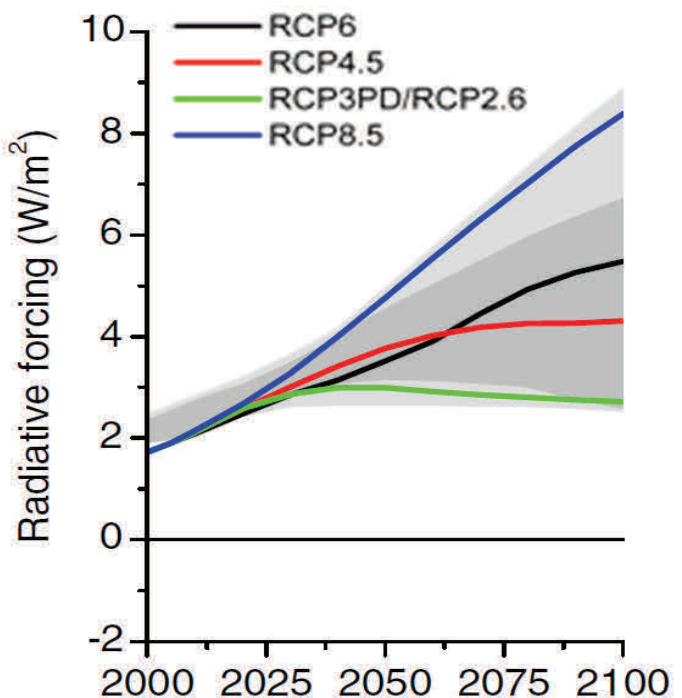


Figure 6. Representative Concentration Pathway total radiative forcing by year in watts/m², image from IPCC

RCPs replace the SRES (Special Report on Emissions Scenarios) used in CMIP3 (AR4). The new RCPs are based on consistent socioeconomic assumptions, unlike SRES. Scenarios are meant to be images of a possible future, and are not a forecast. (figure 6).

Four trajectories are used to eliminate the notion that the middle pathway is most likely.

- RCP 8.5: high emissions pathway
- RCP 6: stabilization scenario
- RCP 4.5: moderate reductions pathway
- RCP 2.6: greenhouse gas emissions zero by 2070, and then going negative (mitigation)

Regional climateprediction.net

Supercomputers that run GCMs are very expensive and take great amounts of time to run. Downscaling helps bring coarse GCM output to a more actionable regional level, but the process is still imperfect. Regional climate modeling experiments, either through regional climate modeling efforts such as NARCCAP (North American Climate Change Assessment Program) or innovative science experiments like climateprediction.net can produce simulations of future climate at a level that is useful for regional level planning.

Since 2000, this experiment at Oxford University, climateprediction.net, has made use of the personal computers of over 50,000 volunteers to perform global climate modeling that can answer fundamental questions about the response of global climate to rising greenhouse gases. For the first time, climateprediction.net will perform regional climate modeling for western North America that provides an unprecedented combination of a large ensemble of individual simulations, fine spatial detail, and many output variables relevant to society. Regional modeling provides better spatial detail, which is critically important in mountainous regions and much needed by decision makers. By producing thousands of simulated model futures, this regional experiment will provide detailed answers to key questions about those aspects of climate change that matter most to society: frost days, heat waves, consecutive dry days, extremely heavy rainfall, wind speed, extremely strong wind events, snowpack (figure 7), and coastal upwelling. These answers will be couched in terms of their probability. Changes in these quantities affect agriculture, energy demand, human health, coastal ecosystems, risk of floods, water supply, and many more economic and environmental values.

Regional climateprediction.net (regCPDN) for the western US is housed at Oregon State University, where researchers are receiving 1000s of simulations at a 25km resolution. The period of regCPDN spans 1960-2009 and 2029-2040, using RCP 4.5.

For more information, and to volunteer for the experiment:

<http://climateprediction.net/weatherathome>

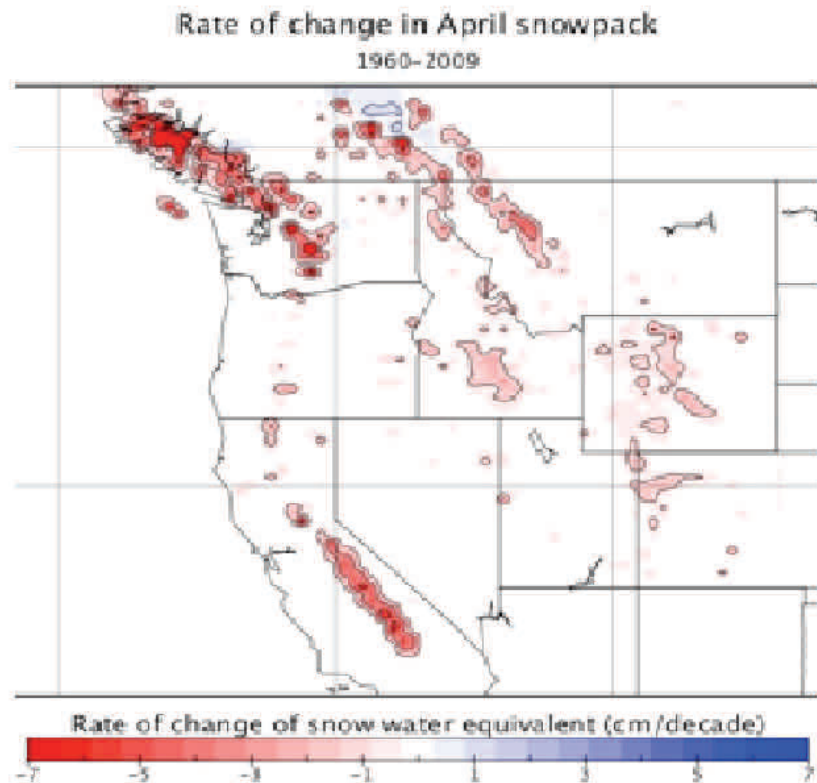


Figure 7. Rate of change in April snowpack, 1960-2009 from regCPDN. Red shows decline in April 1 snowpack from 1960-2009. Figure from David Rupp and Dean Vickers, OCCRI.

CIRC/OCCRI/OCS Water and Climate Projects

- **Willamette Water 2100**

Anticipating water scarcity and informing integrative water system response in the Pacific Northwest

This project is evaluating how climate change, population growth, and economic growth will alter the availability and the use of water in the Willamette River Basin on a decadal to centennial timescale. The project seeks to create a transferable method of predicting where climate change will create water scarcities and where those scarcities will exert the strongest impacts on human society. The five year project began in October 2010, and is a collaborative effort of faculty from Oregon State University, the University of Oregon and Portland State University. It is funded by the National Science Foundation.

<http://water.oregonstate.edu/ww2100/>

- **Water Utility Climate Alliance (WUCA): Piloting Utility Modeling Applications (PUMA)**

Urban water utilities have taken the lead in considering future climate in their planning activities. WUCA is a group of 10 major urban water utilities. The Water Utility Climate Alliance is dedicated to collaborating on climate change issues affecting drinking water utilities. By enhancing climate change research and developing adaptation strategies, water utilities will be positioned to respond to climate change and protect our water supplies.

Piloting Utility Modeling Applications (PUMA) is a collaborative venture bringing together Water Utility Climate Alliance (WUCA) members, Regional Integrated Sciences and Assessments (RISA) leaders, and selected representatives of the climate science and applications community. The PUMA project involves 5 major urban water utilities: Seattle Public Utilities, Portland Water Bureau, San Francisco Public Utilities Commission, Tampa Bay Water and New York City Department of Environmental Protection.

CIRC is the lead Regional Integrated Sciences Assessment (RISA) team, and working with Seattle Public Utilities and Portland Water Bureau on their PUMA assessments.

http://www.wucaonline.org/html/actions_puma.html

More on the Pacific Northwest's Climate Knowledge Network:

The Oregon Climate Change Research Institute is a network of over 100 researchers across the Oregon University System and affiliated state and federal labs. OCCRI is housed in the College of Oceanic and Atmospheric Science at Oregon State University.

<http://www.occri.net>

The Climate Impacts Research Consortium (CIRC) is the NOAA-funded Regional Sciences and Assessment (RISA) for the Pacific Northwest. The Climate Impacts Research Consortium (CIRC) provides information and tools for making decisions about landscape and watershed management in a changing climate.

<http://www.pnwclimate.org>

The Oregon Climate Service serves as the official state climate office for Oregon as recognized by the American Association of State Climatologists (AASC). OCS is the repository for weather and climate data and knowledge for the state of Oregon, focusing on research, outreach, and service.

www.ocs.oregonstate.edu

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photo: Columbia River Gorge, Dan Brown

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Oregon Institute for Water and Watersheds

210 Strand Hall

Oregon State University

Corvallis, OR 97331-2208

T: 541.737.9918

F: 541.737.1887

<http://water.oregonstate.edu>