PACIFIC NORTHWEST

The Pacific Northwest encompasses extensive forests,topography that creates abrupt changes in climate and ecosystems over short distances,and mountain and marine environments in close proximity. The Cascade Mountains divide the region climatically, ecologically, economically, and culturally. Three quarters of the region's population live west of the Cascades,concentrated in the metropolitan areas of Seattle and Portland,where the aerospace and computer industries have largely supplanted the traditional resource sectors of forestry, fishing,and agriculture. The Northwest provides a quarter of the nation's softwood lumber and plywood. The fertile lowlands of eastern Washington produce 60% of the nation's apples and large fractions of its other tree fruit.

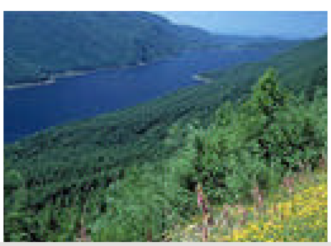
The region has seen several decades of population and economic growth nearly twice the national rate,with population nearly doubling since 1970. The region's moderate climate,quality of life,and outdoor recreational opportunities contribute to its continuing attraction to newcomers. The same environmental attractions that draw people to the region are increasingly stressed by rapid development. Stresses arise from dam operation, forestry, and land-use conversion from natural ecosystems to metropolitan areas,intensively managed forests, agriculture,and grazing. The consequences include loss of old-growth forests, wetlands,and native grasslands;urban air pollution; extreme reduction of salmon runs;and increasing numbers of threatened and endangered species.

KEY ISSUES

- **Changes in Timing of Freshwater Resources**
- **Added Stresses on Salmon**
- **CO_2 and Summer Drought Effects on Forests**
- **Sea-level Rise Impacts on Coastal Erosion**

Observed Climate Trends

Over the 20th century, the region has grown warmer and wetter. Annual-average temperature has increased 1 to 3°F (0.5-1.5°C) over most of the region, with nearly equal warming in summer and winter. Annual precipitation has also increased across the region, by 10% on average,with increases reaching 30 to 40% in eastern Washington and Northern Idaho. The region's climate also shows significant recurrent patterns of year-to-year variability. Warm years tend to be relatively dry with low streamflow and light snowpack,while cool ones tend to be relatively wet with high streamflow and heavy snowpack. Though the differences in temperature and precipitation are small,they have clearly discernible effects on important regional resources. Warmer drier years tend to have summer water shortages,less abundant salmon,and increased probability of forest fires. These variations in the region's climate show clear correlations with two large-scale patterns of climate variation over the Pacific:the El Niño/Southern Oscillation (ENSO) on scales of a few years;and the more recently discovered Pacific Decadal Oscillation (PDO) on



Learning from Water Shortages

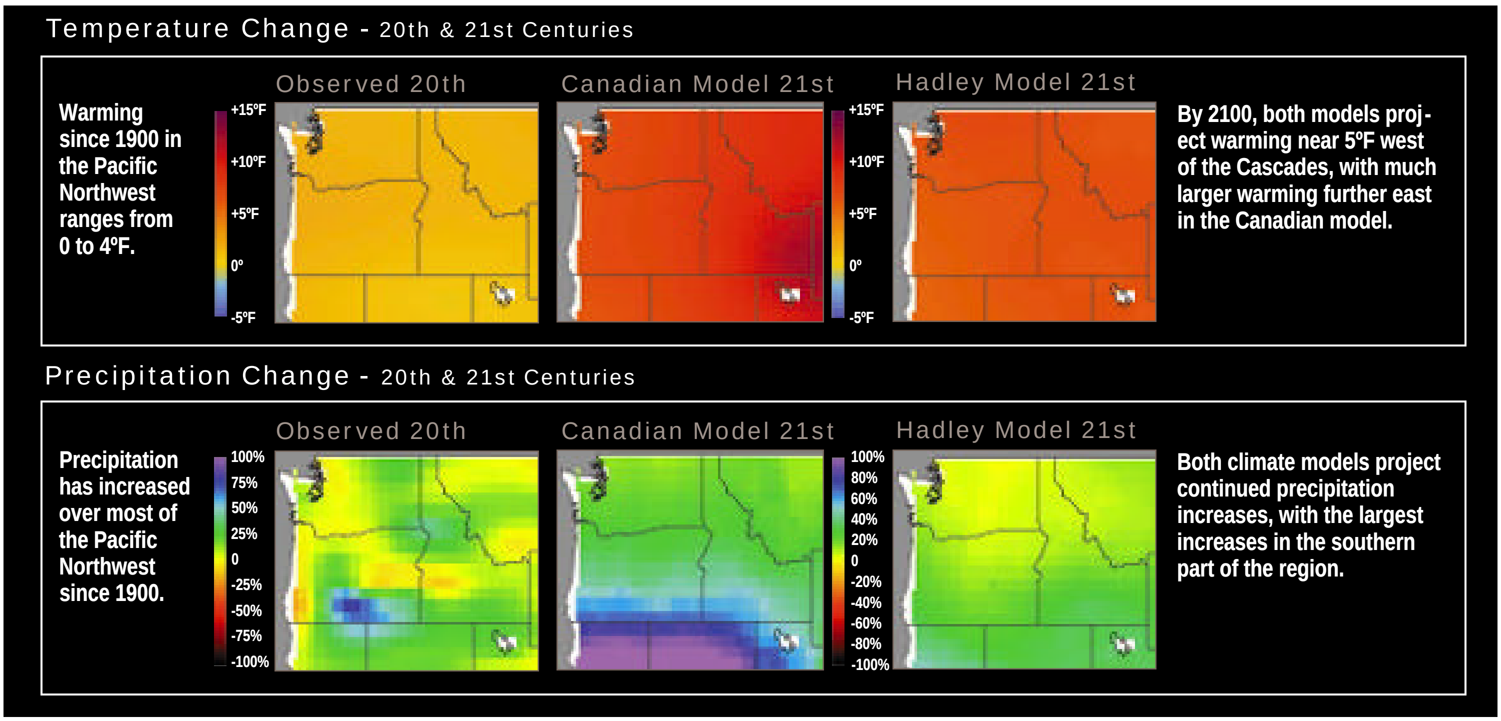
Seattle Public Utilities (SPU) experienced summer droughts and potential shortages in 1987, 1992, and 1998. Their responses to the three events illustrate institutional flexibility and learning. Summer 1987 began with full reservoirs, but a hot dry summer and a late return of autumn rains created a serious shortage in which water quality declined, inadequate flows were maintained for fish, and the main reservoir fell so low that an emergency pumping station had to be installed. In response, the City developed a plan with four levels of response to anticipated shortage: advising the public of potential shortages and monitoring use; requesting voluntary use reductions; mandatory prohibitions of certain uses (such as watering lawns and washing cars); and rationing. Another drought came in 1992, following a winter with low snowpack but in which SPU had followed standard flood-control rules by spilling water from their reservoirs. With a small snowmelt, reservoirs were low by the spring, and SPU invoked mandatory restrictions during the hot dry summer that followed. Water quality declined sharply, prompting a decision to begin building a costly ozone-purification plant.

The ill-advised spilling of early 1992 alerted SPU to the danger of following rigid reservoir rule curves, and they have since taken scales of a few decades.The observed effects of these patterns provide powerful illustrations of regional sensitivities to climate,but how they might interact with future climate change is not yet understood.

By the 2090s, average summer temperatures are projected to rise by 7-8°F (4-4.5°C), while winter temperatures rise by 8-11°F (4.5-6°C). Projected annual average precipitation increases range from a few percent to 20% in the Hadley model, and from 20 to 50% in the Canadian model.

Scenarios of Future Climate

Model scenarios project regional warming in the 21st century to be much greater than observed during the 20th century, with average warming over the region of about 3°F (1.5°C) by the 2030s and 5°F (3°C) by the 2050s. By the 2090s, average summer temperatures are projected to rise by 7-8°F (4-4.5°C),while winter temperatures rise by 8-11°F (4.5-6°C). Through 2050, average precipitation is projected to increase,although some locations have small decreases. Precipitation increases would be concentrated in winter, with little change or a decrease in summer. Because of this seasonal pattern of wetter winters and drier summers, even the projections that show annual precipitation increasing,show water availability decreasing,especially in the Hadley model. By the 2090s,projected annual average precipitation increases range from a few percent to 20% in the Hadley model,and from 20 to 50% in the Canadian model.



a more flexible approach, projecting annual supply and demand using a model including probabilistic predictions based on ENSO and PDO. During the strong El Niño of 1997-1998, SPU took early conservation education measures and allowed higher than normal reservoir fill. When 1998 brought a small snowmelt and a hot dry summer, these measures allowed the drought to pass with the public experiencing no shortage. In integrating seasonal forecasts into its operations, SPU is an uncommonly adaptable resource-management agency. But it still has a long way to go in adapting to longer-term climate variability and change. SPU presently projects that new conservation measures will keep demand at or below present levels until at least 2010, while conservation measures and planned system expansion (including a connection with a neighboring system) will maintain adequate supply until at least 2030. Over this period, climate change is likely to have significant effects on both supply and demand, but is not yet included in planning. The warmer drier summers projected under climate change are likely to stress both supply and demand, requiring earlier capacity expansion, and triggering the more restrictive conservation measures more often. Moreover, the recent shift to cool PDO phase that has been suggested could well mask this effect for a couple of decades, risking sudden appearence of shortages when PDO next shifts back to its warm phase.

PACIFIC NORTHWEST KEY ISSUES

Changes in Timing of Freshwater Resources

Despite its reputation as a wet place,most of the Northwest receives less than 20 inches (0.5 meter) of precipitation a year, and dry summers make freshwater a limiting resource for many ecosystems and human activities. Water resources are already stressed by multiple growing demands. The projected warmer wetter winters will likely increase flooding in rainfed rivers,because there is more precipitation,and because more of it falls as rain. Projected year-round warming and drier summers will likely increase summer water shortages in both rainfed and snowfed rivers,including the Columbia,because there would be less snowpack and because it would melt earlier. In the Columbia, allocation conflicts are already acute,and the system is vulnerable to shortages.

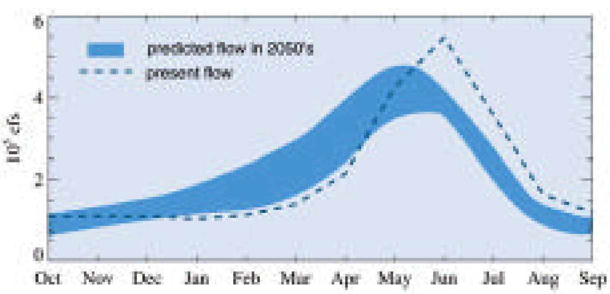
Adaptations: Adapting to projected increases in summer shortages will likely require a combination of reducing demand,increasing supply, and reforming institutions to increase flexibility and regional problem-solving capacity. In the Colombia Basin,current infrastructure and institutions are inflexible and inadequate to deal with the projected scarcity.

Increased winter flooding, reduced summer and fall flows, and rising stream and estuary temperatures are all harmful for salmon. In addition, it is possible that earlier snowmelt and peak spring streamflow will deliver juveniles to the ocean before there is adequate food for them.

Added Stresses on Salmon

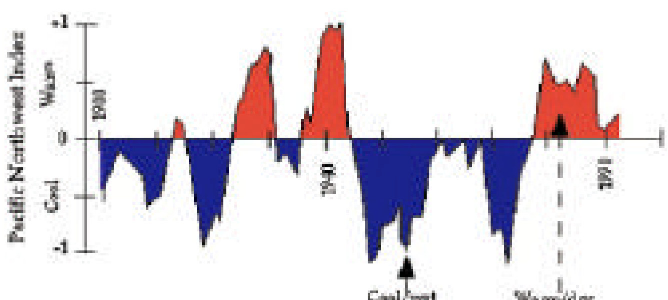
While non-climatic stresses on Northwest salmon presently overwhelm climatic ones,salmon abundances have shown a clear correlation with 20th century variations in climate from decade to decade. Climate models cannot yet project the most important oceanic conditions for salmon,but the likely effects on their freshwater habitat all appear unfavorable. Increased winter flooding, reduced summer and fall flows,and rising stream and estuary temperatures are all harmful for salmon. In addition,it is possible that earlier snowmelt and peak spring streamflow will deliver juveniles to the ocean before

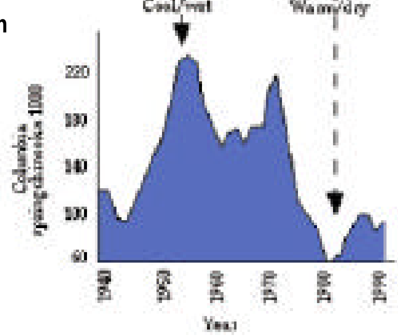
Columbia Streamflow Changes



Relative to present flows (dashed), the wetter winters and drier summers simulated by climate models are very likely to shift peak streamflow earlier in the year, increasing the risk of late-summer shortages. Though the Columbia system is only moderately sensitive to climate change, allocation conflicts and a cumbersome network of interlocking authorities restrict its ability to adapt, producing substantial vulnerability to these shortages.

Observed Effects of Climate Variability on Salmon





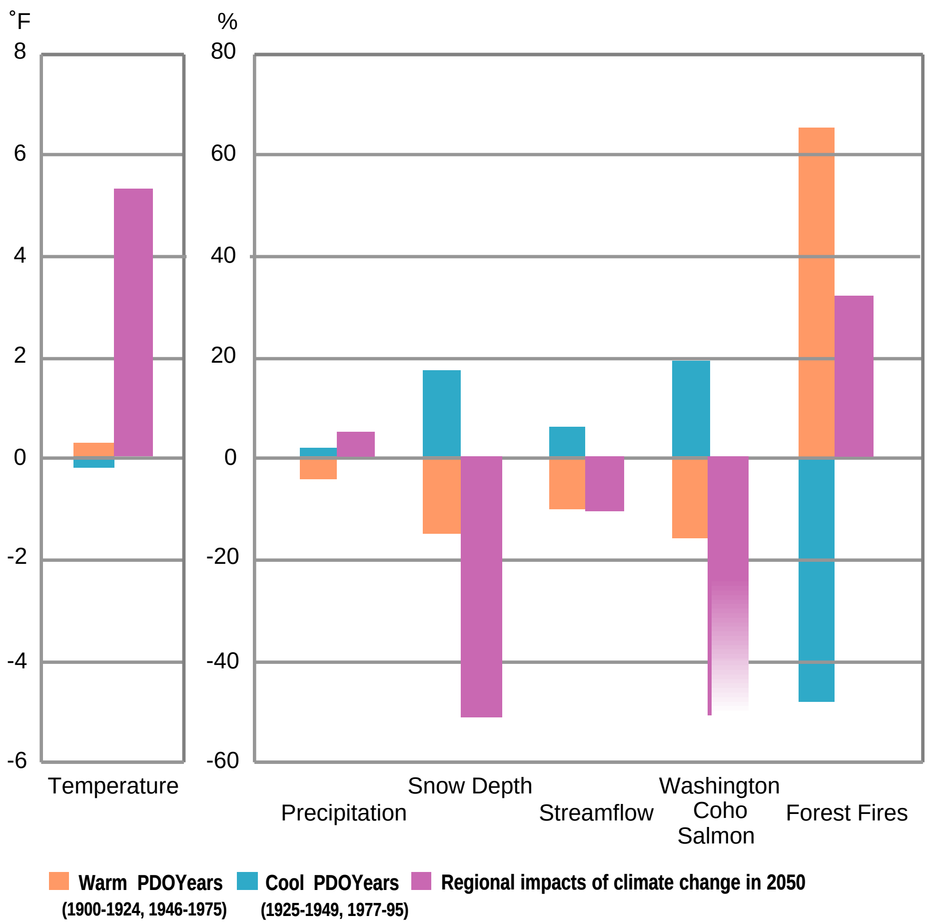
Abundances of many salmon stocks closely track inter-decadal climate variation since 1940. Upper Columbia bright spring Chinook are abundant when the Pacific Northwest Index (one measure of decadal climate variation) is negative. Both are 5-year moving averages.

there is adequate food for them. Climate change is consequently very likely to hamper efforts to restore already depleted salmon stocks,and to stress presently healthy stocks.

Adaptations: It is possible that operational changes on managed rivers would reduce current stream warming and slow future warming,although such measures will very likely be overwhelmed by continued climate warming. Measures to reduce general stress on fish,such as changing dam operations to provide adequate late-summer streamflows,might possibly increase salmon's resilience to other stresses,including climate. It is very likely that maintaining such flows will become increasingly difficult,however, under the projected regional warming that will very likely shift peak streamflows to earlier in the year. Other options include maintaining the diversity of salmon by increasing preservation of their habitat,or removing existing dams and accepting reduced ability to manage summer shortages.

Water resources are already stressed by multiple growing demands. The projected year-round warming and drier summers will likely increase summer water shortages, because there is less snowpack and because it melts earlier.

Regional Impacts:
Climate Change projected for 2050 vs observed 20th century variability



This chart compares possible Northwest impacts from climate change by the 2050s with the effects of natural climate variations during the 20th century. The orange bars show the effects of the warm phase of the Pacific Decadal Oscillation (PDO), relative to average 20th century values. During warm-PDO years, the Northwest is warmer, there is less rain and snow, stream flow and salmon catch are reduced, and forest fires increase. The blue bars show the corresponding effects of cool-phase years of the PDO, during which opposite tendencies occurred.

The pink bars show projected impacts expected by the 2050s, based on the Hadley and Canadian scenarios. Projected regional warming by this time is much larger than variations experienced in the 20th century. This warming is projected to be associated with a small increase in precipitation, a sharp reduction in snowpack, a reduction in streamflow, and an increase in area burned by forest fires. Although quite uncertain, large reductions in salmon abundance ranging from 25 to 50%, are judged to be possible based on projected changes in temperature and streamflow.

Temperature	**Change in annual average regional temperature (ºF)**
Precipitation	**Change in annual average regional precipitation (%)**
Snow depth	**Change in average winter snow depth at Snoqualmie Pass, WA (%)**
Streamflow	**Change in annual streamflow at The Dalles on the Columbia River (corrected for changing effects of dams) (%)**
Salmon	**Change in annual catch of Washington Coho salmon (%)**
Forest fires	**Change in annual area burned by forest fires in WA and OR (%)**

PACIFIC NORTHWEST **KEY ISSUES**

CO_2 and Summer Drought Effects on Forests

Evergreen coniferous forests dominate the landscape of much of the Northwest. West of the Cascades,coniferous forests cover about 80% of the land,and include about half the world's temperate rainforest. Northwest forests have been profoundly altered by timber management and land-use conversion. These forests are quite sensitive to climate variation because warm dry summers stress them directly, by limiting seedling establishment and summer photosynthesis,as well as indirectly, by creating conditions favorable to pests and fire. The extent,species mix,and productivity of Northwest forests are likely to change under projected 21st century climate change,but the specifics of these changes are not known with confidence at present. They are very likely to depend on interactions between the timing and amount of precipitation,the seasonal water-storage capacity of forest soils,and changes in trees' water-use efficiency under elevated CO_2. It is very likely that these factors will jointly determine the consequences of the likely increase in summer moisture stress, which will also depend on interactions with forest management practices,land-use conversion,and other pressures from development.

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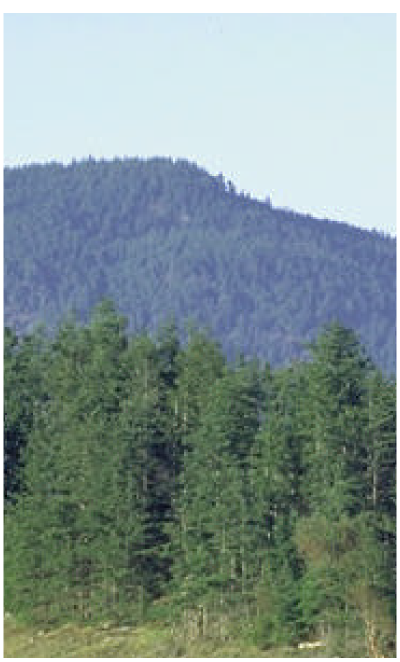
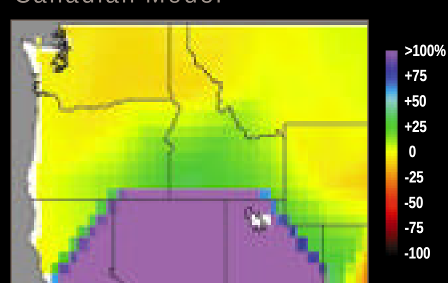
Adaptations: Options include planting species adapted to projected climate rather than present climate;managing forest density to reduce susceptibility to drought stress and fire risk;and using prescribed burning to reduce the risk of large,high-intensity fires. Increased capacity for long-term monitoring and planning would likely help with management. Reduced tree cutting, reduced road construction,and establishment of large buffers around streams are some of the ways to promote diversity of plant and animal species and the services provided by forest ecosystems (such as purifying air and water). Improved seasonal forecasts,and knowledge of the typical effects of ENSO and PDO, could possibly assist in decision making on timing and species of planting,and use and timing of prescribed burning.



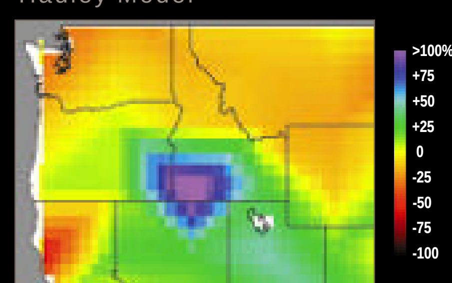
Summer Soil Moisture Change - 21st Century

Canadian Model



The Canadian model also projects drier soils over important forest areas, but to a lesser degree. Soil moisture is projected to decrease by 10 to 15% in the Puget Sound area.

Hadley Model



The Hadley model projects drier soils over important forest areas. For example, soil moisture decreases reach 25% in the Puget Sound area.

Sea-level Rise Impacts on Coastal Erosion

Sea-level rise is likely to require substantial investments in order to avoid coastal inundation,especially in the low-lying communities of southern Puget Sound where coastal subsidence is occurring. Other likely effects include increases in winter landslides,and increased erosion on sandy stretches of the Pacific Coast. Severe storm surges and erosion are presently associated with El Niño events,which raise sea level for several months and change the direction of prevailing winds. Climate change is projected to bring similar shifts. Projected heavier winter rainfall is likely to increase soil saturation,landsliding,and winter flooding. All these changes would likely increase the danger to property and infrastructure on bluffs and beachfronts,and beside rivers.

Adaptations: The current coastal management system is not particularly adaptable, even to current climate variability and risks,and there is little inclination to restrict development in vulnerable locations. Adaptation strategies would involve conserving remaining natural coastal areas,placing less property at risk in low-lying or flood- or slide-prone areas,assigning more of the associated risk to property owners through insurance rates,and more effective transfer of climate change information to local governments,where most planning authority lies.

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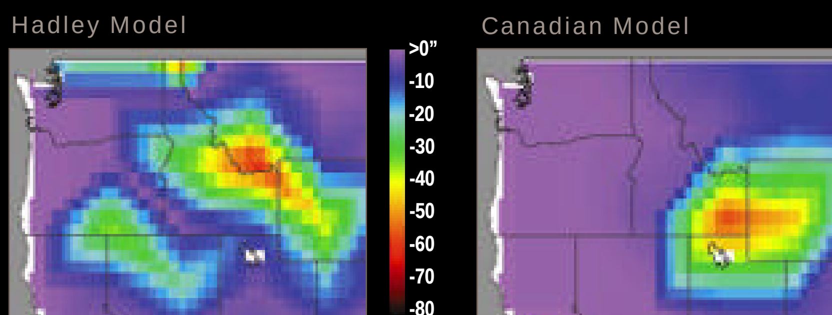
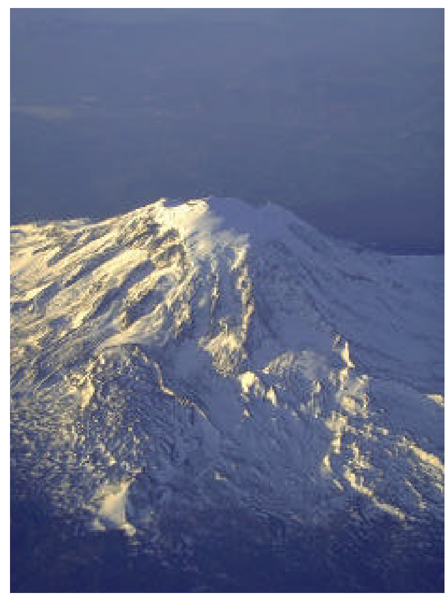
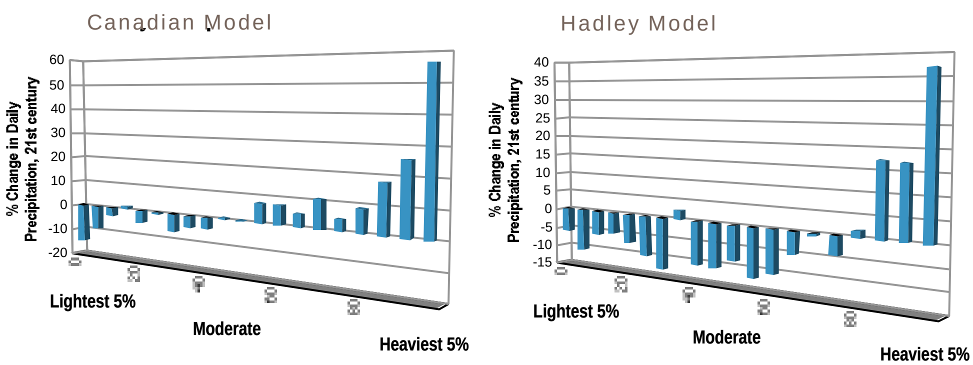
Winter Snow Depth Change - 21st Century



These maps show projected changes in annual snow depth, averaged over December, January, and February. The Hadley and Canadian models project 30 to 50-inch reductions in average snow depth in the mountains of the Pacific Northwest and West during the 21st century. (Due to limitations in model resolution, the highest mountains appear to be farther east than they actually are).



Projected Northwest Daily Precipitation Change - 21st Century



Days receiving precipitation, sorted by percentile.

Over the 21st century, both models project increases in annual average precipitation and in extreme precipitation events. As the graphs for both models show, the largest precipitation increases are projected to occur on days already receiving the most.