ANTHROPOGENIC CLIMATE CHANGE AND SNOW IN THE PACIFIC NORTHWEST

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ABSTRACT

The Pacific Northwest is unusually vulnerable to a warning climate owing to its heavy reliance on snowpack to store water for summer use. This paper outlines the state of global climate science and describes efforts by the Climate Impacts Group at the University of Washington to understand how a warming, of plausible magnitude could affect the Pacific Northwest, specifically with regard to streamflow and snowpack.

THE SCIENCE OF GLOBAL CLIMATE CHANGE

There is a growing consensus among climate scientists that the Earth's climate is already showing- signs of unnatural changes that can be traced to human activity (chiefly the burning of fossil fuels like coal, oil, and natural gas). The evidence that humans have already altered the climate is outlined in the most recent comprehensive assessment produced by the Intergovernmental Panel on Climate Change (IPCC; the report was released in January 2001 and the summary is available online at www ipcc.ch), which required about three years of work by several hundred, climate scientists. The evidence for a warming world includes

- the instrumental record of temperature changes: about 1.1°F in the past 100 years
- the 1990's were the warmest decade in the instrumental record (-140 years) and very likely the warmest decade in at least the last 1,000 years
- well-documented retreat by nearly all alpine glaciers in the world
- melting permafrost, reduction in Arctic sea ice
- biological changes like earlier spring bloom and migrations of temperature-sensitive species.

Evidence that this warming is at least partly due to human activity comes from the following considerations:

- reconstructions of northern hemisphere temperature over the past 1,000 years shows that the rate and magnitude of warming in the 20th century was unprecedented
- the magnitude of 20th century warming is consistent with that simulated by climate models in which the carbon dioxide history increases as observed (32% from pre-industrial times to now)
- climate models run for thousands of years with constant CO_2 forcing do not show anything, like the degree of warming during this century
- efforts to simulate the climate changes of the 20th century using various combinations of forcing factors (solar variability, volcanic eruptions, CO_2 changes) only succeed when CO_2 changes are included.

Given the strength of evidence for human influence on climate, the IPCC goes on to project increases in globally averaged surface temperature of 3- 10'F over the next 100 years. The uncertainty in the range stems largely from uncertainty in socioeconomic projections, and less from uncertainty about how the climate will react to a doubling Of CO_2.

PROJECTIONS OF REGIONAL CLIMATE CHANGE IN THE NORTHWEST

The UW Climate Impacts Group has examined output from 8 IPCC climate models to determine projected changes in climate for the Pacific Northwest (Columbia River Basin plus the remaining portions of Washington and Oregon). The models simulated 20th century climate using observed increases in "equivalent CO_2". then projected forward into the 21st century using a simplified assumption of 1%/year increase in equivalent CO_2- On average, the models project a warming of 3.6°F by the 2020s and 5.0°F by the 2040s (Mote et al., 1999; Mote et al.. 2001). A simulation of mid-21st century climate with a regional climate model (Leung and Ghan, 1999) gave roughly similar regionally averaged warming.

All the climate models preserve the sharp seasonality of the region's precipitation, with wet winters and dry summers. However, the winters are projected to become wetter in nearly all the models, owing mostly to the greater amount of moisture that a warmer atmosphere can hold but also in some models to large-scale circulation

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changes over the Pacific Ocean. The average change for October-March precipitation is a modest +7% for the 2040s. Summertime precipitation is projected to change very little.

In short, winters are projected to become warmer and slightly wetter, and summers are simply projected to become warmer.

HYDROLOGICAL IMPACTS OF CLIMATE CHANGE IN THE NORTHWEST

Using a hydrology model for the Columbia River Basin, we have simulated the effects of these projected changes on the snowpack and streamflow of the region, and also estimated the impacts on ski season length and quality at four ski areas in the region. The hydrology model is the Variable Infiltration Capacity (VIC) model (Liang et al., 1994), which includes several soil layers and a physically-based representation of snow accumulation and ablation. VIC has been used to simulate the effects of climate change on the Columbia River Basin (Hamlet and Lettenmaier, 1999) and other watersheds around the world. Simulations with VIC were performed at 1/8 degree resolution, and employed two of the 8 climate models mentioned above; these models produced neither the warmest nor the coolest of the simulations. One climate model, the HadCM2, produces a climate scenario for the Northwest that is on the cool wet side of the average of the 8 models, and the other, ECHAM4, is on the warm dry side.

In a warming climate, the average snowline moves up, reducing the area covered by snow and therefore the total volume of snow. With only modest changes in precipitation projected by the climate models, snow water equivalent at almost every location is projected to decrease. Total Columbia Basin snowpack in March, at the peak of the snow accumulation season, drops by 16% in the 2020s for the cooler, wetter HadCM2 scenario and 27% for the warmer, drier ECHAM4 scenario. For the 2040s, the decreases are 37% for HadCM2 and 46% for ECHAM4. As the warming climate unfolds, a larger fraction of spring snowpack is held in the colder. mountainous regions of Canada, a prospect that has suggests an increasing role for binational cooperation in water management.

Simulation of climate changes on ski area operations were accomplished using a multi-elevational subgrid model to simulate behavior of snow at ski area base and other elevations. Ski seasons are affected differently depending on their location, aspect, and background climate. Most sensitive is Snoqualmie Pass, just east of Seattle, which sees a reduction in ski season length (defined as the number of days when snow water equivalent exceeds 240mm) from 118 days for present climate to 87 days for the HadCM2 2020s climate and 58 days for the ECHAM4 2040s climate. Stevens Pass, northeast of Seattle and slightly higher and colder than Snoqualmie Pass. sees a reduction from 115 to 102 days for HadCM2 2020s and to 70 days for ECHAM4 2040s. Mission Ridge, near Wenatchee in eastern Washington, and Schweitzer Mountain in northern Idaho, are less sensitive. seeing only modest reductions in ski season duration even for the warm, dry scenario.

In a warmer climate, snowfed rivers like the Columbia and its major tributaries east of the Cascades see a shift in their hydrograph. Winter streamflow increases modestly, the spring freshet moves earlier in the year, and summer streamflow decreases markedly. These changes will have profound and largely negative impacts on uses of water in the Northwest; the year 2001, which has much-below normal snowpack (thou-h for very different reasons), may be a preview of what's to come in a warming, world.

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