

# Understanding the Effects of Climate Change on Water Resources in the Pacific Northwest

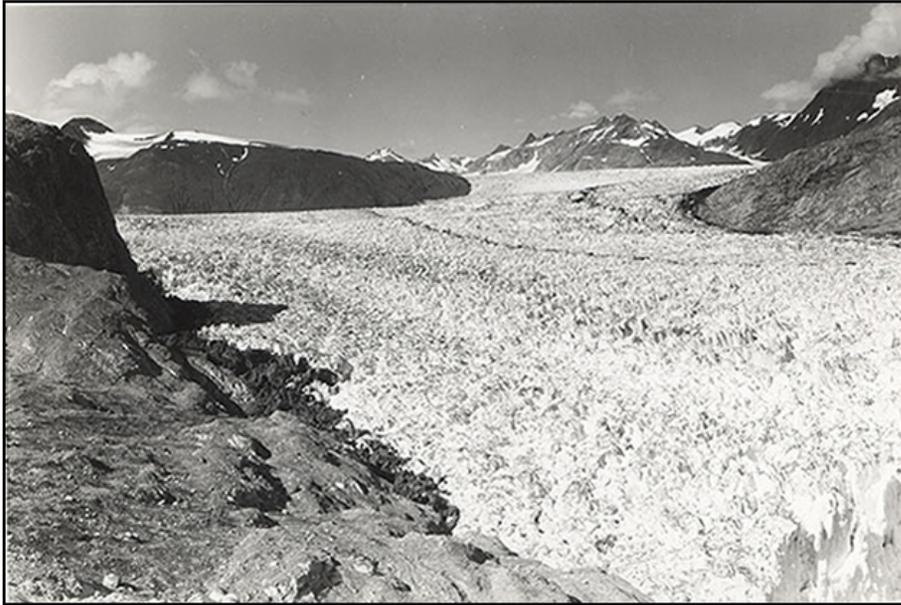
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Department of Civil  
and Environmental  
Engineering

# Recession of the Muir Glacier

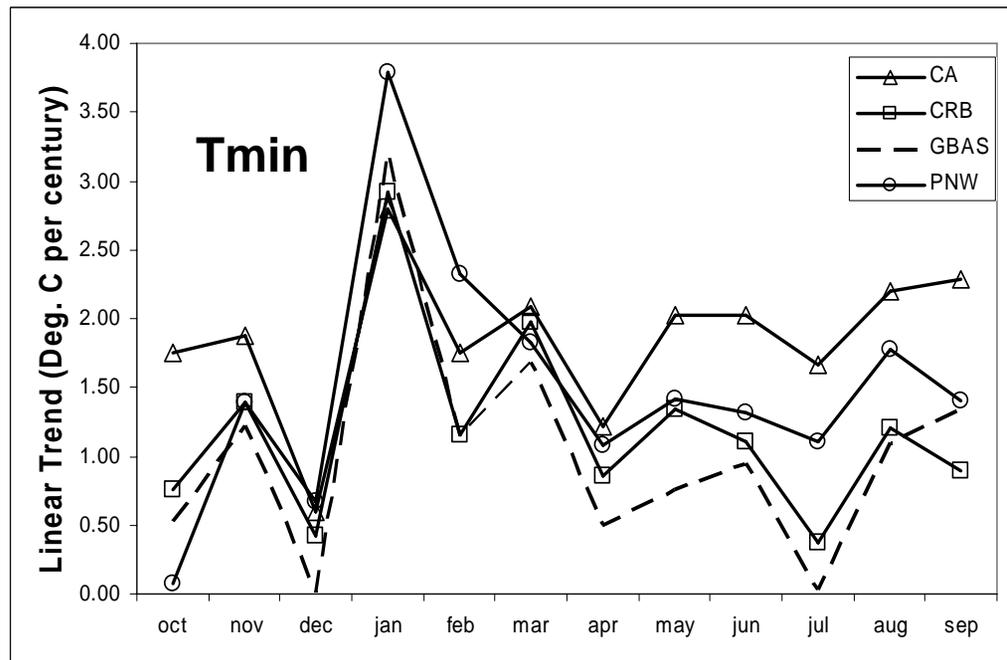
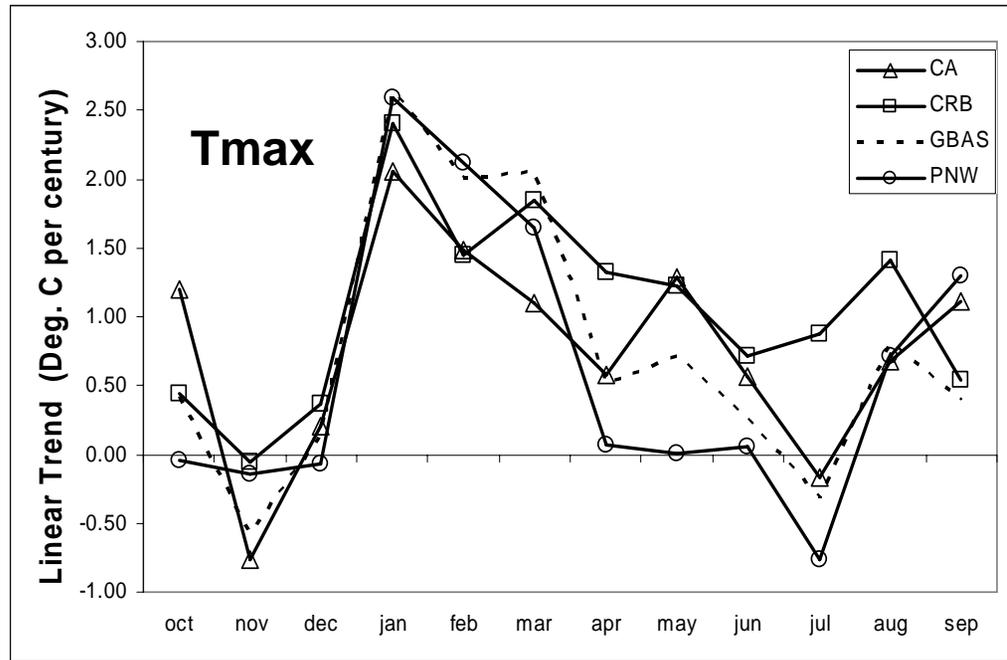
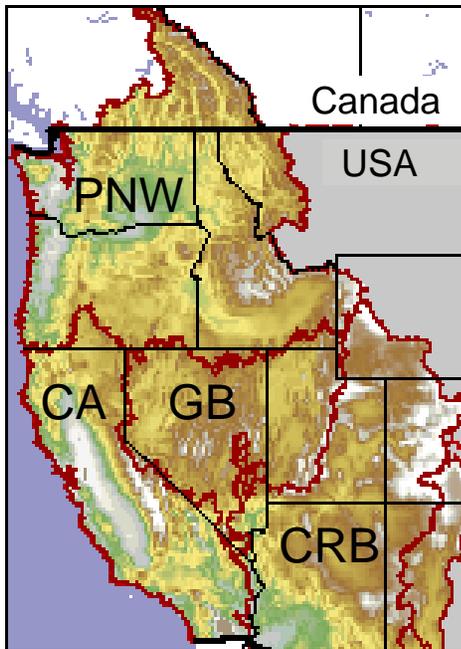


Aug, 13, 1941

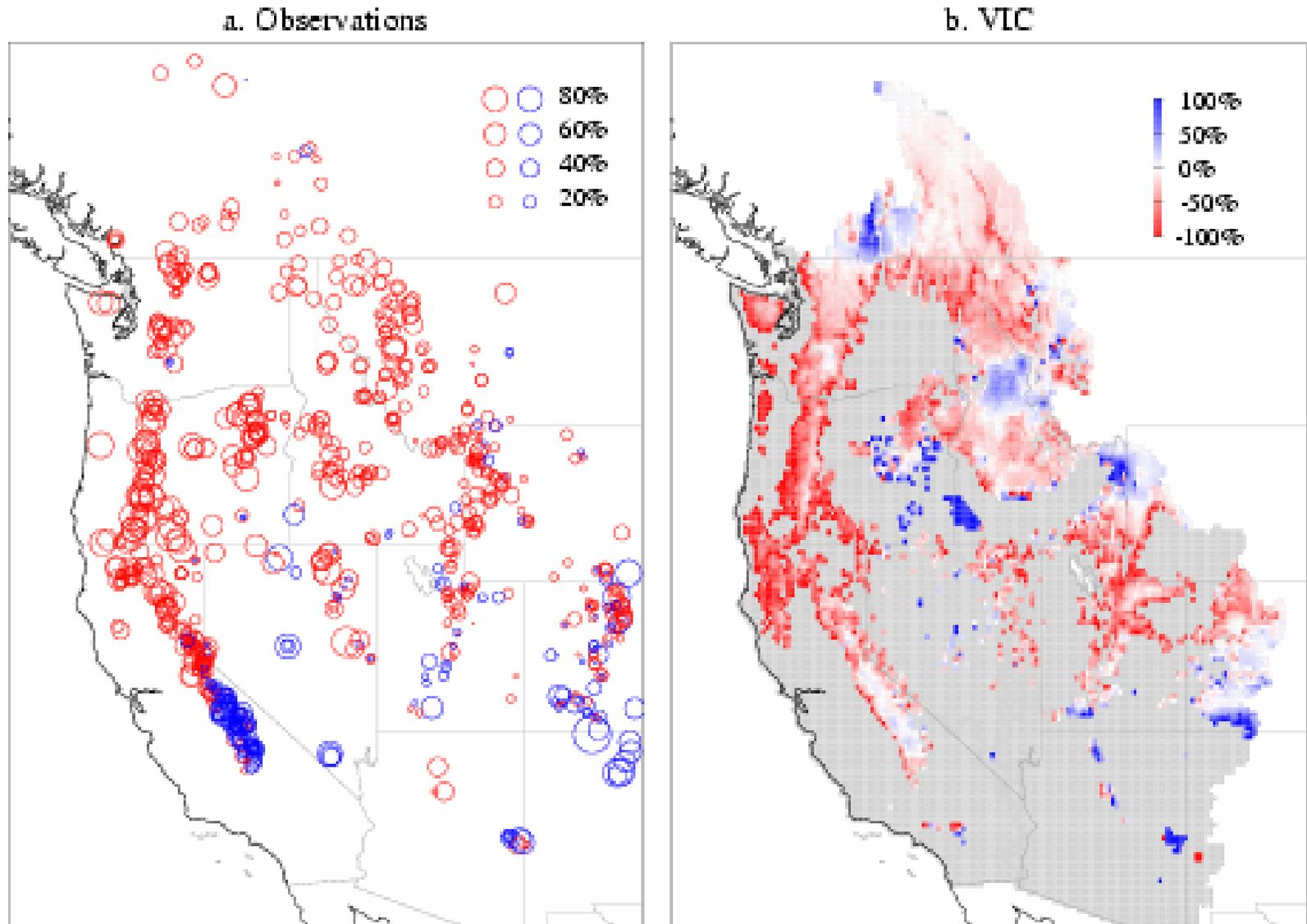


Aug, 31, 2004

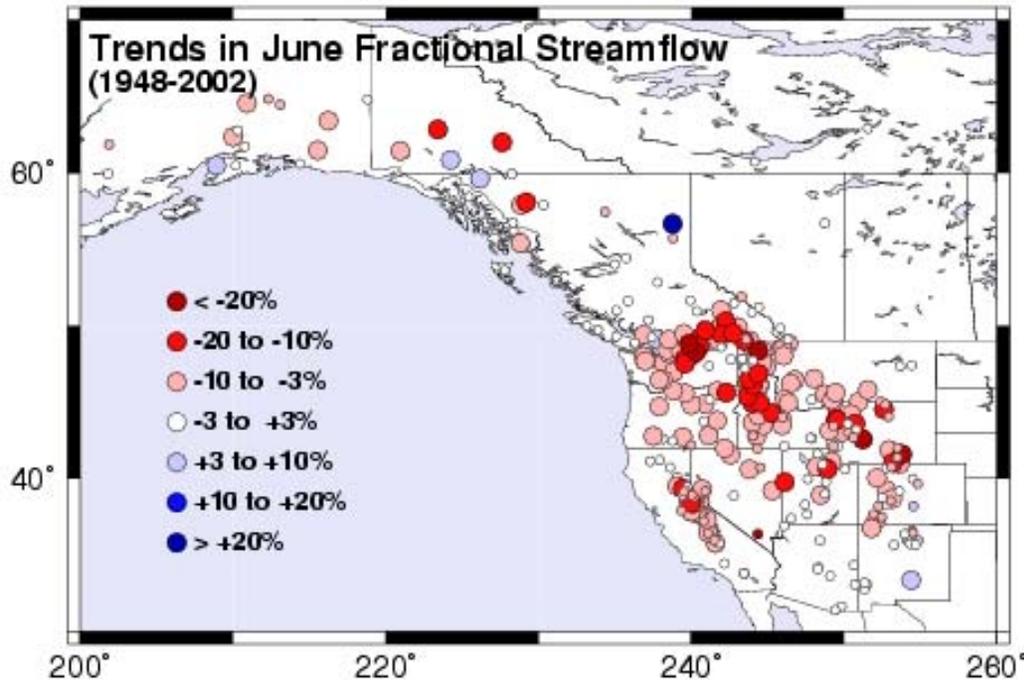
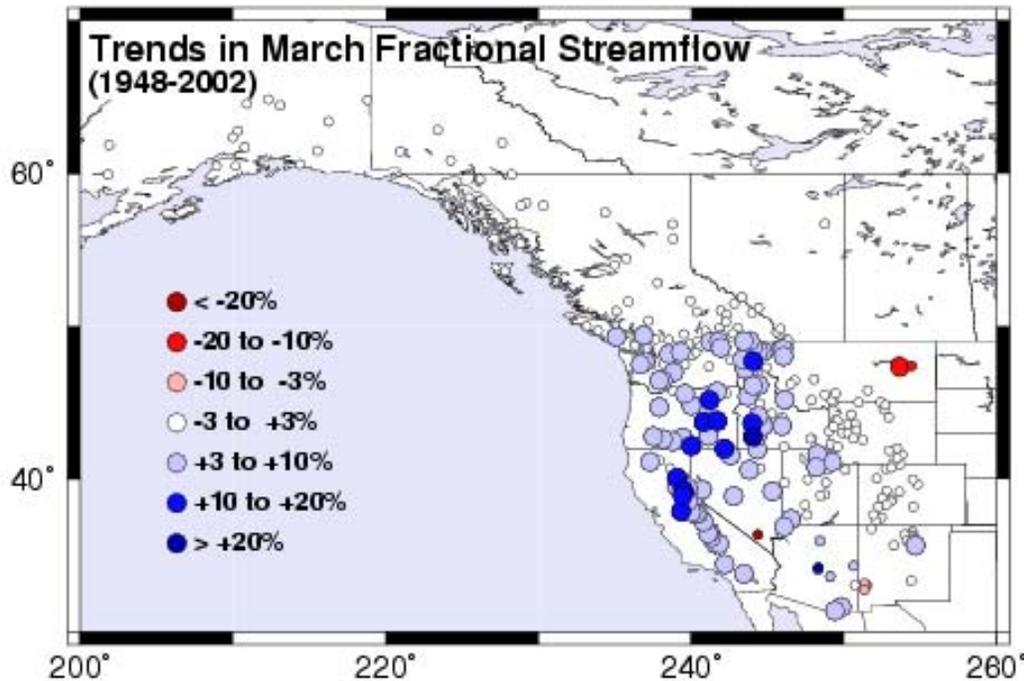
Image Credit: *National Snow and Ice Data Center, W. O. Field, B. F. Molnia*  
[http://nsidc.org/data/glacier\\_photo/special\\_high\\_res.html](http://nsidc.org/data/glacier_photo/special_high_res.html)



# Trends in April 1 SWE 1950-1997



Mote P.W., Hamlet A.F., Clark M.P., Lettenmaier D.P., 2005, Declining mountain snowpack in western North America, BAMS, 86 (1): 39-49

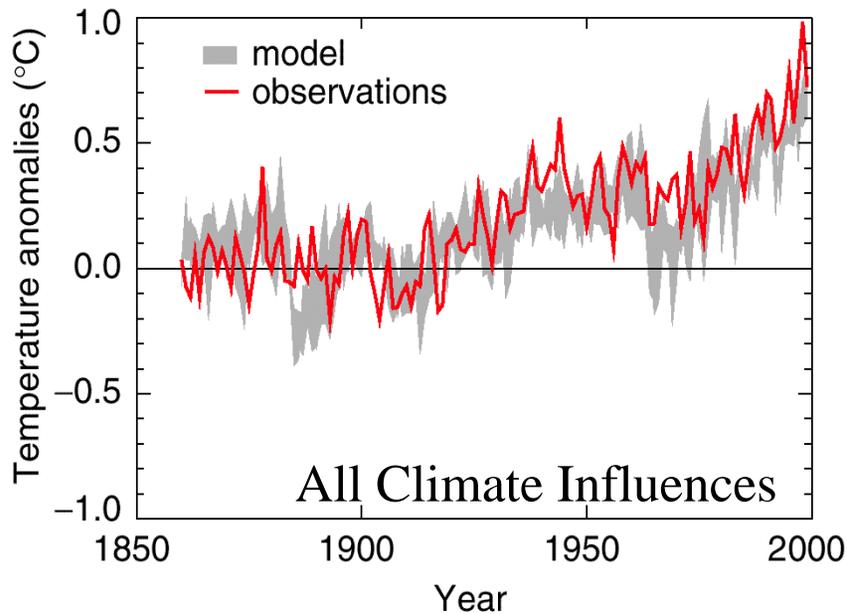
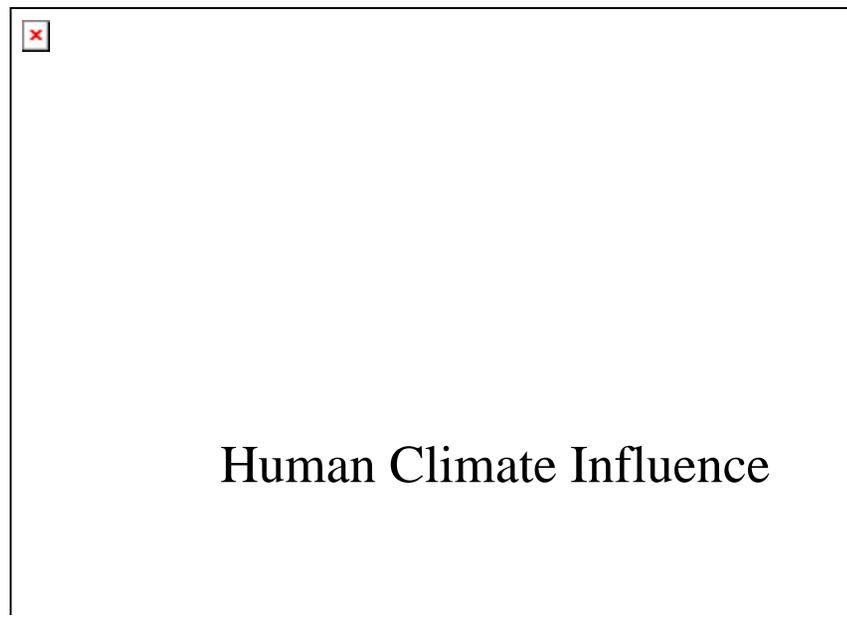
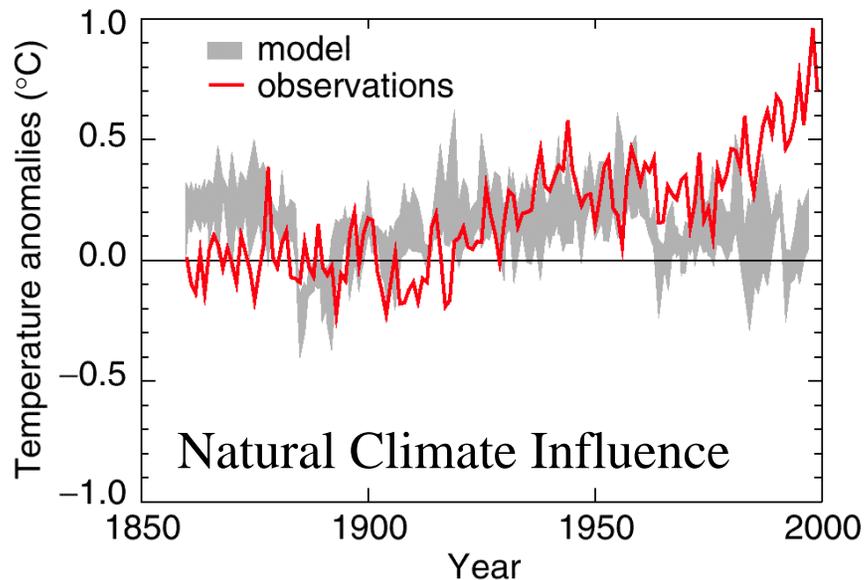


As the West warms,  
spring flows rise  
and summer flows  
drop

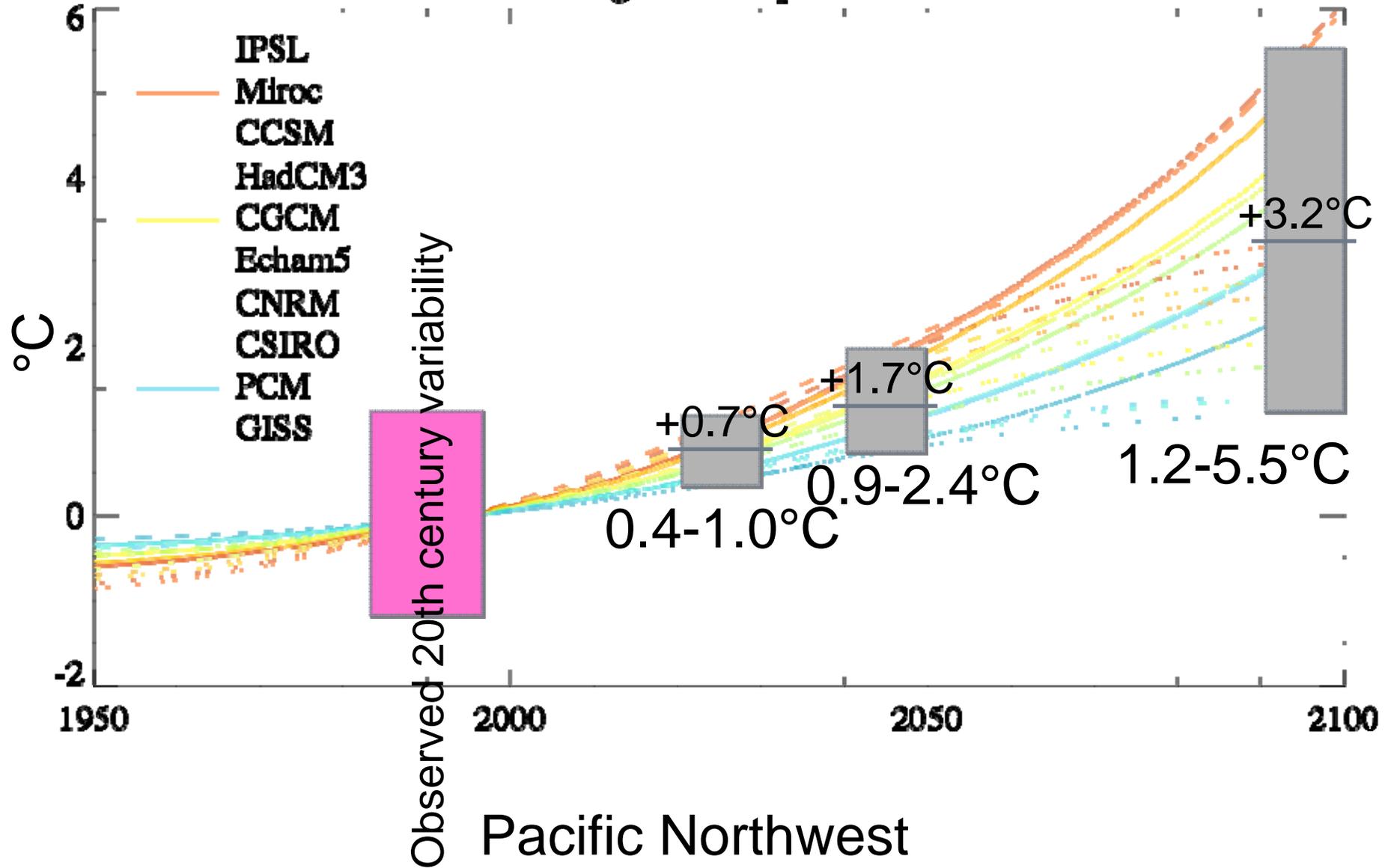
Stewart IT, Cayan DR,  
Dettinger MD, 2005:  
Changes toward earlier  
streamflow timing across  
western North America, J.  
Climate, 18 (8): 1136-1155

# Projections for the Future Using Global Climate Models

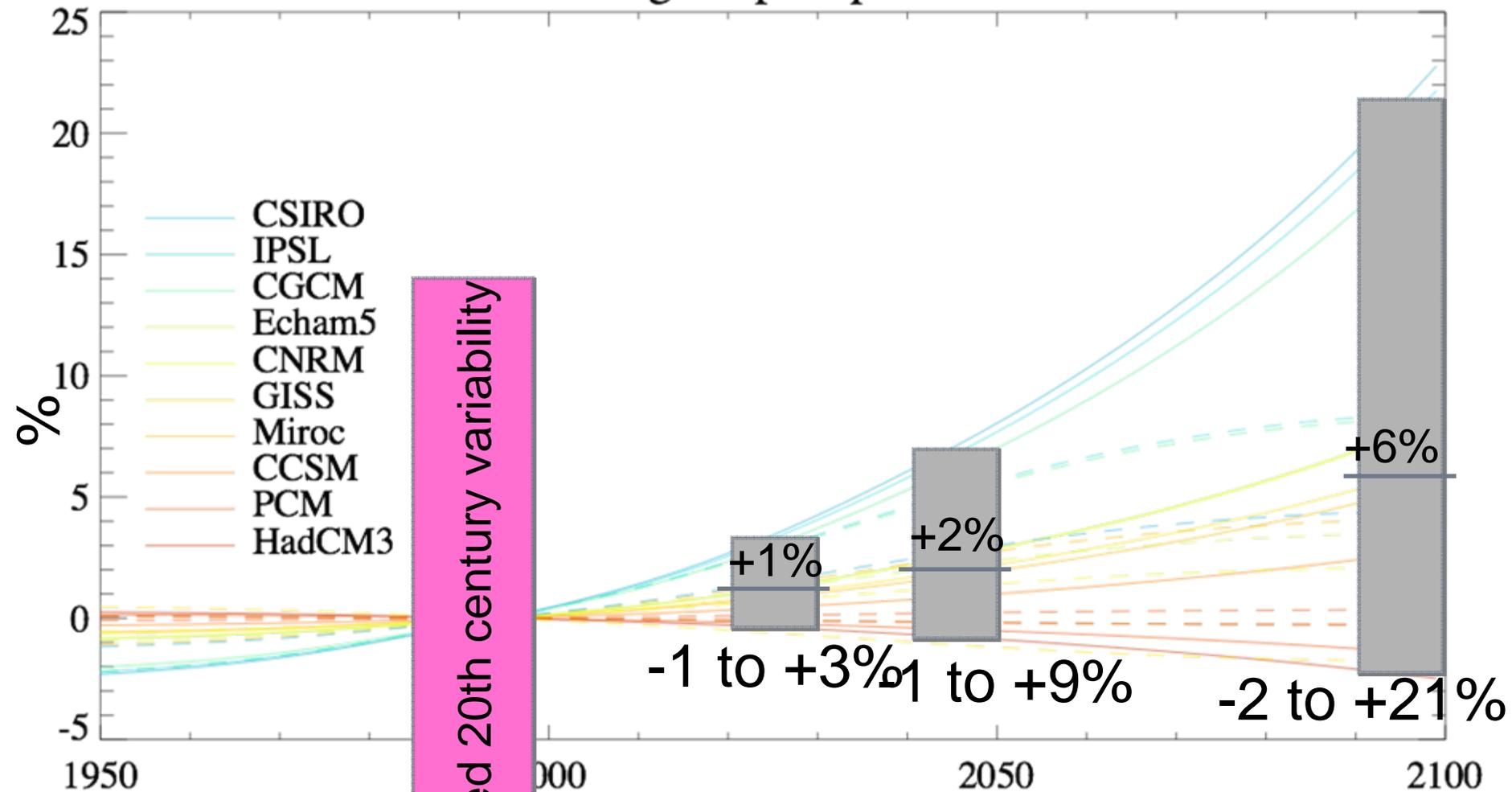
# Natural AND human influences explain the observations of global warming best.



# Change in temperature



# Change in precipitation



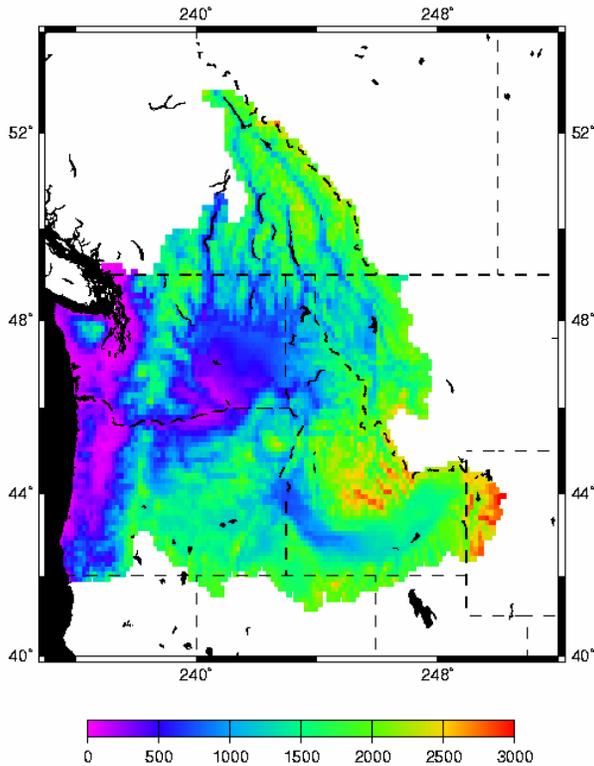
Pacific Northwest

# Hydroclimatology of the Pacific Northwest

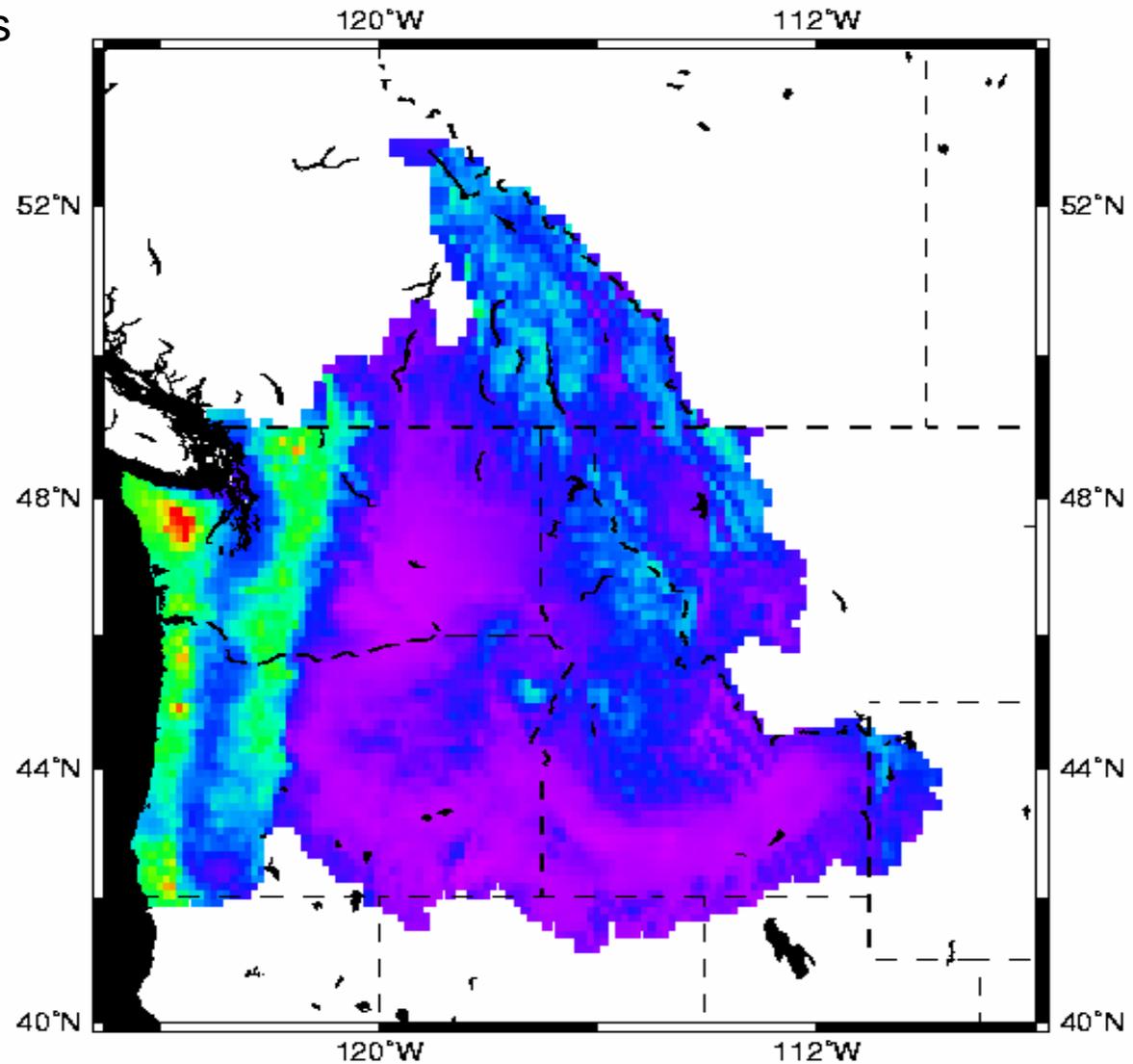
# Annual PNW Precipitation (mm)

Winter climate in the mountains is the key driver of streamflow.

Snowpack functions as a natural reservoir.

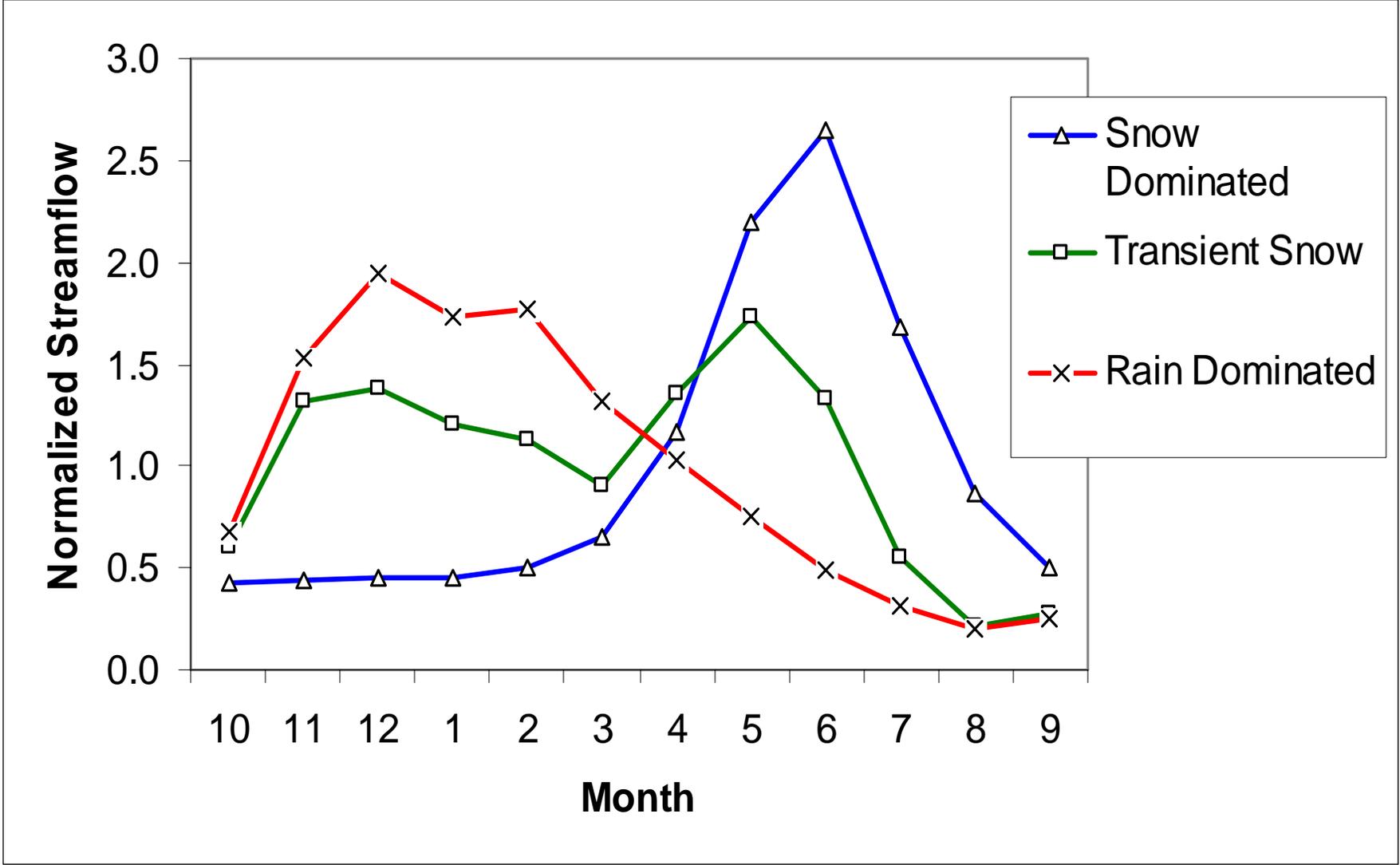


Elevation (m)



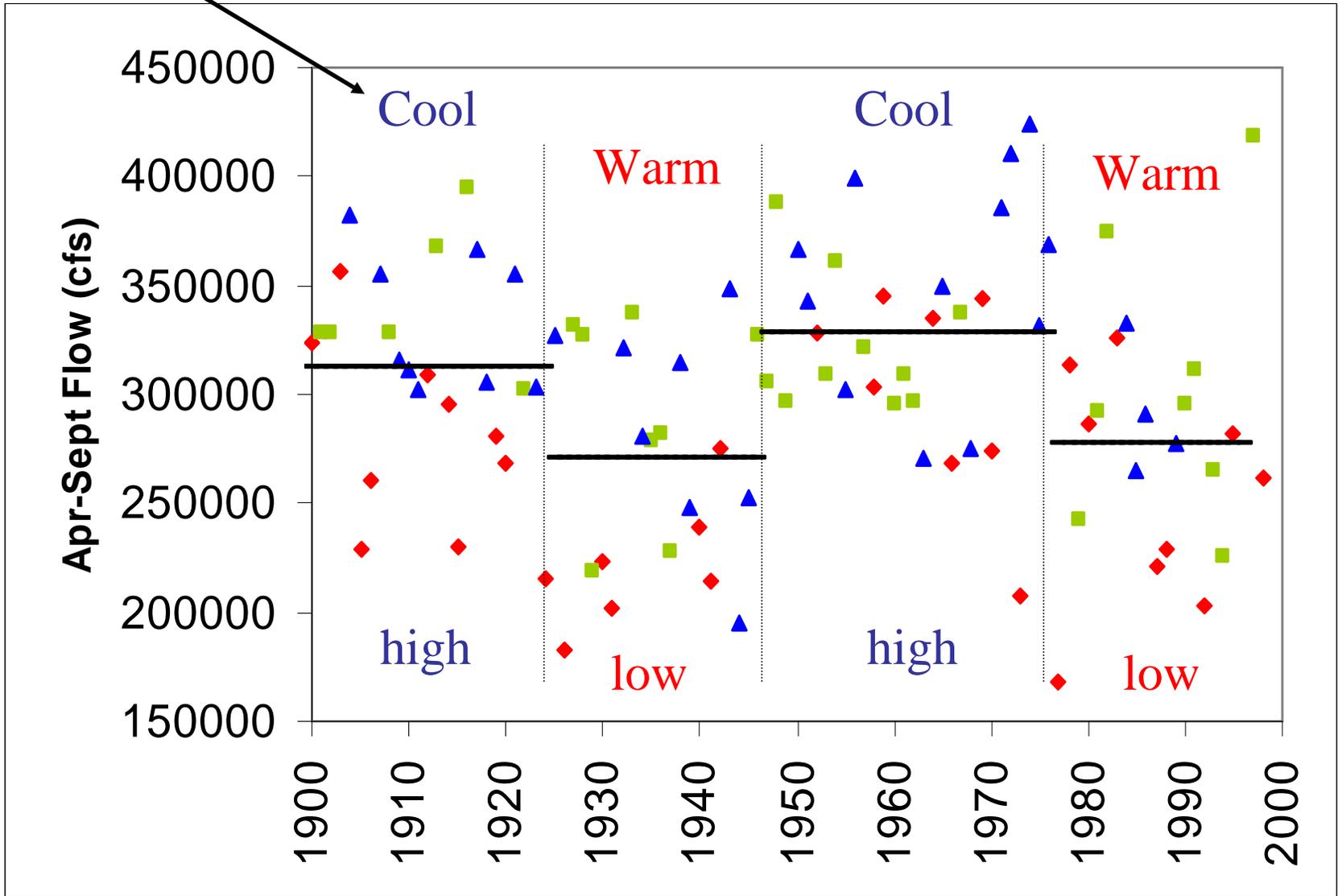
0 500 1000 1500 2000 2500 3000 3500 4000 4500

# Hydrologic Characteristics of PNW Rivers



# Effects of the PDO and ENSO on Columbia River Summer Streamflows

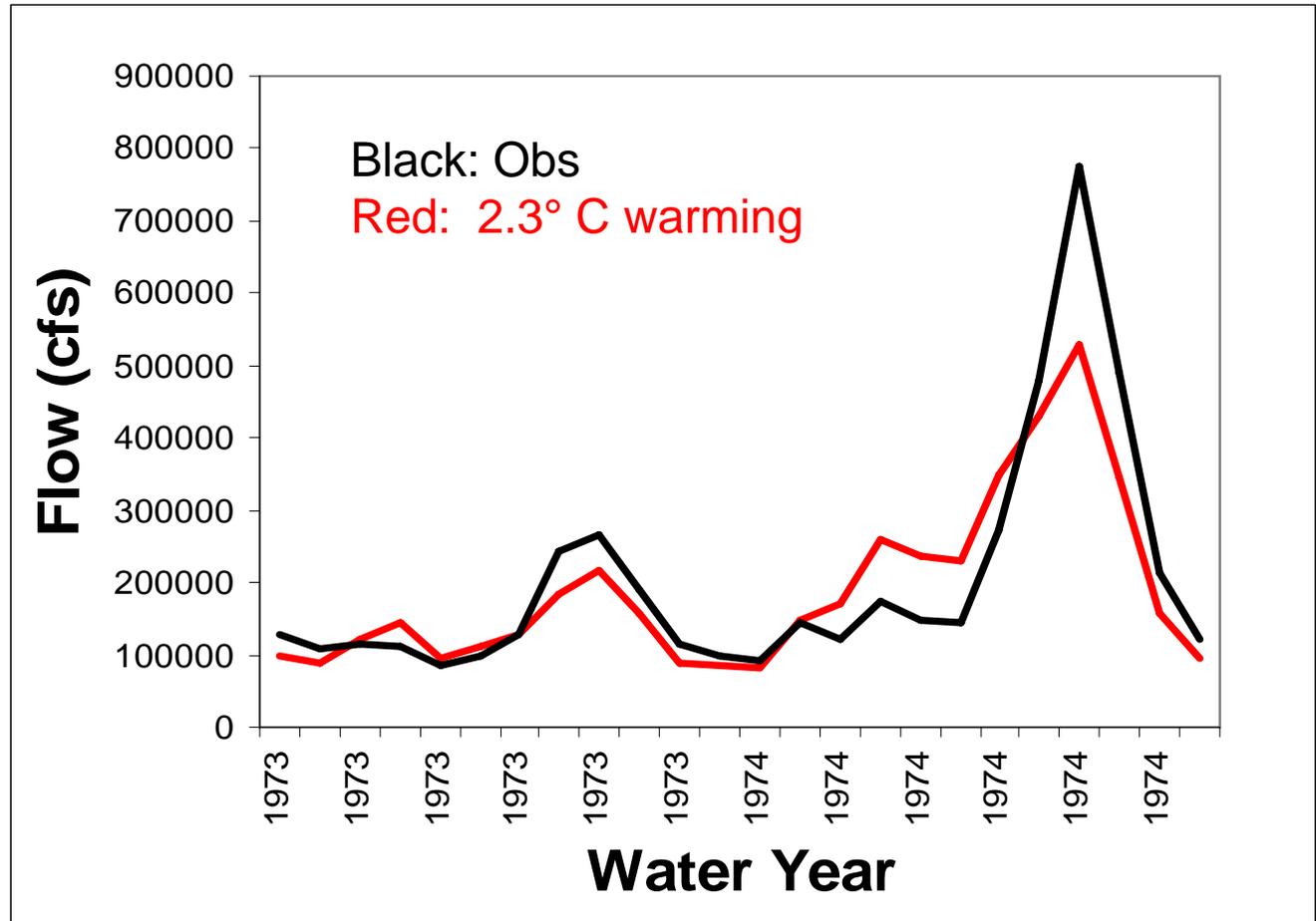
**PDO**



# Warming Affects Streamflow *Timing*

**Temperature warms, precipitation unaltered:**

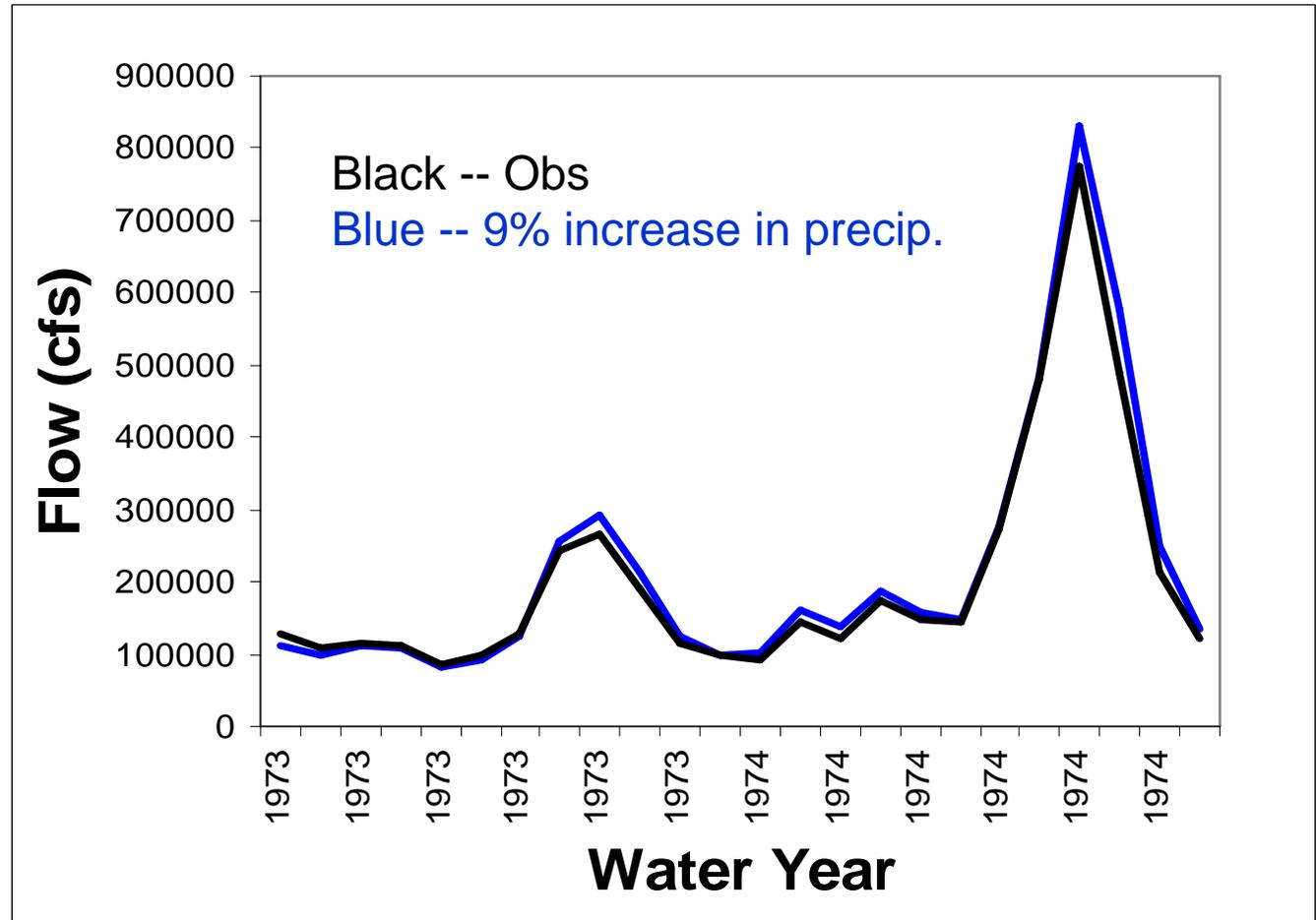
- Streamflow timing is altered
- Annual volume may be somewhat lower due to increased ET



# Precipitation Affects Streamflow *Volume*

**Precipitation increases, temperature unaltered:**

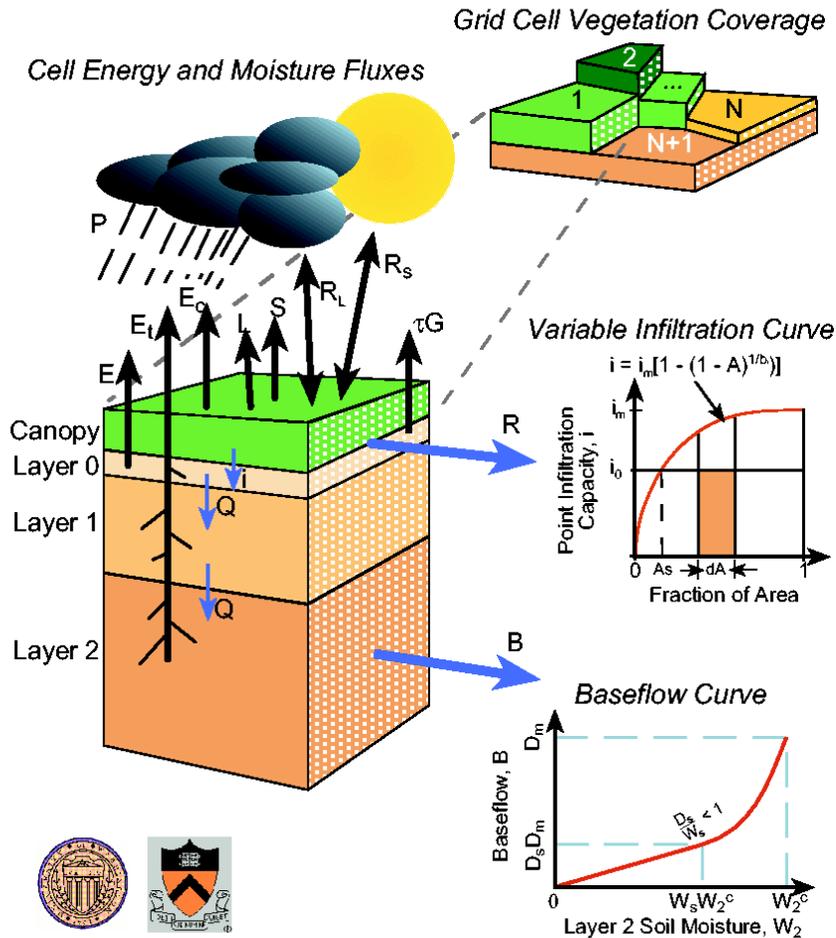
- Streamflow timing stays about the same
- Annual volume is altered



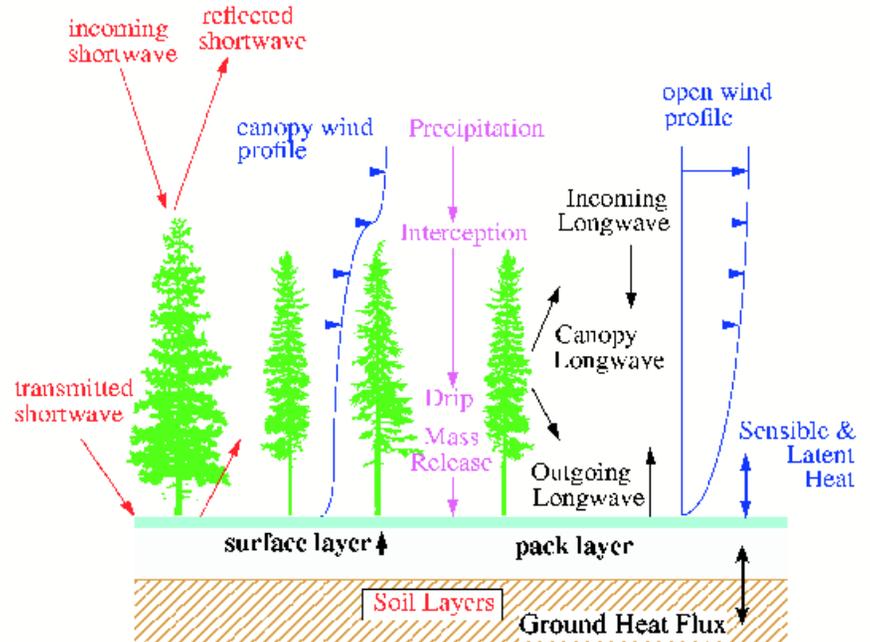
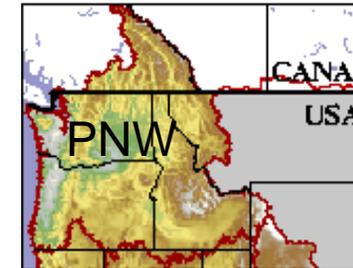
# Hydrologic Impacts for the PNW

# Schematic of VIC Hydrologic Model and Energy Balance Snow Model

## Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model



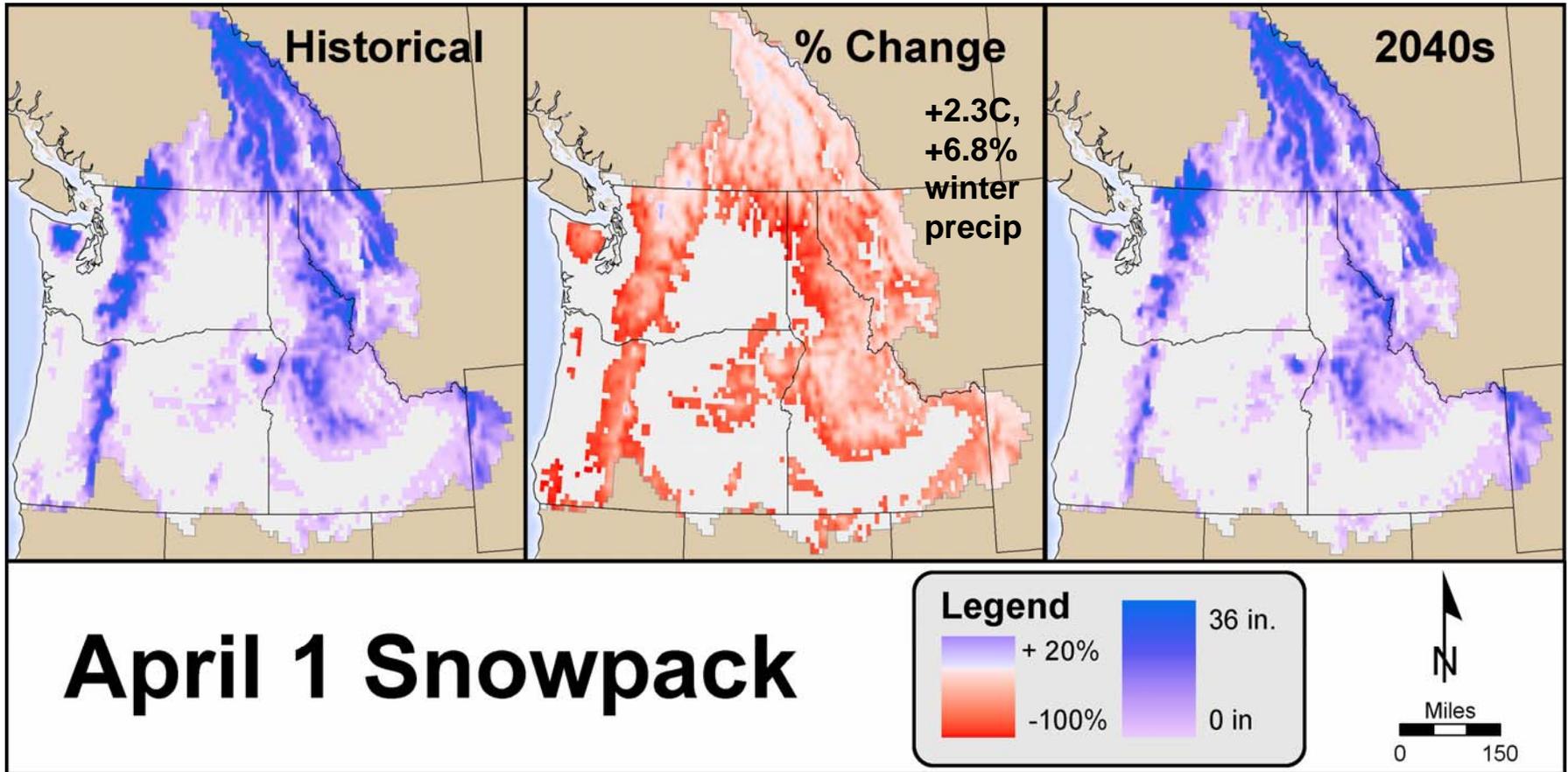
6 km  
6 km  
1/16<sup>th</sup>  
Deg.



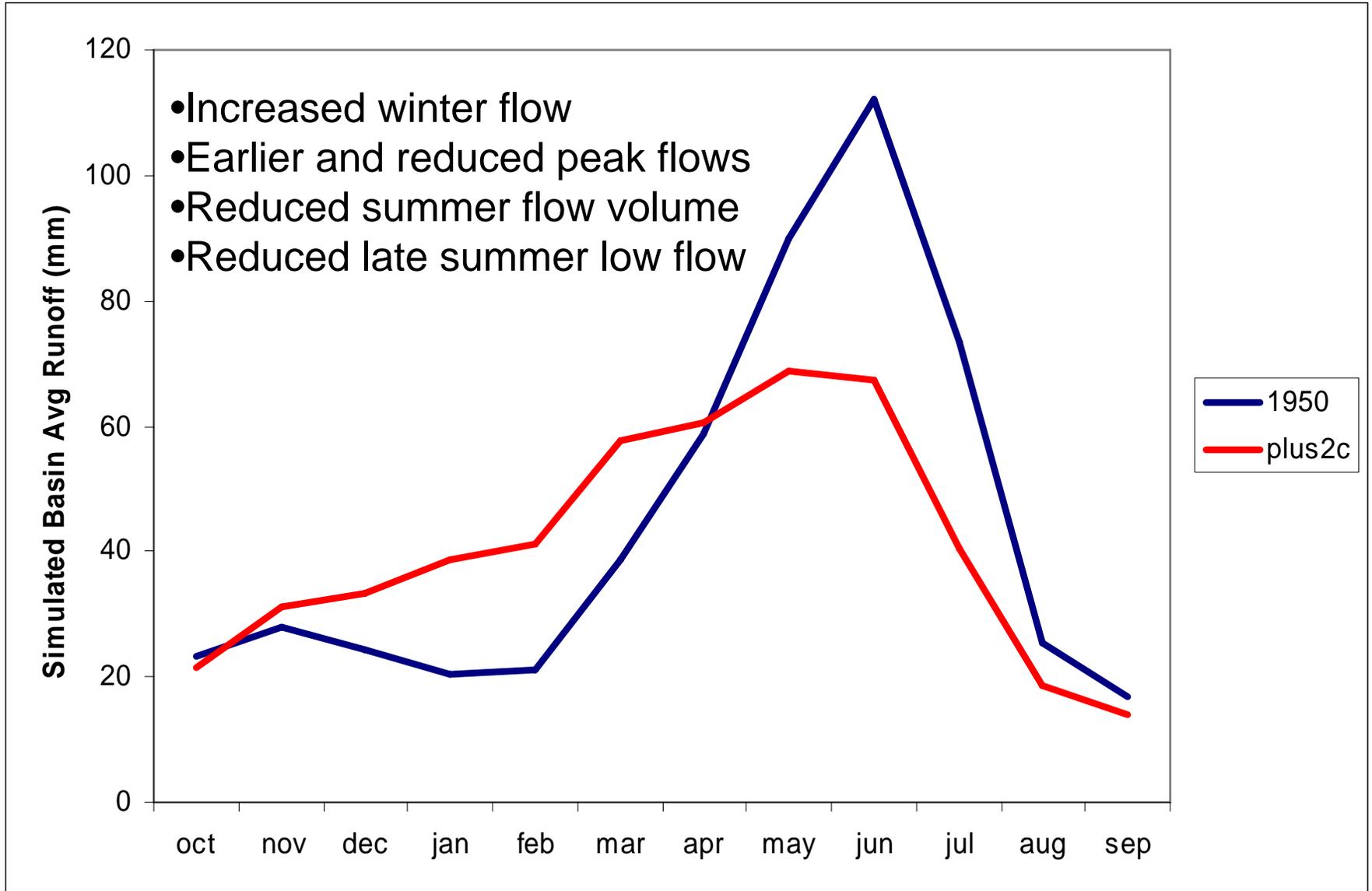
Snow Model



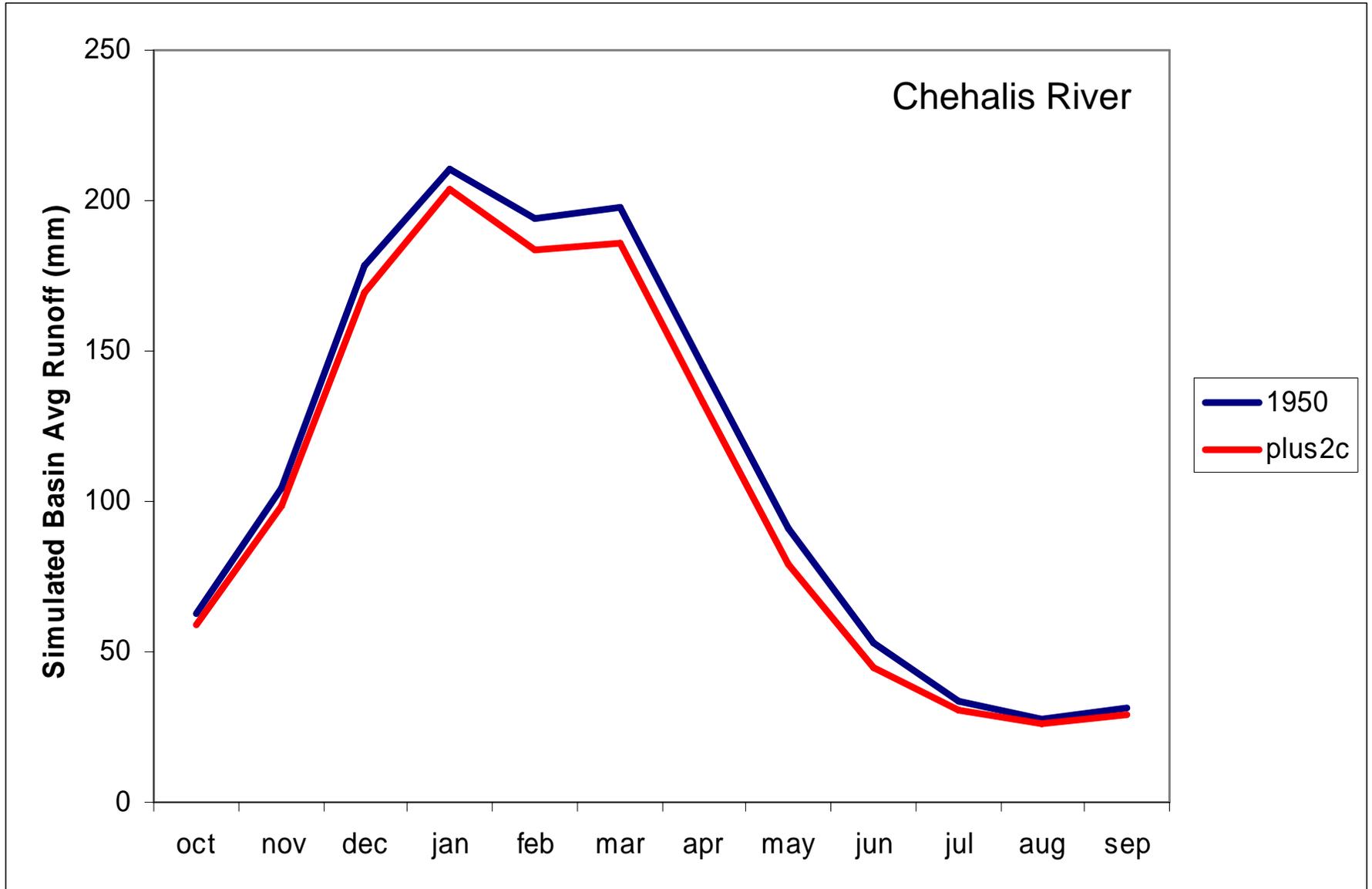
# The warmest locations that accumulate snowpack are most sensitive to warming



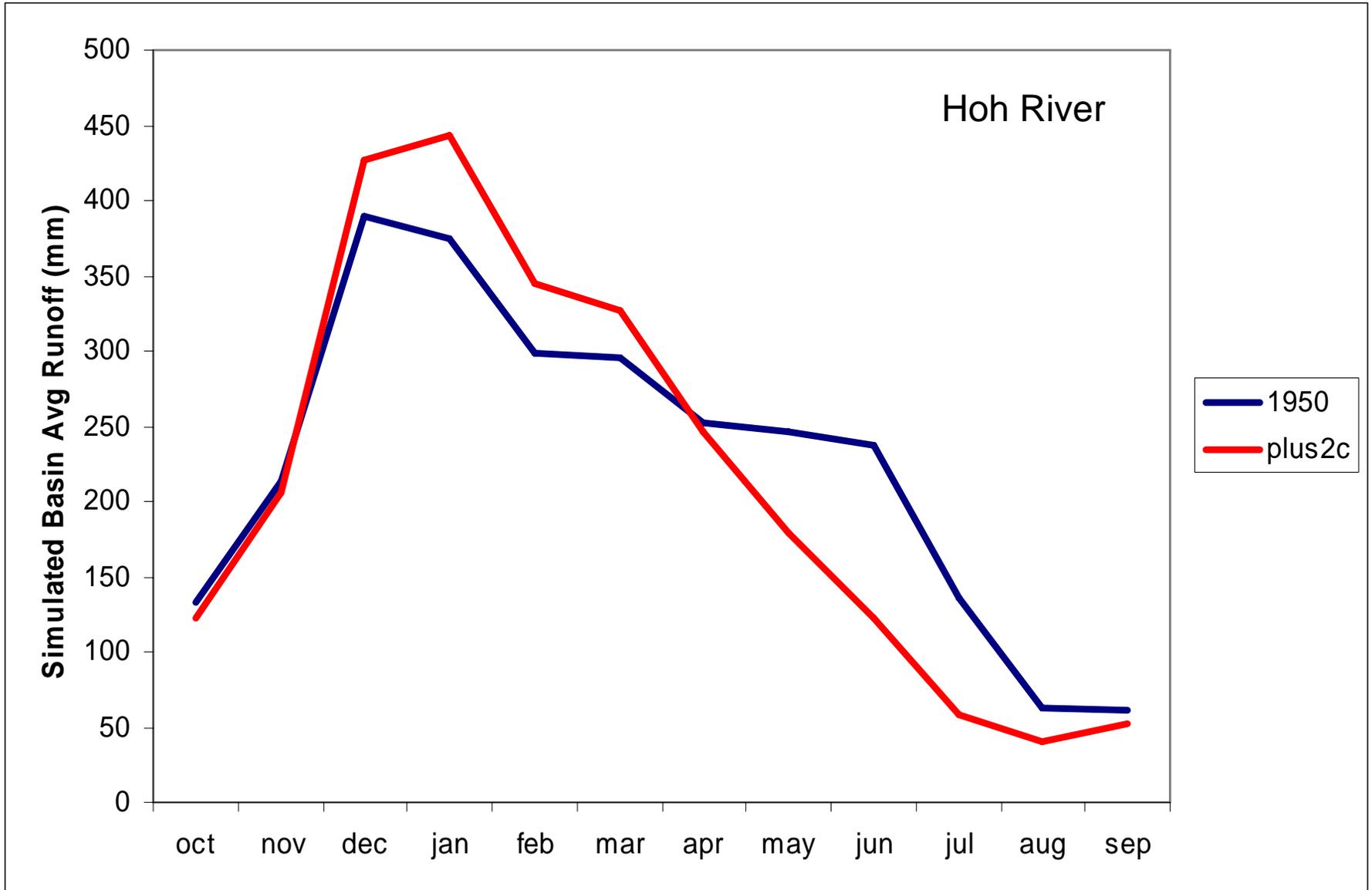
# Simulated Changes in Natural Runoff Timing in the Naches River Basin Associated with 2 C Warming



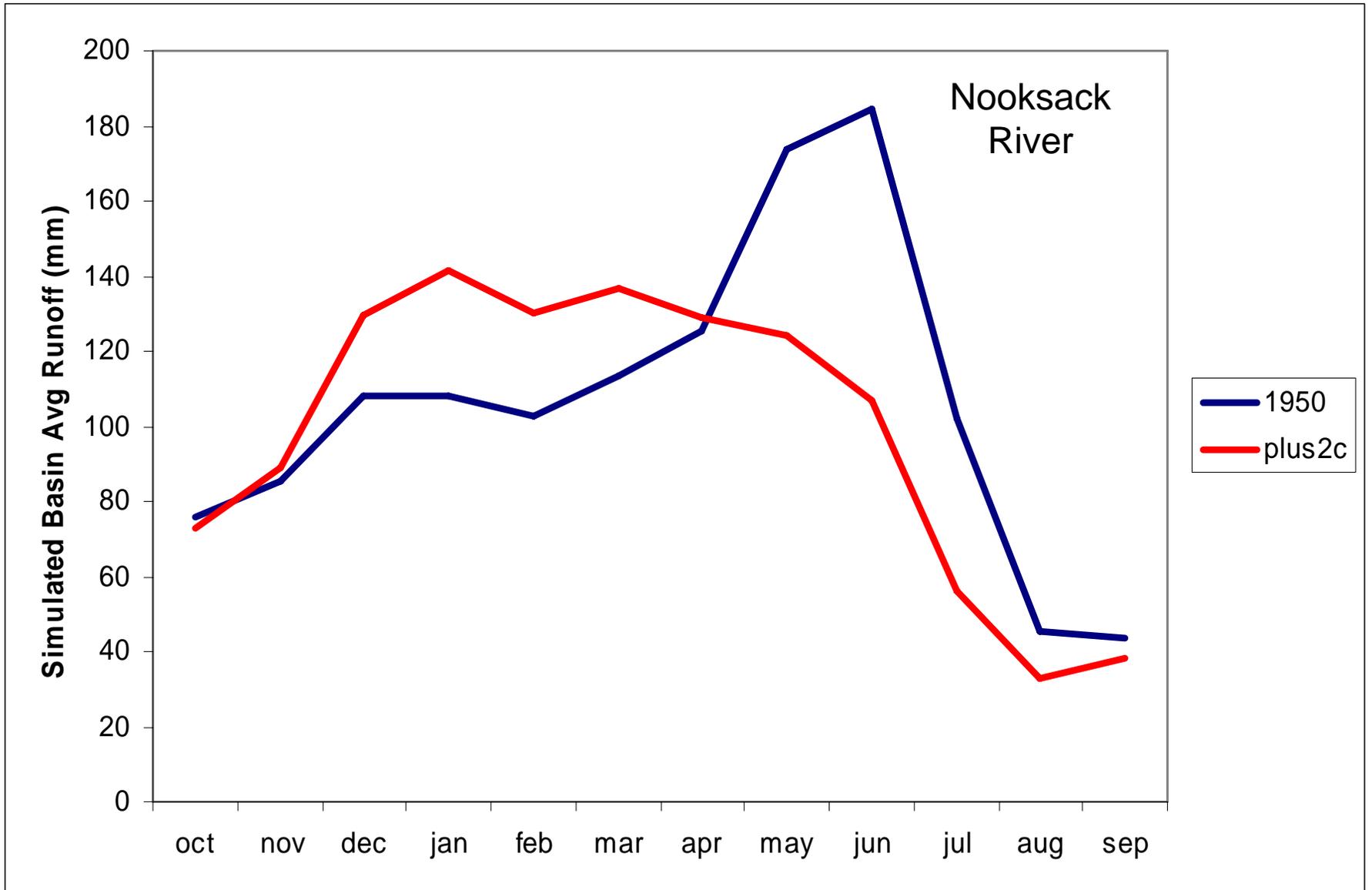
# Rain Dominant



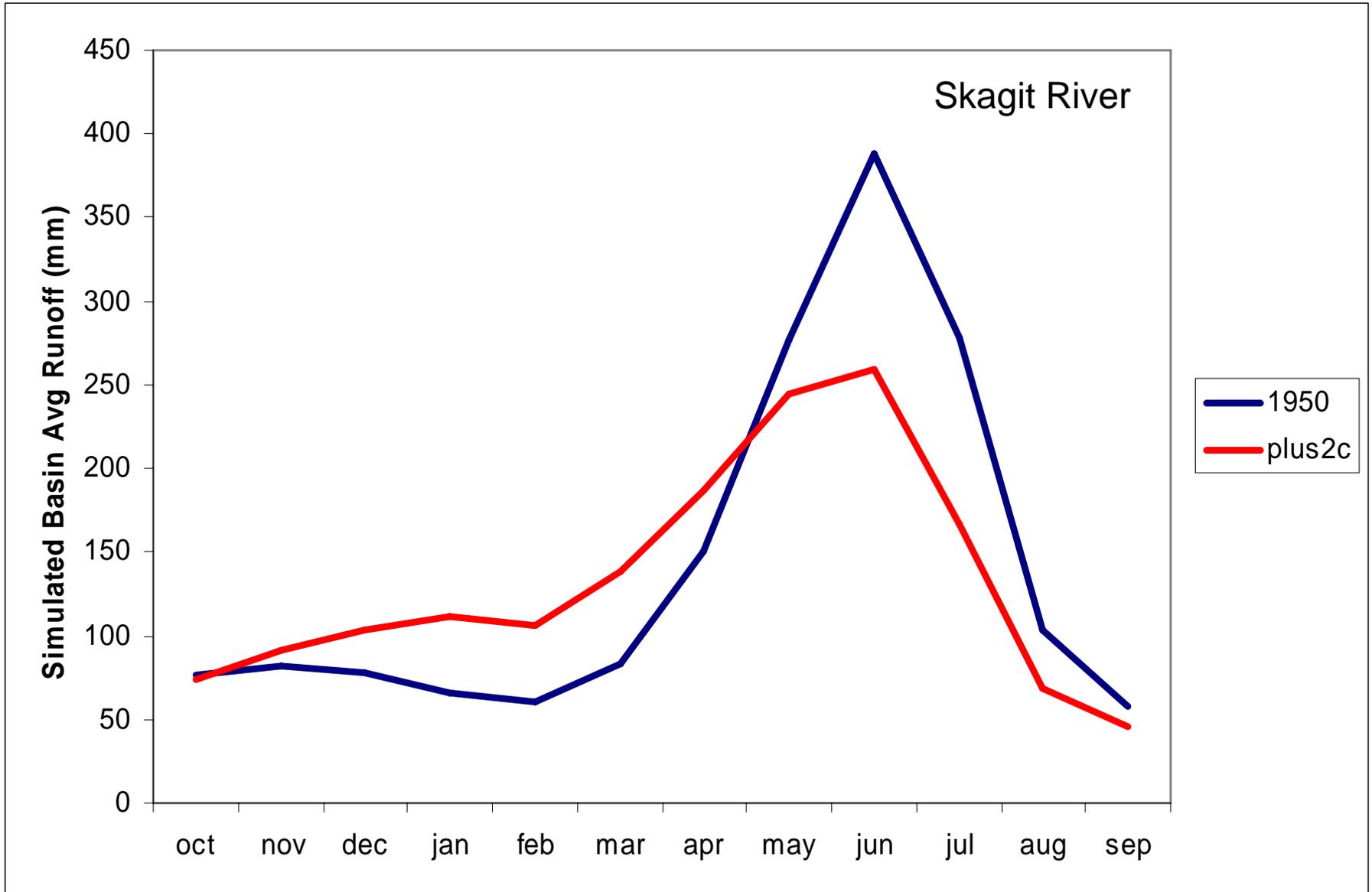
# Warm Transient Snow



# Cooler Transient Snow



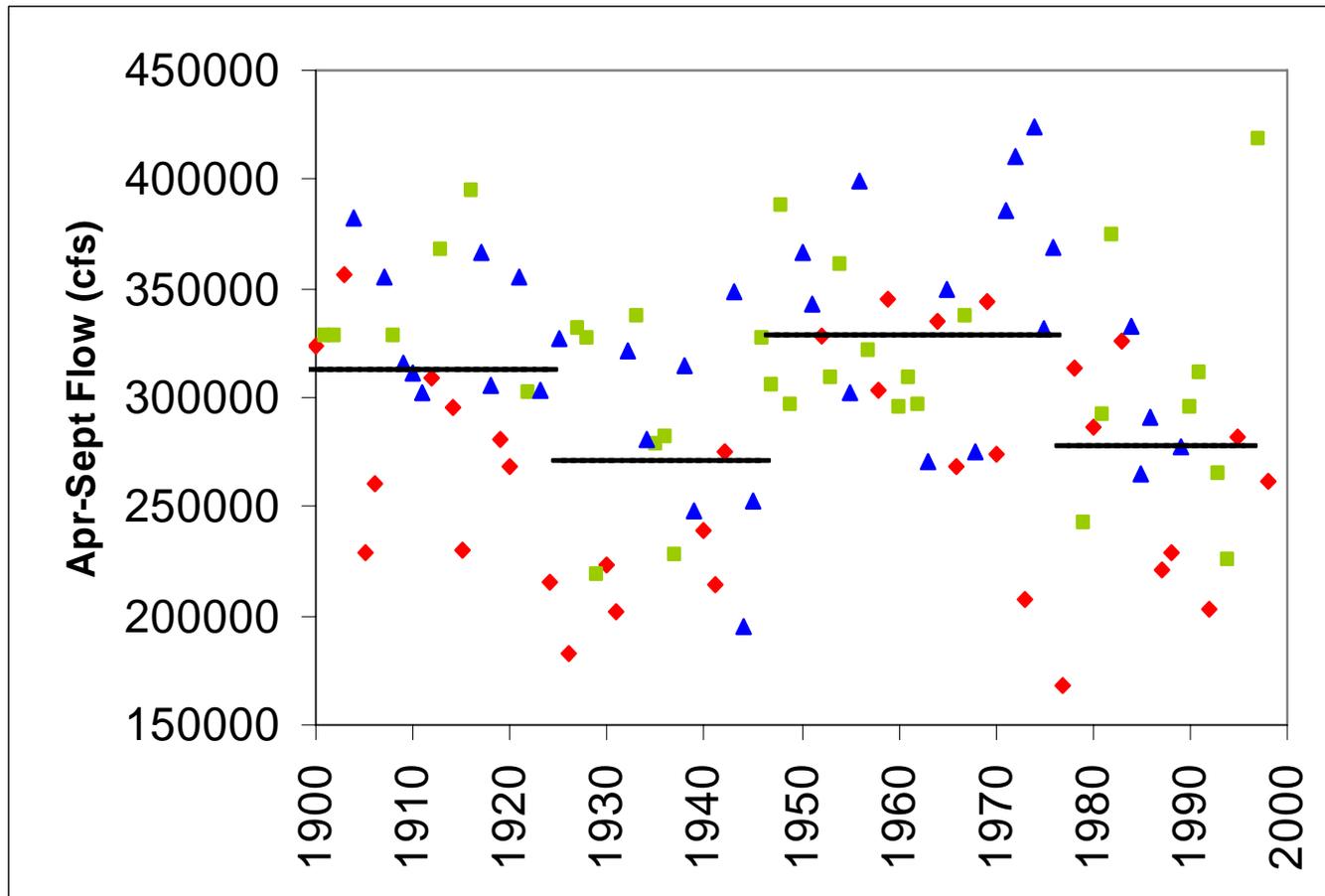
# Snowmelt Dominant



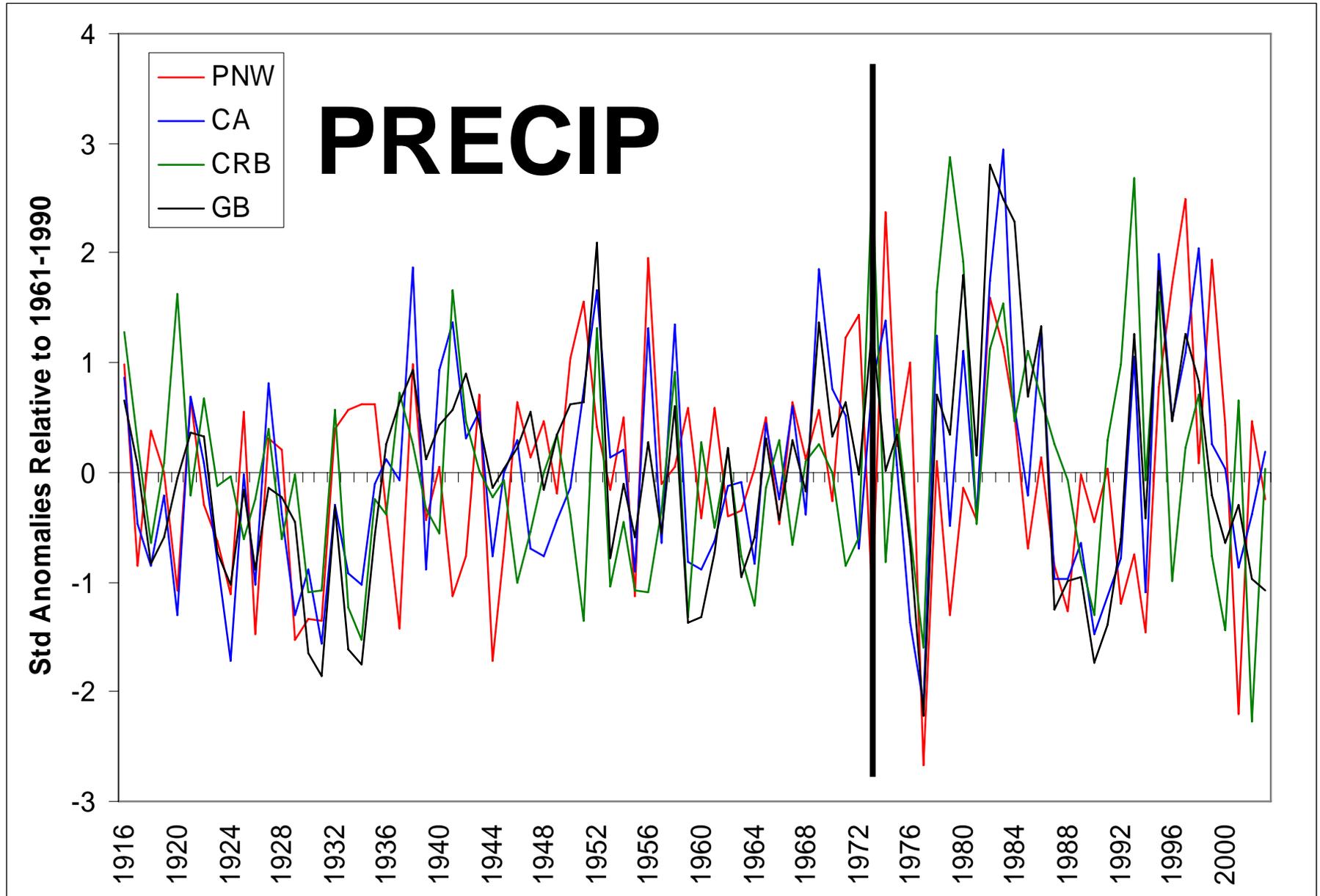
# Decadal Climate Variability and Climate Change

# Will Global Warming be “Warm and Wet” or “Warm and Dry”?

Answer: Probably BOTH!



# Regionally Averaged Cool Season Precipitation Anomalies



# Overview of Some Water Resources Impact Pathways

## **Water Supply and Demand**

- Changes in the seasonality water supply (e.g. reductions in summer)
- Changes in water demand (e.g. increasing evaporation)
- Changes in drought stress
- Increasing conflicts between water supply and other uses and users of water

## **Energy Supply and Demand**

- Changes in the seasonality and quantity of hydropower resources
- Changes in energy demand
- Increasing conflicts between hydro and other uses and users of water

## **Instream Flow Augmentation**

- Changes in low flow risks
- Changes in the need for releases from storage to reproduce existing streamflow regime.
- Changes in water resources management related to water quality (e.g. to provide dilution flow or to control temperature)

## **Flood Control and Land Use Planning**

- Changes in flood risks
- Changes in flood control evacuation and timing to maintain refill reliability
- Dam safety
- Changes in land use policy

## **Transboundary Relationships and Agreements**

- Differential impacts in different regions (e.g. in Canada and the U.S.)
- Increased conflict over water resources
- Unbalancing of existing agreements

## **Long-Term Planning, Water Law and Policy**

- Water allocation agreements in a non-stationary climate (e.g. water permitting)
- Appropriateness of the historic streamflow record as a legal definition of climate variability
- Need for new planning frameworks in a non-stationary climate

# Overview of Some Existing Climate Change Water Planning Studies

- Seattle Water Supply (Wiley 2004)
- White River Basin (Ball 2004)
- Snohomish Basin (Battin et al. 2007)
- Columbia Hydro System (Hamlet et al. 1999; Payne et al. 2004, NWPCC 2005)

Ball, J. A. 2004. Impacts of climate change on the proposed Lake Tapps-White River water supply, M.S.C.E. thesis, Dept. of Civil and Environmental Engineering, College of Engineering, University of Washington, Seattle.

Battin J., Wiley, M.W., Ruckelshaus, M.H., Palmer, R.N., Korb, E., Bartz, K.K., Imaki, H., 2007. Projected impacts of climate change on salmon habitat restoration, Proceedings of the National Academy of Sciences of the United States of America, 104 (16): 6720-6725

Hamlet, A. F. and D. P. Lettenmaier. 1999b. Effects of climate change on hydrology and water resources in the Columbia River Basin. *Journal of the American Water Resources Association* 35(6):1597-1623.

Payne, J. T., A. W. Wood, A. F. Hamlet, R. N. Palmer, and D. P. Lettenmaier. 2004. Mitigating the effects of climate change on the water resources of the Columbia River basin. *Climatic Change* 62:233-256.

NW Power and Conservation Council, 2007, Effects of Climate Change on the Hydroelectric System, Appendix N to the NWPCC Fifth Power Plan, <http://www.nwcouncil.org/energy/powerplan/plan/Default.htm>

Wiley, M. W. 2004. Analysis techniques to incorporate climate change information into Seattle's long range water supply planning. M.S.C.E. thesis, Dept. of Civil and Environmental Engineering, College of Engineering, University of Washington, Seattle.