

Hydrologic Implications of Climate Change for the Western U.S., Pacific Northwest, and Columbia River Basin

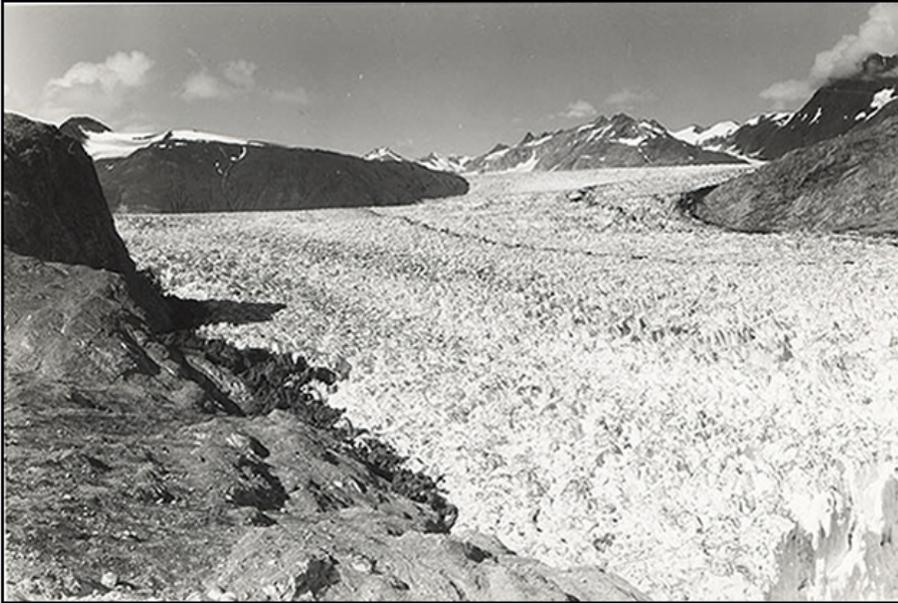
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- Dept. of Civil and Environmental Engineering
University of Washington



Department of Civil
and Environmental
Engineering

Recession of the Muir Glacier



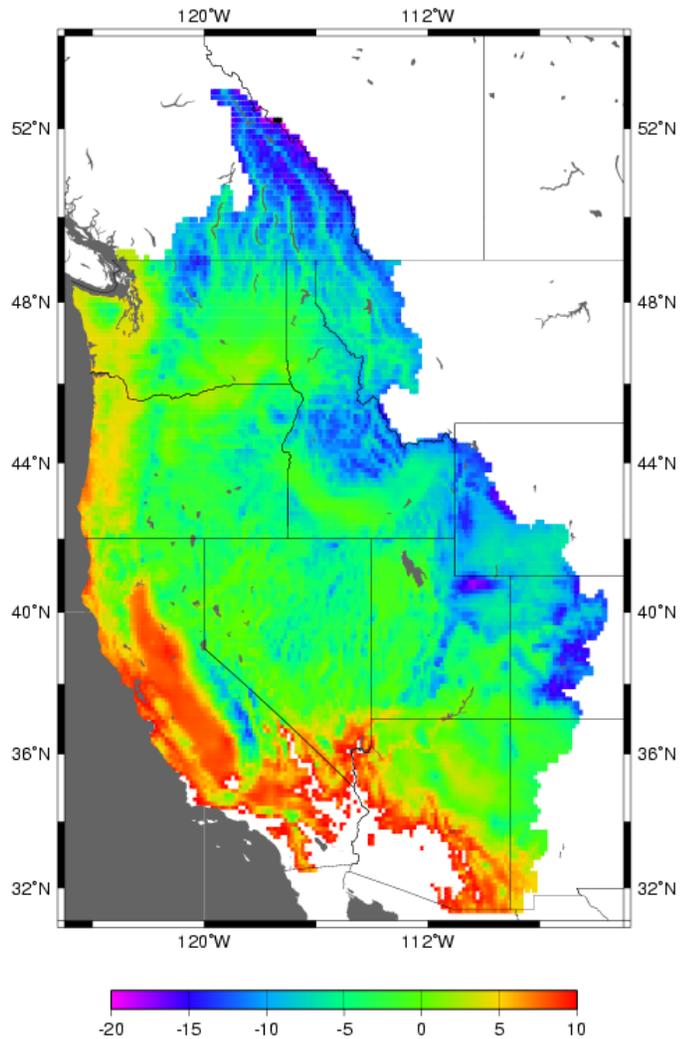
Aug, 13, 1941



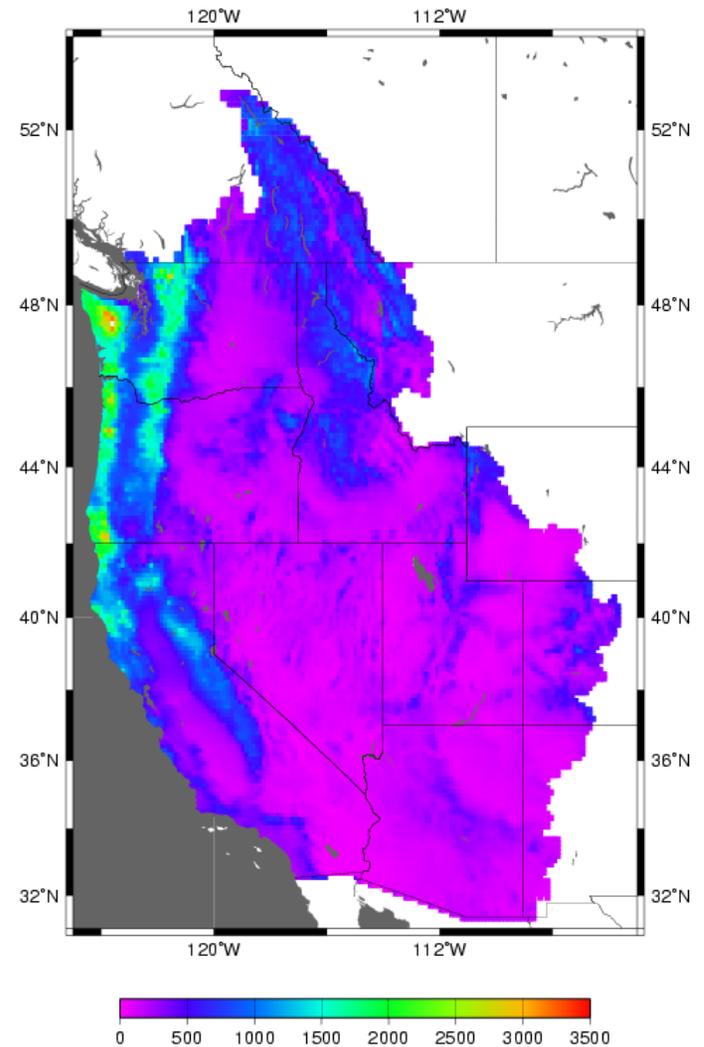
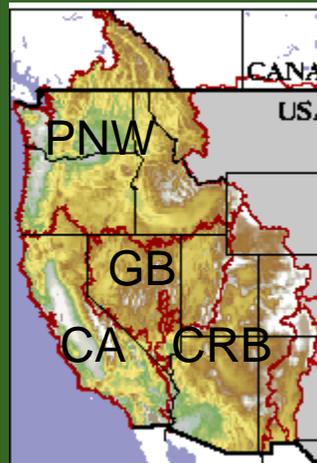
Aug, 31, 2004

Image Credit: *National Snow and Ice Data Center, W. O. Field, B. F. Molnia*
http://nsidc.org/data/glacier_photo/special_high_res.html

Cool Season Climate of the Western U.S.



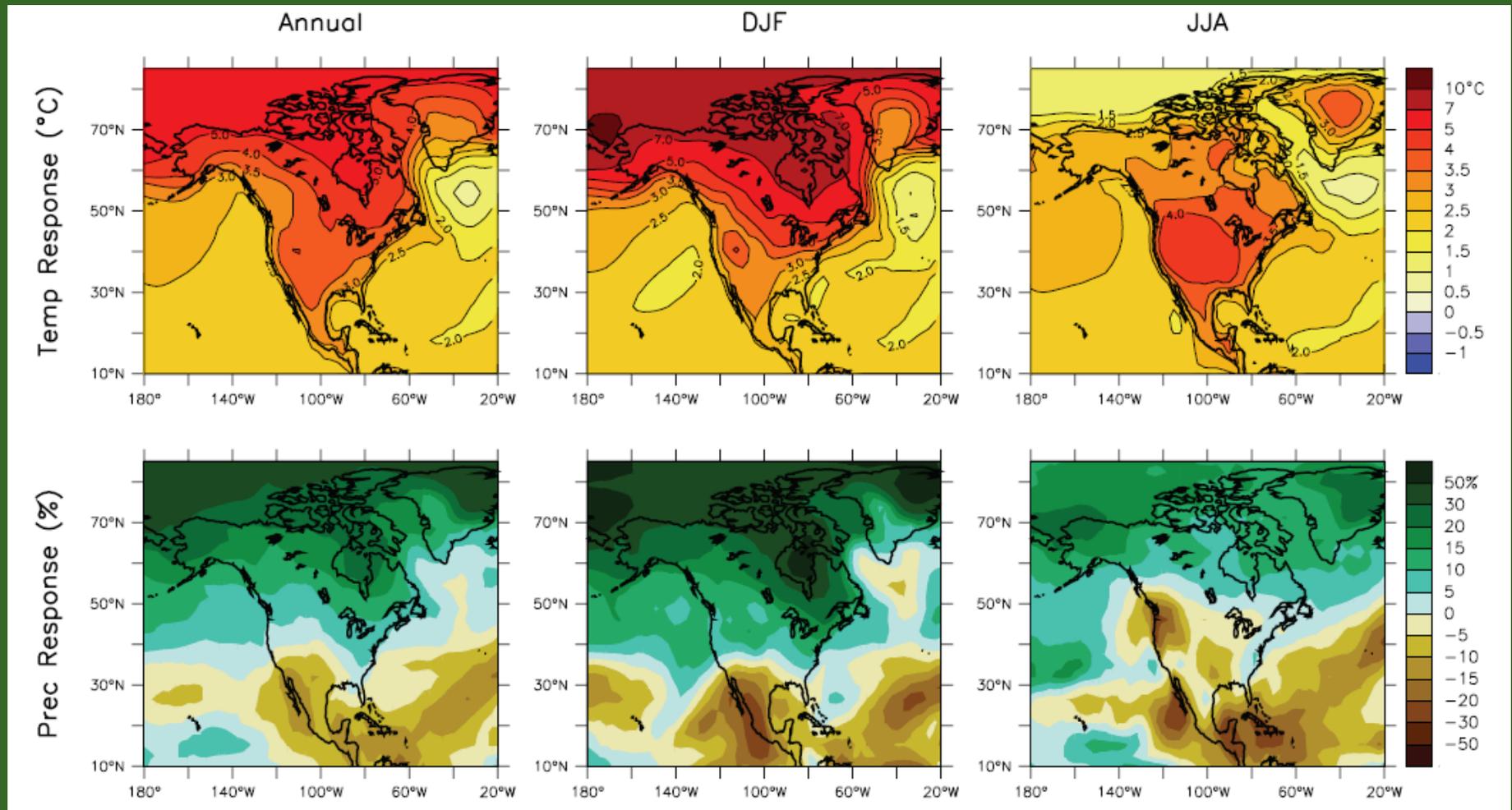
DJF Temp (°C)



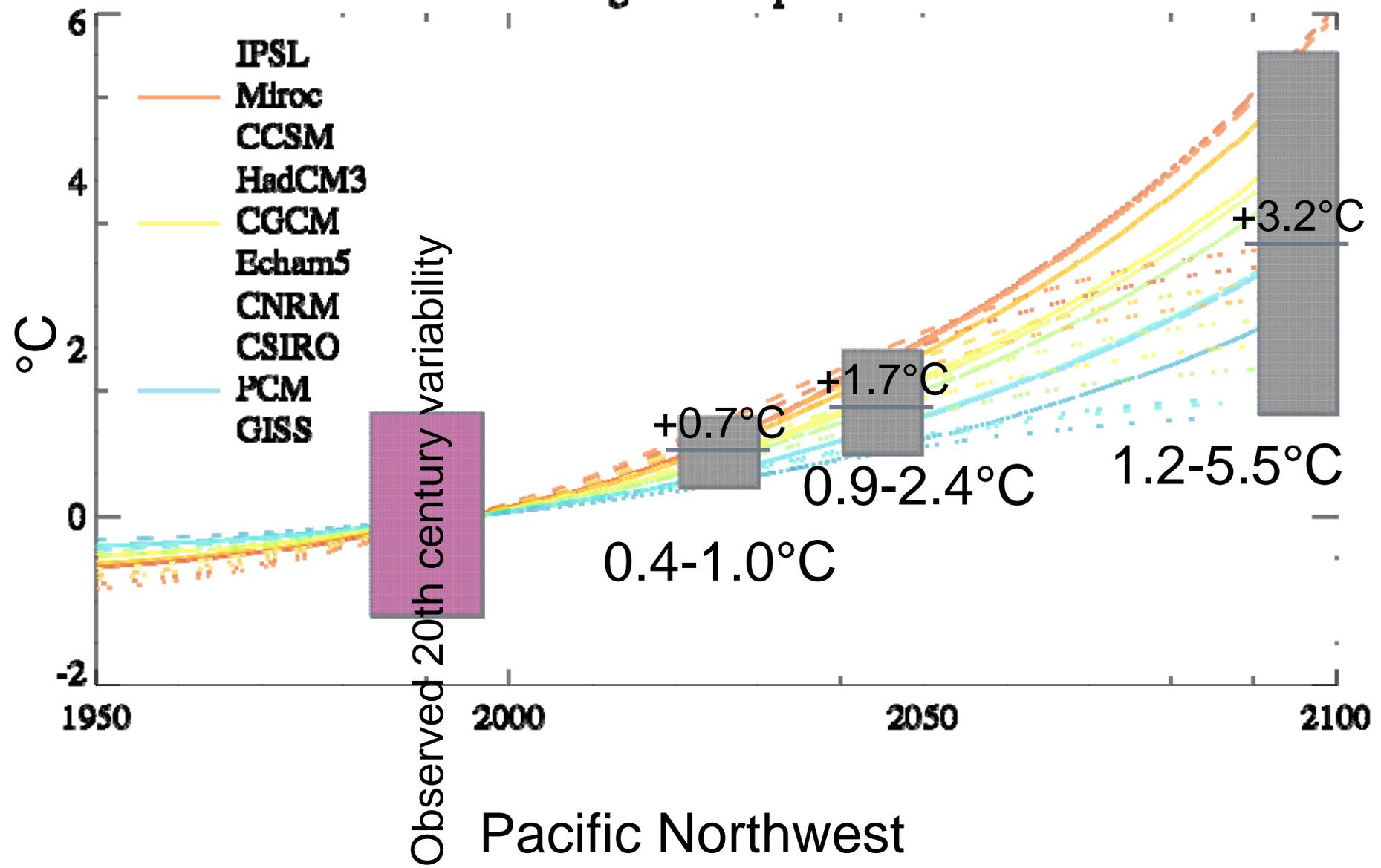
NDJFM Precip (mm)

Global Climate Change Scenarios and Hydrologic Impacts for the PNW

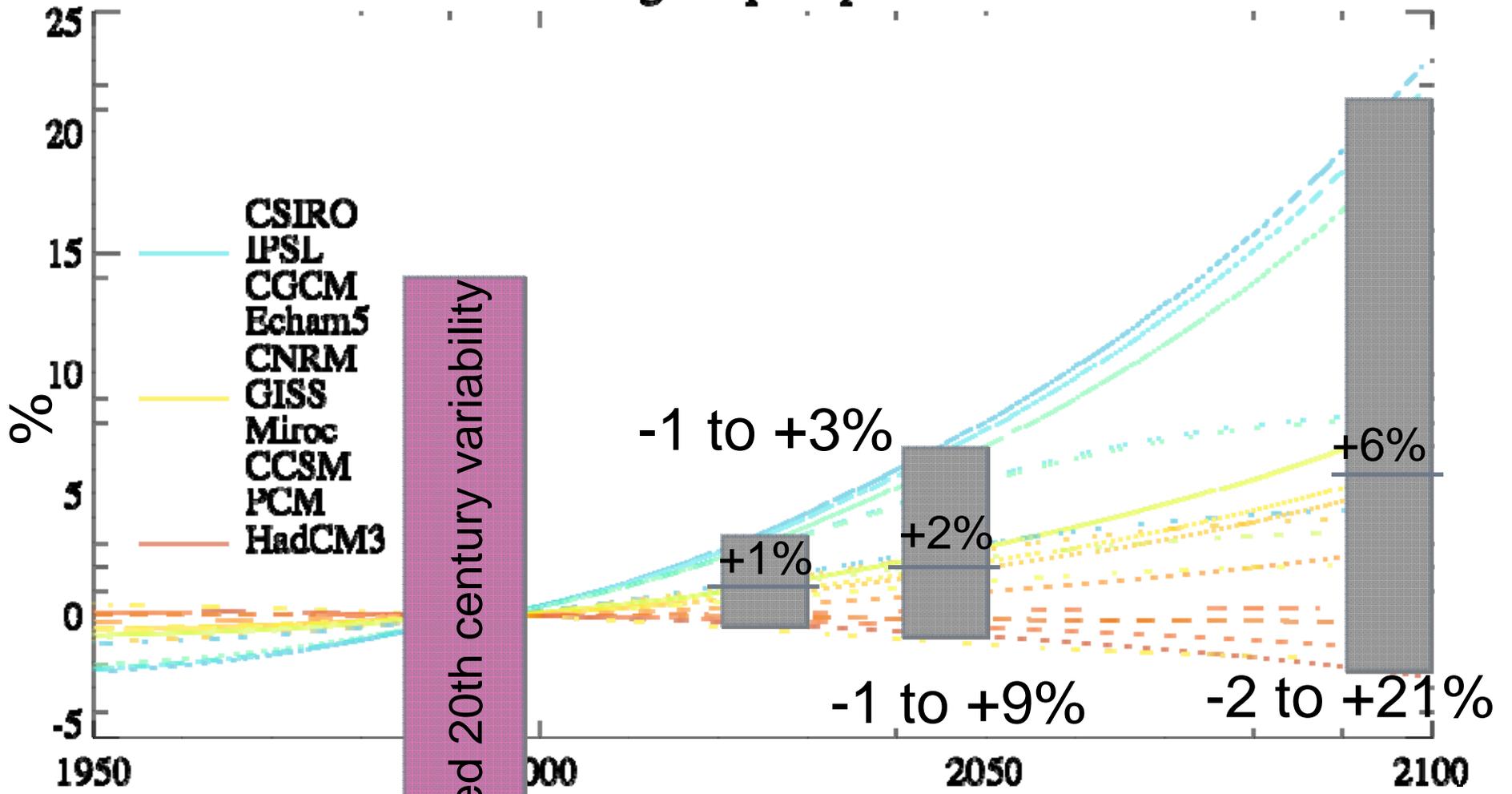
Consensus Forecasts of Temperature and Precipitation Changes from IPCC AR4 GCMs



Change in temperature



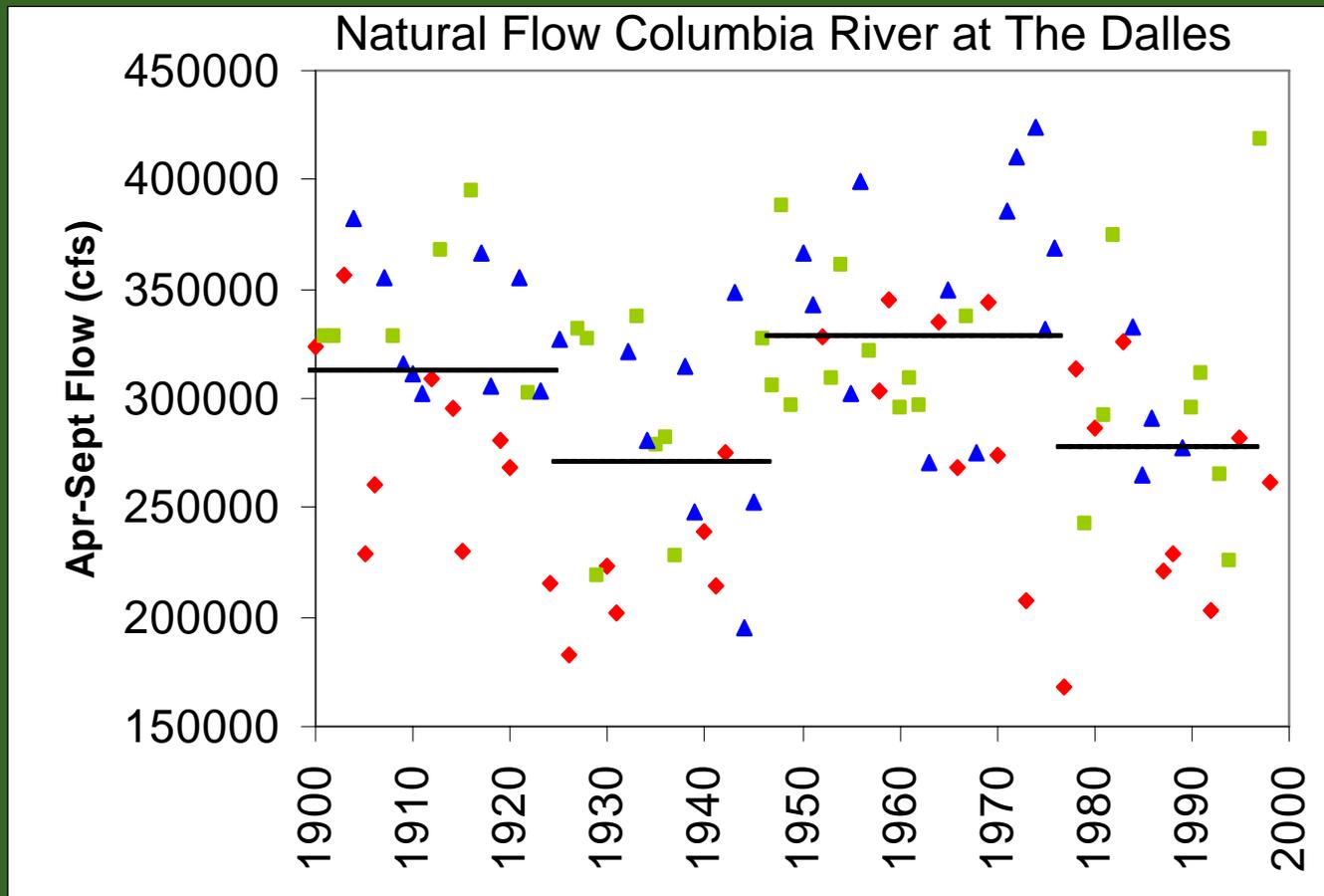
Change in precipitation



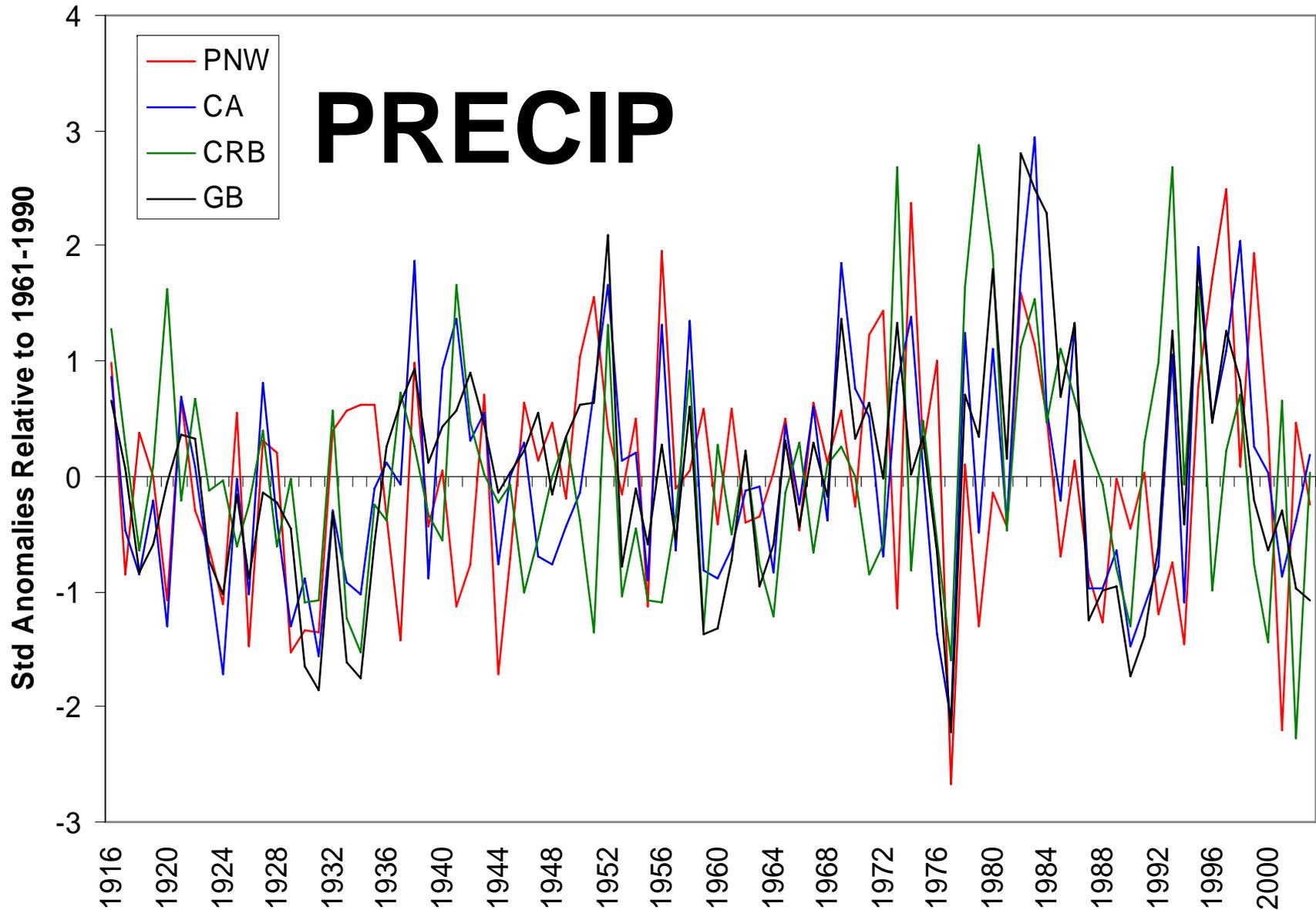
Pacific Northwest

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

Answer: Probably BOTH!

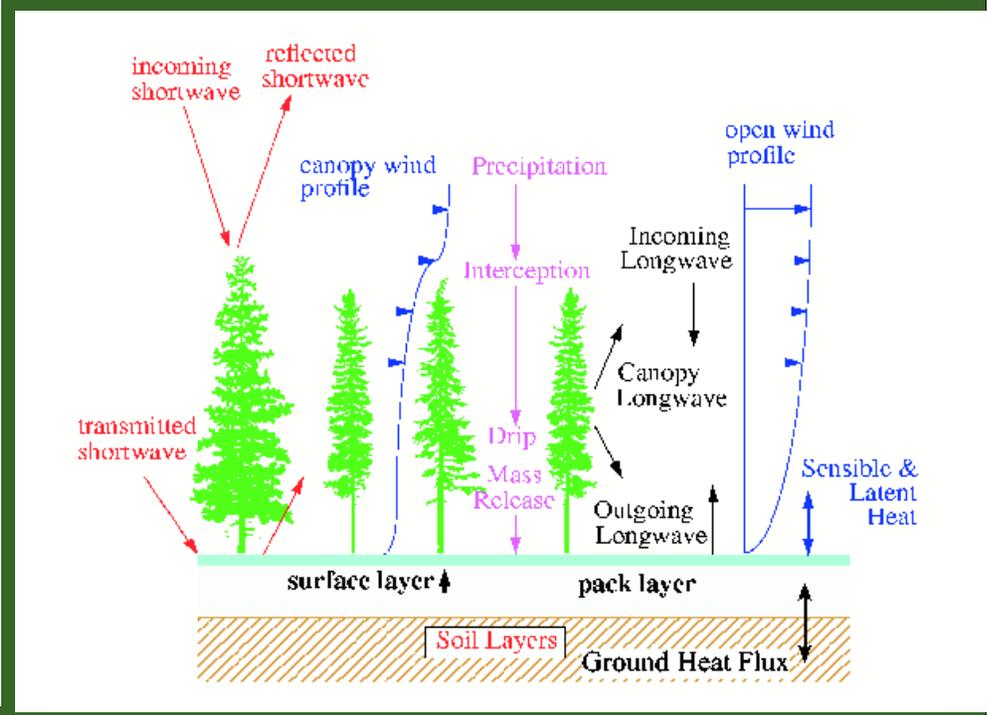
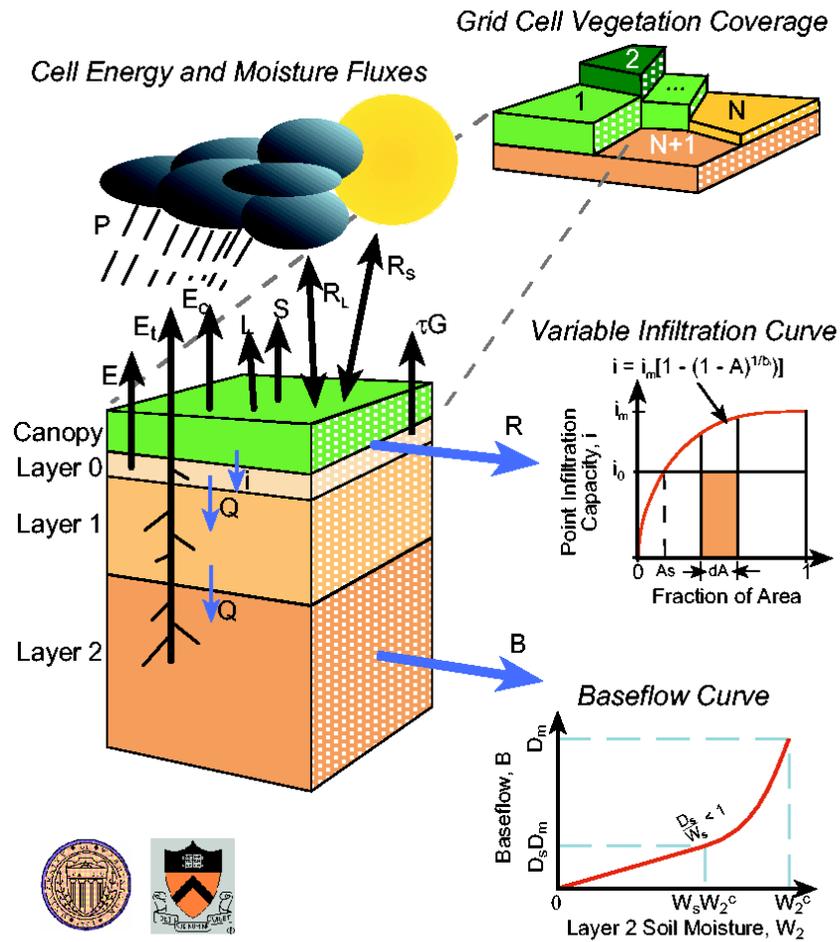


Regionally Averaged Cool Season Precipitation Anomalies



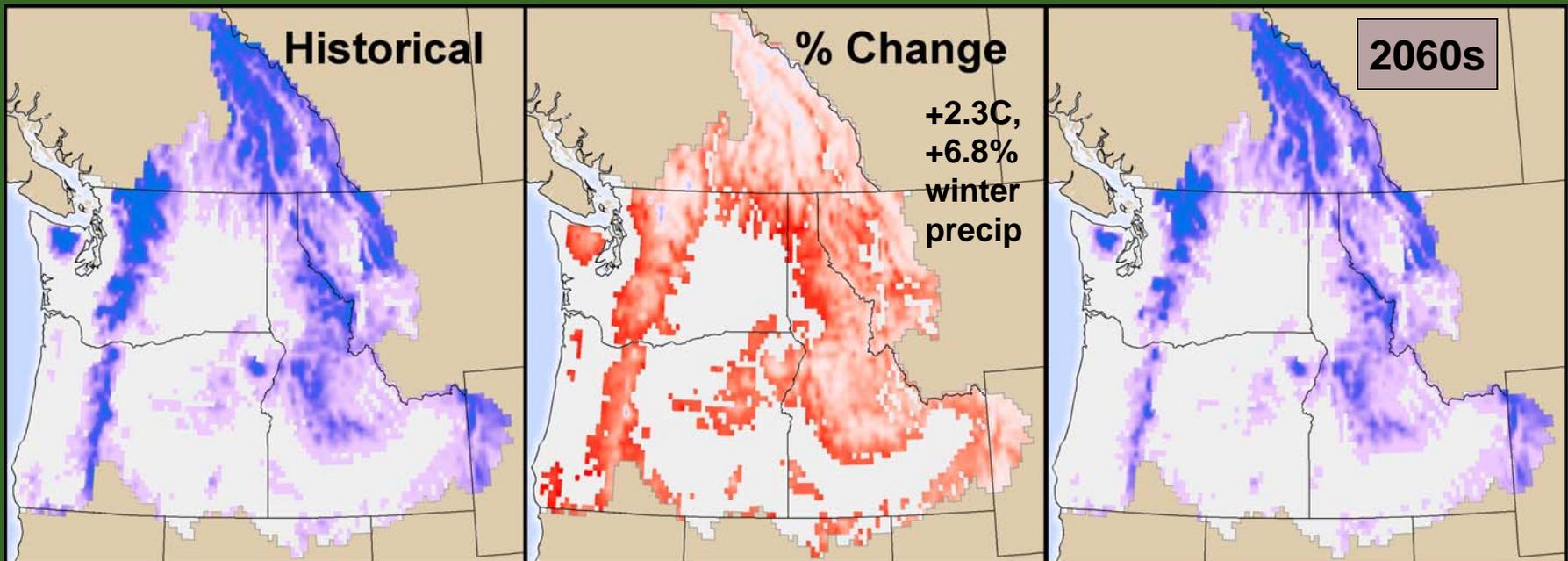
Schematic of VIC Hydrologic Model and Energy Balance Snow Model

Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model

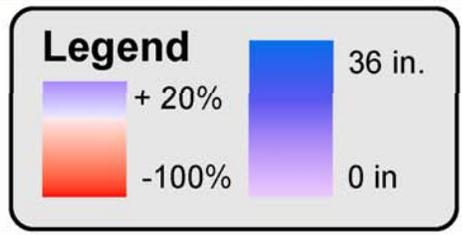


Snow Model

The warmer locations are most sensitive to warming



April 1 Snowpack

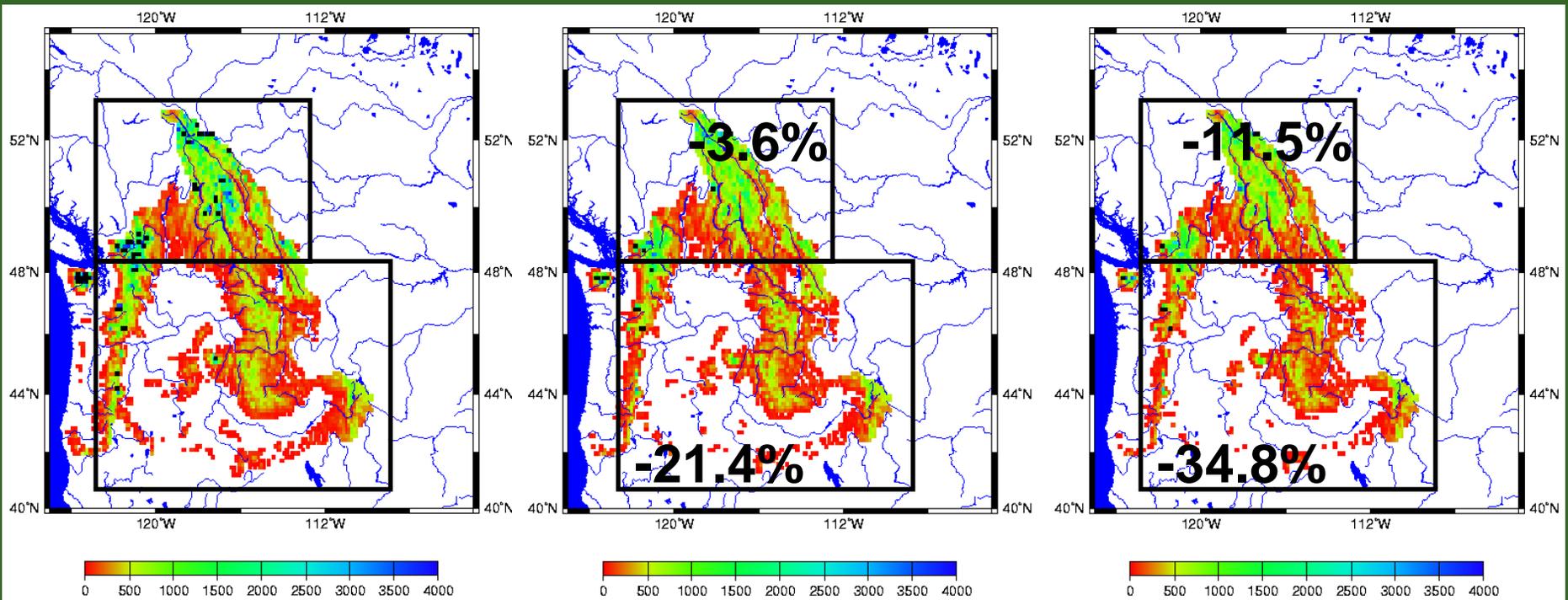


Changes in Simulated April 1 Snowpack for the Canadian and U.S. portions of the Columbia River basin (% change relative to current climate)

20th Century Climate

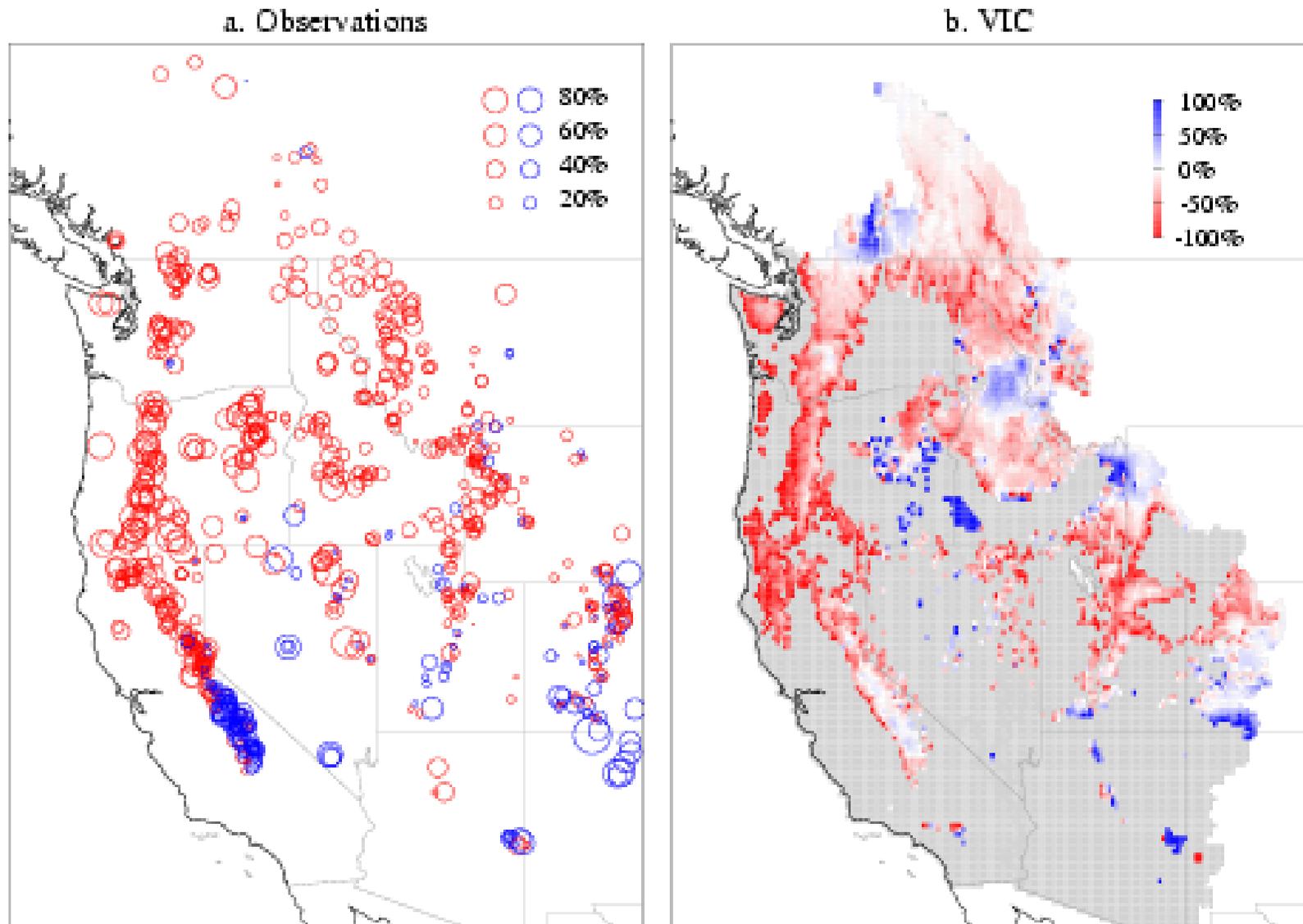
“2040s” (+1.7 C)

“2060s” (+ 2.25 C)



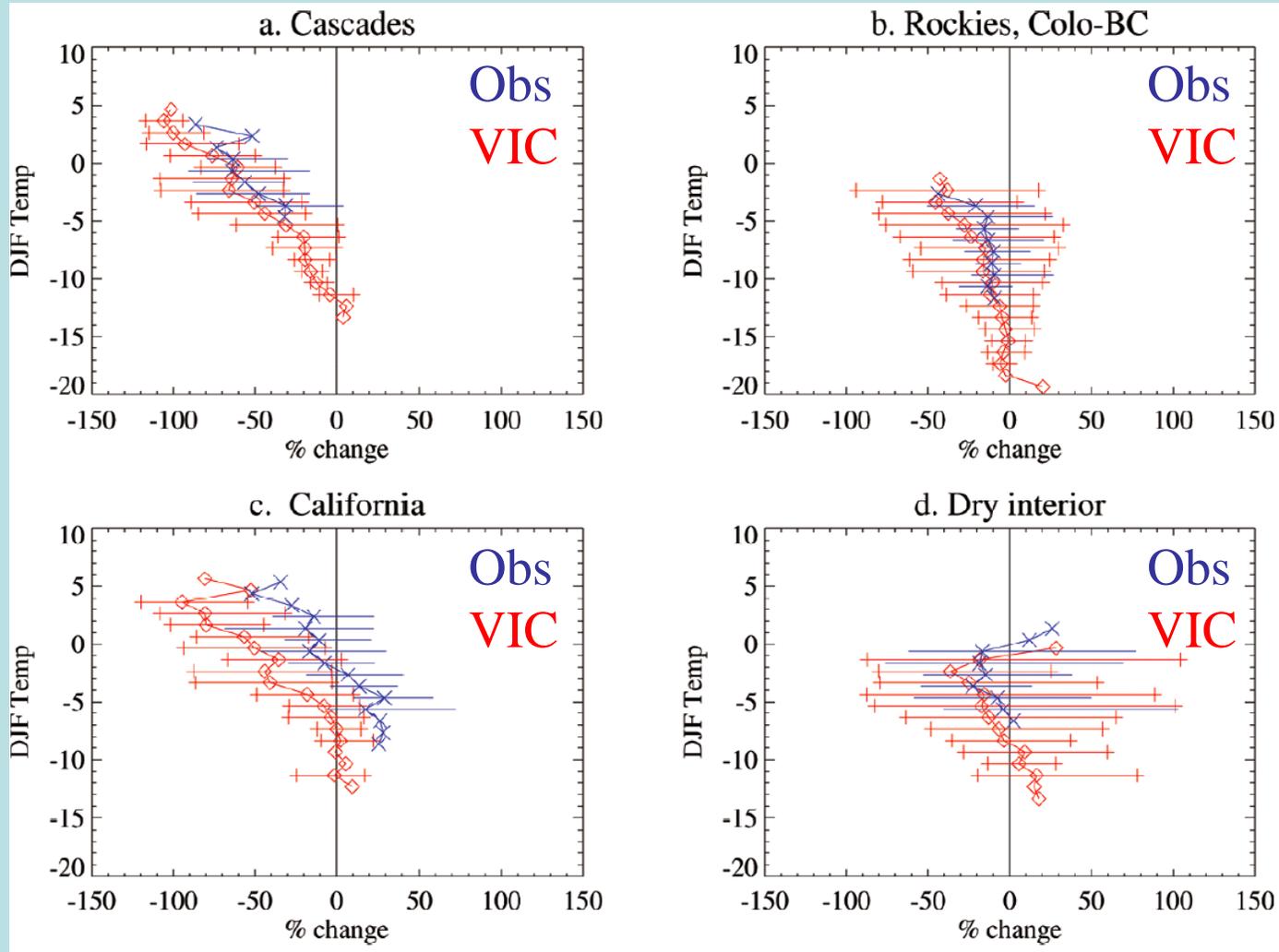
April 1 SWE (mm)

Trends in April 1 SWE 1950-1997

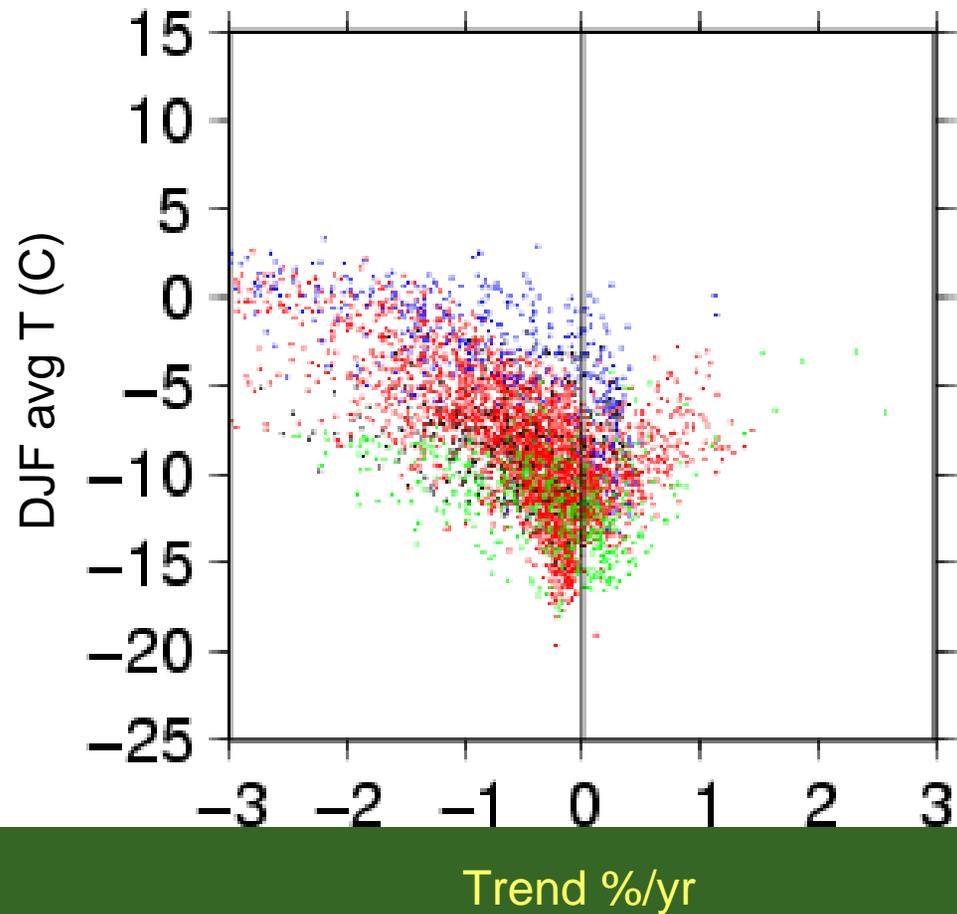
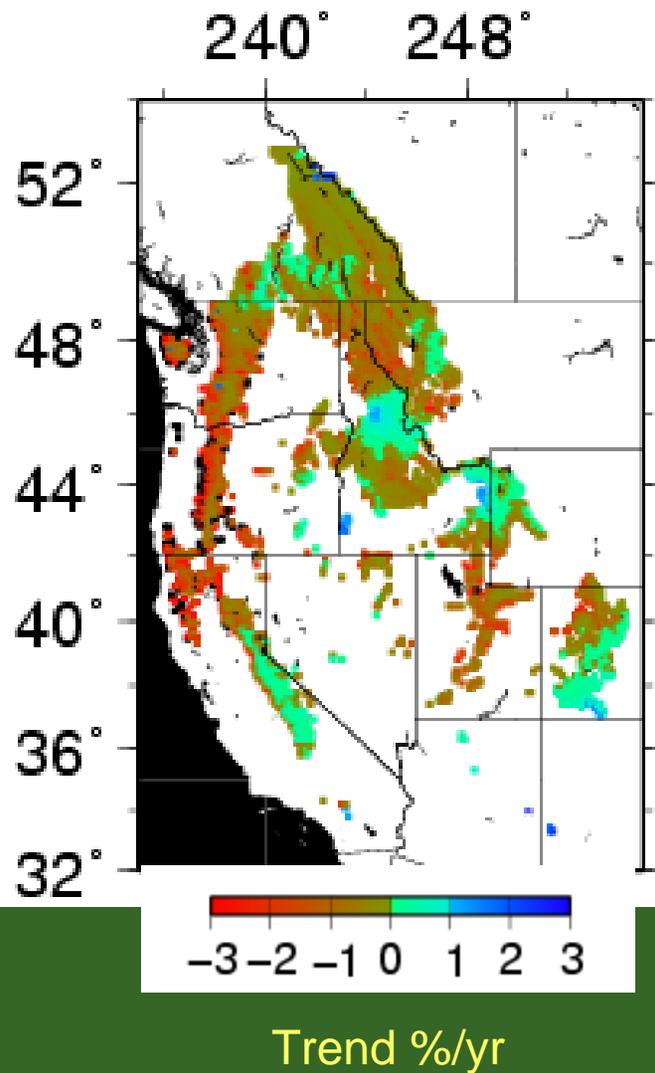


Mote P.W., Hamlet A.F., Clark M.P., Lettenmaier D.P., 2005, Declining mountain snowpack in western North America, BAMS, 86 (1): 39-49

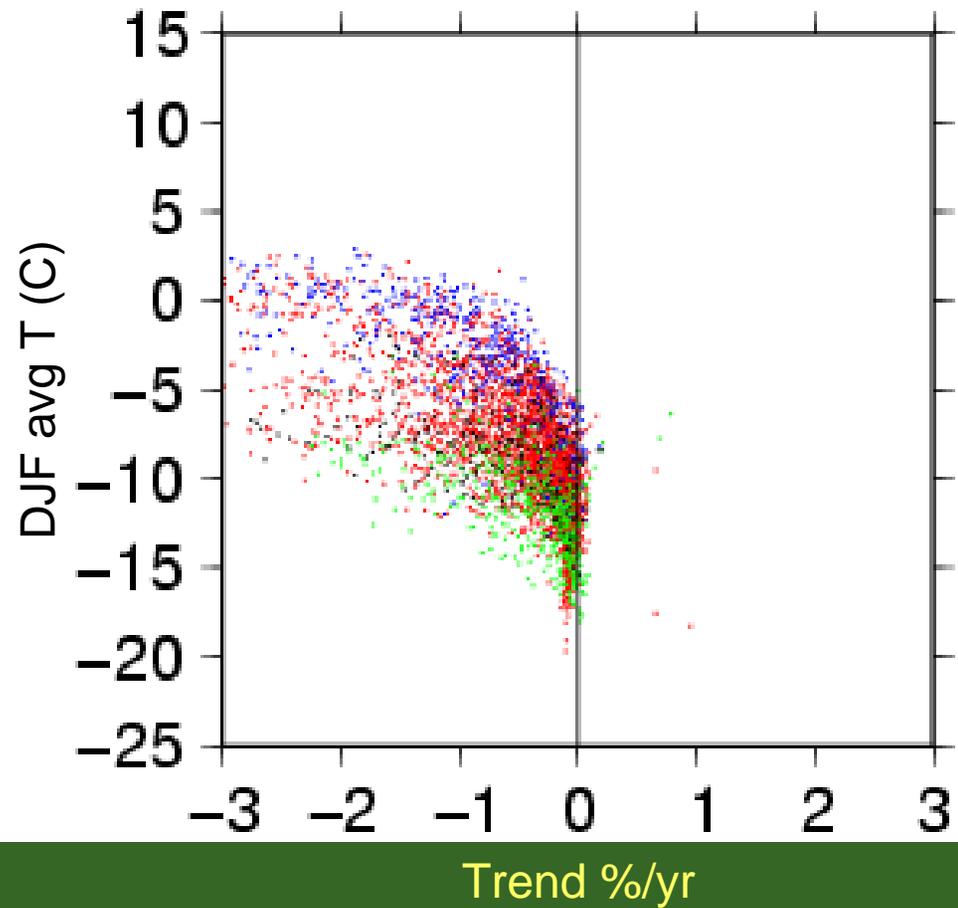
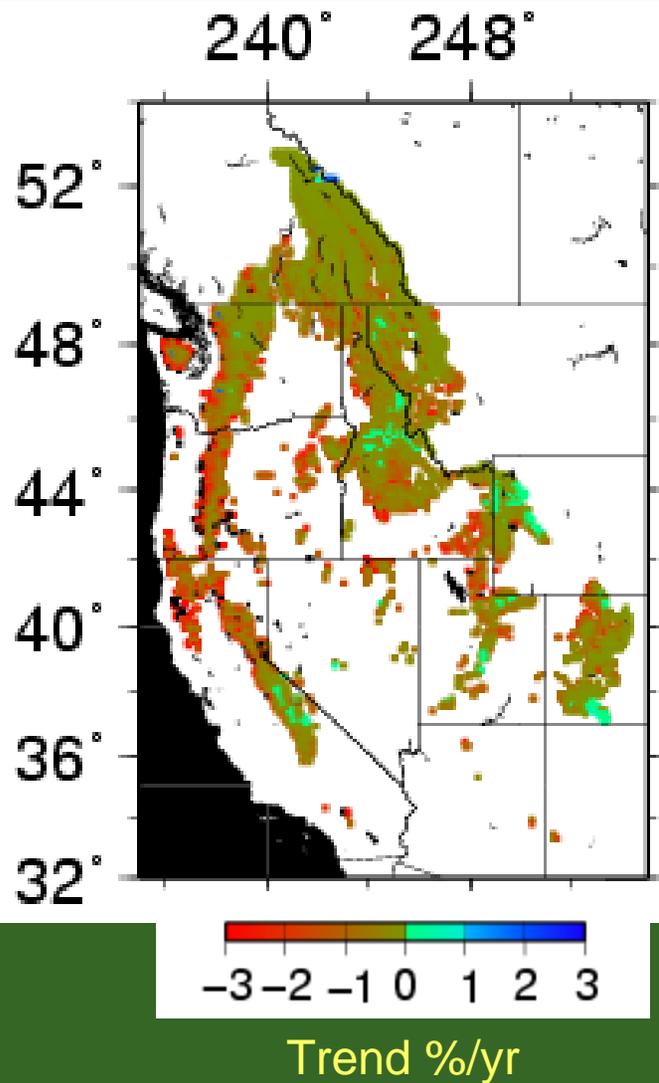
1950-1997 relative trends in April 1 SWE vs DJF temperature



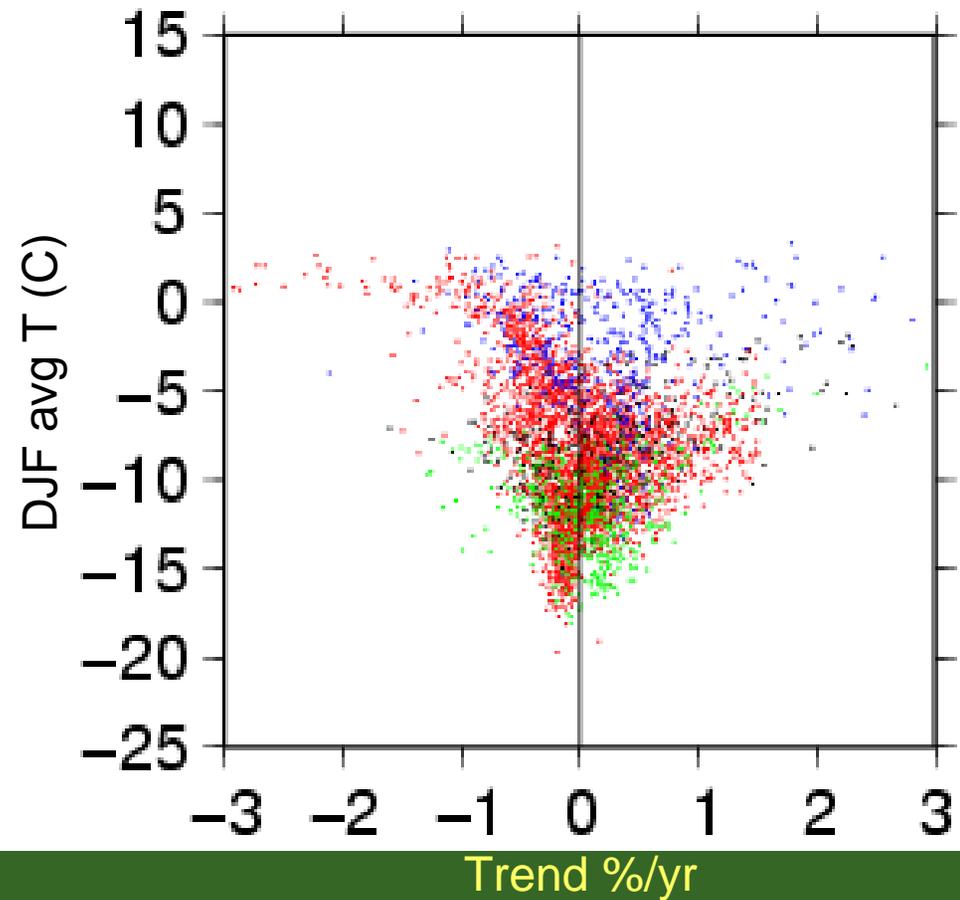
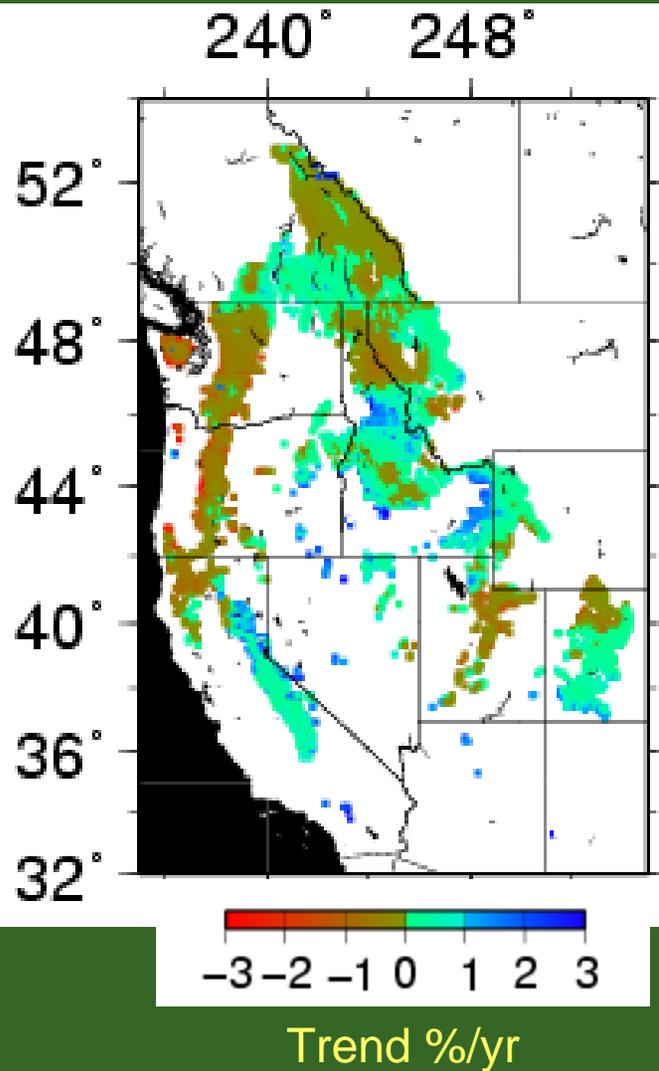
Overall Trends in April 1 SWE from 1947-2003



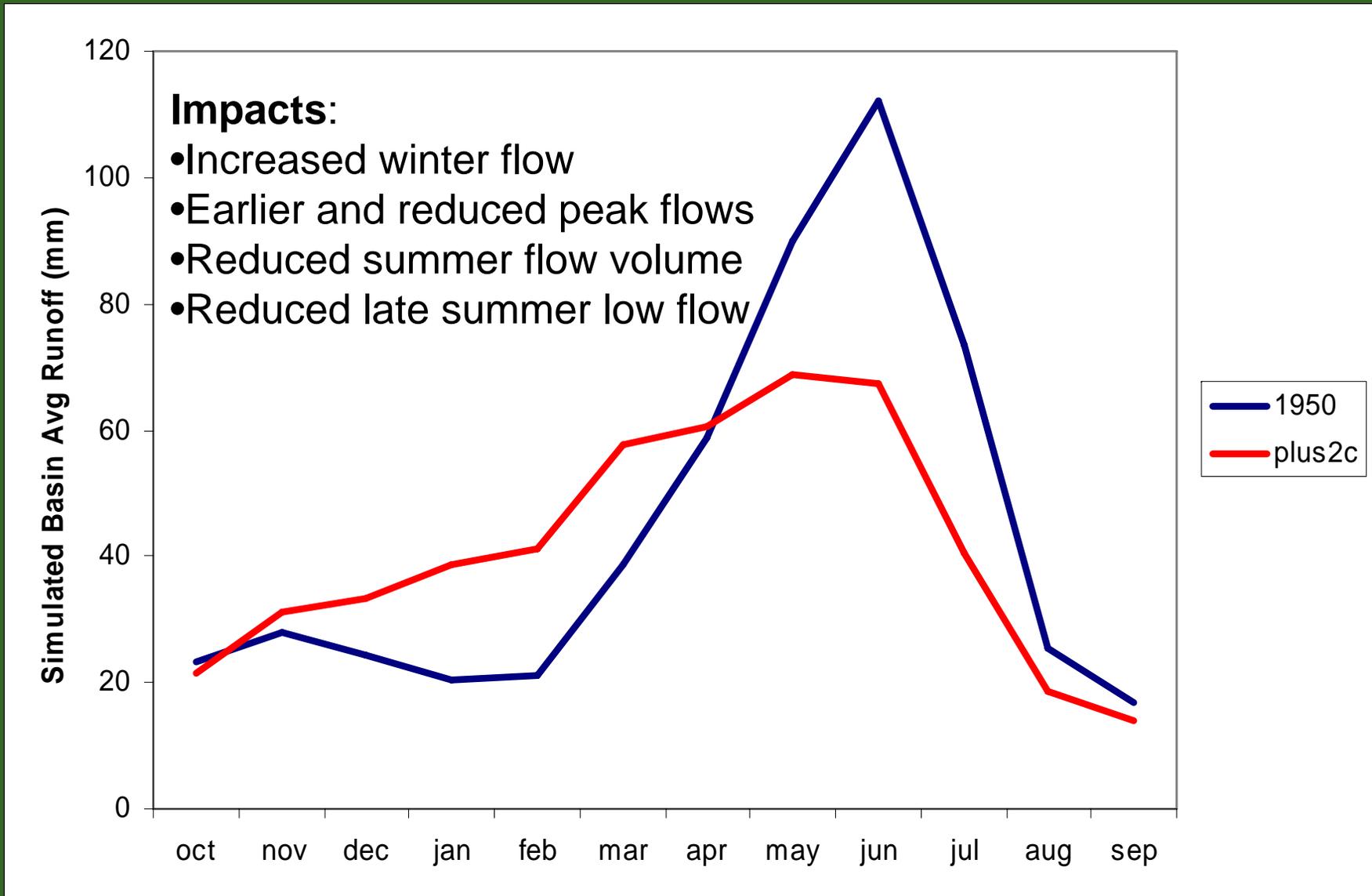
Temperature Related Trends in April 1 SWE from 1947-2003



Precipitation Related Trends in April 1 SWE from 1947-2003

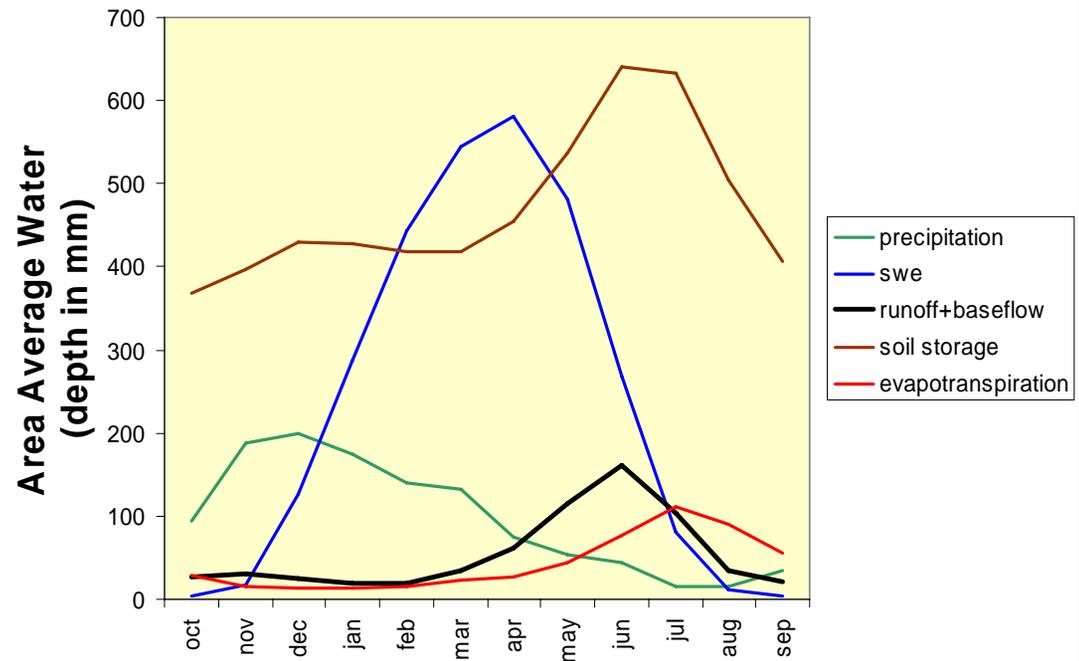


Simulated Changes in Natural Runoff Timing in the Naches River Basin Associated with 2 C Warming

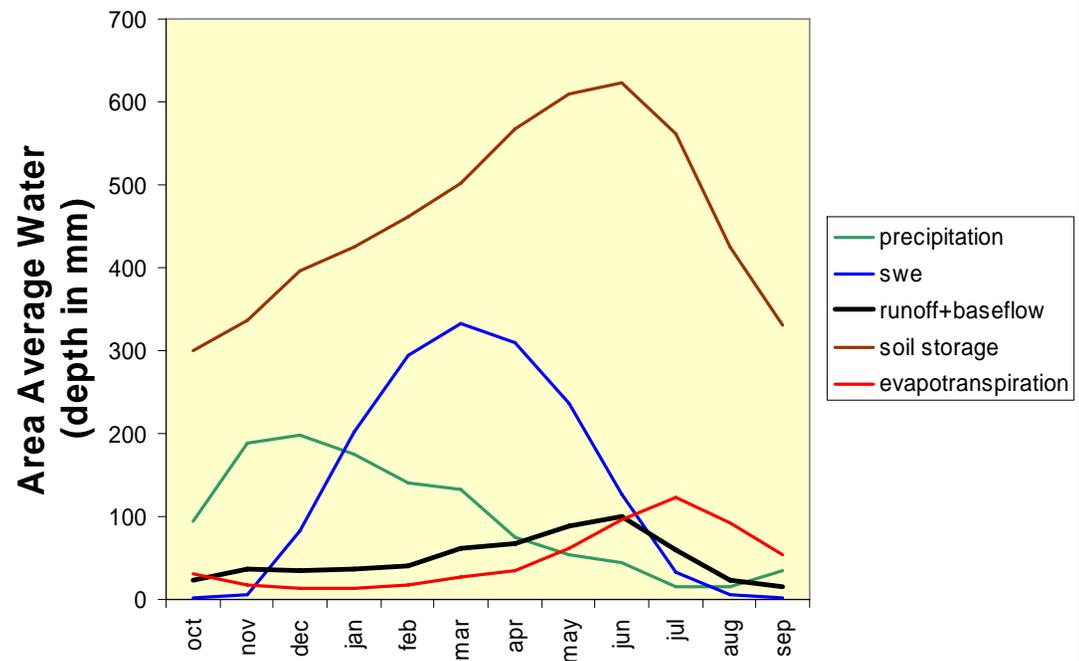


Seasonal Water Balance Naches Basin

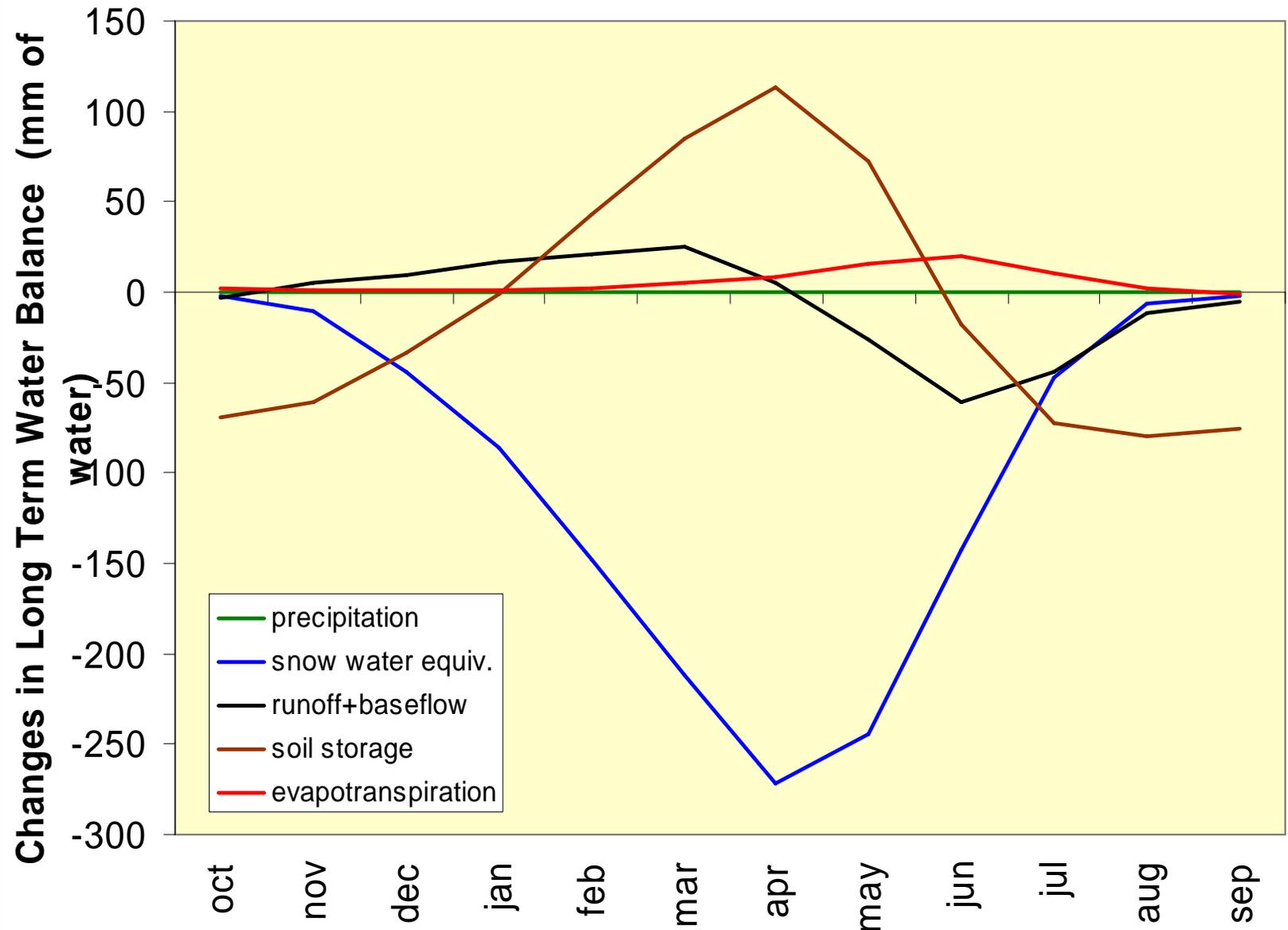
20th Century Climate

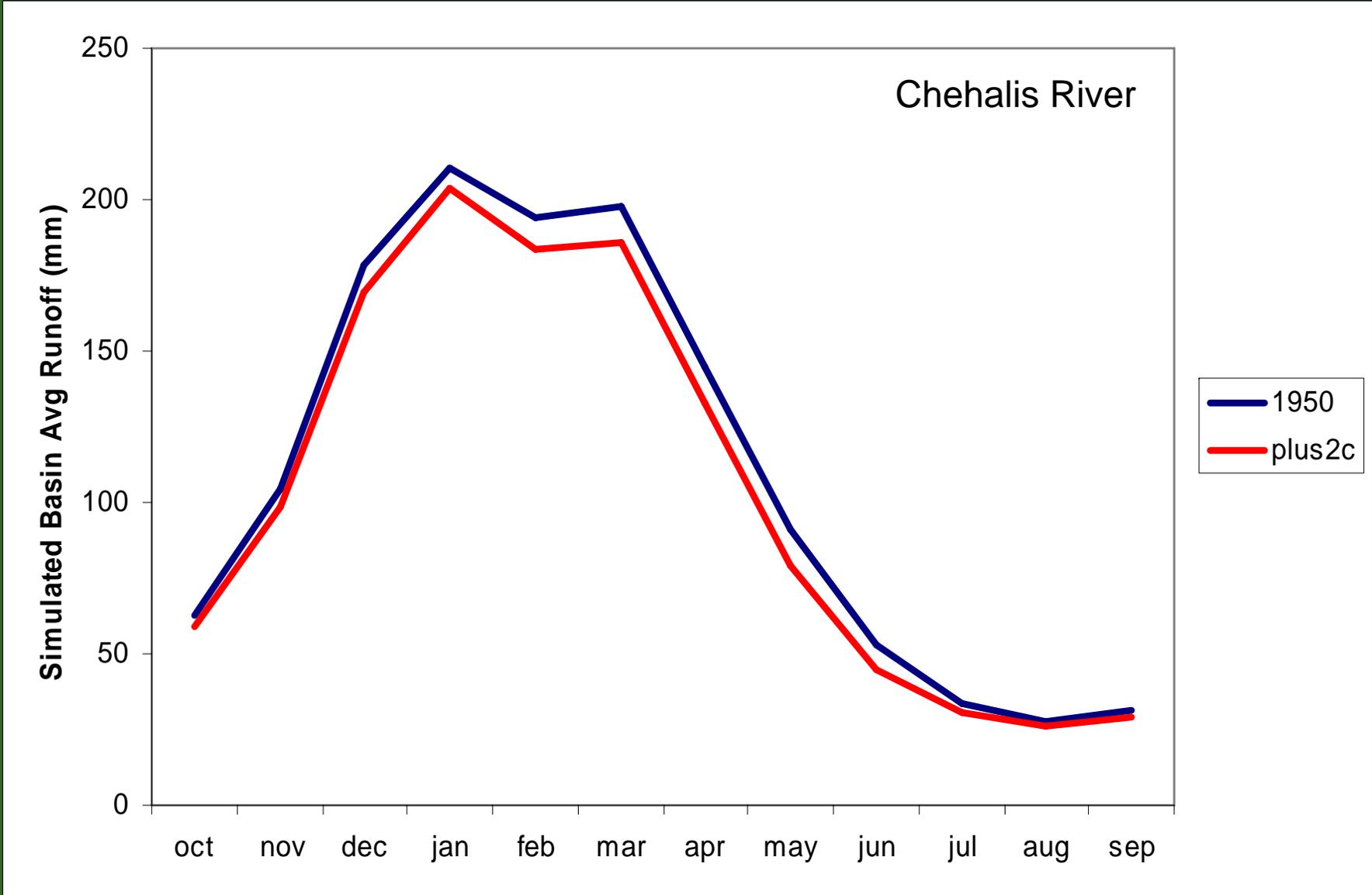


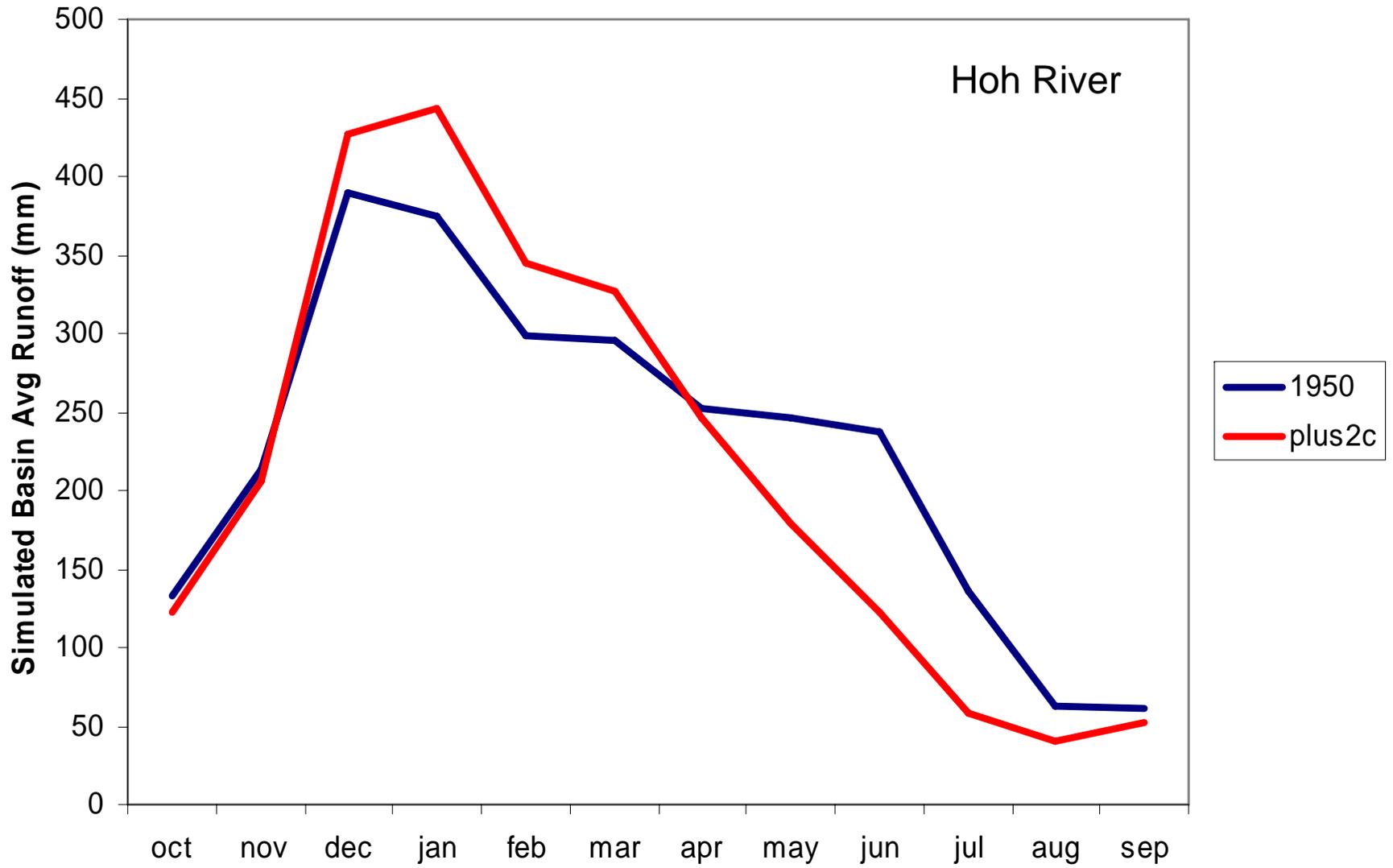
20th Century Climate + 2.0 C

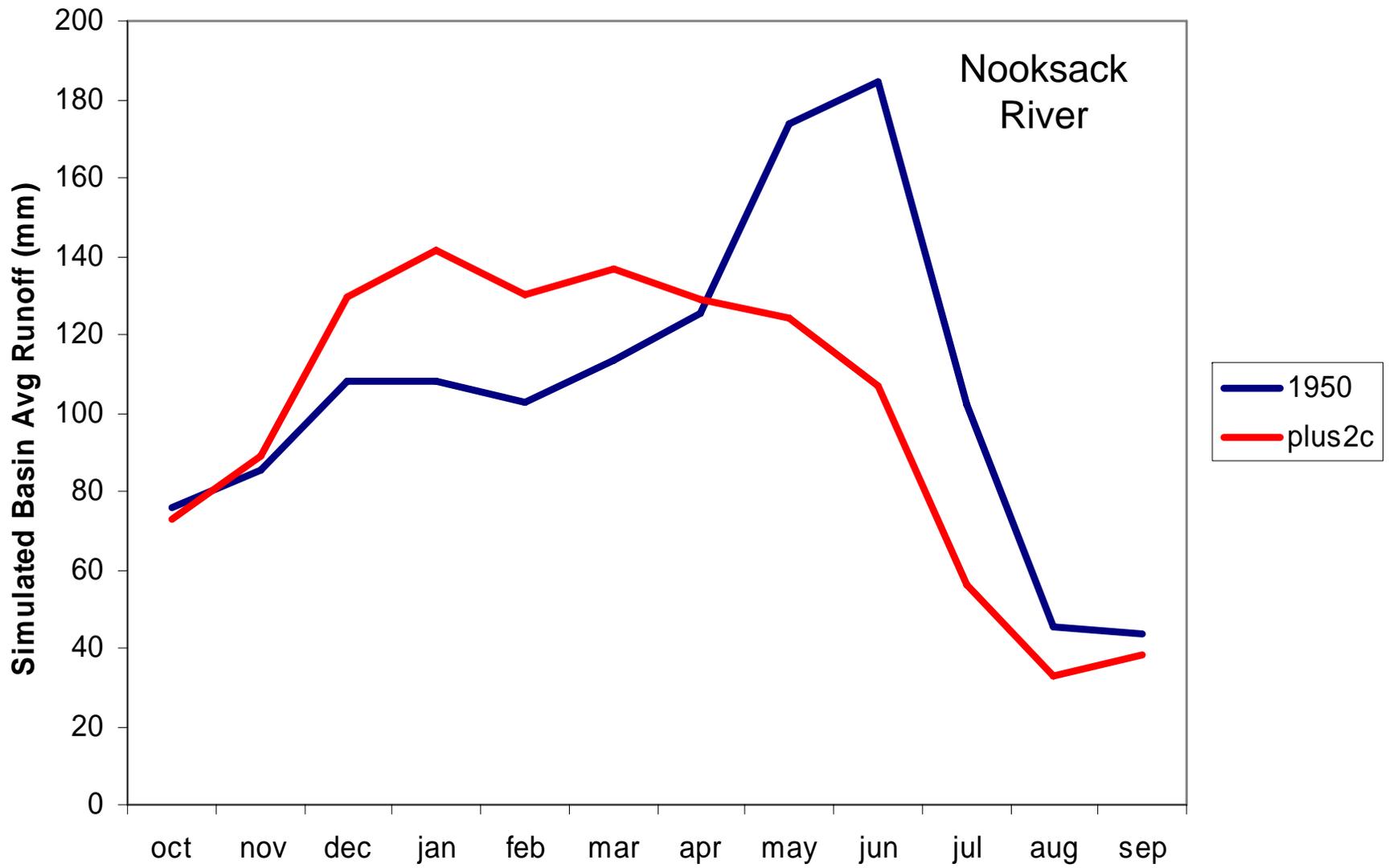


Seasonal Changes in Water Balance for the Naches Basin (+2.0 C Simulation – 20th Century Simulation)



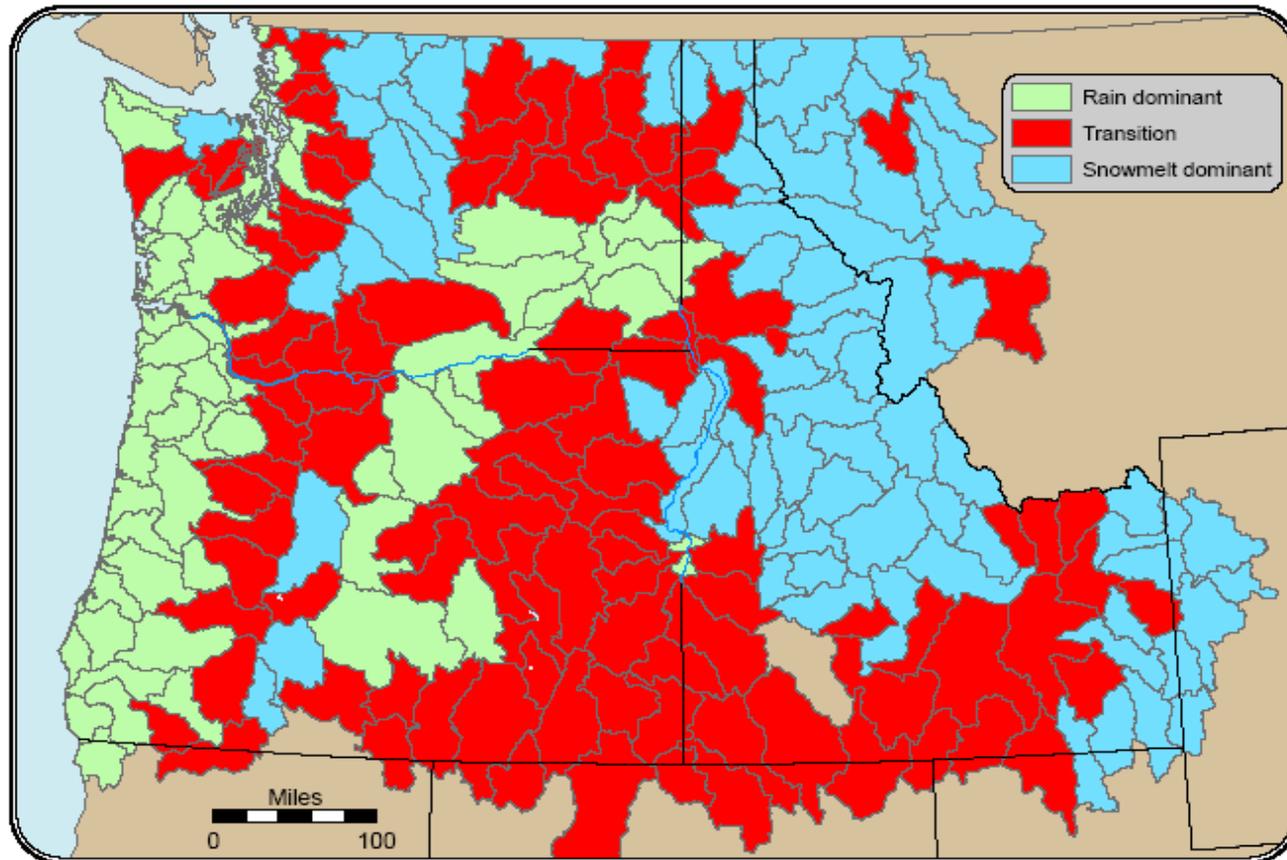




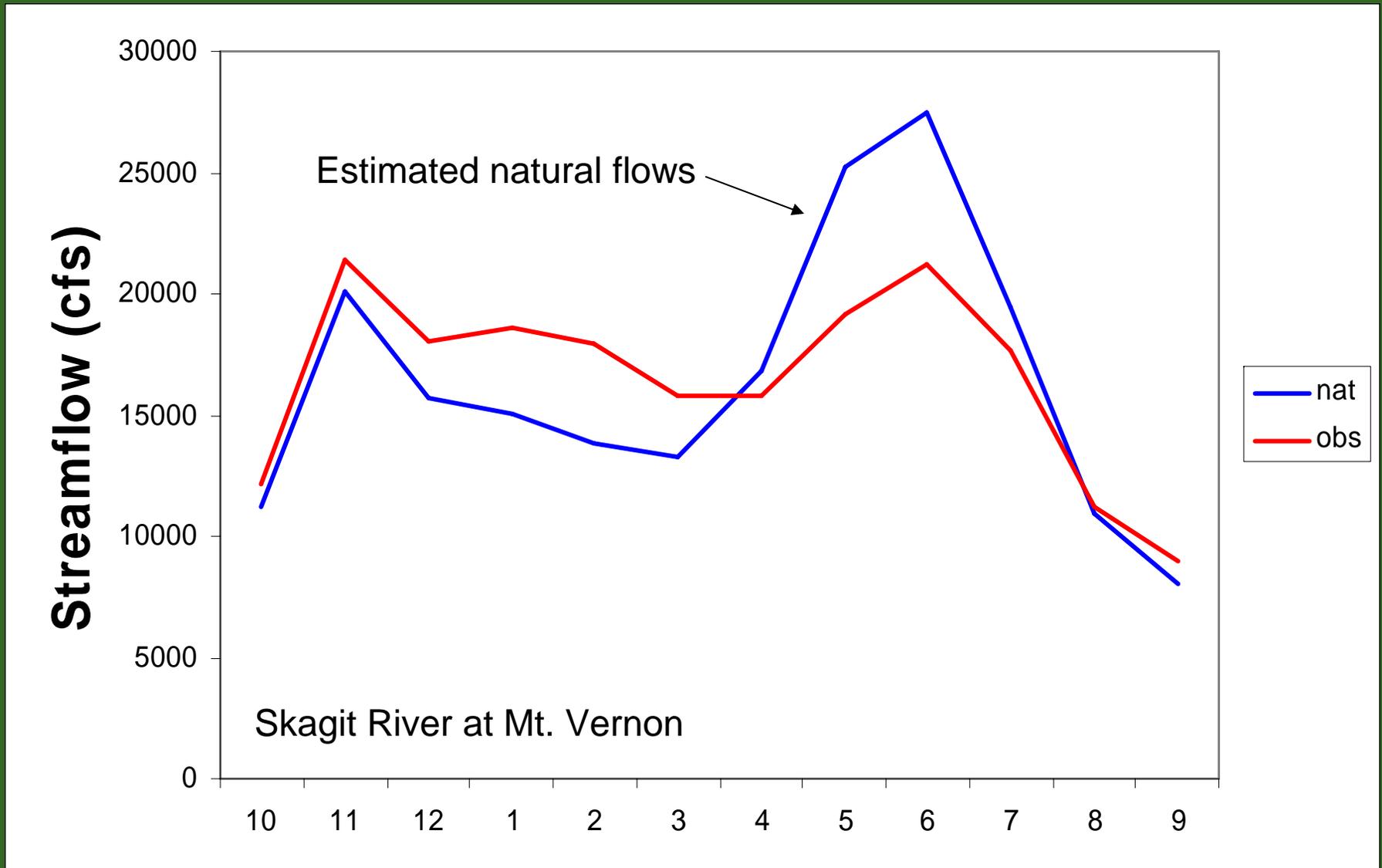


Mapping of Sensitive Areas in the PNW by Fraction of Precipitation Stored as Peak Snowpack

HUC 4 Scale Watersheds in the PNW

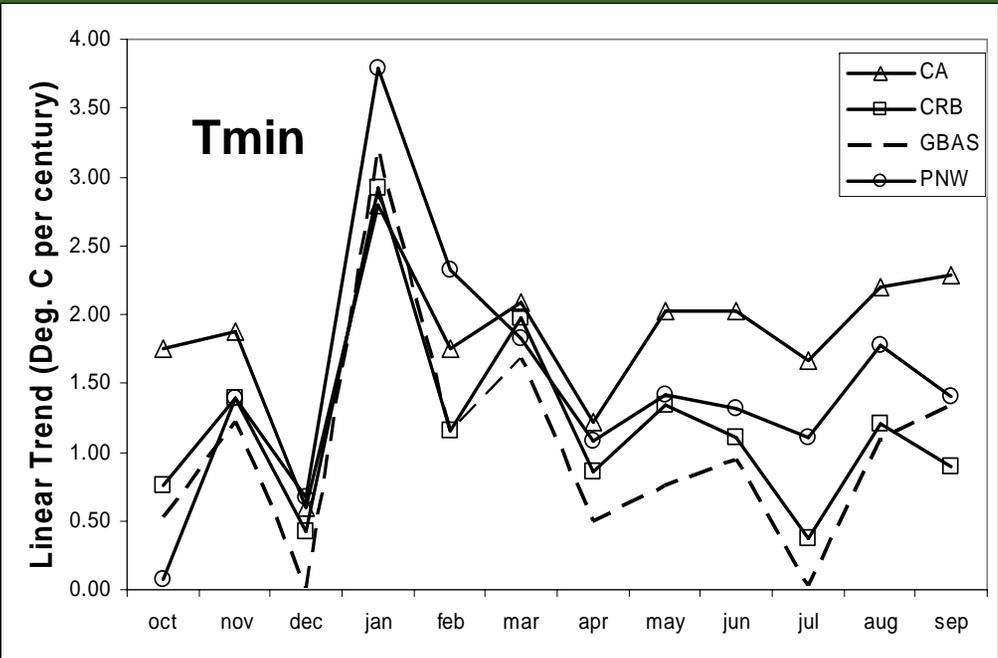
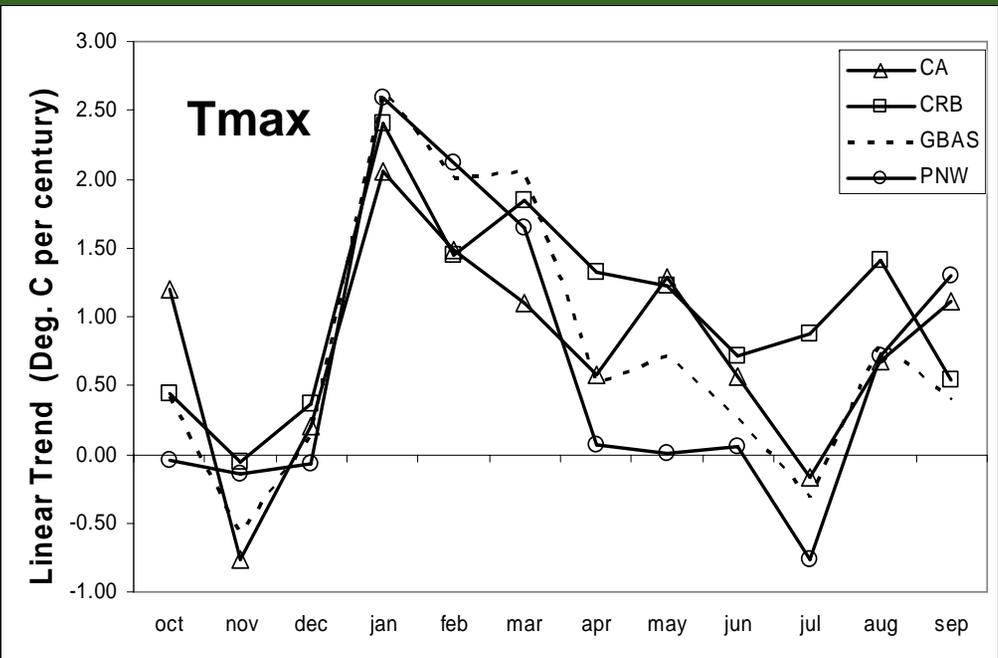
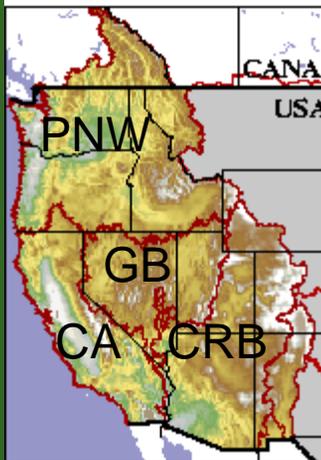


Climate Change Impacts are Similar to Impacts of Water Management in PNW Hydropower Systems

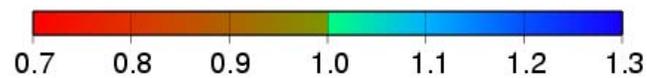
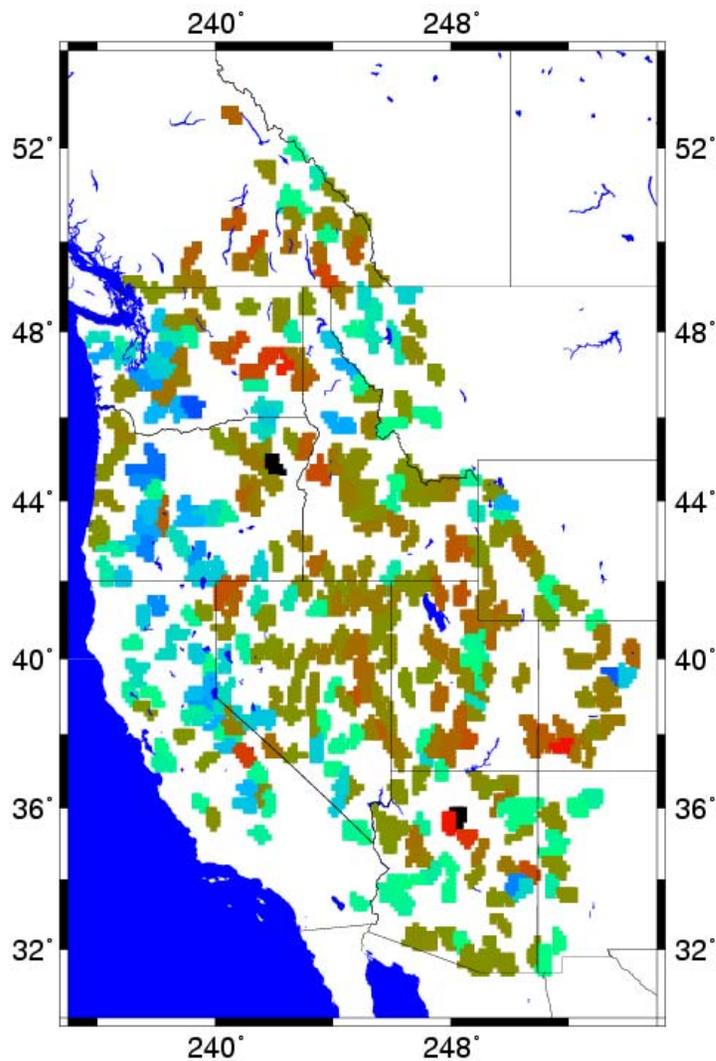


Changes in Flood Risk in the Western U.S.

Regionally Averaged Temperature Trends Over the Western U.S. 1916-2003

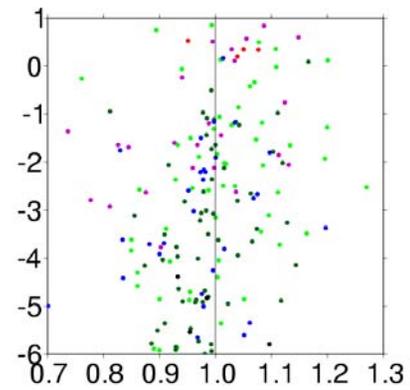


Simulated Changes in the 20-year Flood Associated with 20th Century Warming



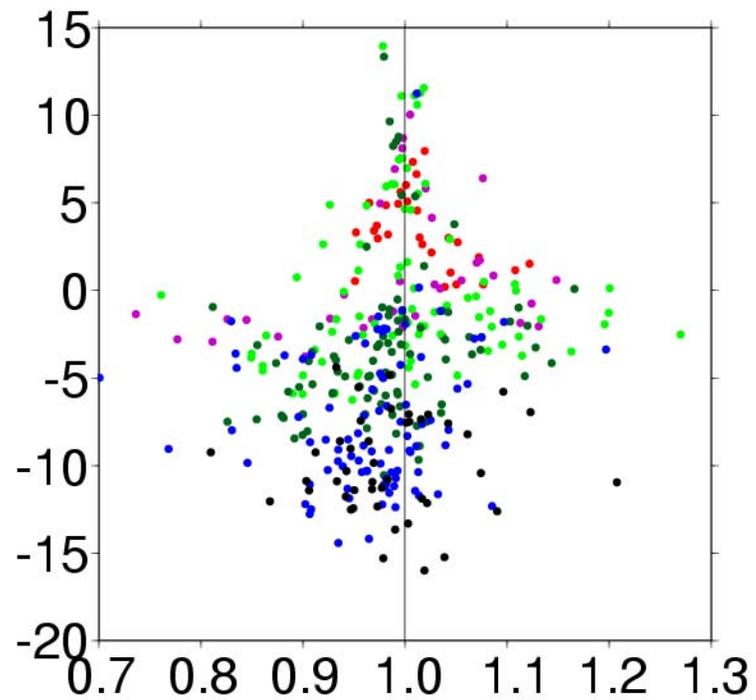
$X_{20} \text{ 2003} / X_{20} \text{ 1915}$

DJF Avg Temp (C)



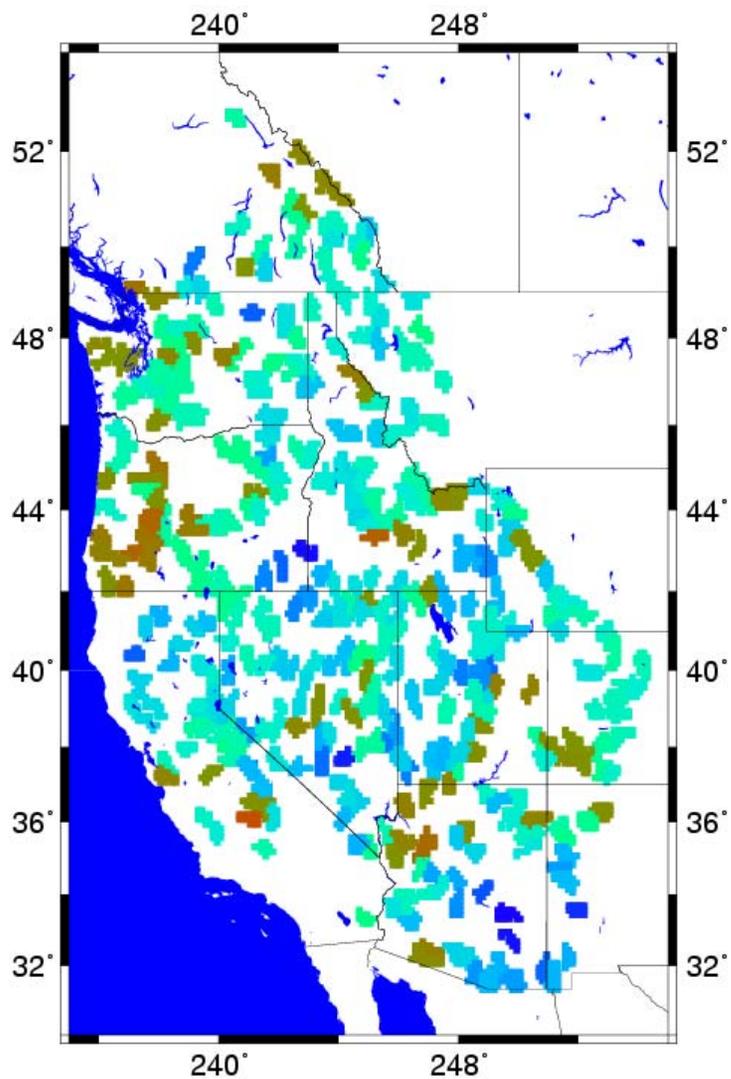
$X_{20} \text{ 2003} / X_{20} \text{ 1915}$

DJF Avg Temp (C)



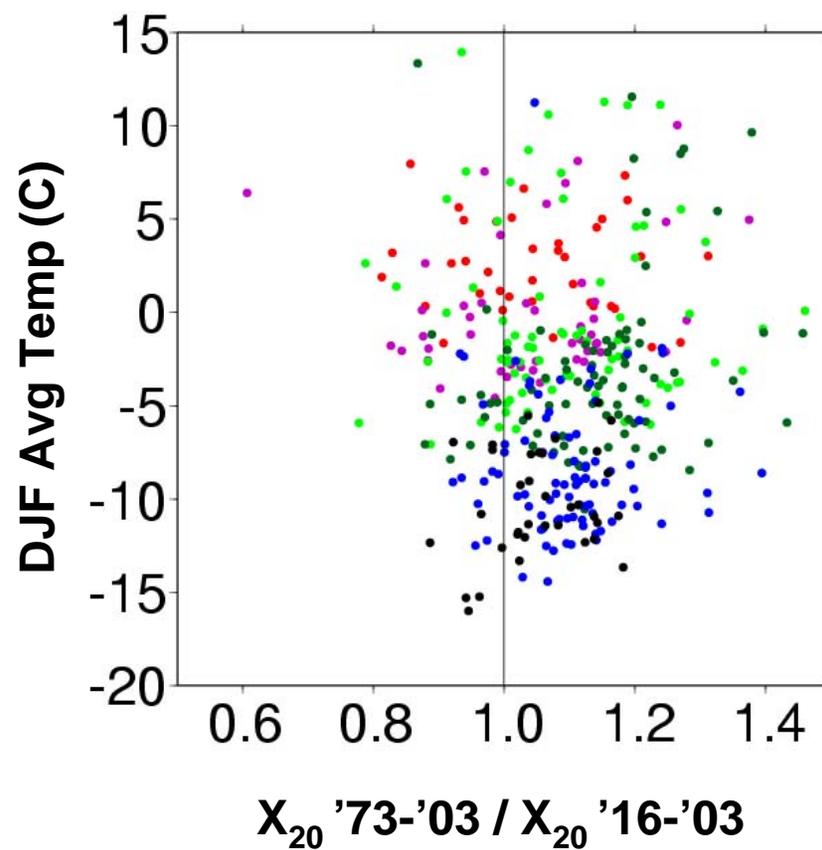
$X_{20} \text{ 2003} / X_{20} \text{ 1915}$

20-year Flood for "1973-2003" Compared to "1916-2003" for a Constant Late 20th Century Temperature Regime



0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5

X_{20} '73-'03 / X_{20} '16-'03



Summary of Flooding Impacts

Rain Dominant Basins:

Possible increases in flooding due to increased precipitation variability, but no significant change from warming alone.

Mixed Rain and Snow Basins Along the Coast:

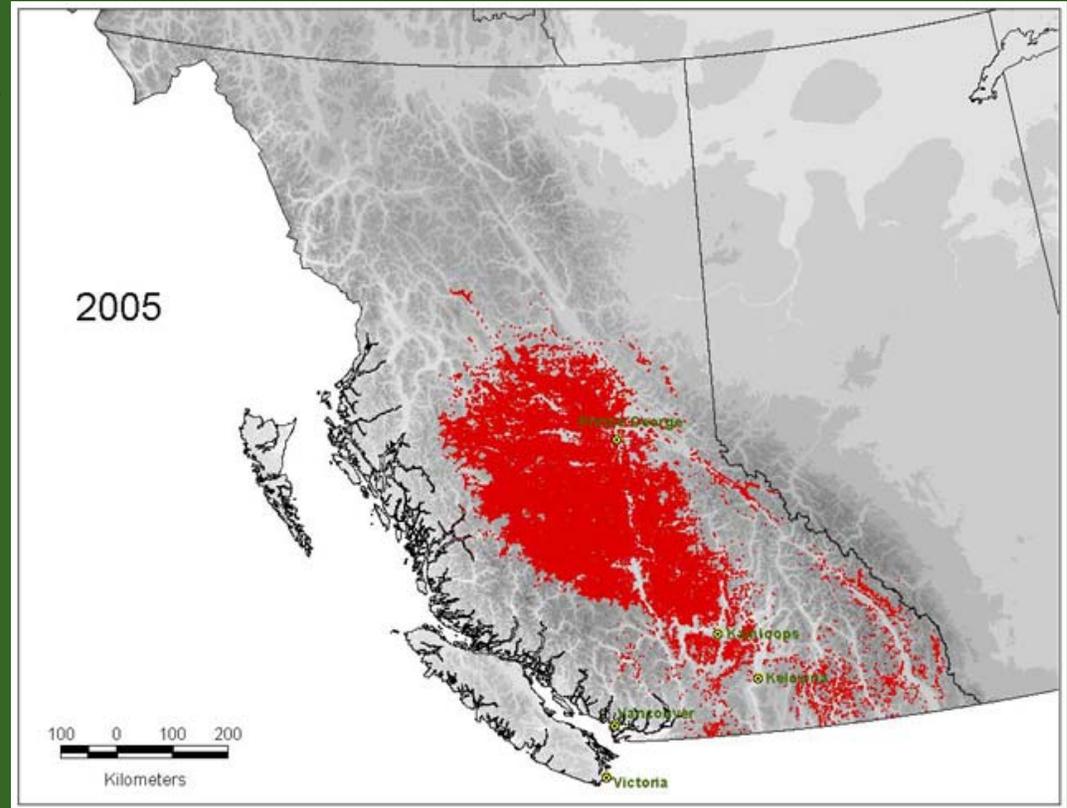
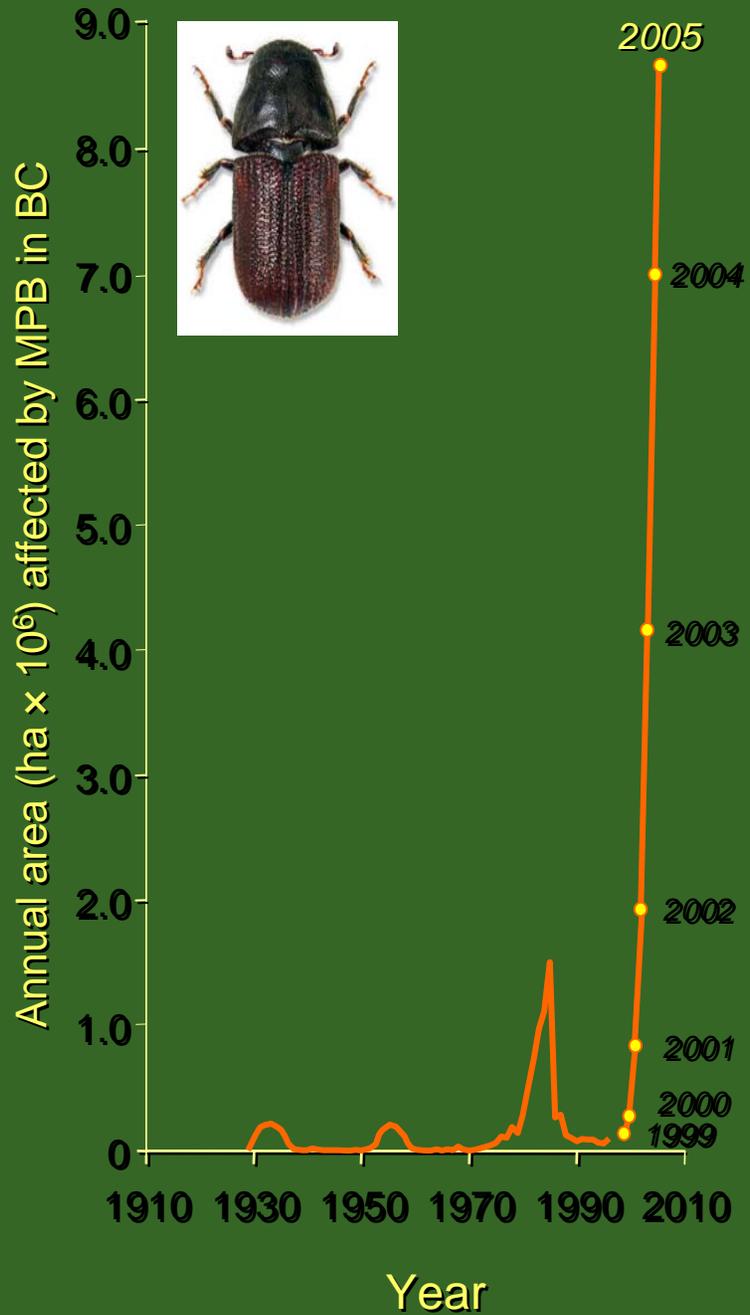
Strong increases due to warming and increased precipitation variability (both effects increase flood risk)

Inland Snowmelt Dominant Basins:

Relatively small overall changes because effects of warming (decreased risks) and increased precipitation variability (increased risks) are in the opposite directions.

Landscape Scale Ecosystem Impacts

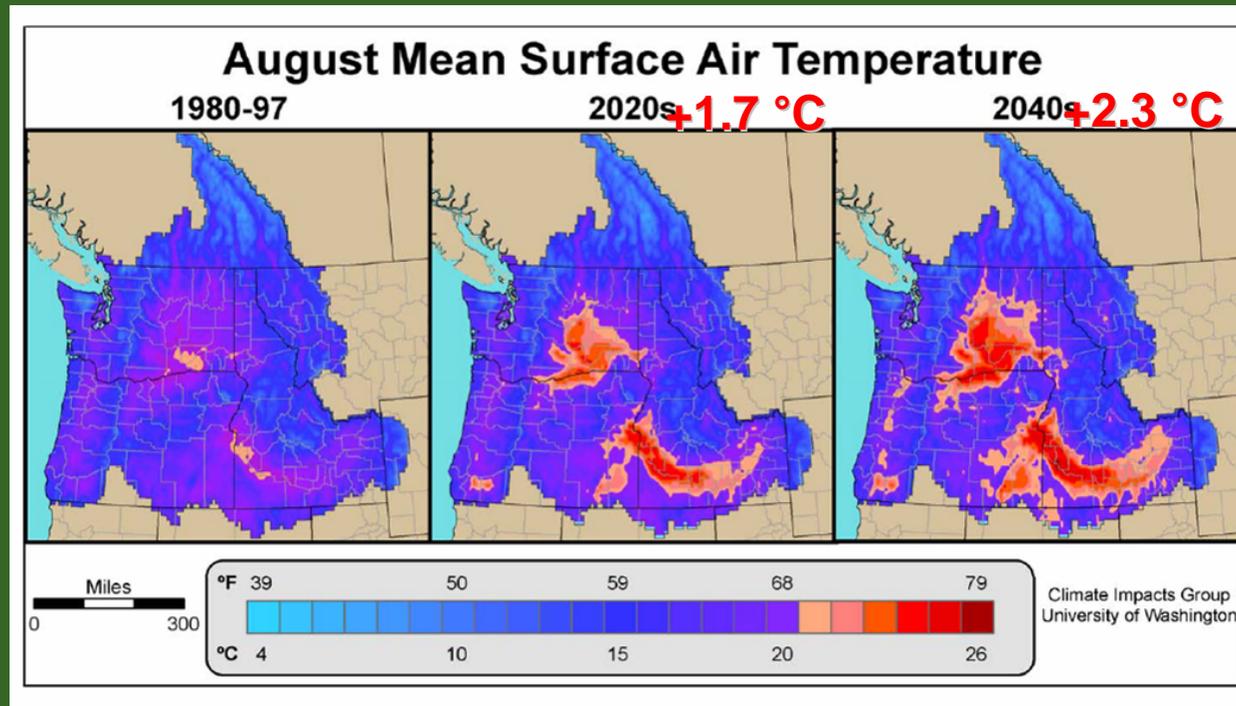
Bark Beetle Outbreak in British Columbia



(Figure courtesy Allen Carroll)

Temperature thresholds for coldwater fish in freshwater

- Warming temperatures will increasingly stress coldwater fish in the warmest parts of our region
 - A monthly average temperature of 68°F (20°C) has been used as an upper limit for resident cold water fish habitat, and is known to stress Pacific salmon during periods of freshwater migration, spawning, and rearing



Wide-Spread Glacial Retreat has Accompanied 20th Century Warming.

Loss of glacial mass may *increase* summer flow in the short term and *decrease* summer flow in the long term.



1902



2002

The recession of the Illecillewaet Glacier at Rogers Pass between 1902 and 2002. Photographs courtesy of the Whyte Museum of the Canadian Rockies & Dr. Henry Vaux.

Impact Pathways Associated with Climate

- **Changes in water quantity and timing**

 - Reductions in summer flow and water supply

 - Increases in drought frequency and severity

 - Changes in hydrologic extremes

 - Changing flood risk (up or down)

 - Summer low flows (glacial losses)

 - Changes in groundwater supplies

- **Changes in water quality**

 - Increasing water temperature (flow timing/loss of glaciers)

 - Changes in sediment loading (up or down)

 - Changes in nutrient loadings (up or down)

- **Changes in land cover via disturbance**

 - Forest fire

 - Insects

 - Disease

 - Invasive species

Impact Pathways Associated with Climate

- **Changes in the energy sector**

 - Hydropower

 - Energy demand

- **Changes in outdoor recreation**

 - Tourism

 - Skiing

 - Camping

 - Boating

- **Changes in environmental impacts and services**

 - Fish and wildlife management

 - Streamflow augmentation and temperature control

 - Hatchery design and management

 - Habitat restoration programs

 - Endangered species recovery programs

 - Invasive species (e.g. warm water fish)

Impact Pathways Associated with Climate

- **Changes in transportation corridors**

 - Changing risk of flooding, avalanche or debris flows

- **Sea level rise**

 - Coastal engineering

 - Land use planning

- **Changes in engineering design standards**

 - Road construction and maintenance

 - Storm water systems

 - Flood plain definitions

 - Building design

 - Land slide risks

Approaches to Adaptation and Planning

- **Anticipate changes.** Accept that the future climate will be substantially different than the past.
- **Use scenario based planning** to evaluate options rather than the historic record.
- **Expect surprises** and plan for flexibility and robustness in the face of uncertain changes rather than counting on one approach.
- **Plan for the long haul.** Where possible, make adaptive responses and agreements “self tending” to avoid repetitive costs of intervention as impacts increase over time.