Hydrologic Implications of Climate Change for the Western U.S.

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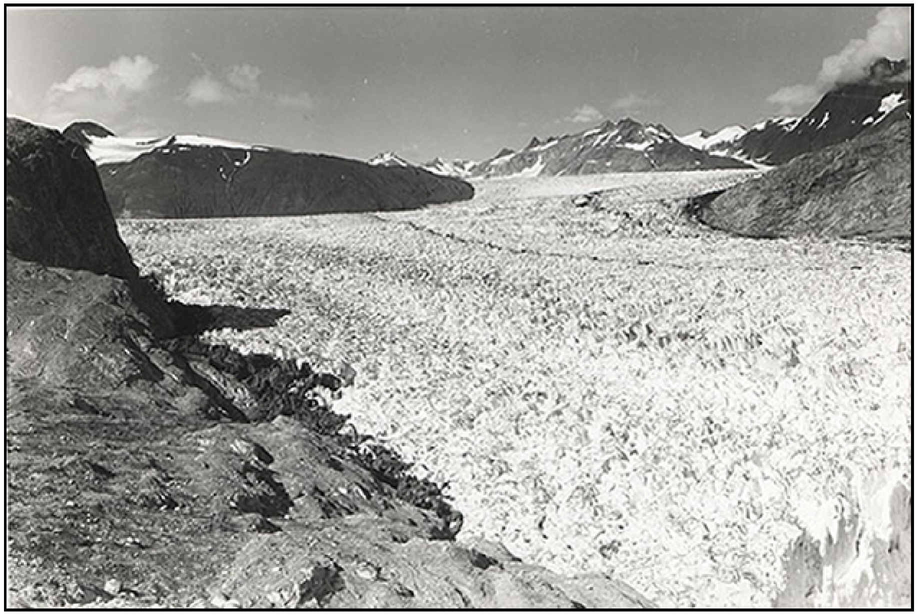
Department of Civil and Environmental Engineering

Recession of the Muir Glacier

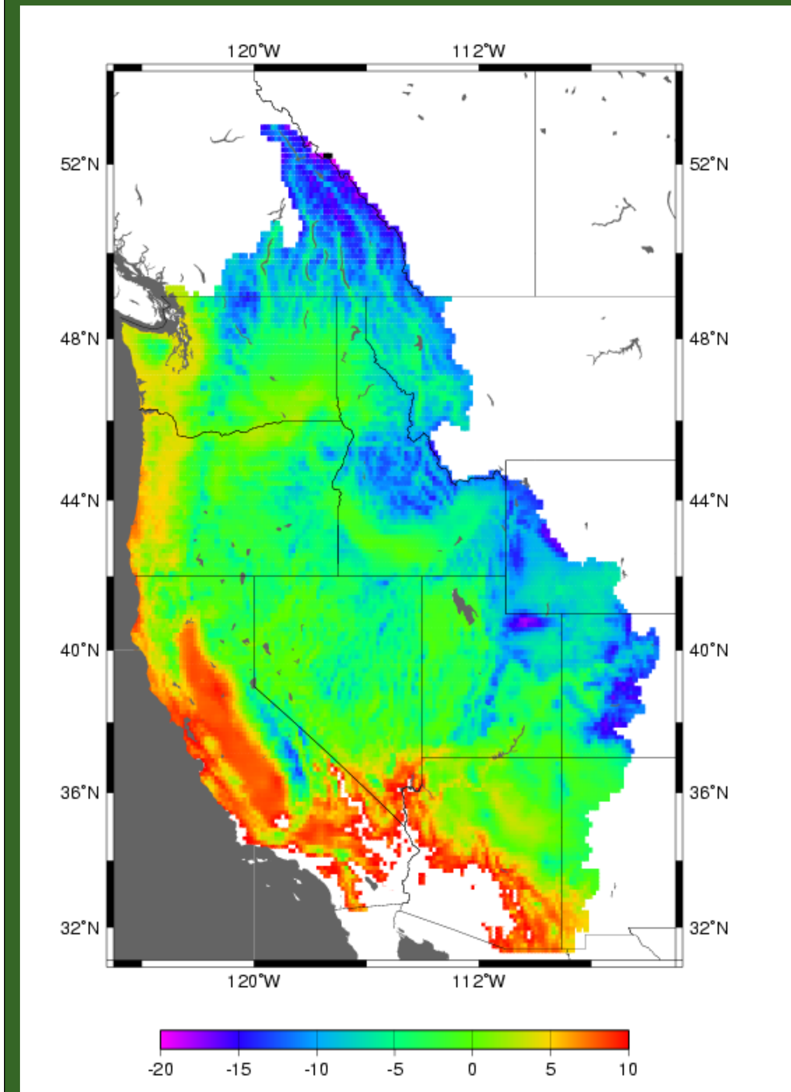


Aug, 13, 1941

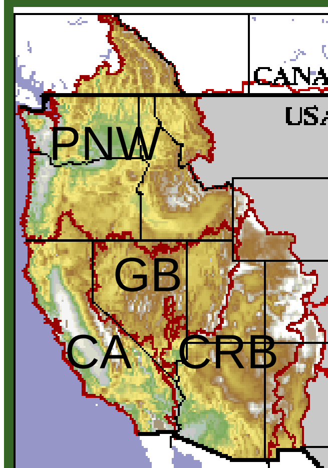
Aug, 31, 2004

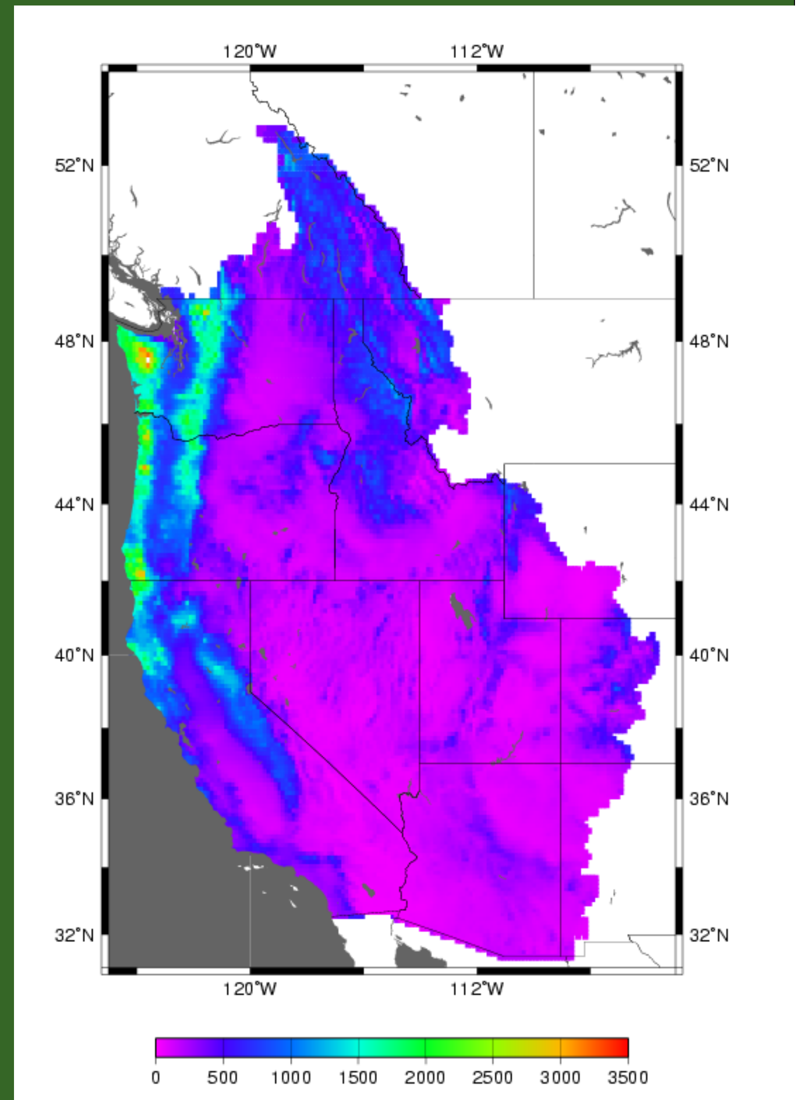
Image Credit: *National Snow and Ice Data Center, W. O. Field, B. F. Molnia*
http://nsidc.org/data/glacier_photo/special_high_res.html

Cool Season Climate of the Western U.S.



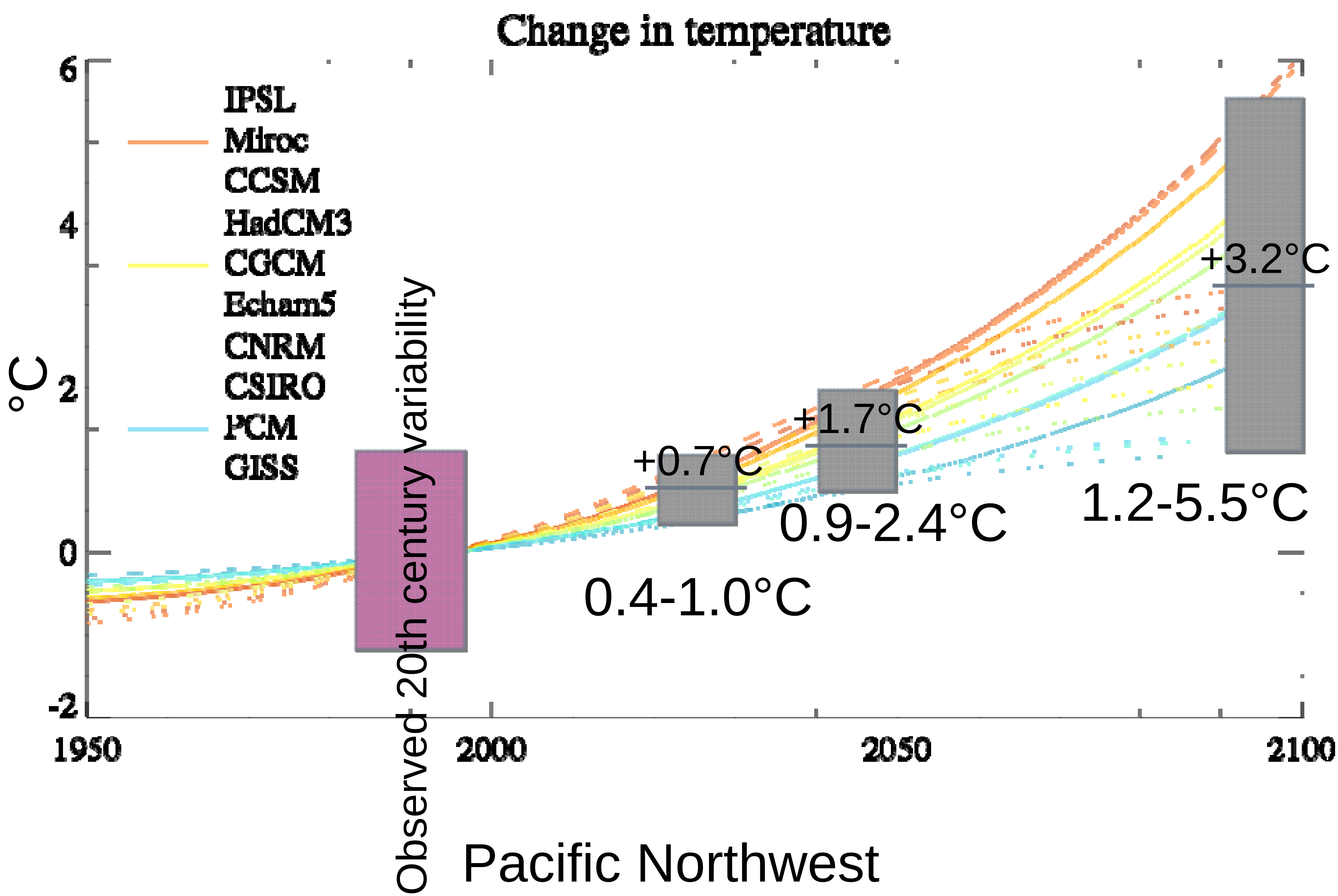
DJF Temp (°C)

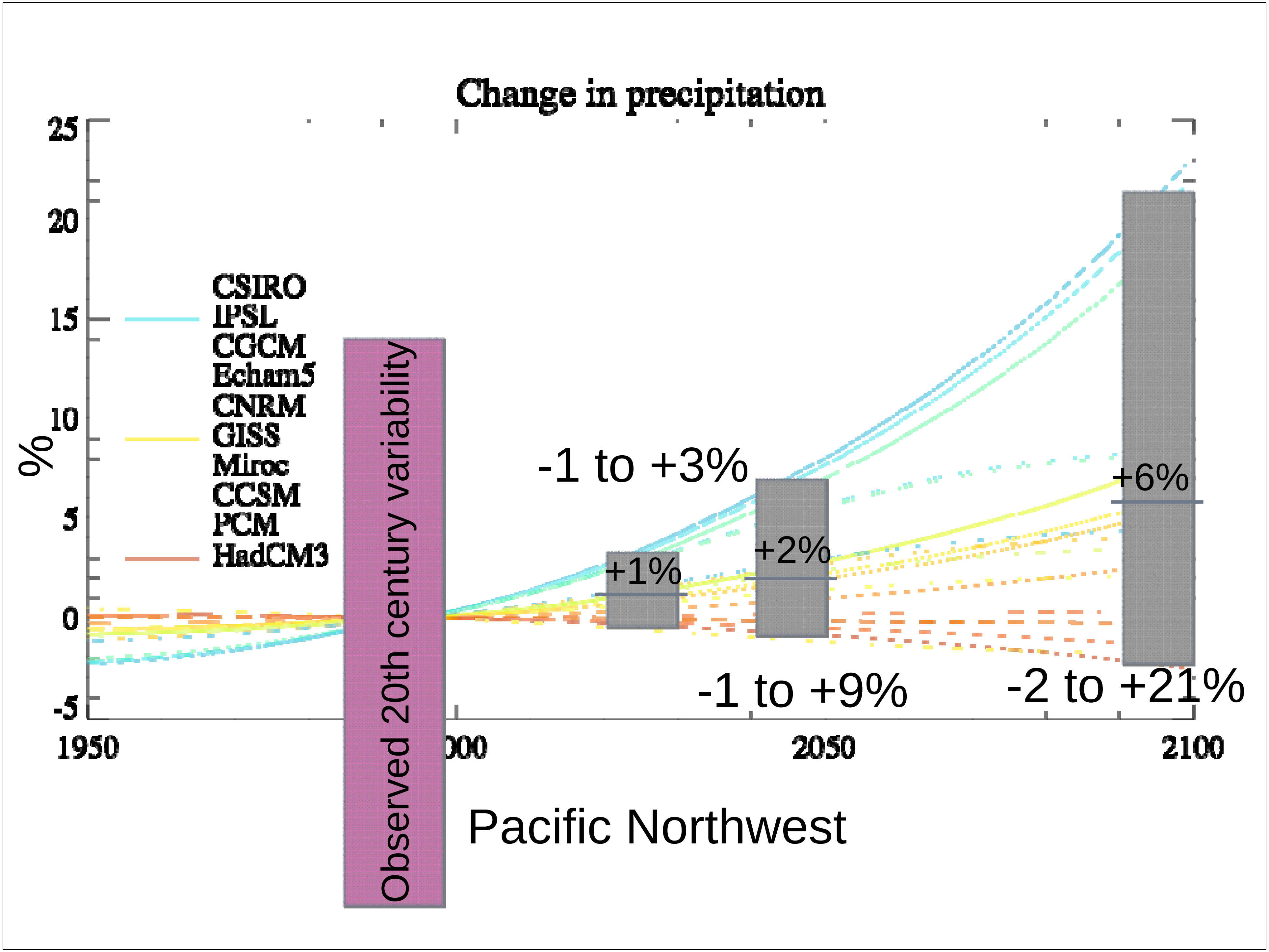




NDJFM Precip (mm)

Global Climate Change Scenarios and Hydrologic Impacts for the PNW

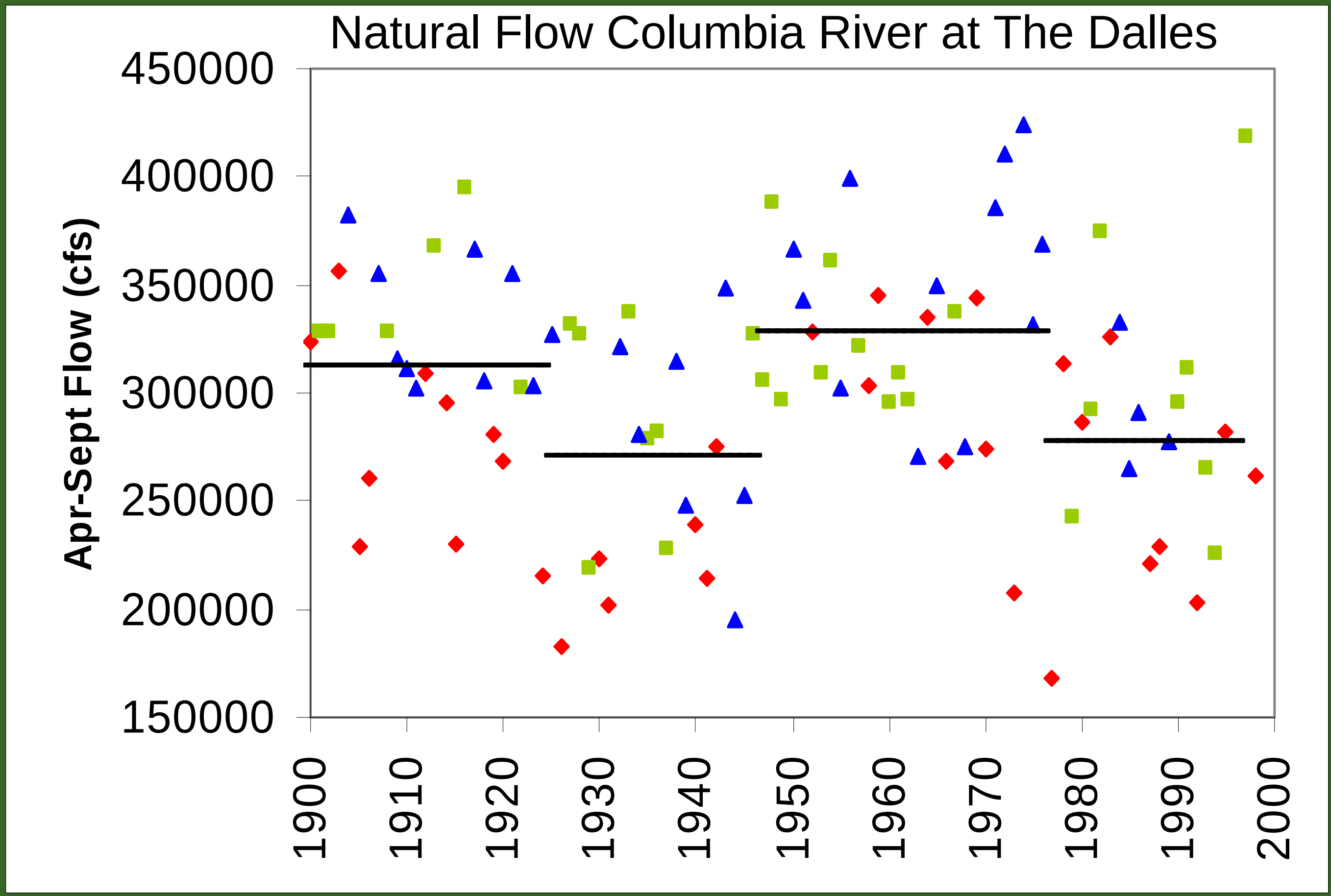

Change in temperature
°C
6
4
2
0
-2
1950
2000
2050
2100
IPSL
Miroc
CCSM
HadCM3
CGCM
Echam5
CNRM
CSIRO
PCM
GISS
Observed 20th century variability
+0.7°C
0.4-1.0°C
+1.7°C
0.9-2.4°C
+3.2°C
1.2-5.5°C
Pacific Northwest



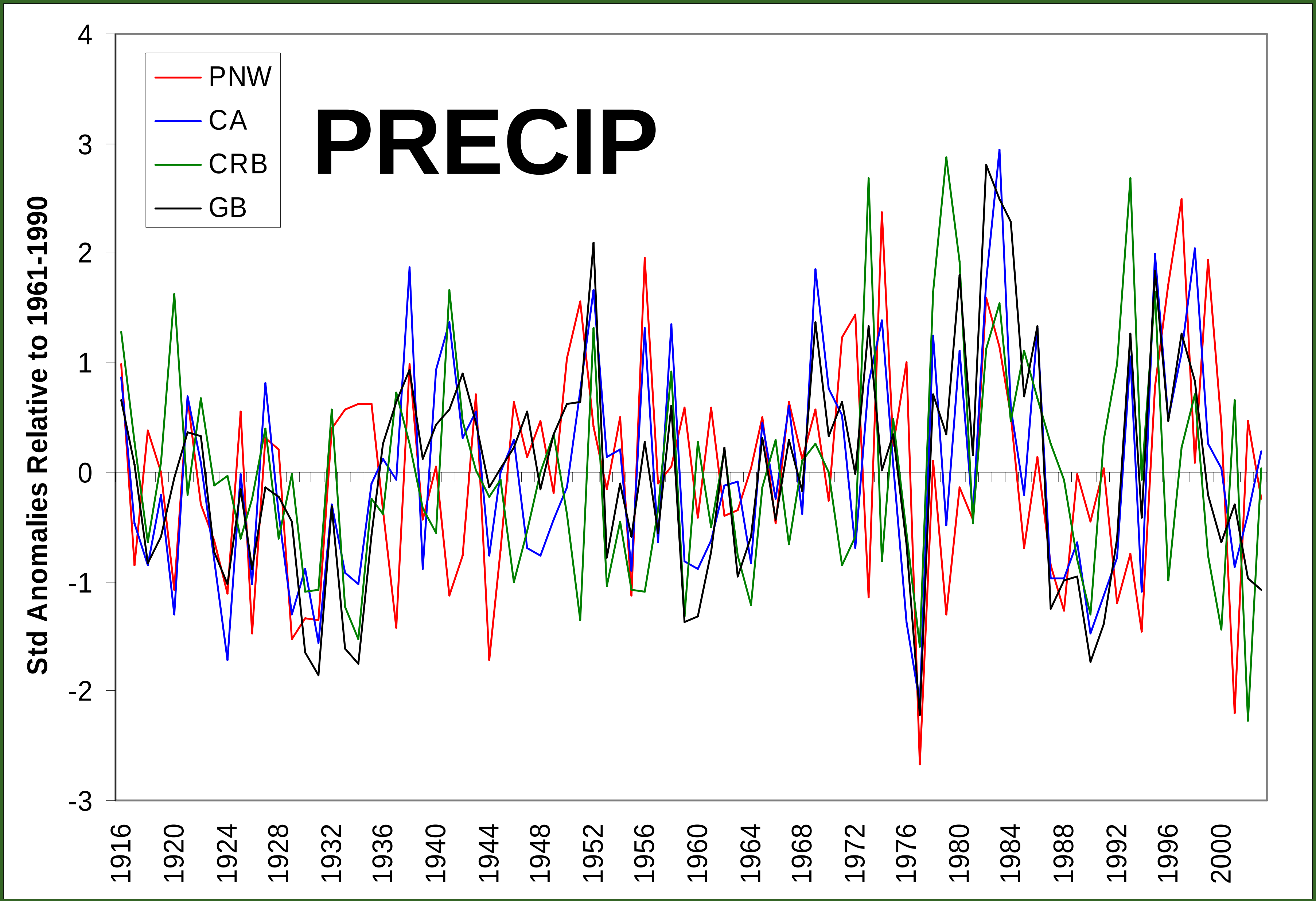
Change in precipitation
25
20
15
10
5
0
-5
%
CSIRO
IPSL
CGCM
Echam5
CNRM
GISS
Miroc
CCSM
PCM
HadCM3
Observed 20th century variability
-1 to +3%
+1%
+2%
-1 to +9%
+6%
-2 to +21%
1950
2050
2100
Pacific Northwest

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

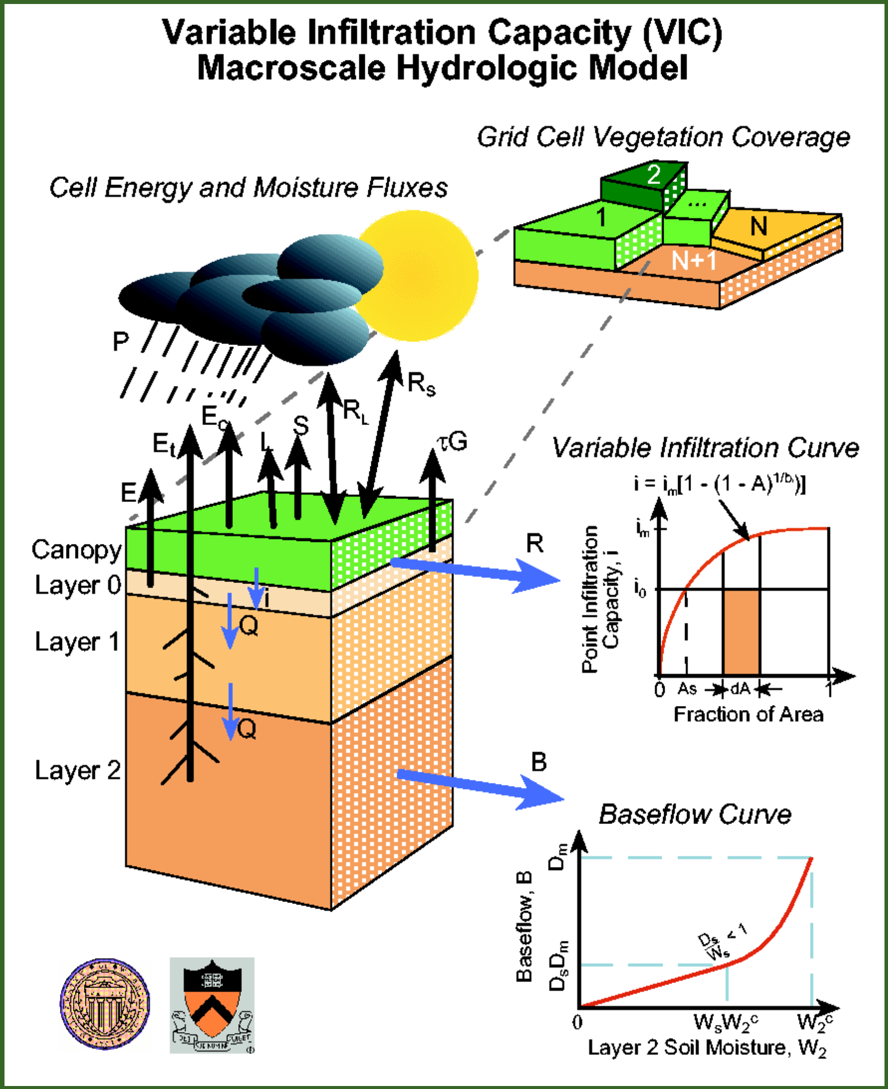
Answer: Probably BOTH!

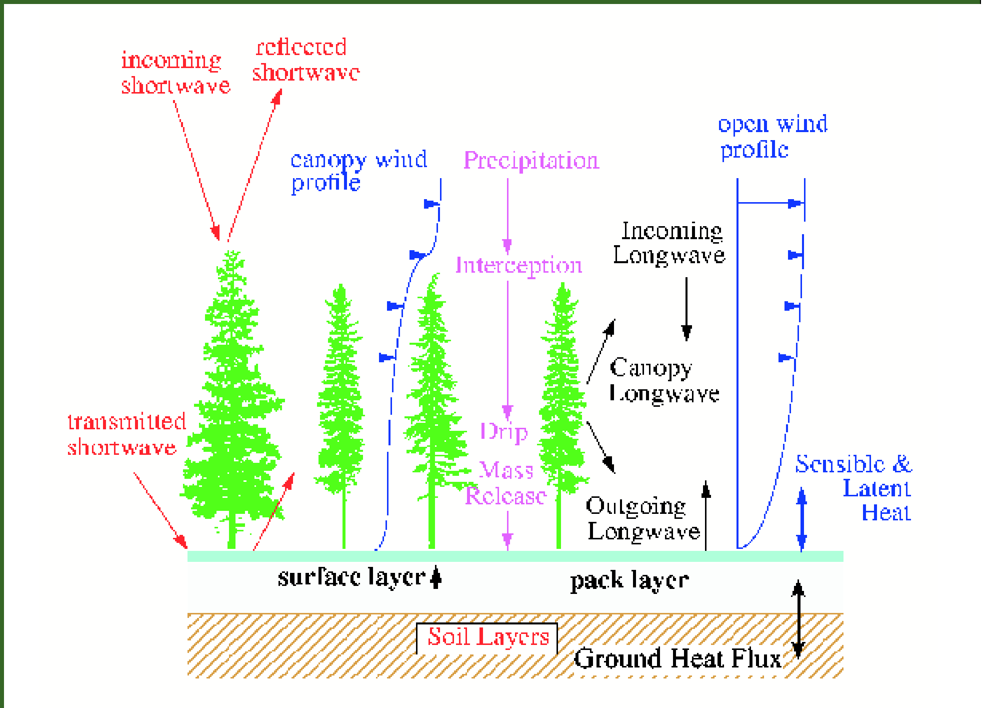


Regionally Averaged Cool Season Precipitation Anomalies



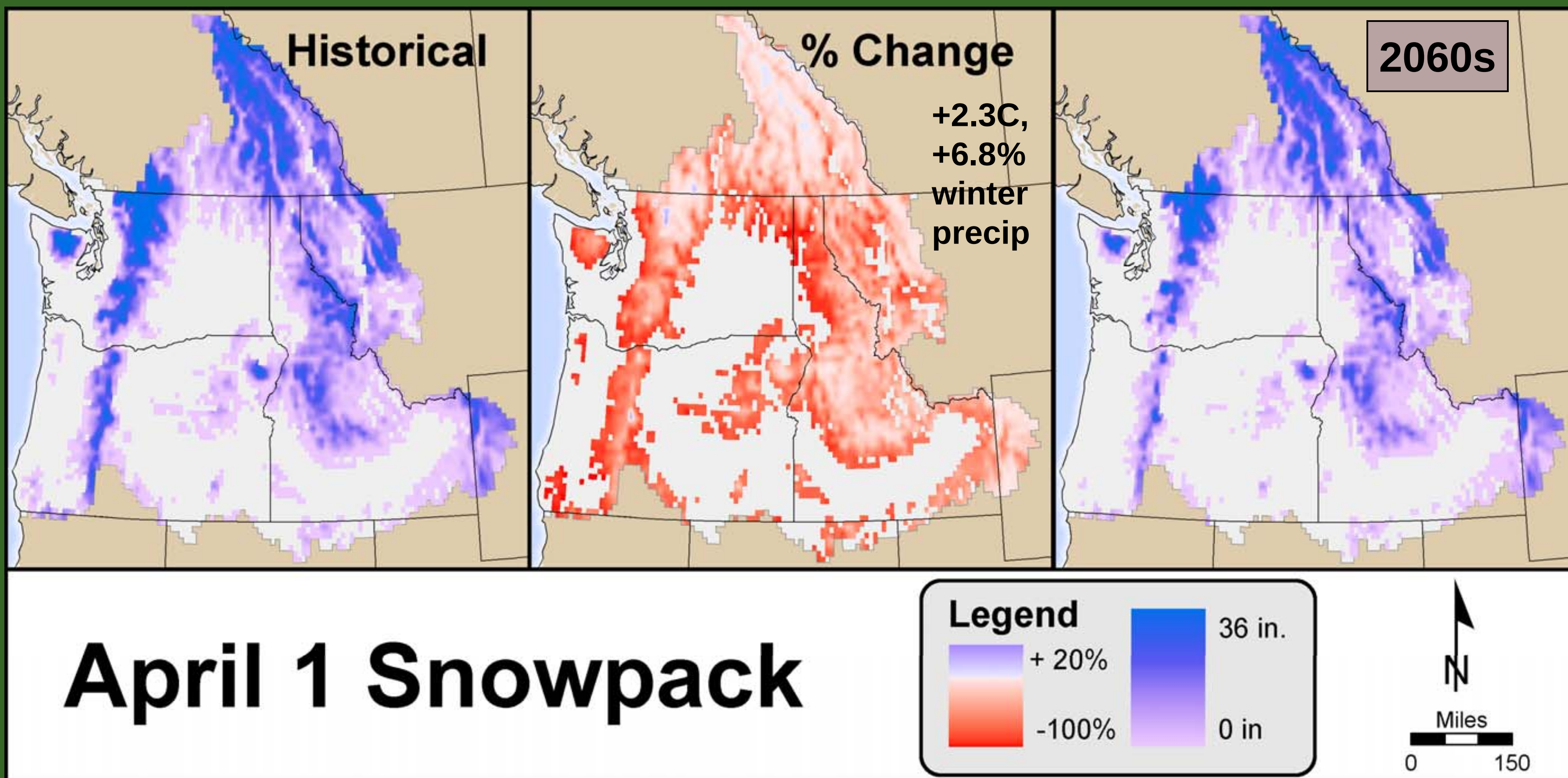
Schematic of VIC Hydrologic Model and Energy Balance Snow Model





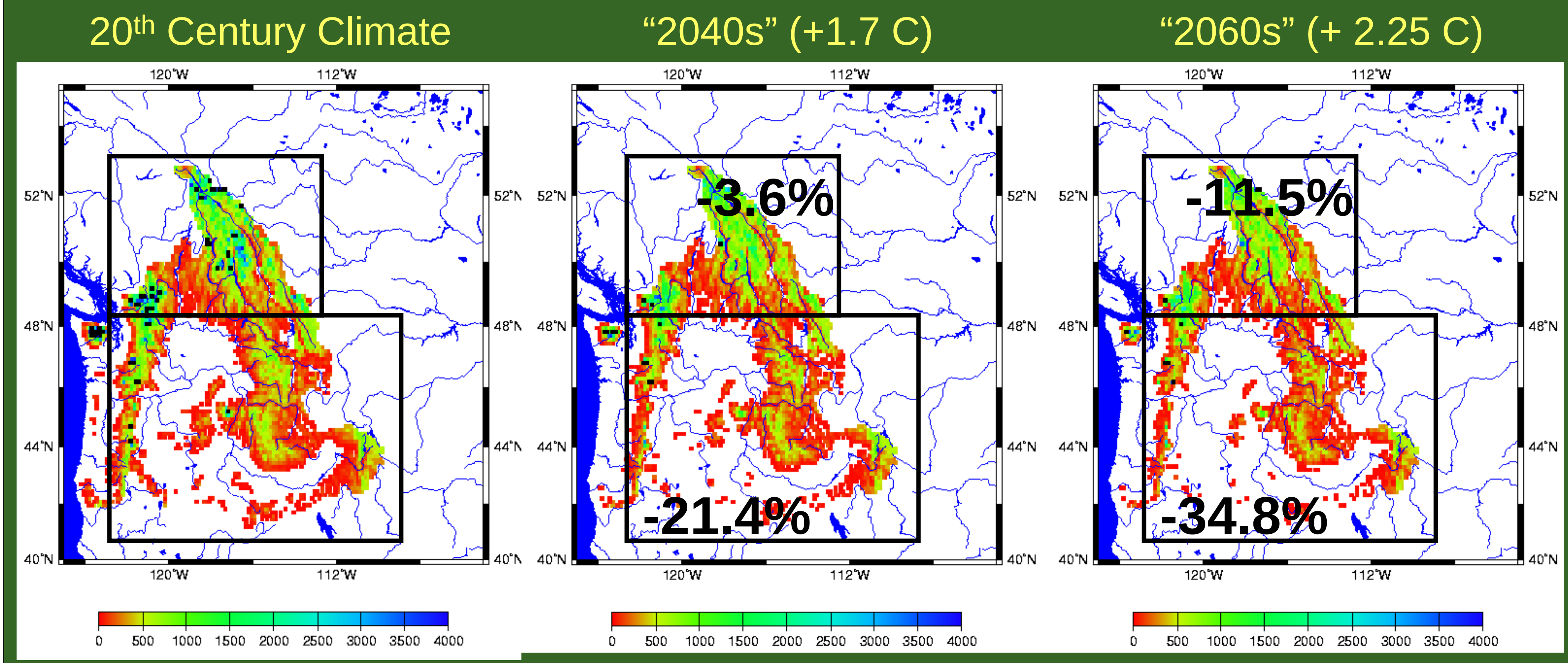
Snow Model

The warmer locations are most sensitive to warming



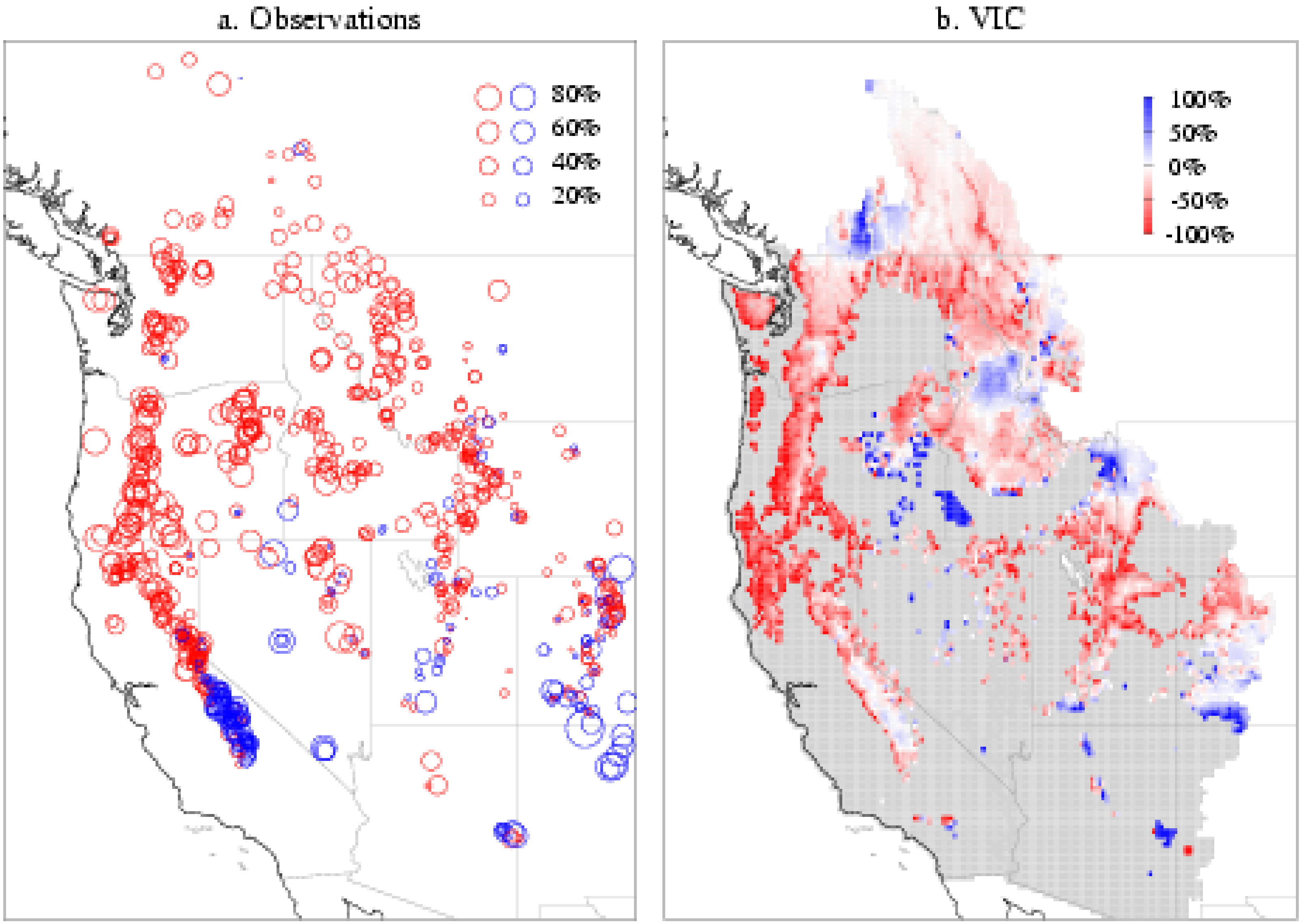
Changes in Simulated April 1 Snowpack for the Canadian and U.S. portions of the Columbia River basin

(% change relative to current climate)



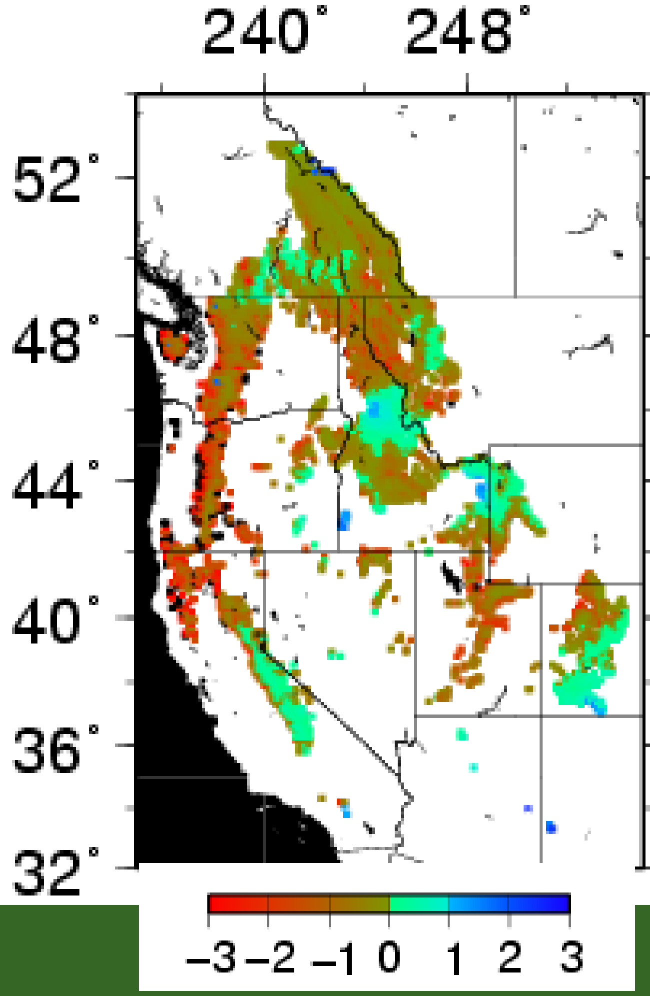
April 1 SWE (mm)

Trends in April 1 SWE 1950-1997

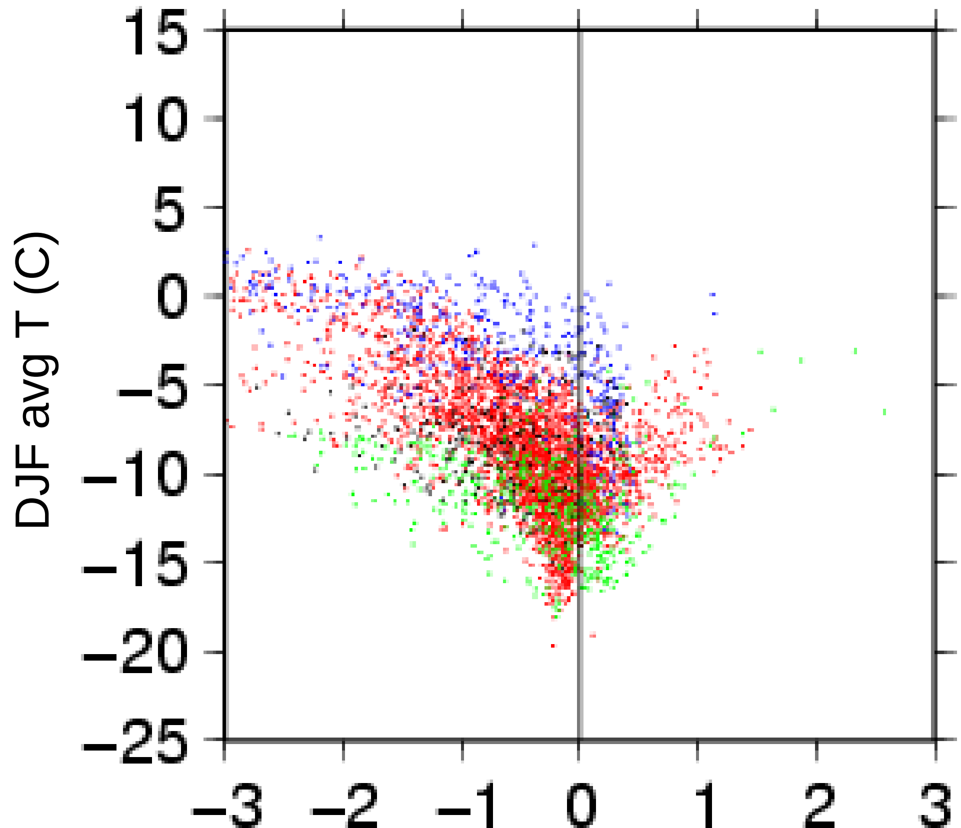


Mote P.W.,Hamlet A.F., Clark M.P., Lettenmaier D.P., 2005, Declining mountain snowpack in western North America, BAMS, 86 (1): 39-49

Overall Trends in April 1 SWE from 1947-2003

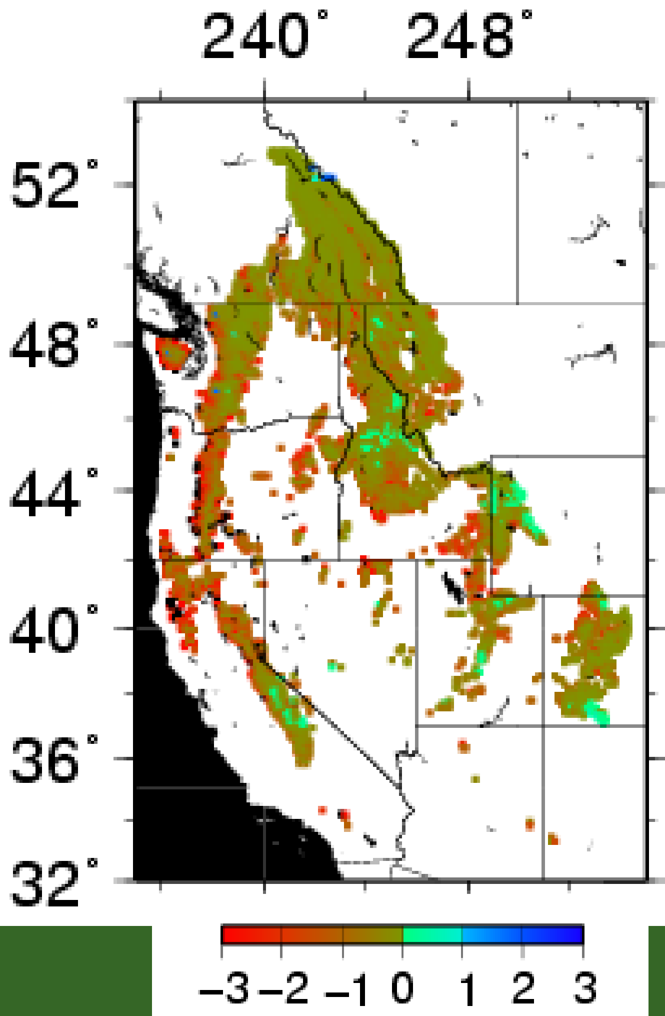


Trend %/yr

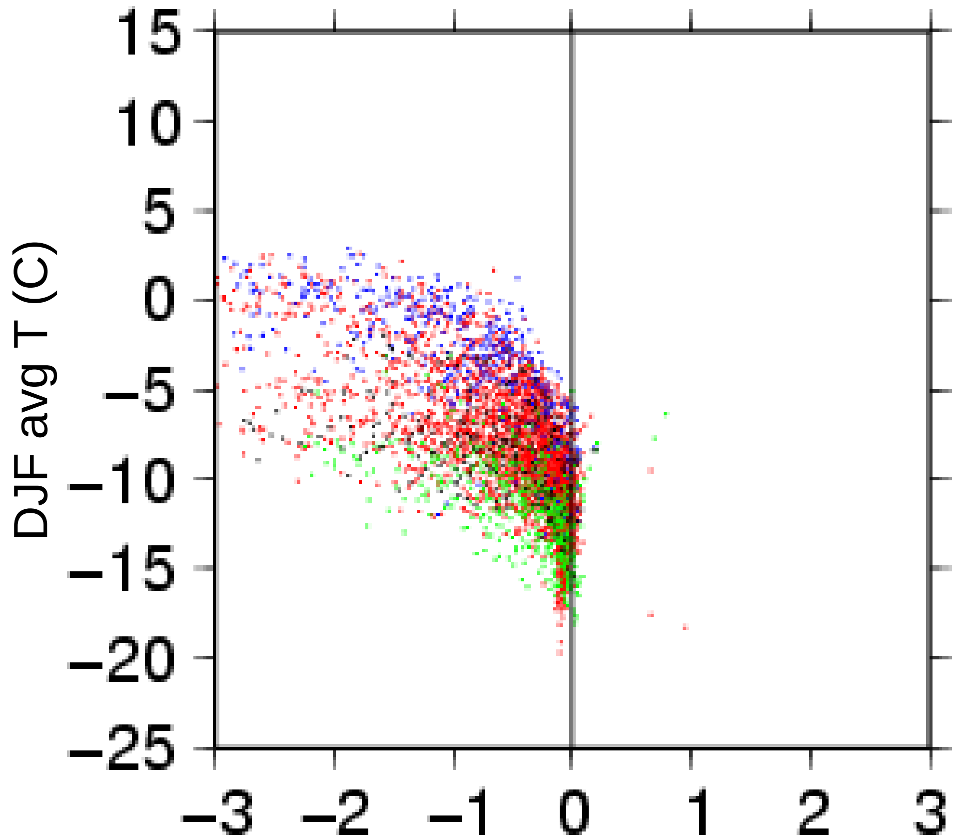


Trend %/yr

Temperature Related Trends in April 1 SWE from 1947-2003

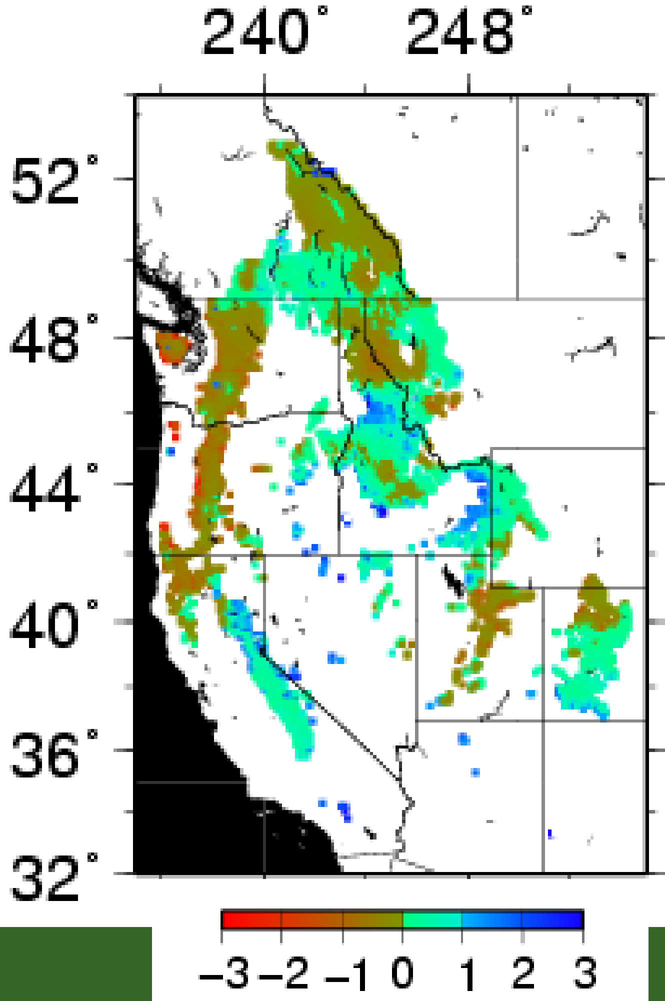


Trend %/yr

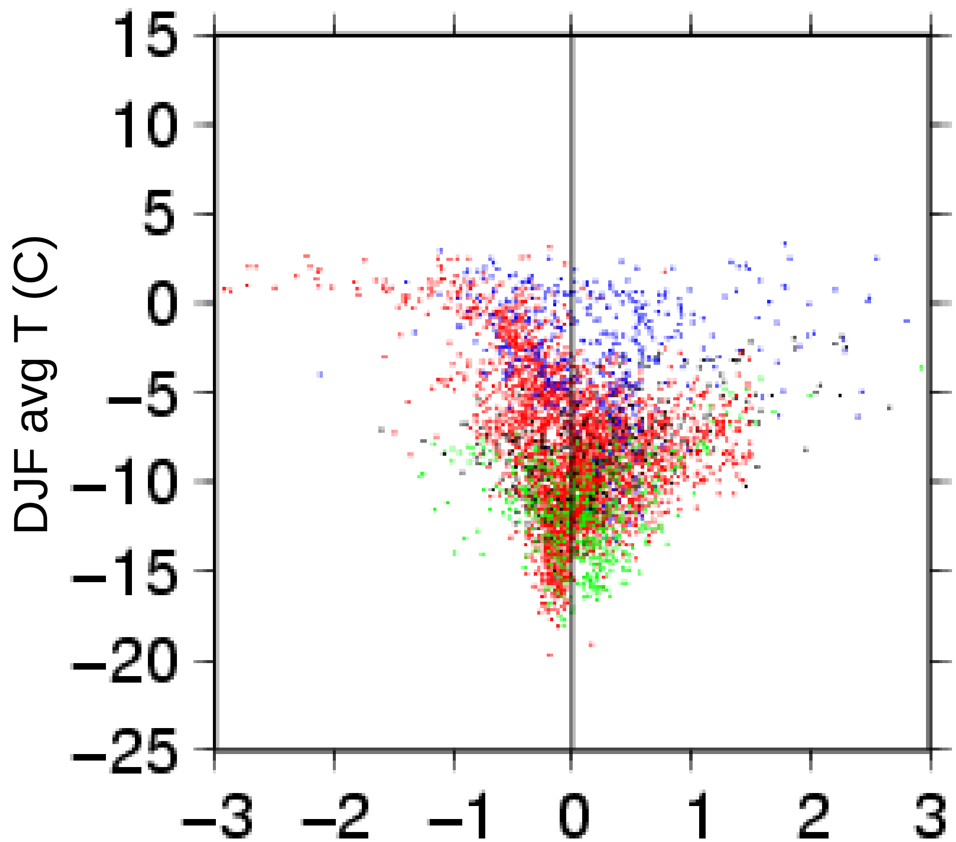


Trend %/yr

Precipitation Related Trends in April 1 SWE from 1947-2003

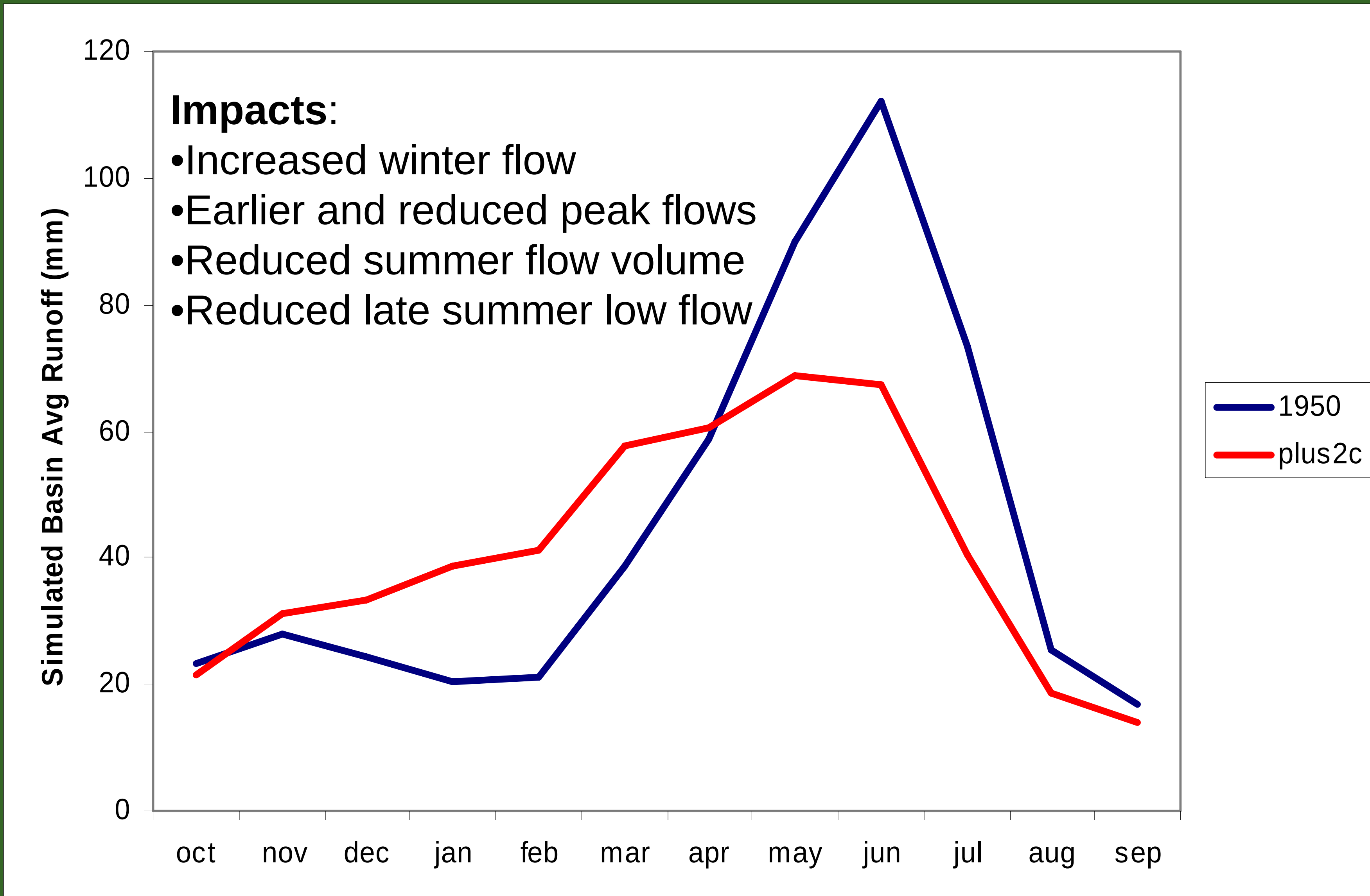


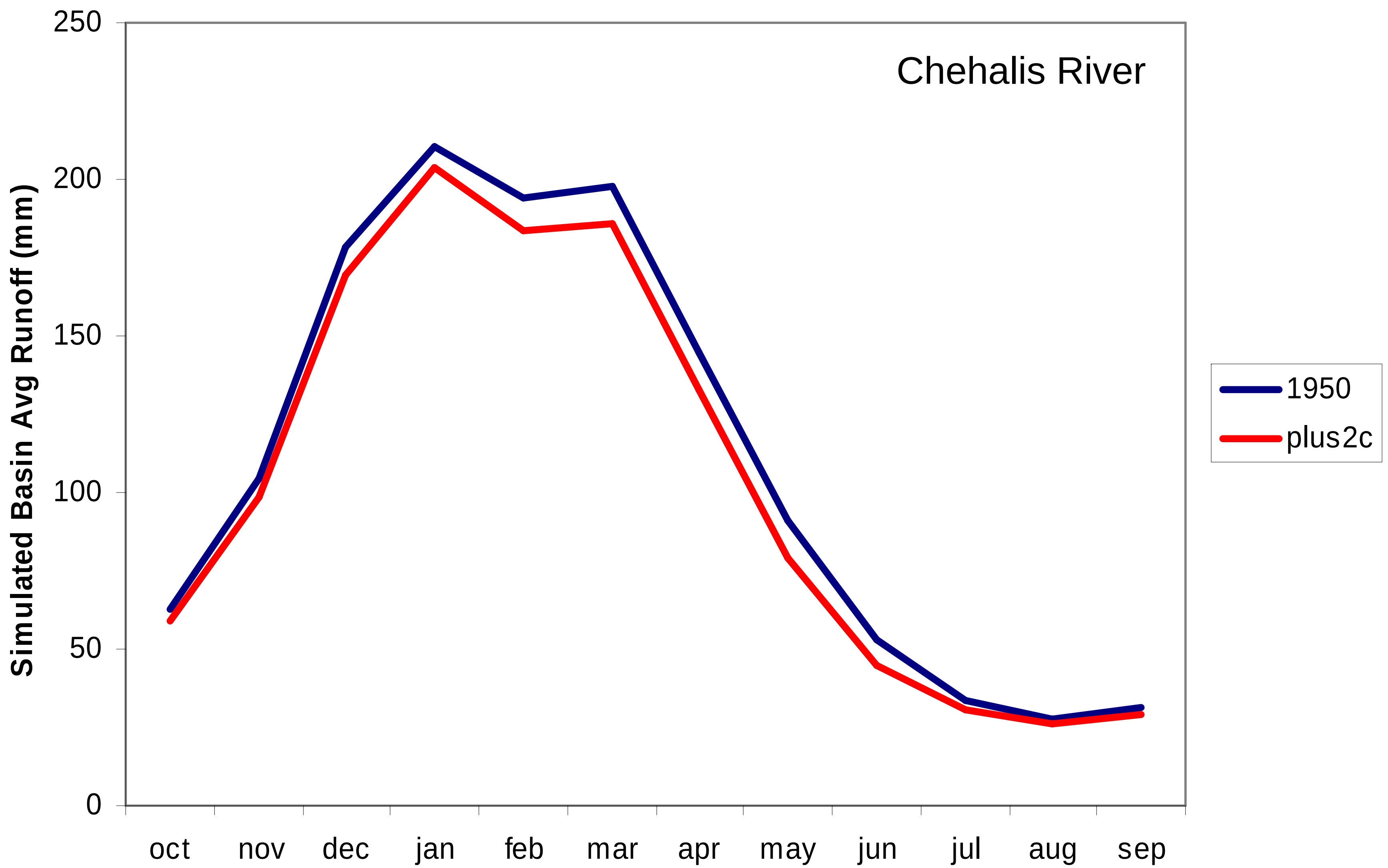
Trend %/yr



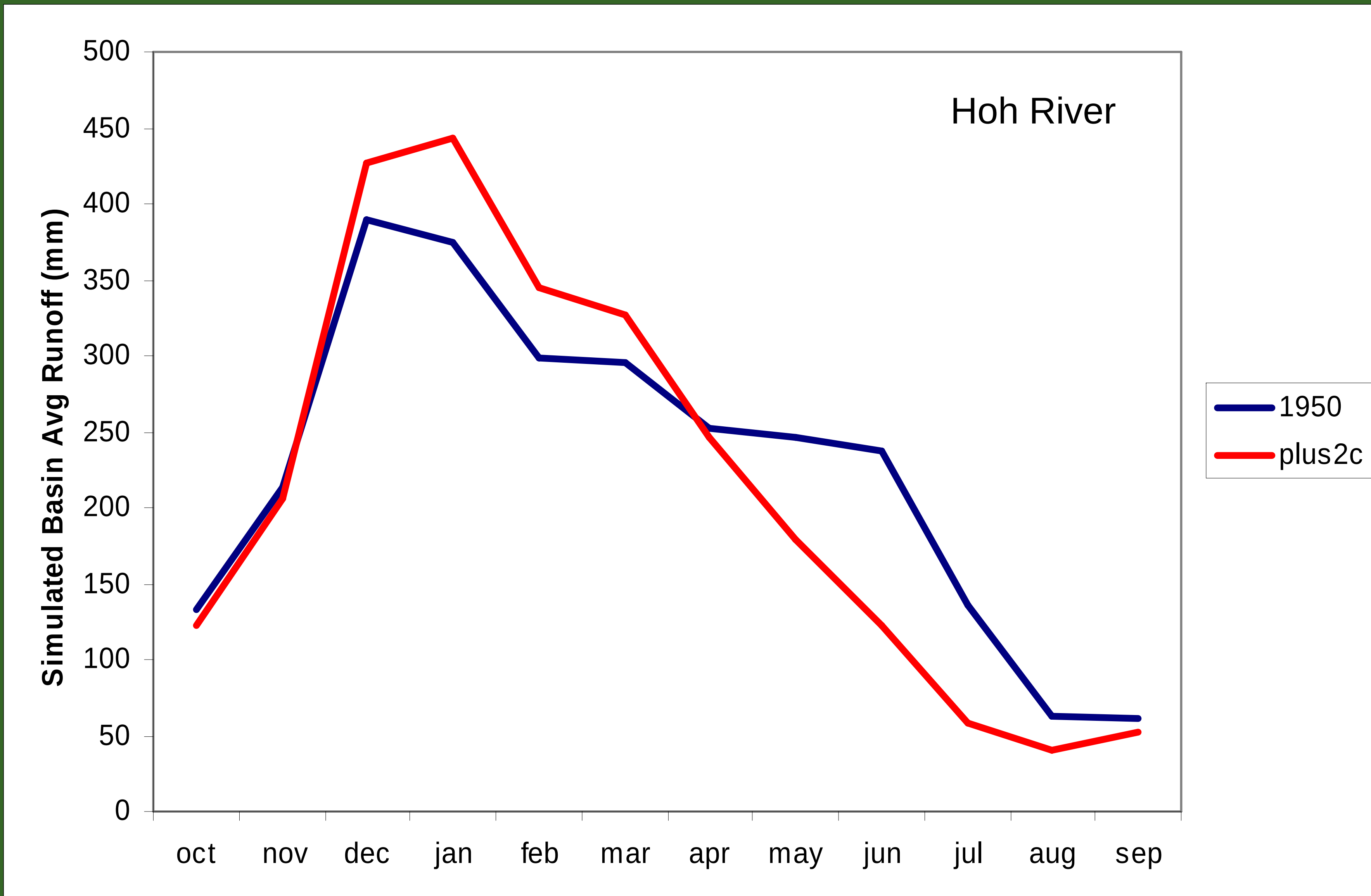
Trend %/yr

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

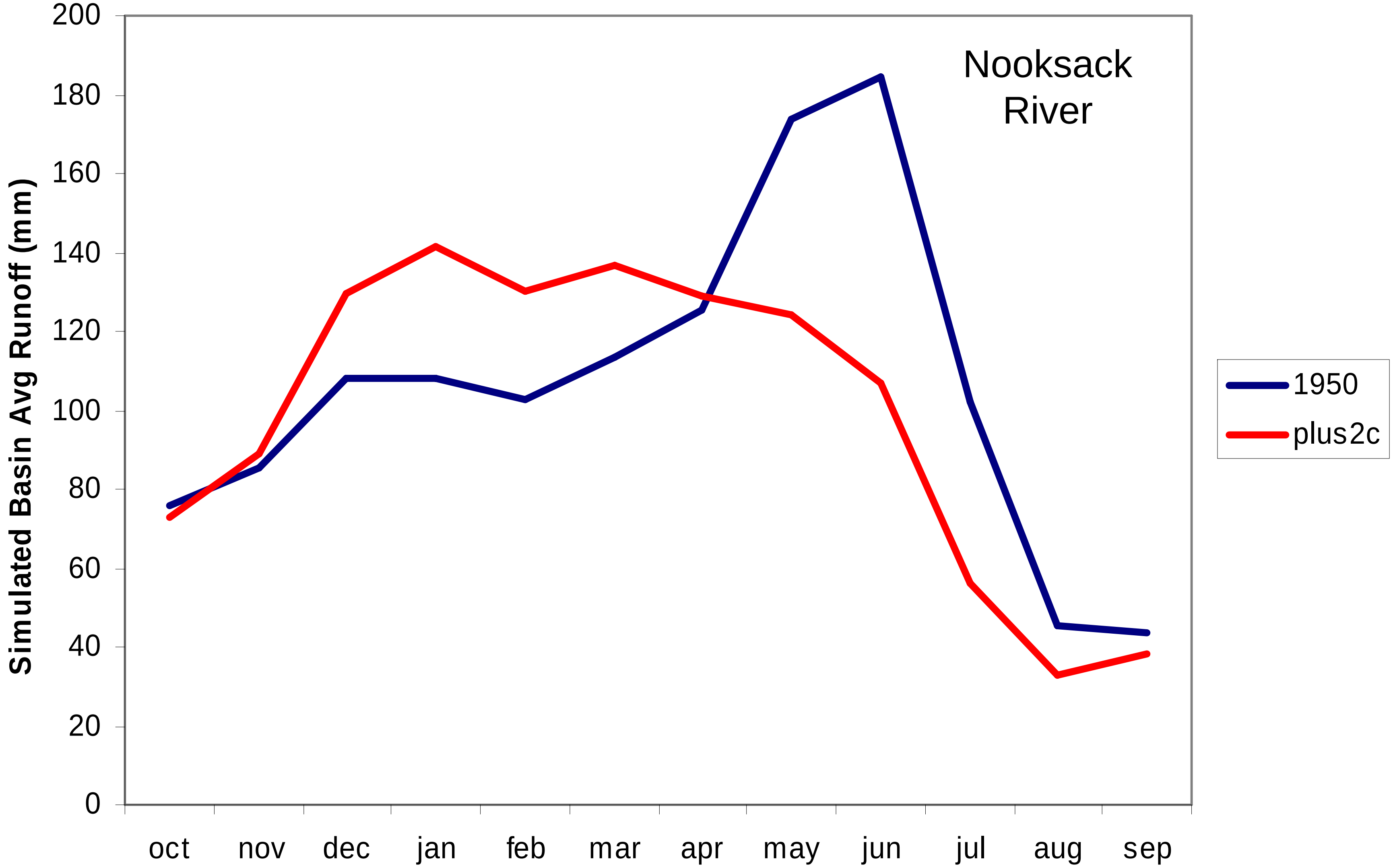




Chehalis River
Simulated Basin Avg Runoff (mm)
250
200
150
100
50
0
oct
nov
dec
jan
feb
mar
apr
may
jun
jul
aug
sep
1950
plus2c

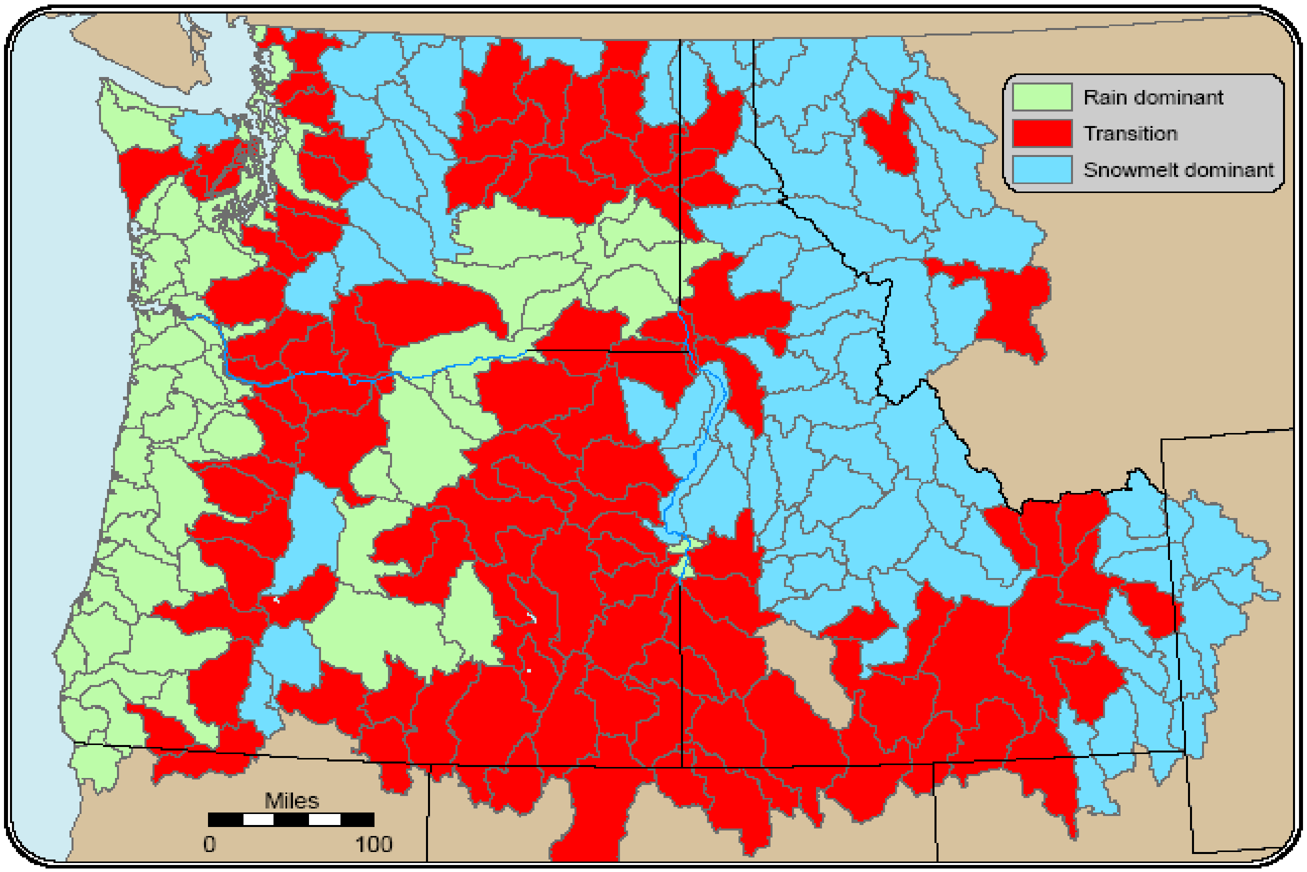


Hoh River
Simulated Basin Avg Runoff (mm)
500
450
400
350
300
250
200
150
100
50
0
oct
nov
dec
jan
feb
mar
apr
may
jun
jul
aug
sep
1950
plus2c

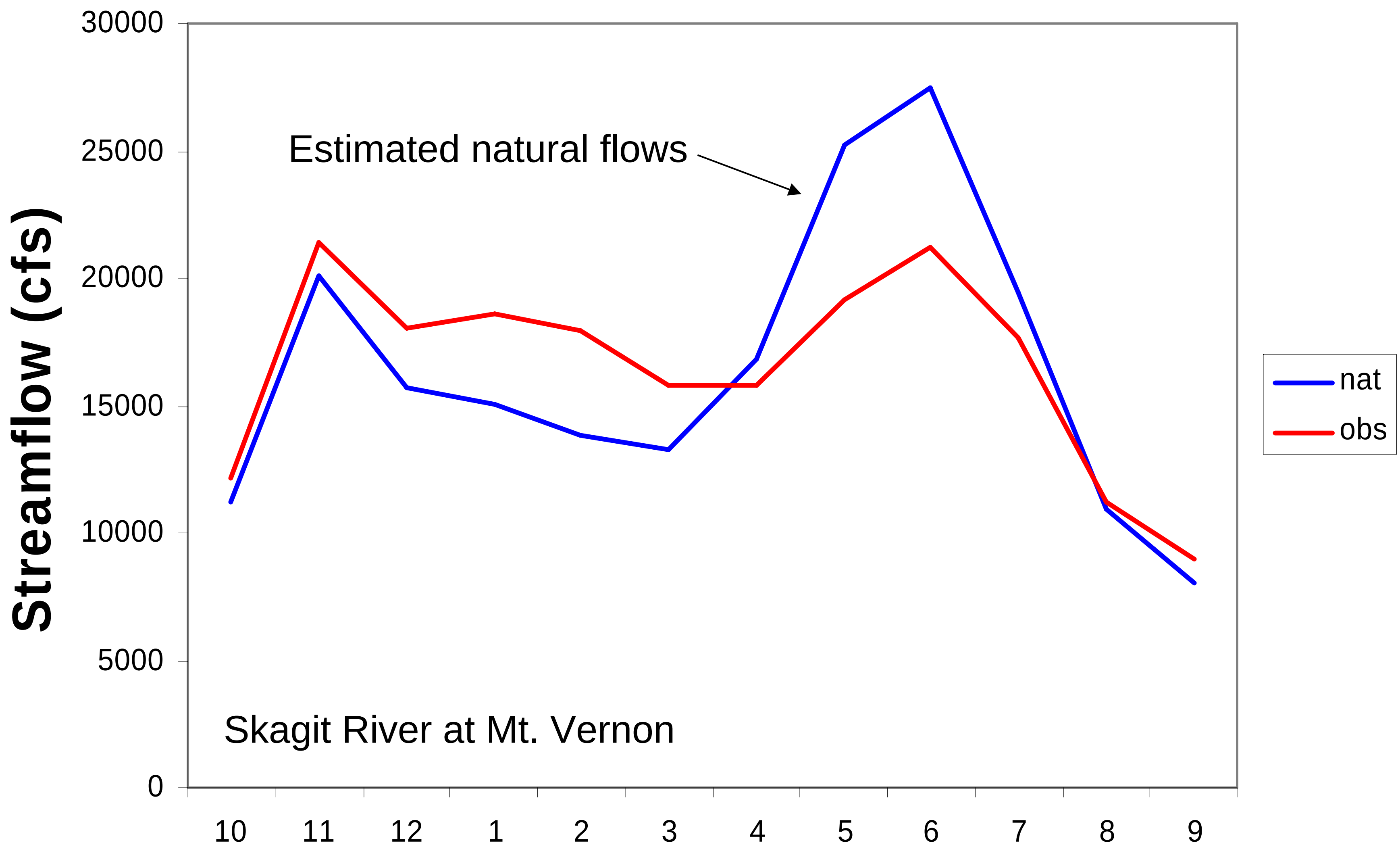

Nooksack River
Simulated Basin Avg Runoff (mm)
200
180
160
140
120
100
80
60
40
20
0
oct
nov
dec
jan
feb
mar
apr
may
jun
jul
aug
sep
1950
plus2c

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

HUC 4 Scale Watersheds in the PNW

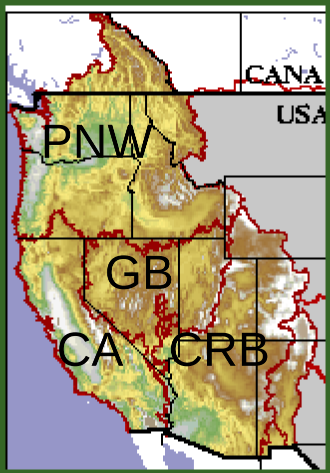


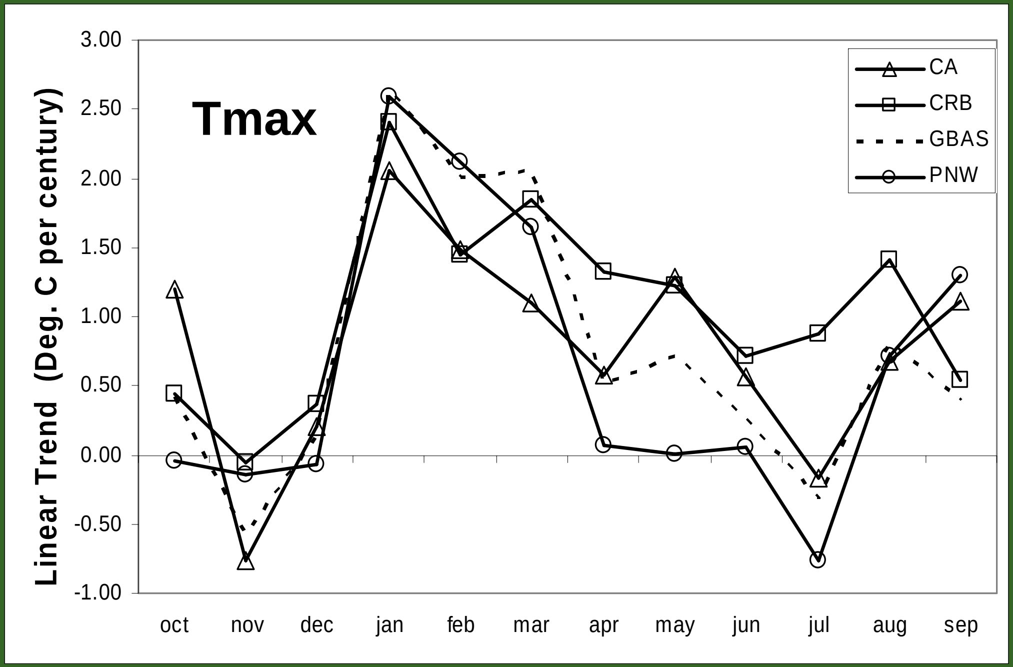
Climate Change Impacts are Similar to Impacts of Water Management in PNW Hydropower Systems

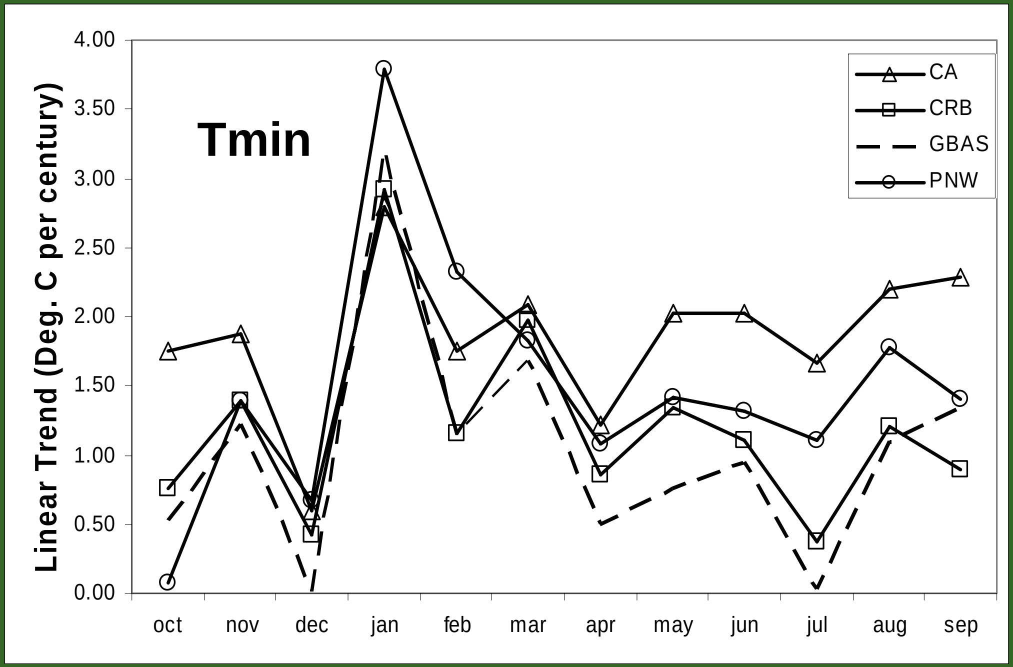


Changes in Flood Risk in the Western U.S.

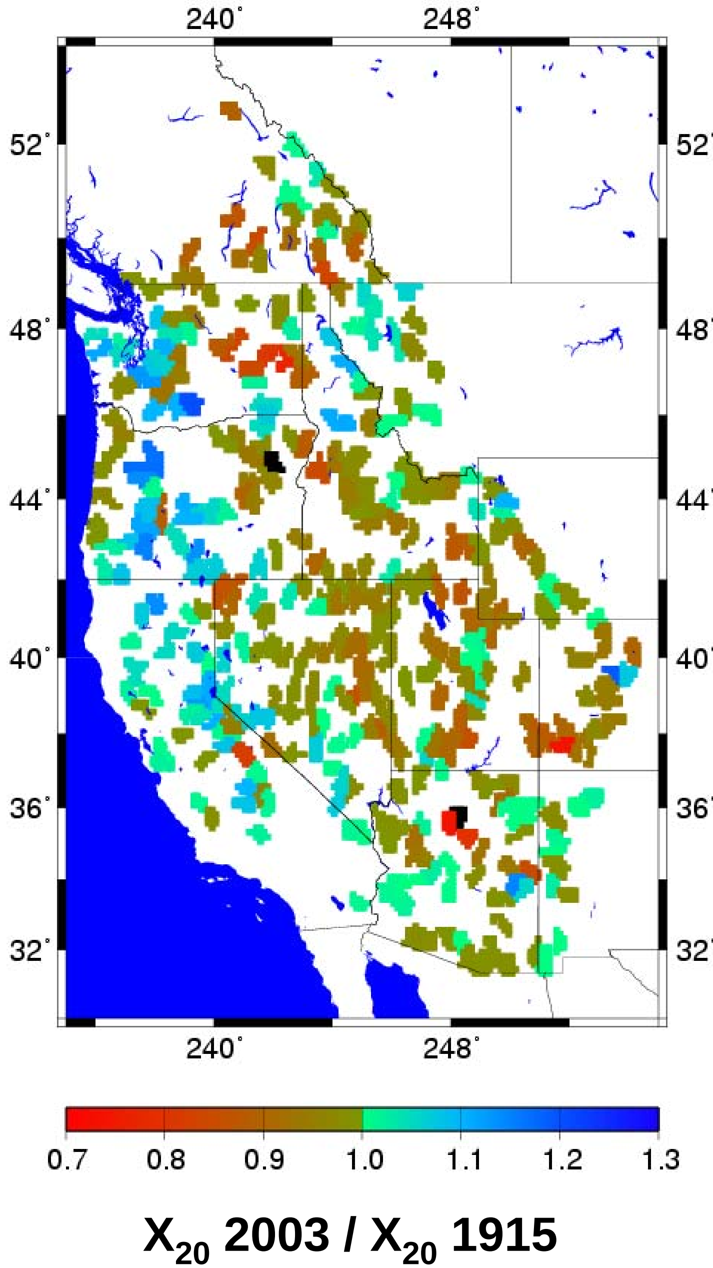
Regionally Averaged Temperature Trends Over the Western U.S. 1916-2003

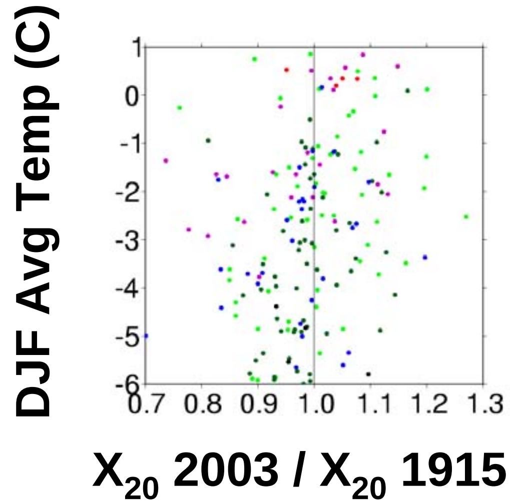


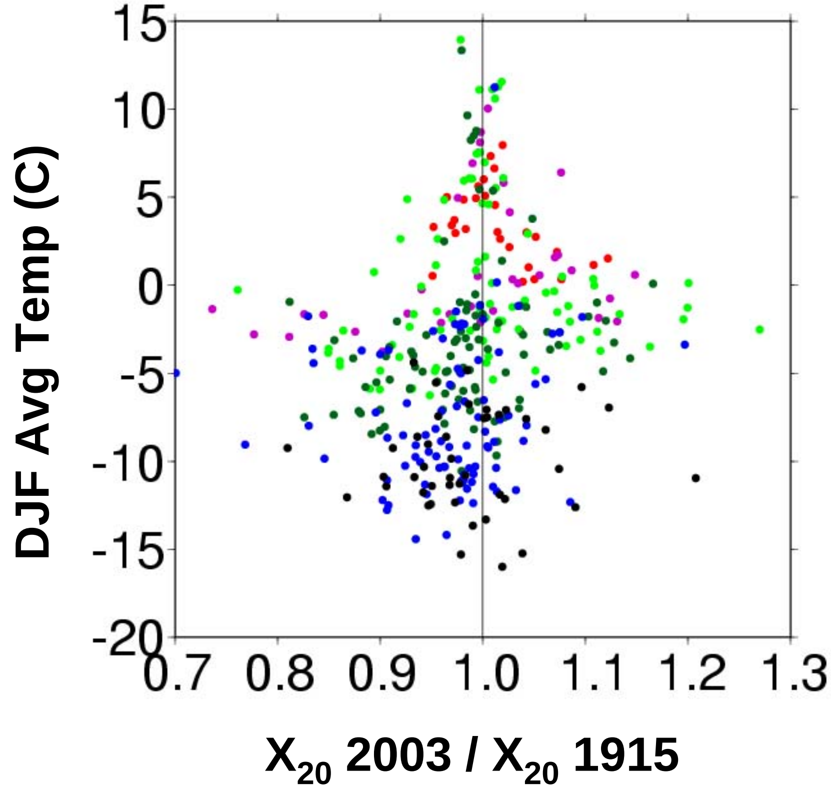




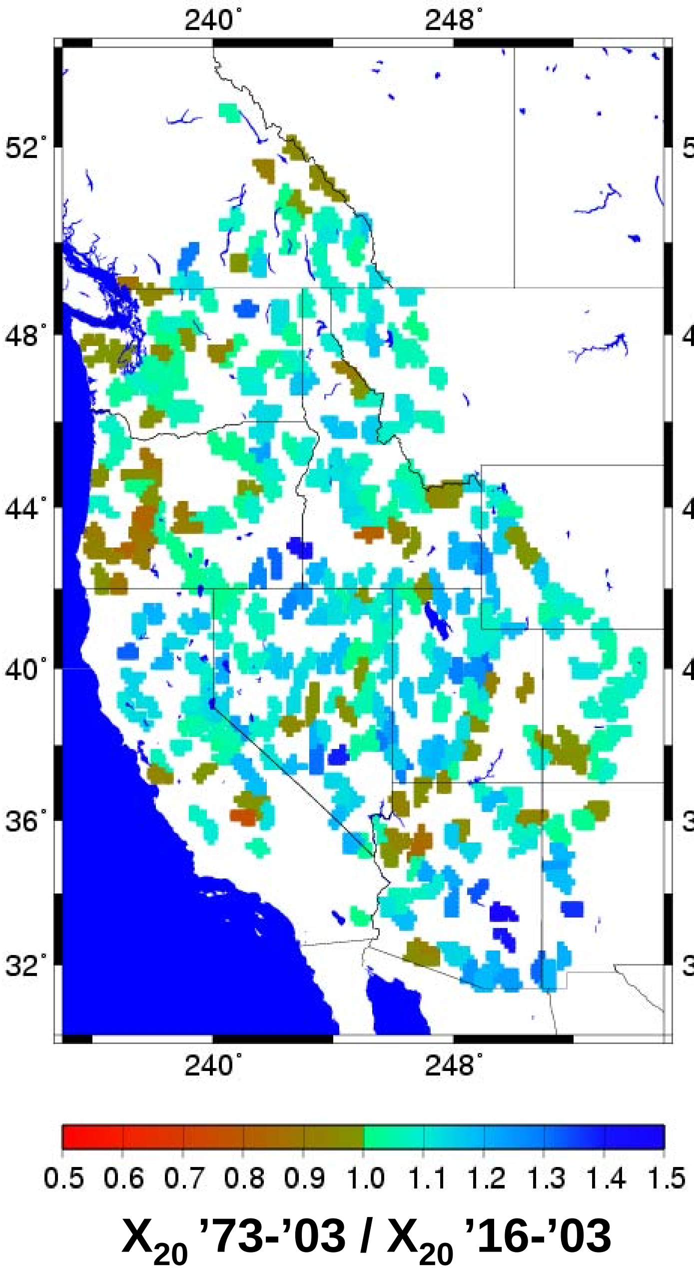
Simulated Changes in the 20-year Flood Associated with 20th Century Warming

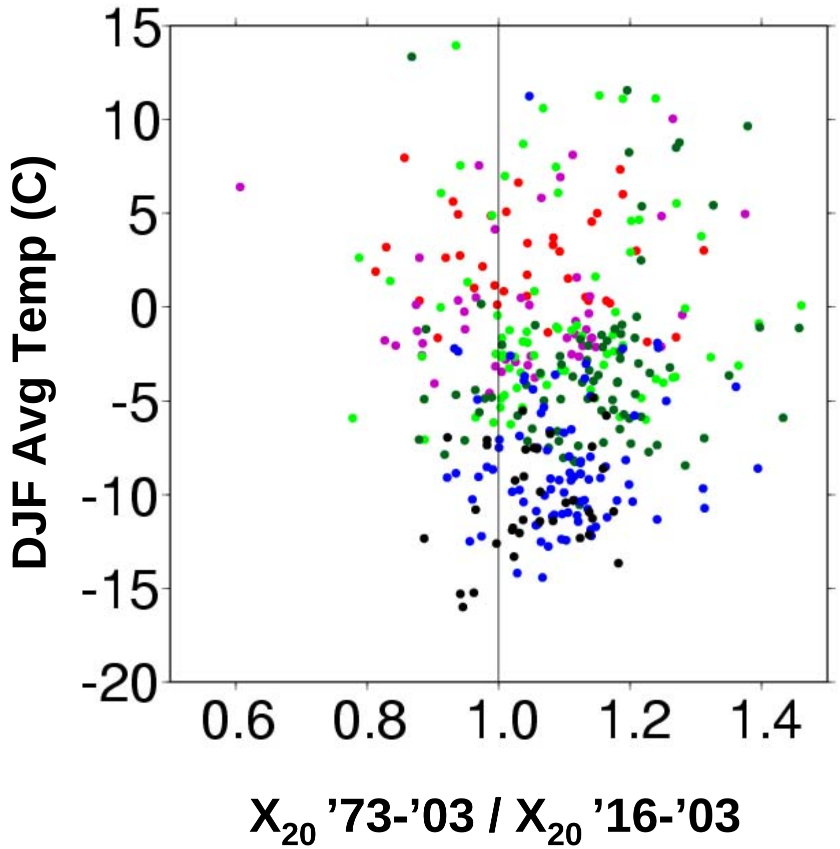






20-year Flood for "1973-2003" Compared to "1916-2003" for a Constant Late 20th Century Temperature Regime





Summary of Flooding Impacts

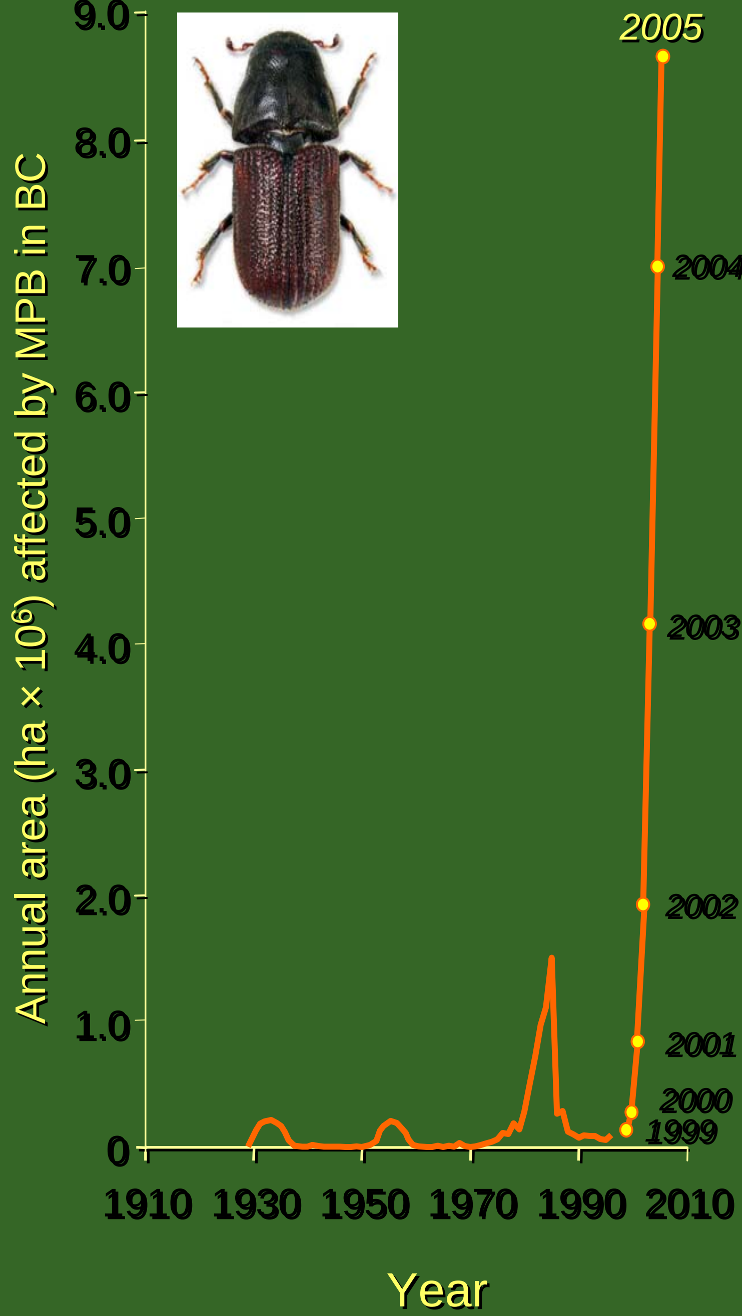
Rain Dominant Basins:
Possible increases in flooding due to increased precipitation variability, but no significant change from warming alone.

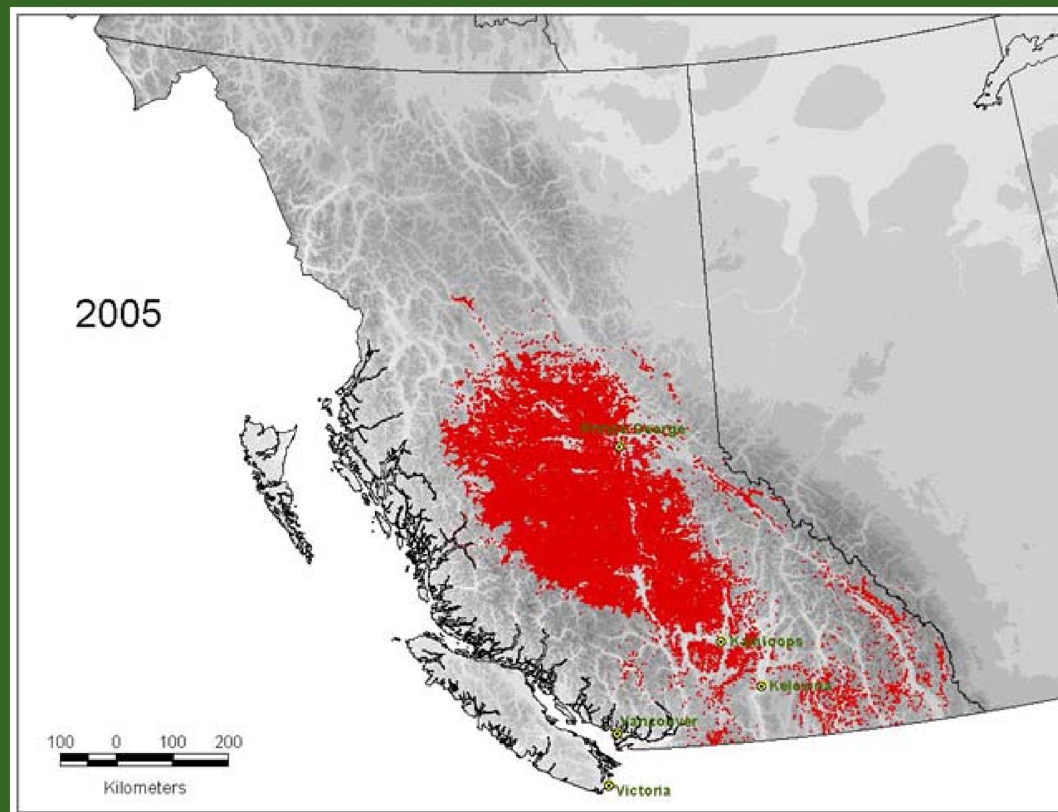
Mixed Rain and Snow Basins Along the Coast:
Strong increases due to warming and increased precipitation variability (both effects increase flood risk)

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

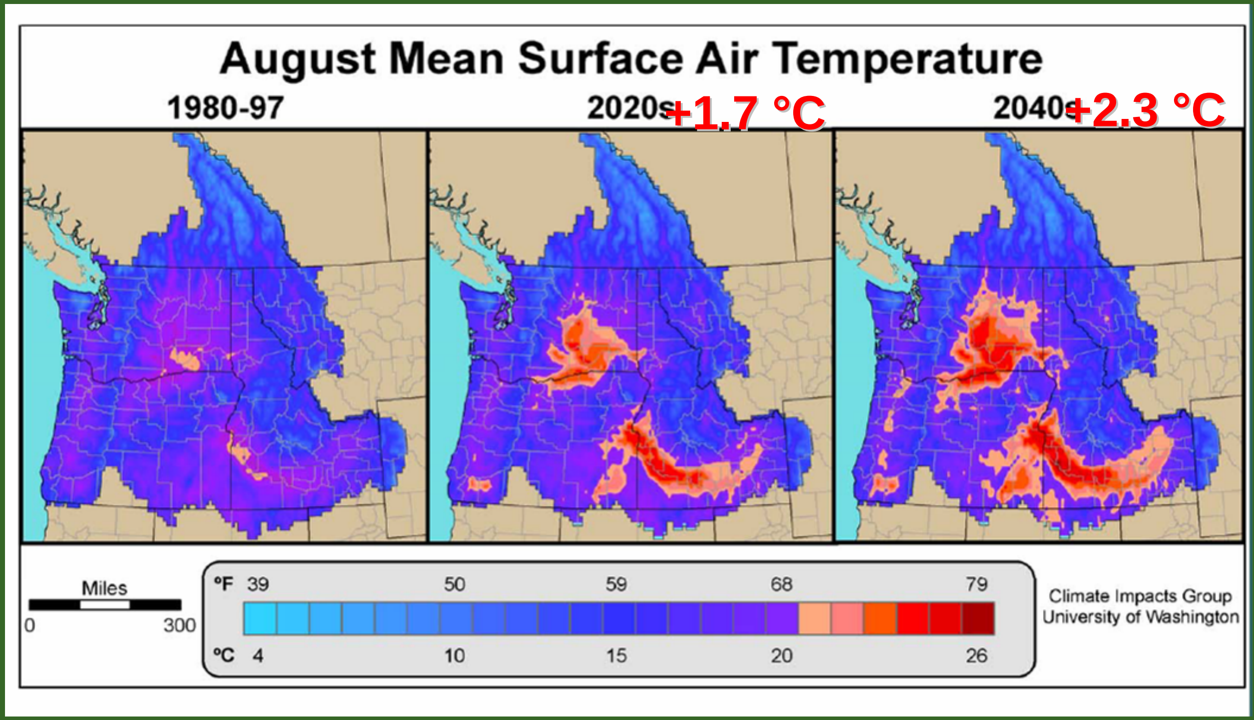




(Figure courtesy Allen Carroll)

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 68ºF (20ºC) 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



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
  - Changes in groundwater supplies
- **Changes in water quality**
  - Increasing water temperature
  - 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 water management practice**
  - Hydropower production (energy demand)
  - Flood control operations (changing flood risk and refill statistics)
  - Instream flow augmentation
  - Use of storage to control water temperature
- **Changes in Ecosystem Protection and Recovery Planning**
  - Design of fish and wildlife recovery plans
  - Habitat restoration efforts
  - ESA listings (as a process)
  - Monitoring programs

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.