High and Dry: Declining Precipitation in the Mountains of the Pacific Northwest

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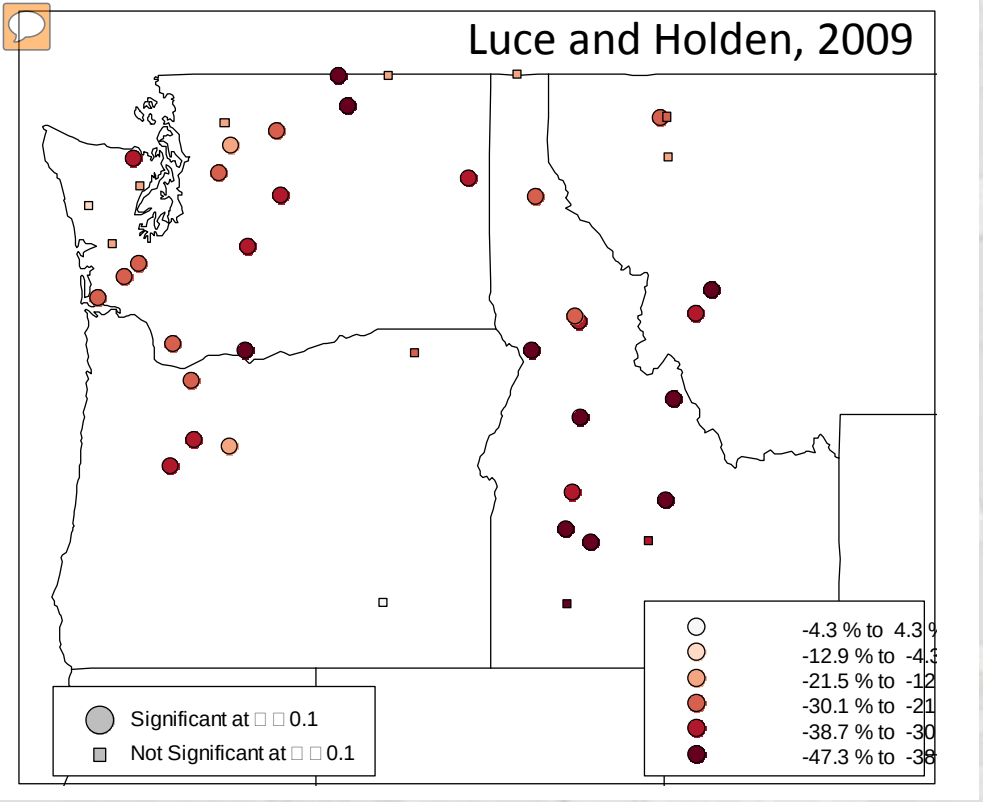
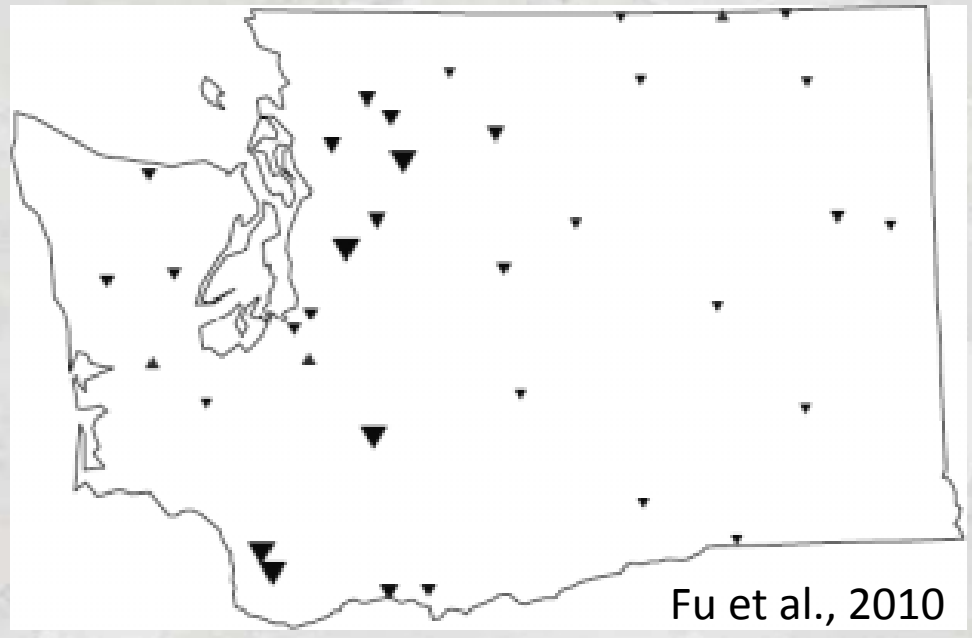
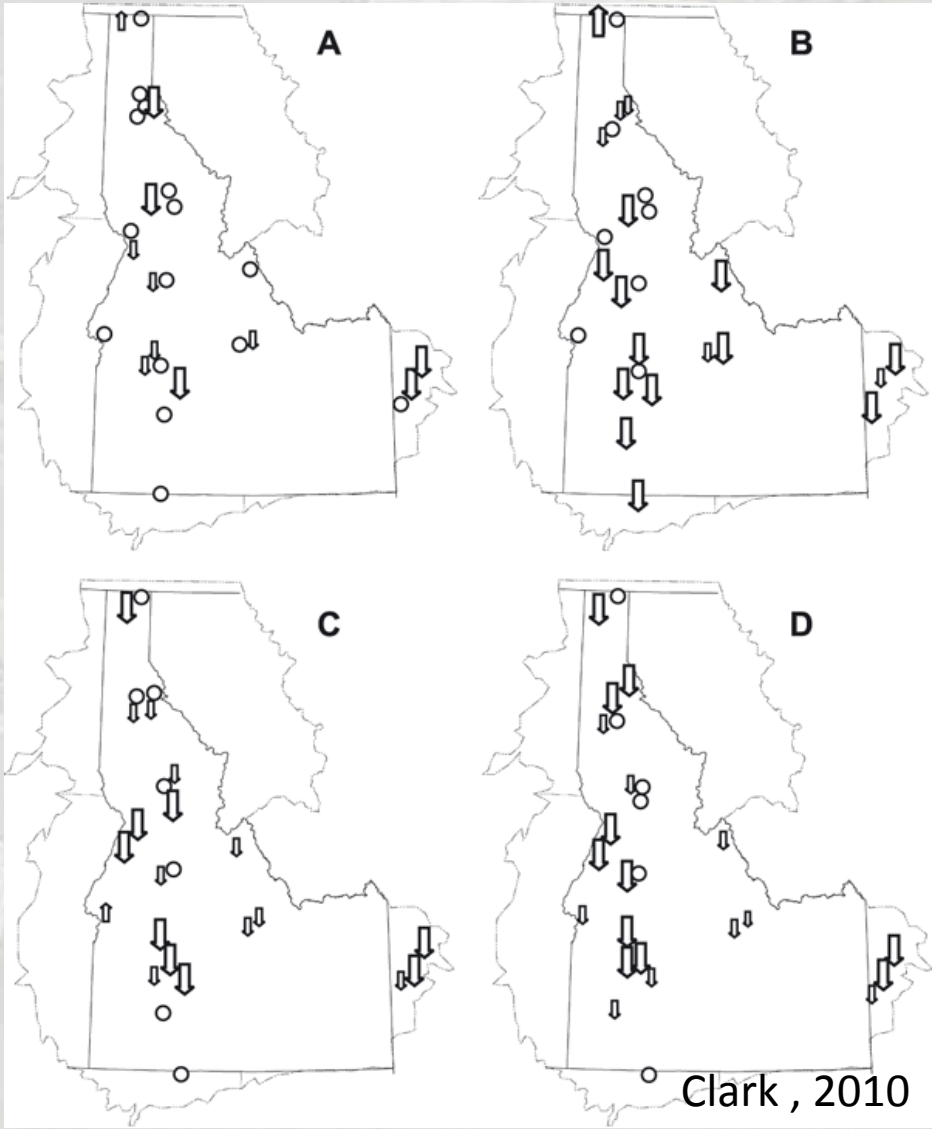
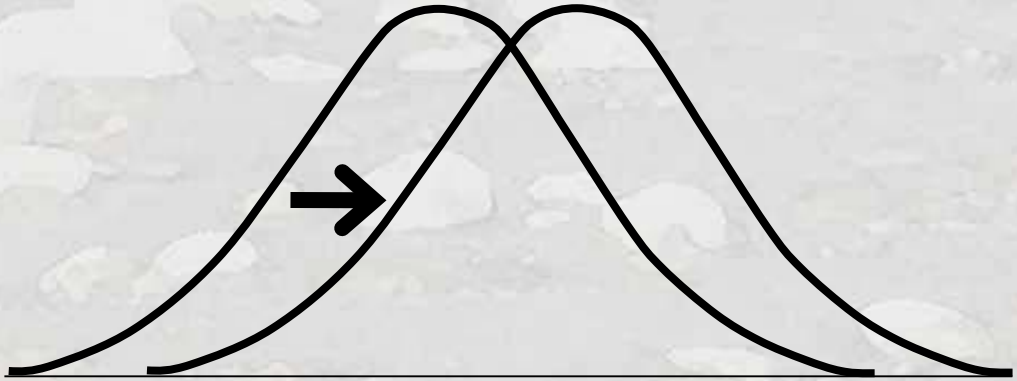
Declining PNW Streamflows





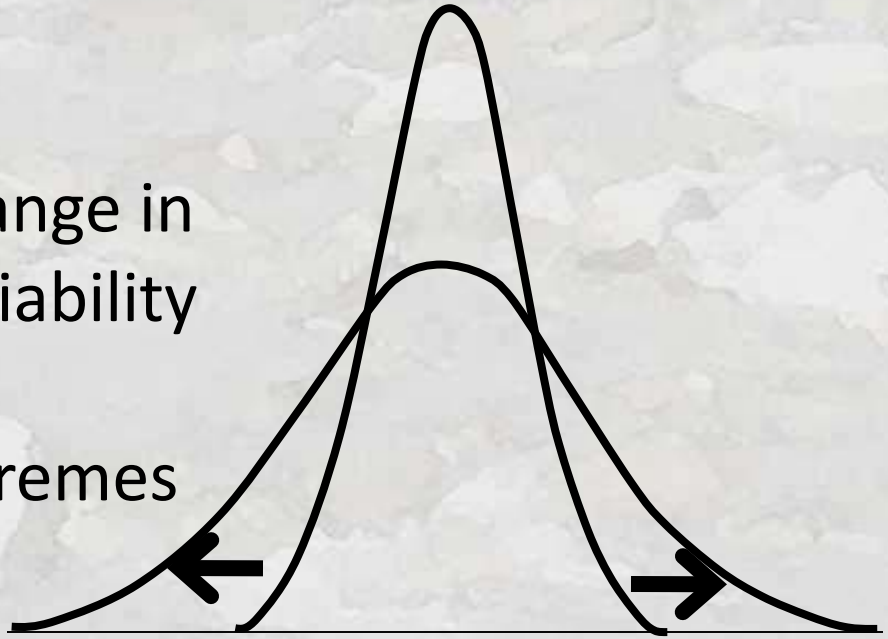


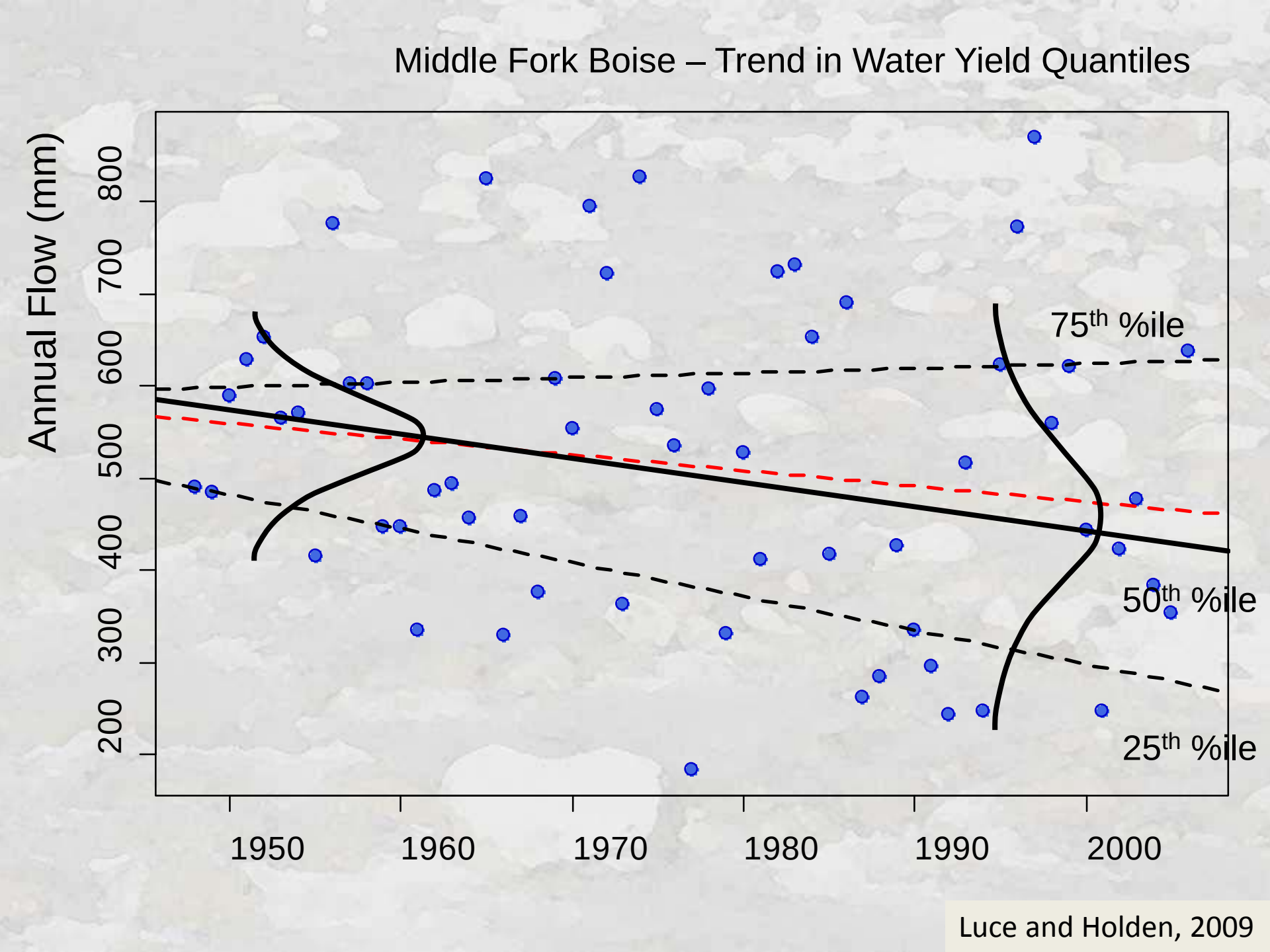
Two Kinds of ‘Trends’



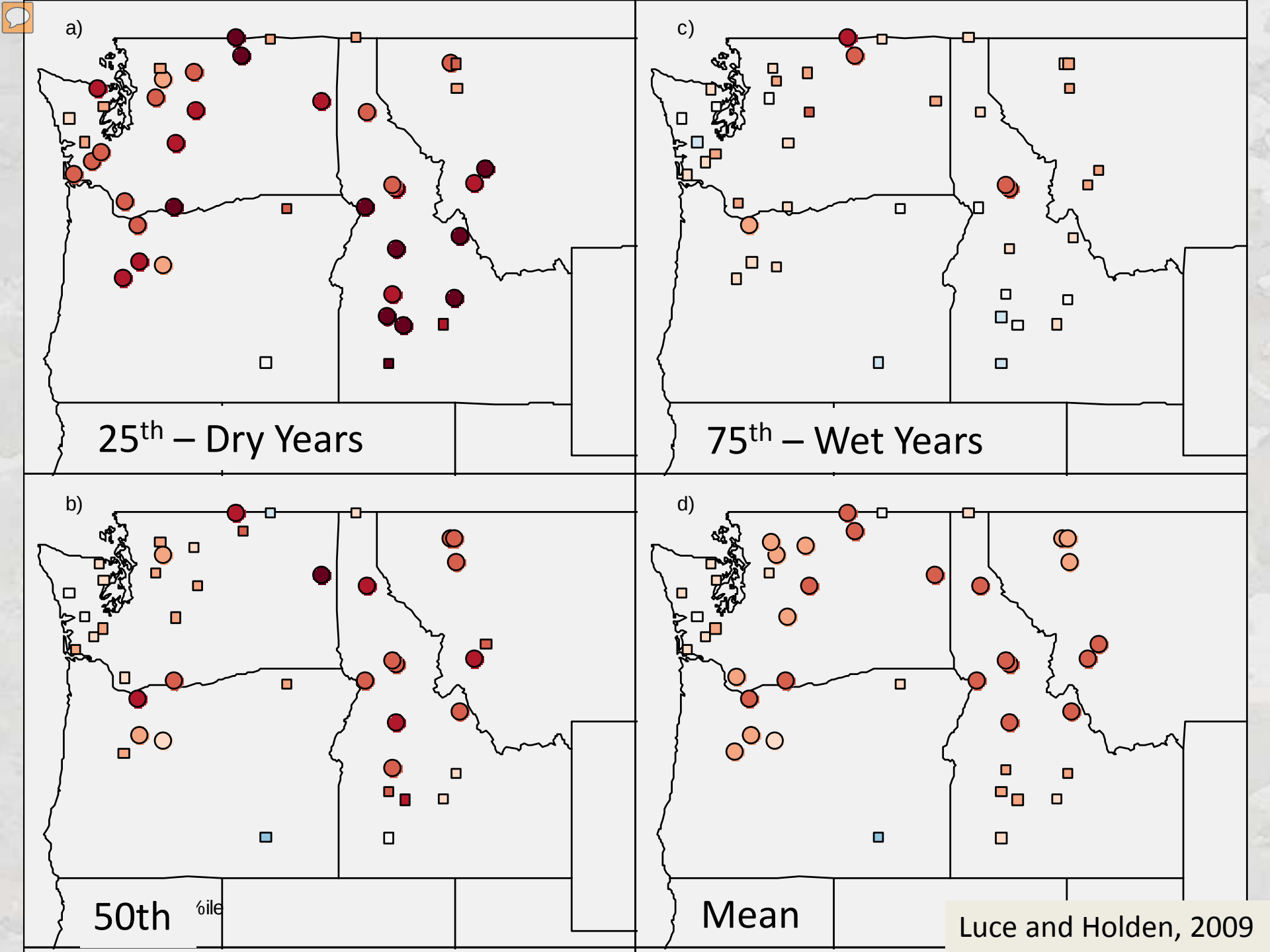
Change in Mean

Change in Variability Or Extremes





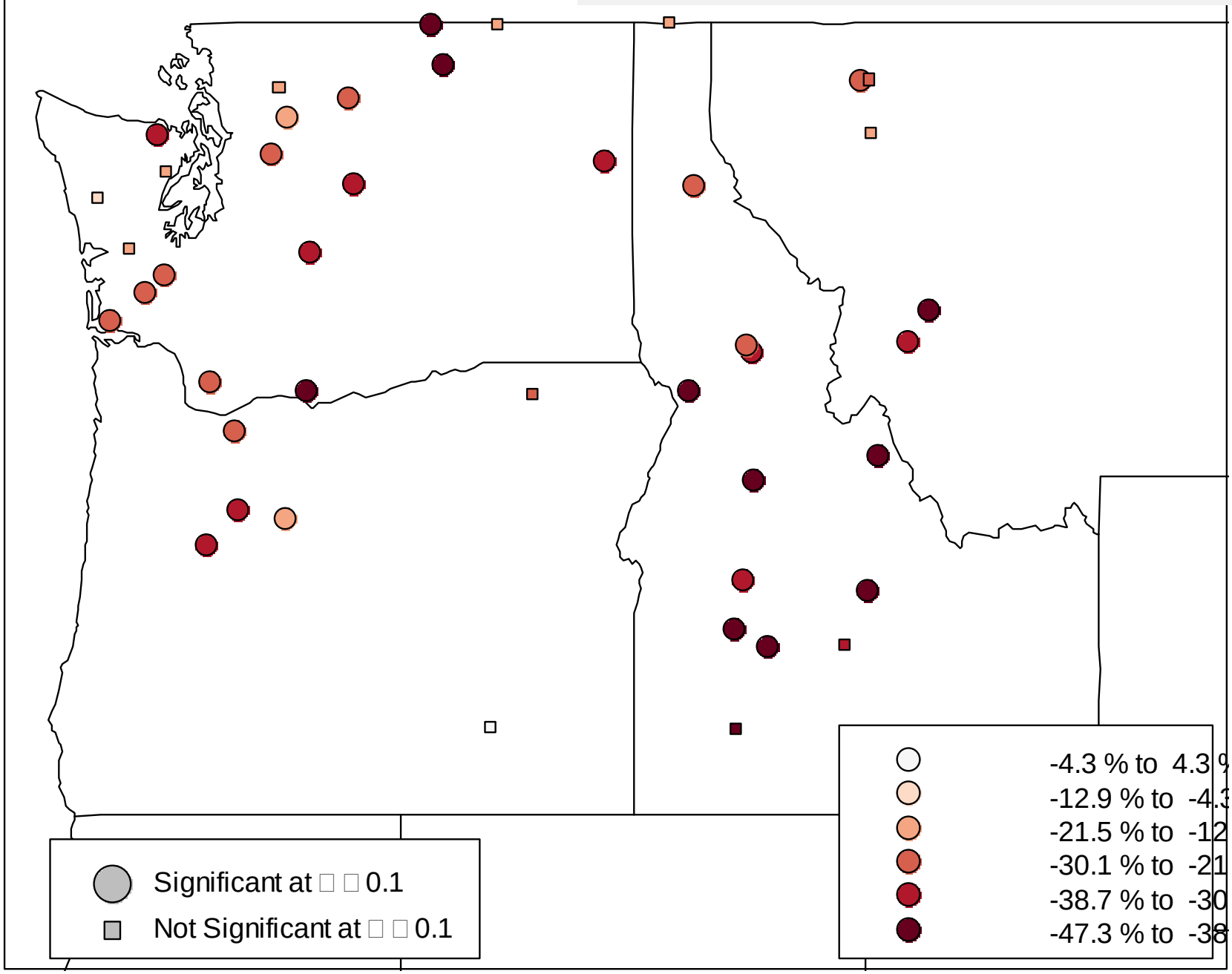
Luce and Holden, 2009



Luce and Holden, 2009

Luce and Holden, 2009

Change in 25th %ile annual flow

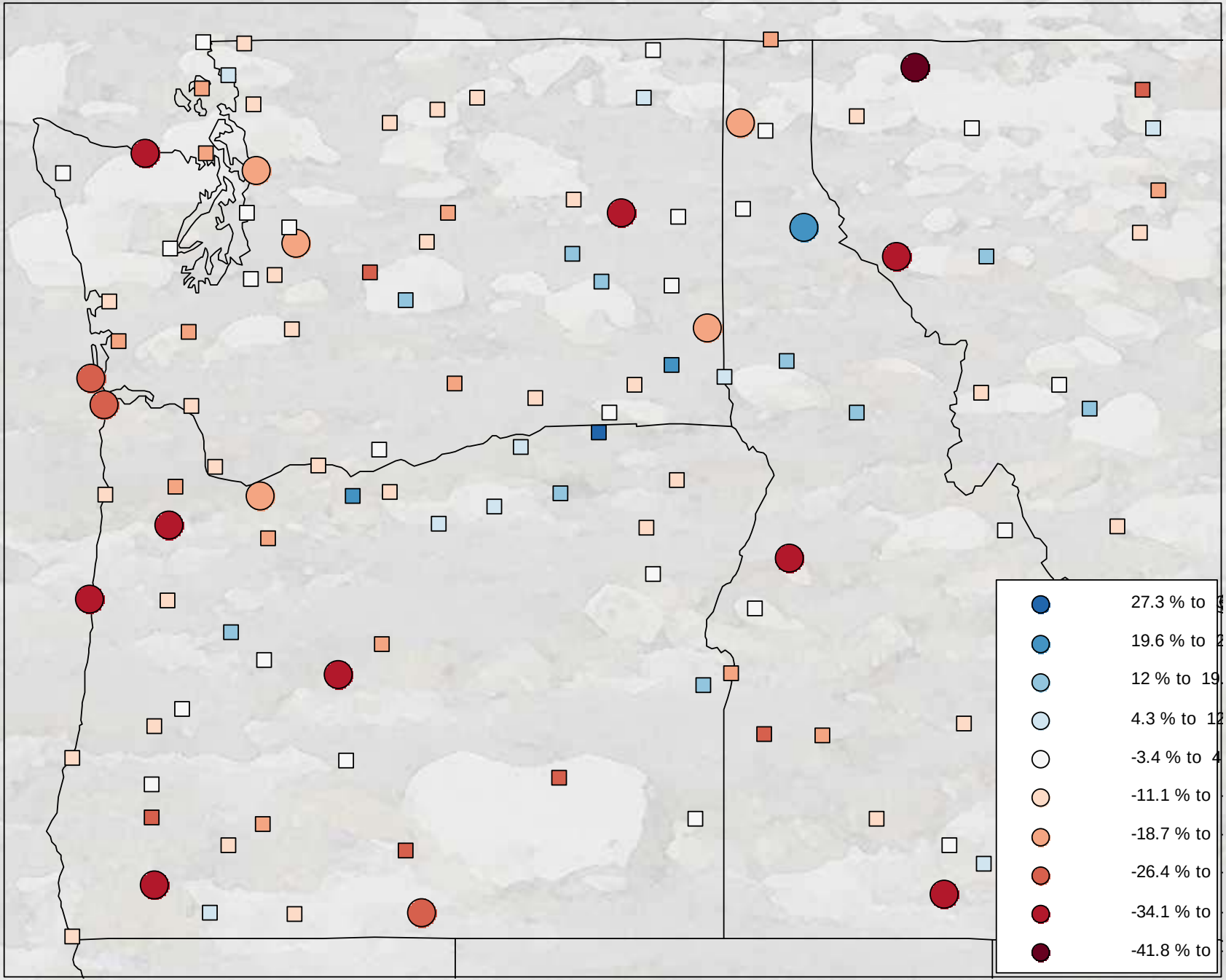


Why?

E

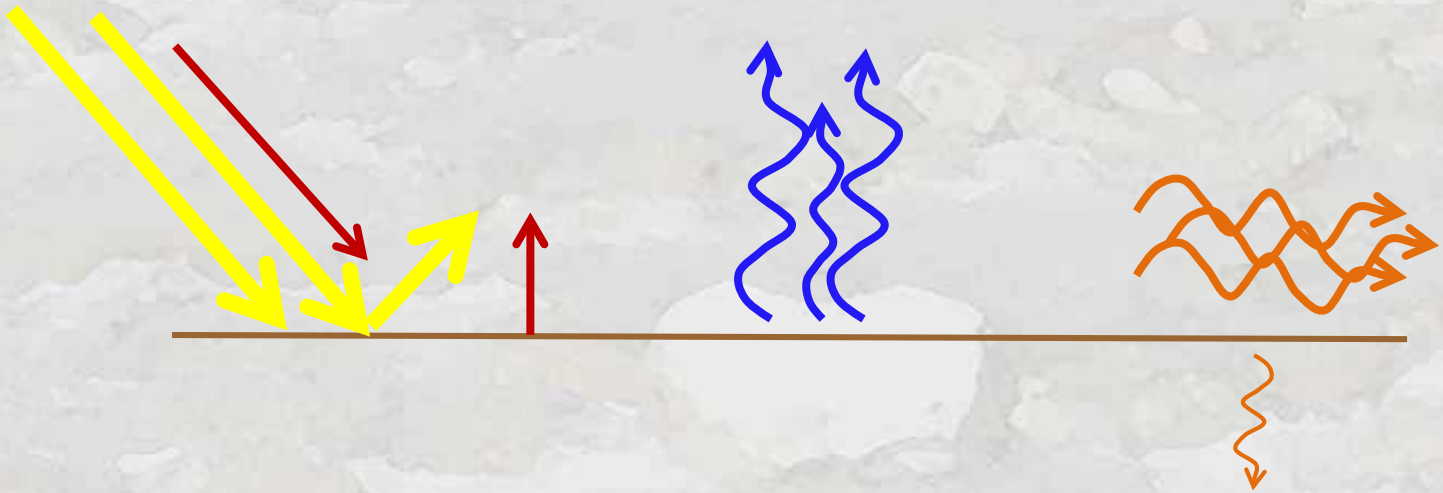
P

Trends in HCN2 Precipitation (% change in 25th %ile)

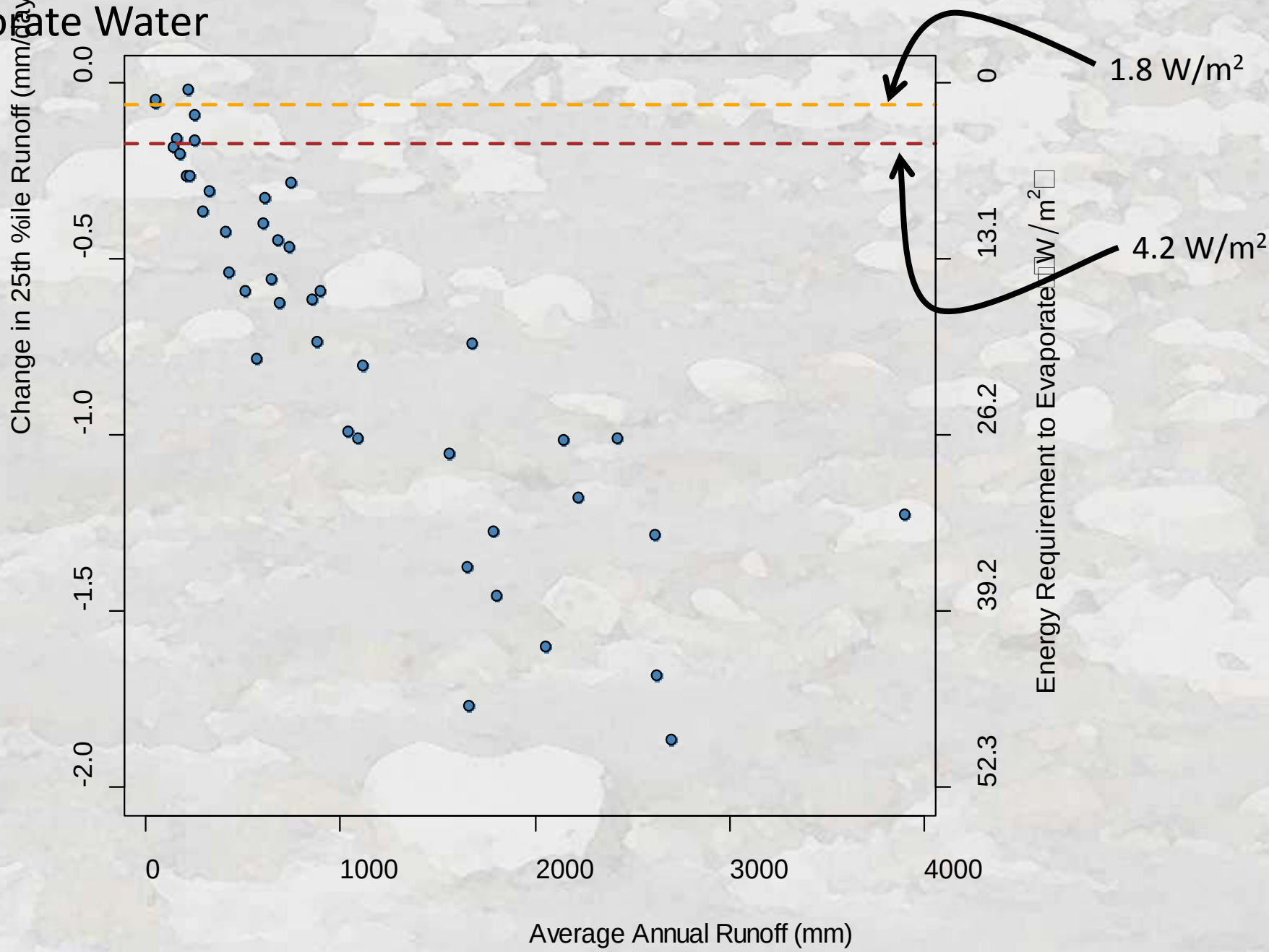


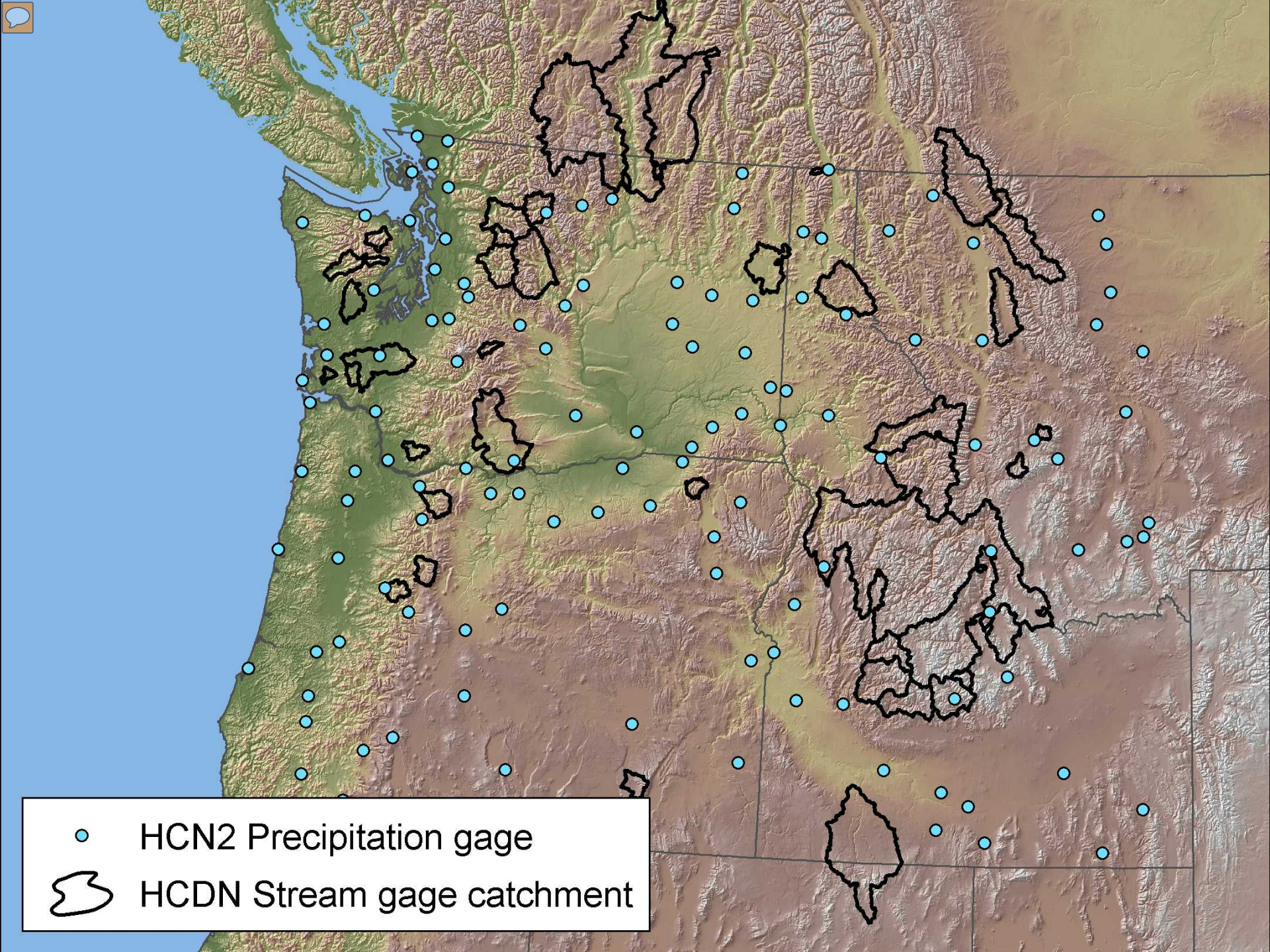
Energy Balance of a Surface

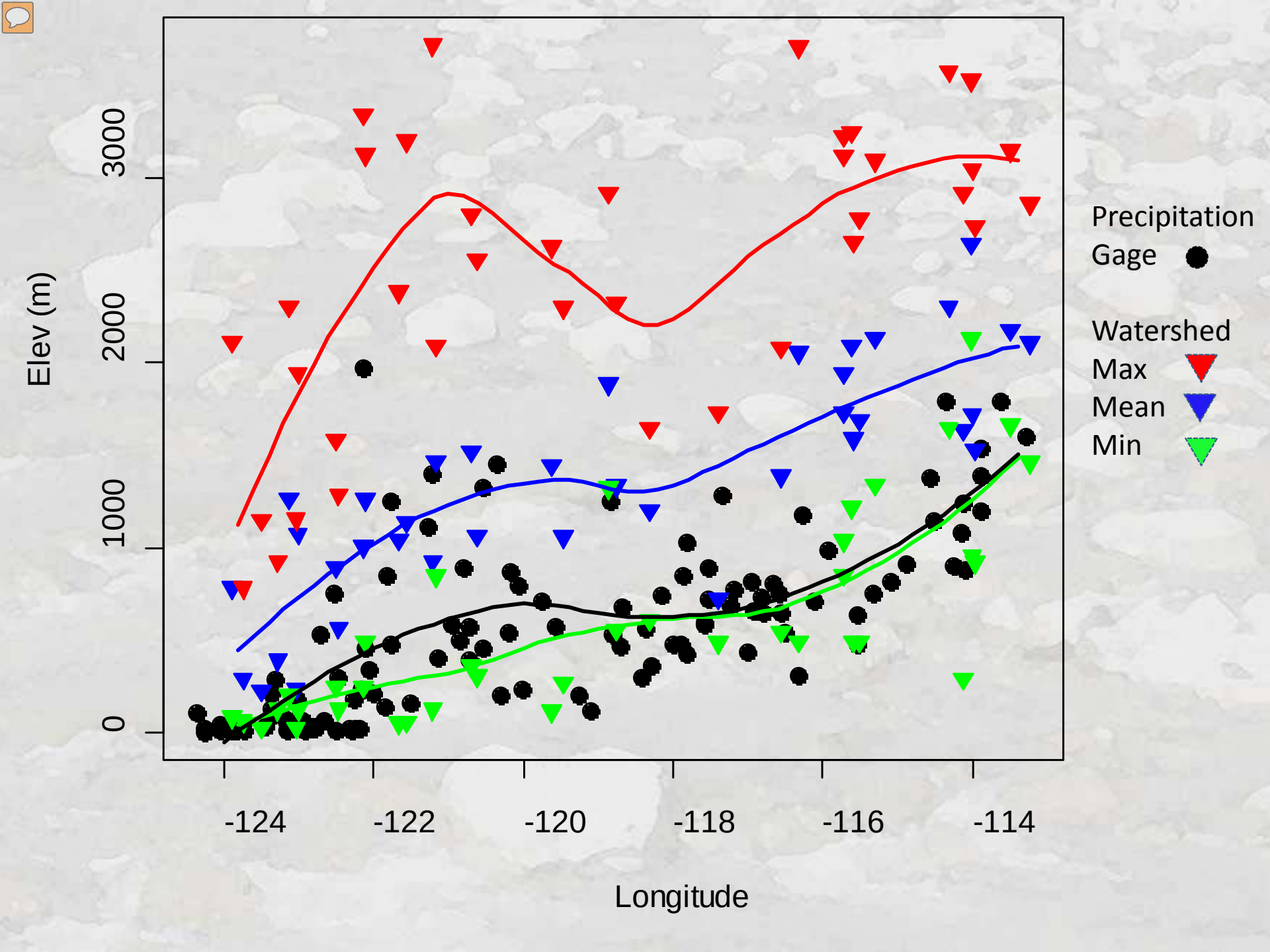
Net Incoming Radiation = Heat Lost through Evaporation + Temperature Change



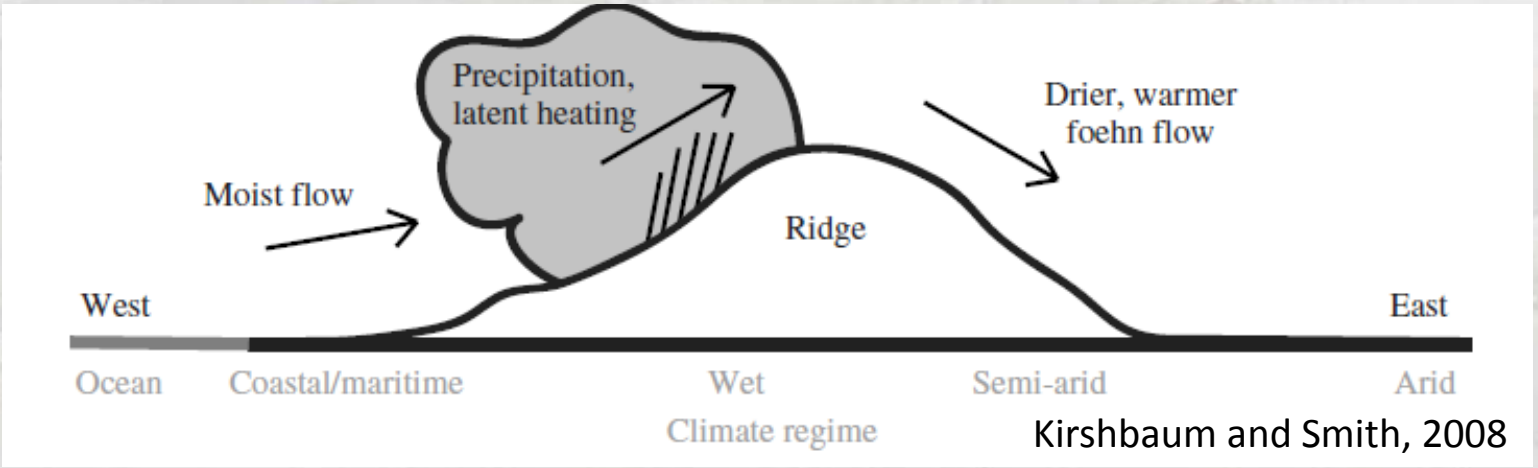
Insufficient Additional Energy Available to Evaporate Water




HCN2 Precipitation gage
HCDN Stream gage catchment

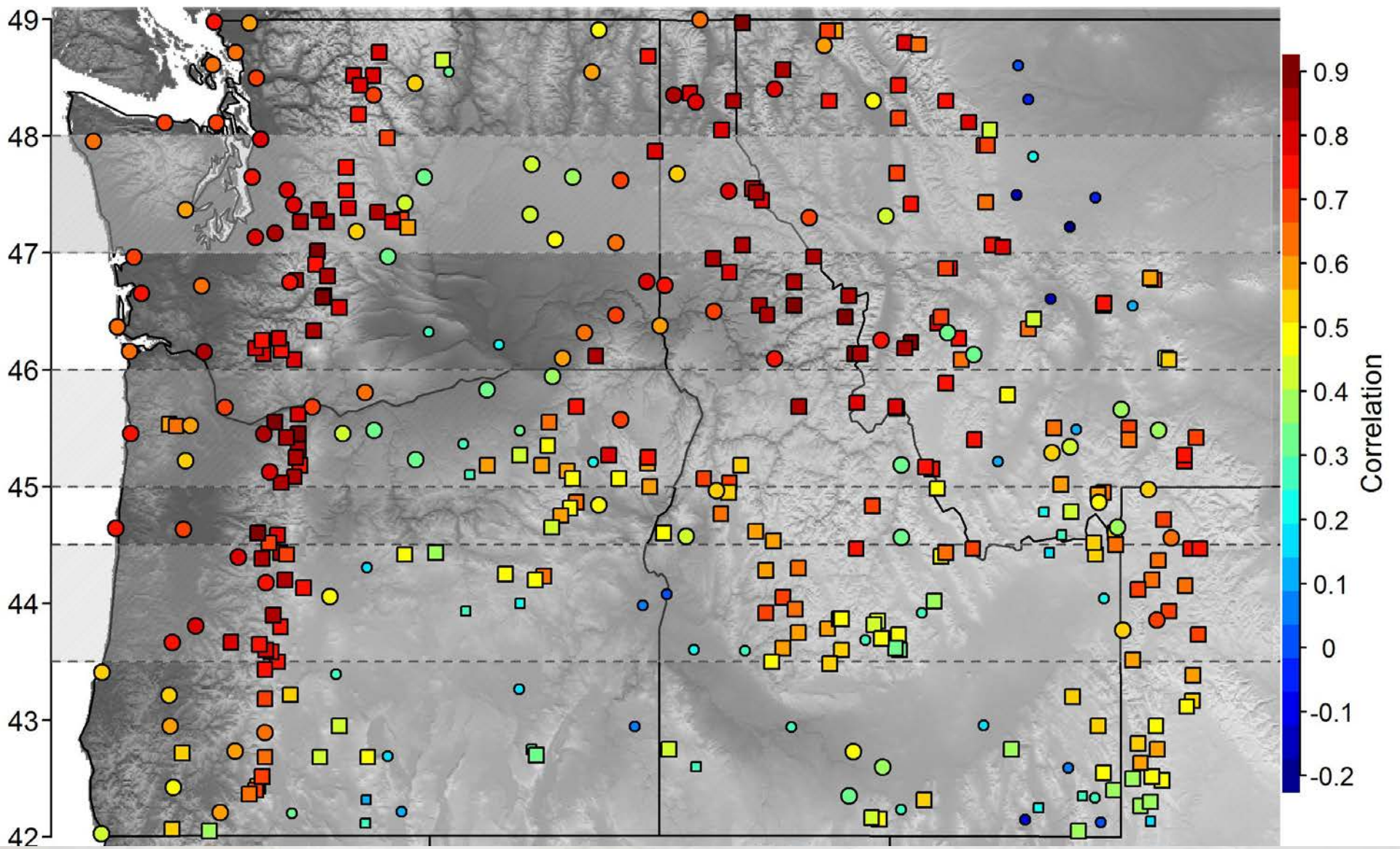

Elev (m)
0
1000
2000
3000
-124
-122
-120
-118
-116
-114
Longitude
Precipitation
Gage
Watershed
Max
Mean
Min

Orographic Precipitation

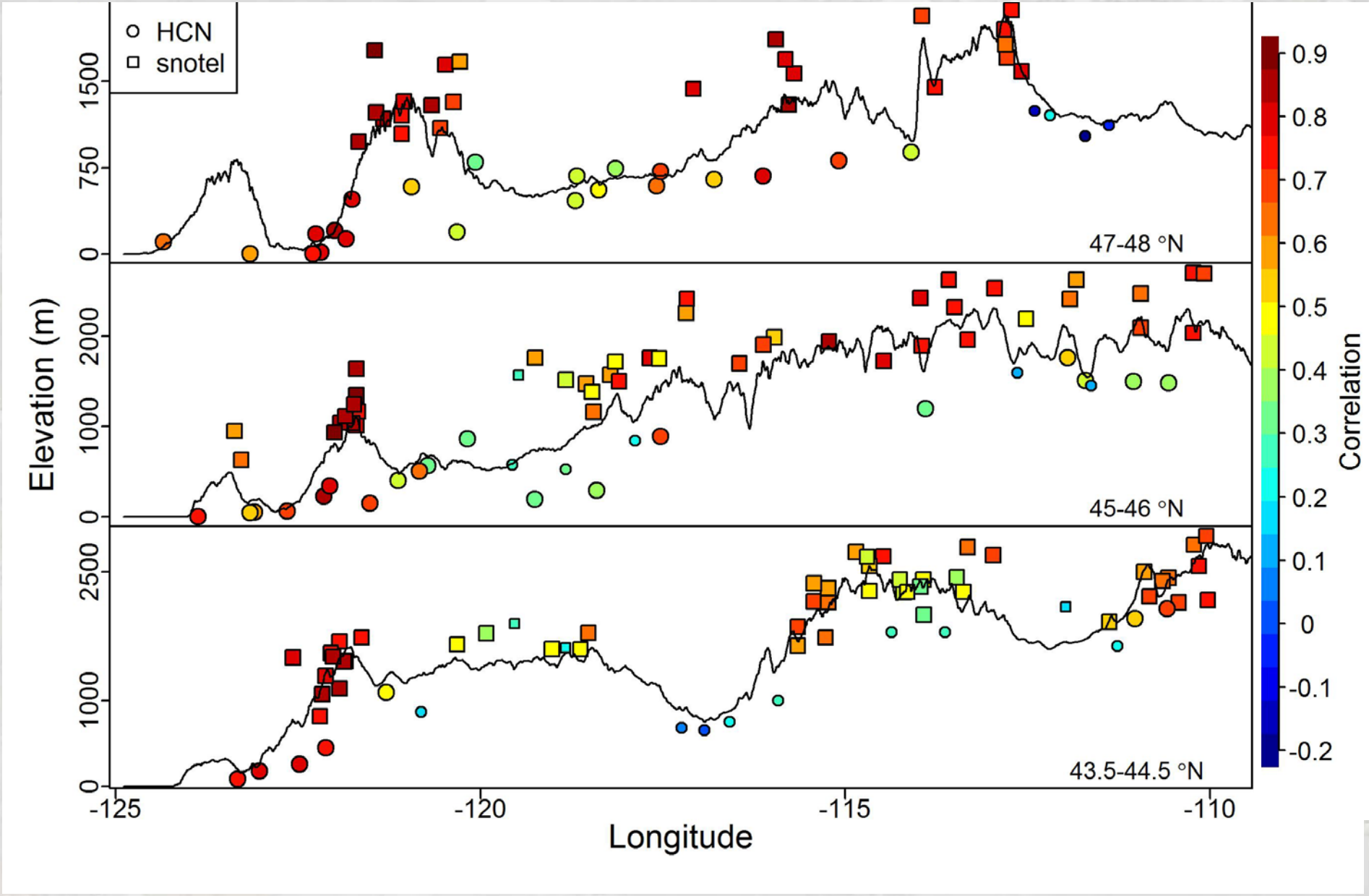


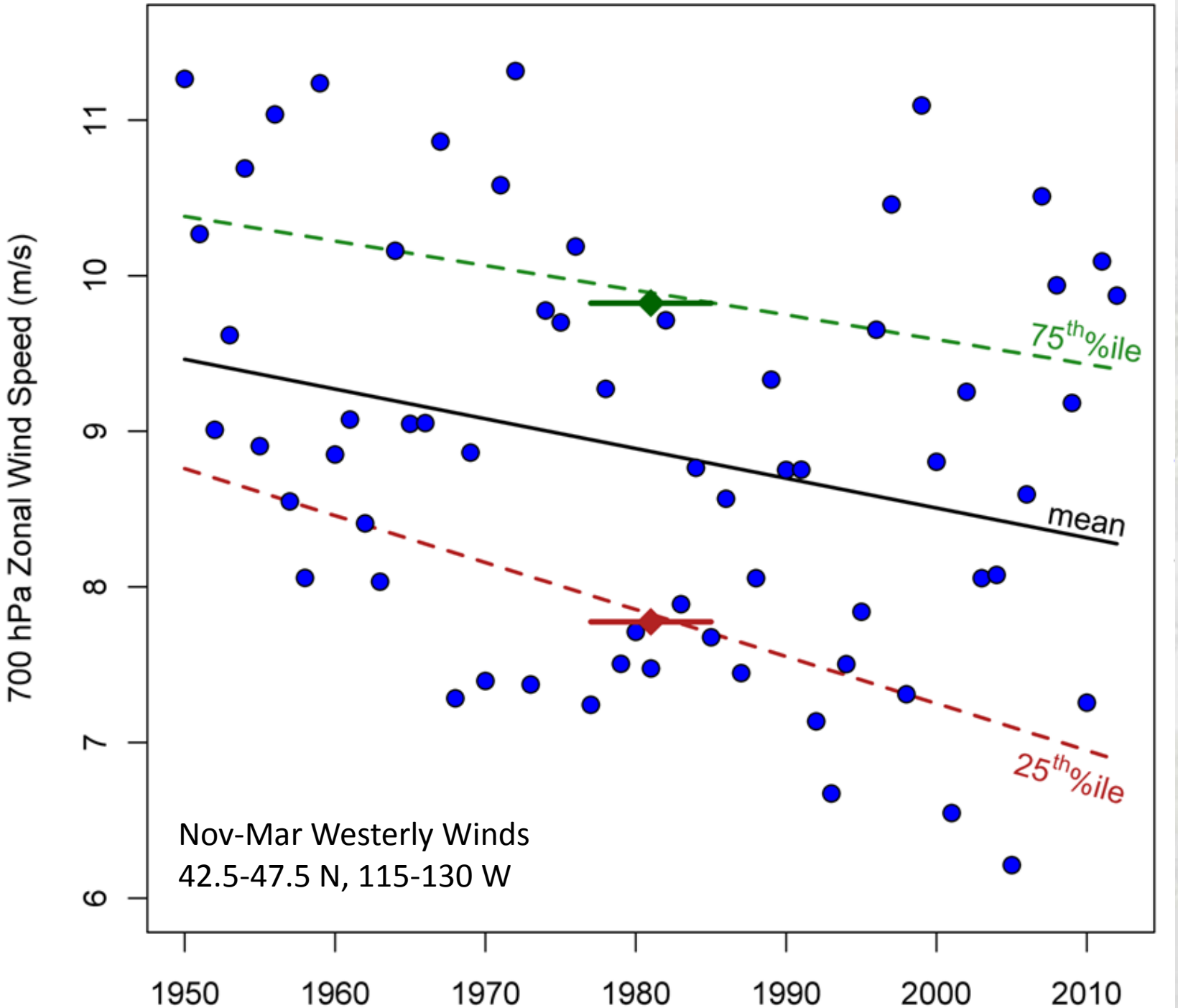
Kirshbaum and Smith, 2008

Precipitation Correlation with Regional Westerly Wind Speed



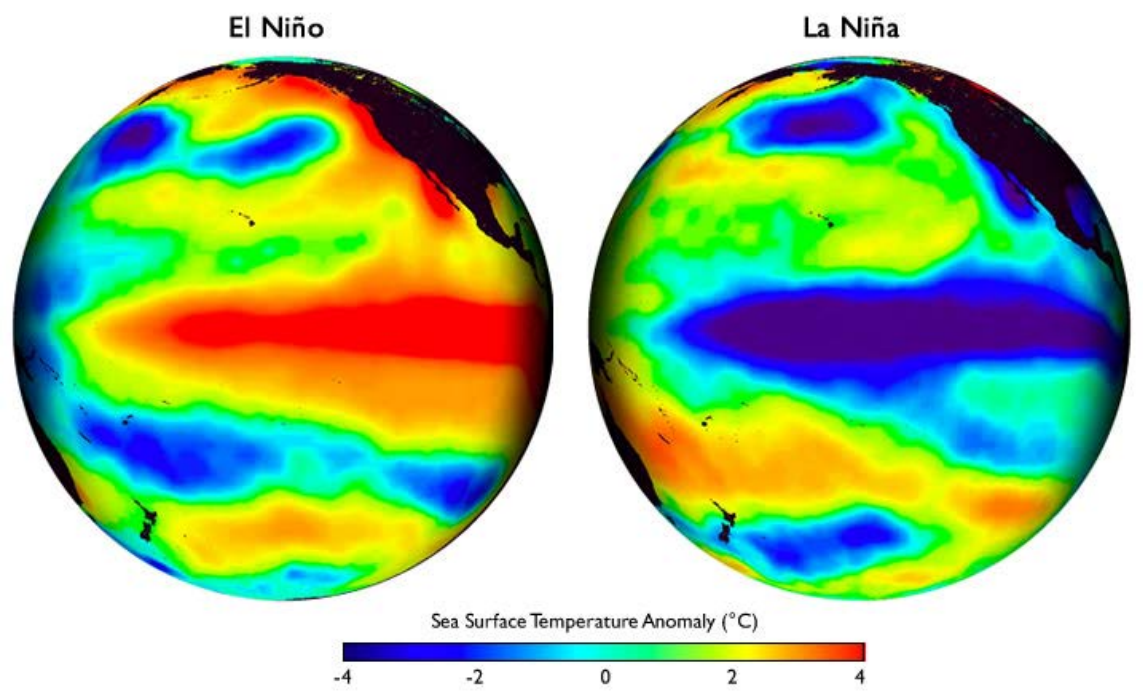
Precipitation Correlation with Regional Westerly Wind Speed

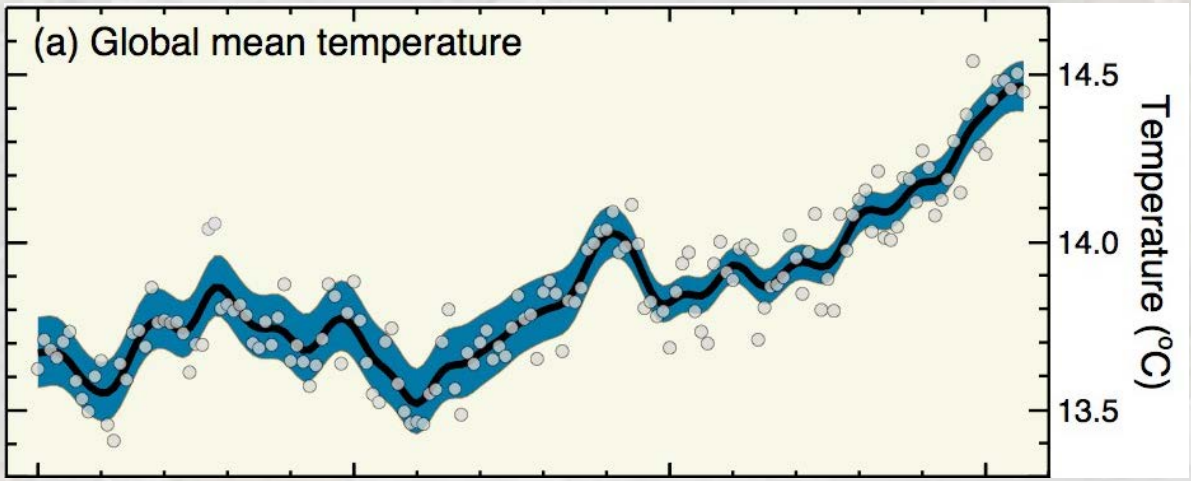



700 hPa Zonal Wind Speed (m/s)
11
10
9
8
7
6
1950
1960
1970
1980
1990
2000
2010
75th%ile
mean
25th%ile
Nov-Mar Westerly Winds
42.5-47.5 N, 115-130 W

The Story So Far …

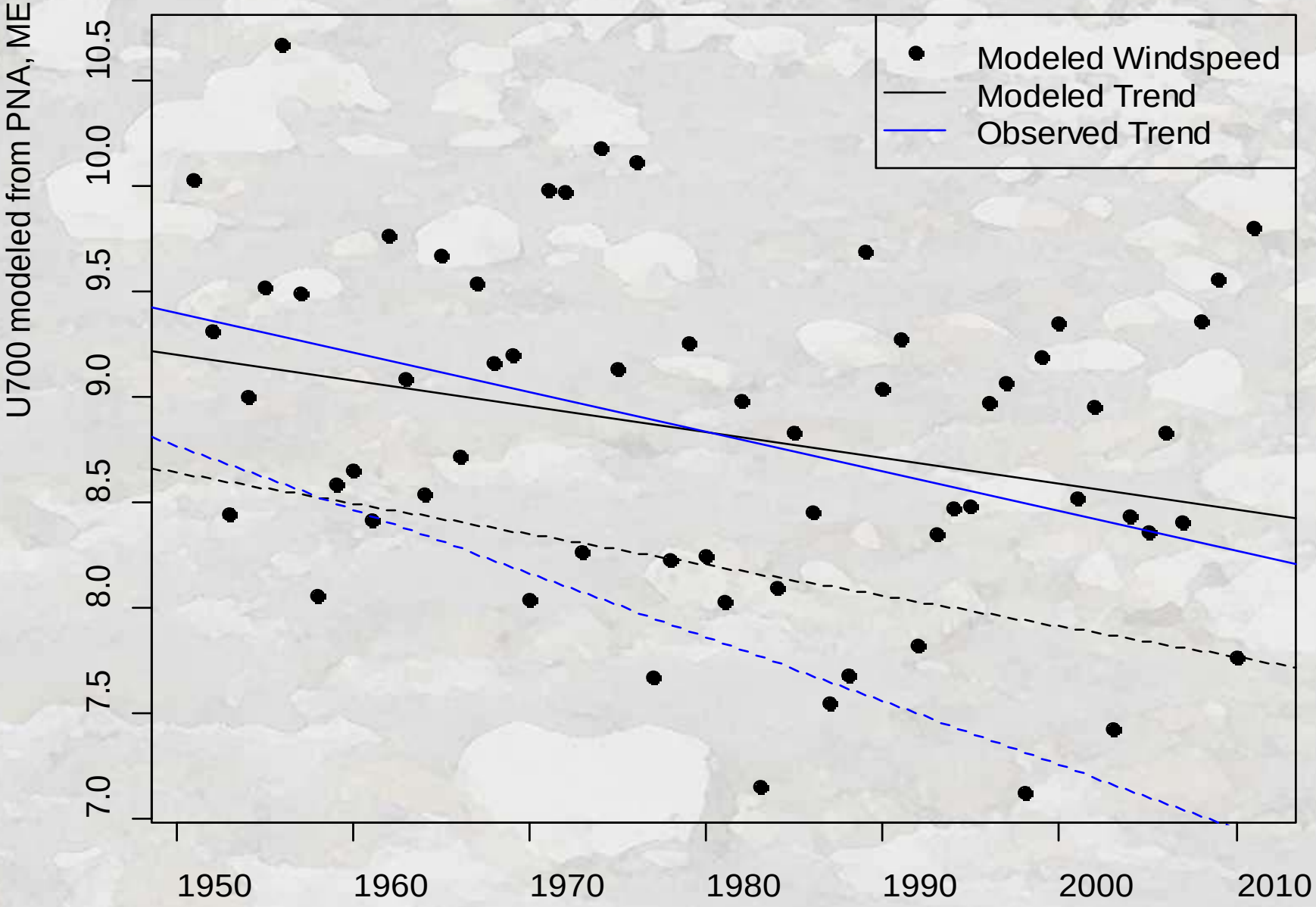
Why did the wind slow?

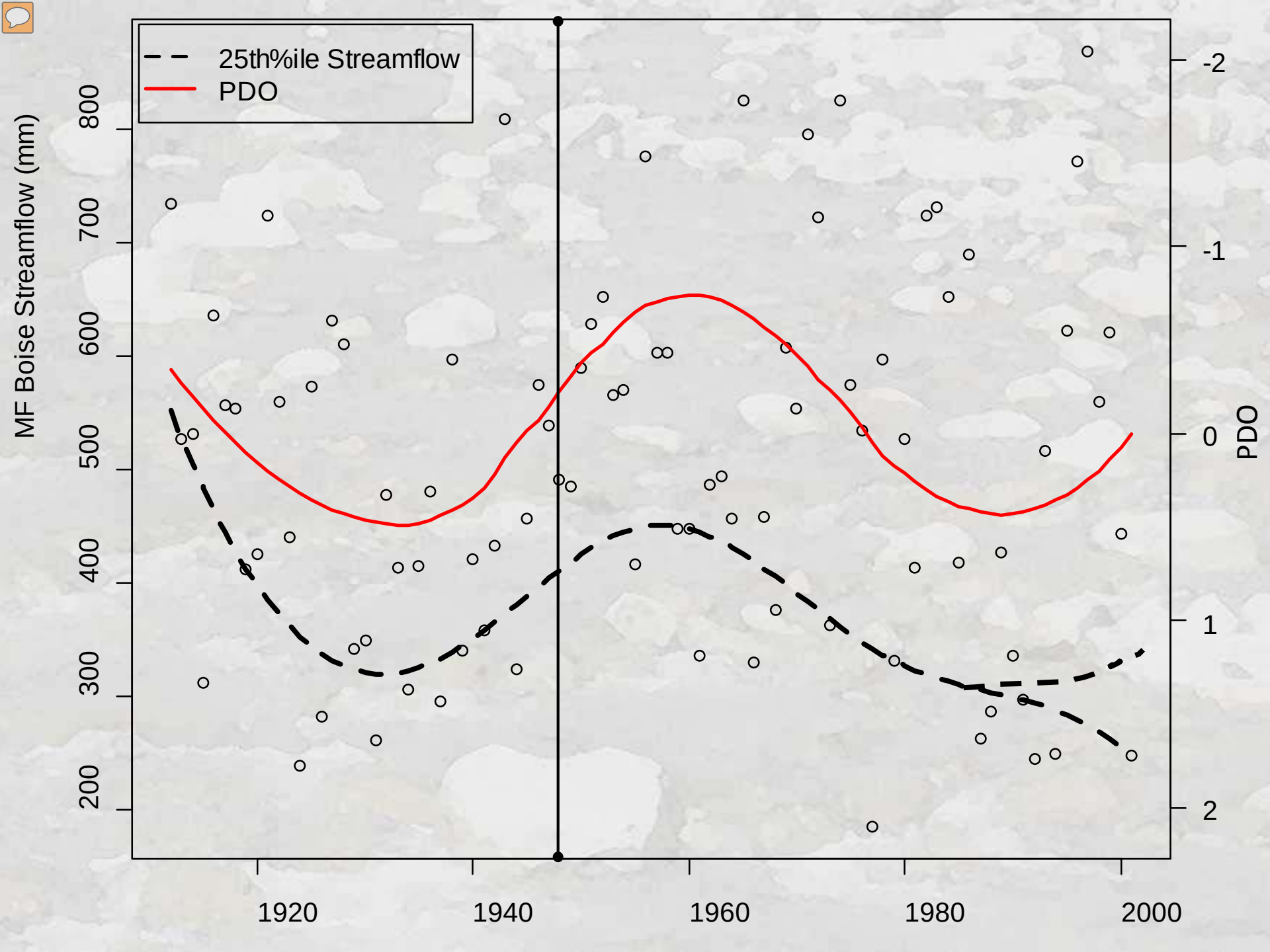


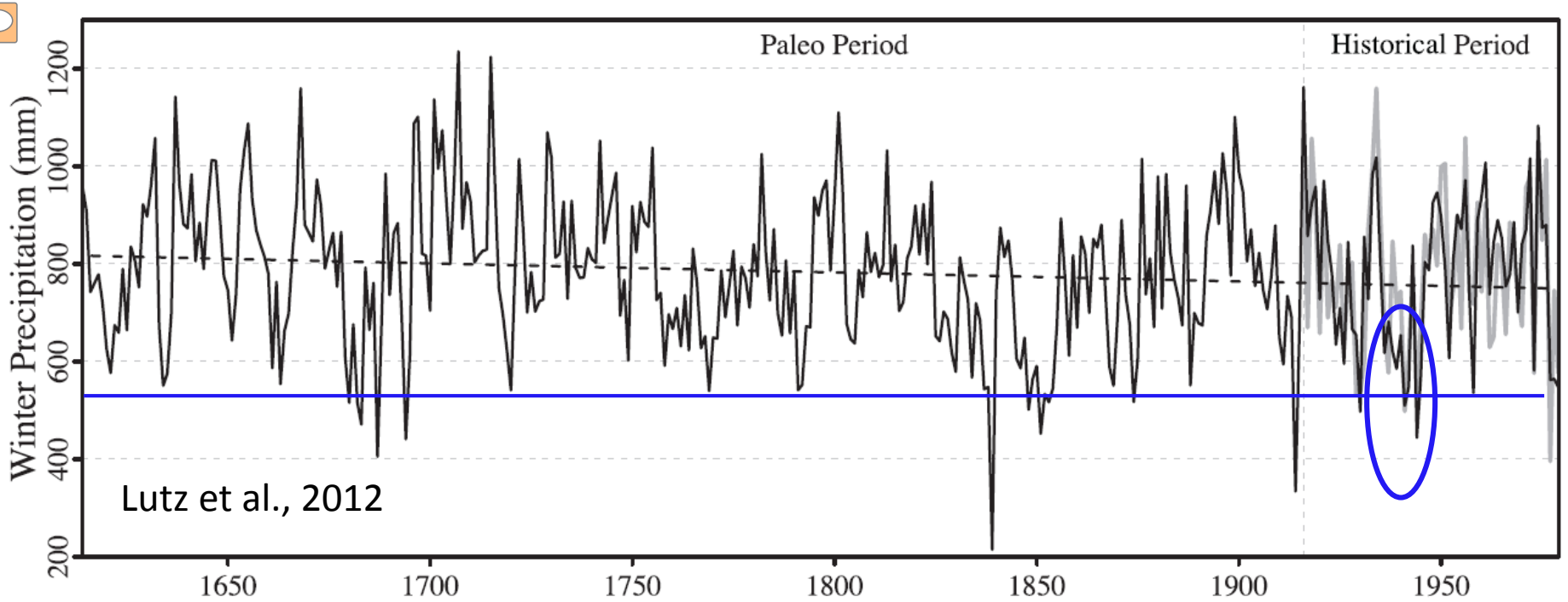


Influence of Climate Modes on Wind

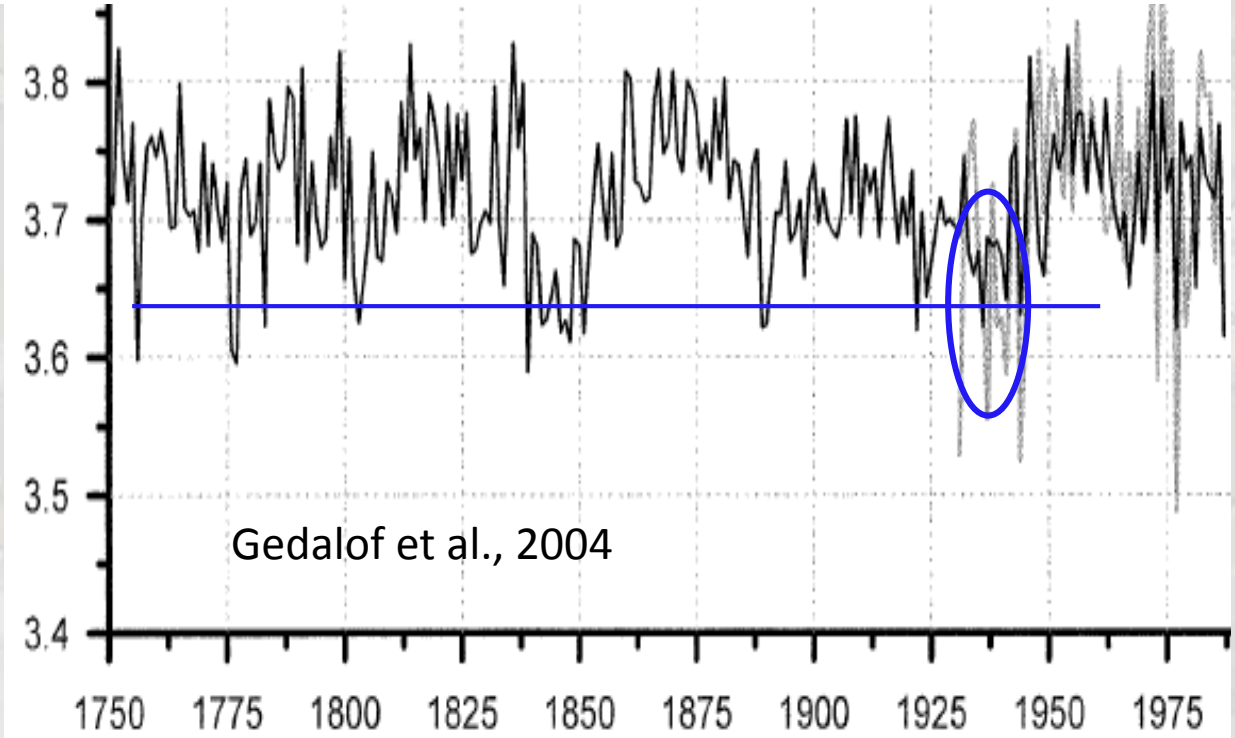
U700=f(MEI,PNA,PDO), R^2=0.37, P<0.001



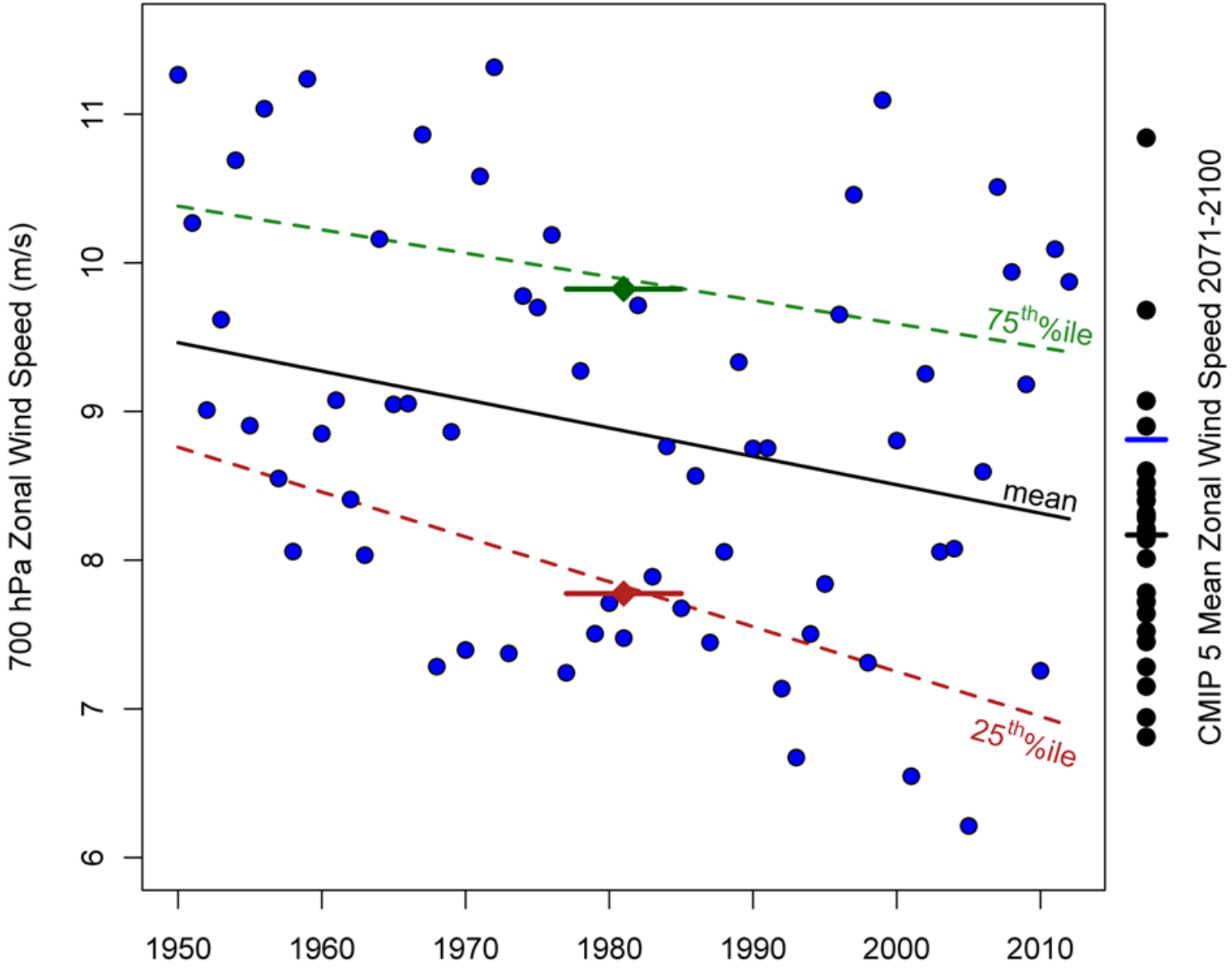

25th%ile Streamflow
PDO
MF Boise Streamflow (mm)
PDO
200
300
400
500
600
700
800
-2
-1
0
1
2
1920
1940
1960
1980
2000



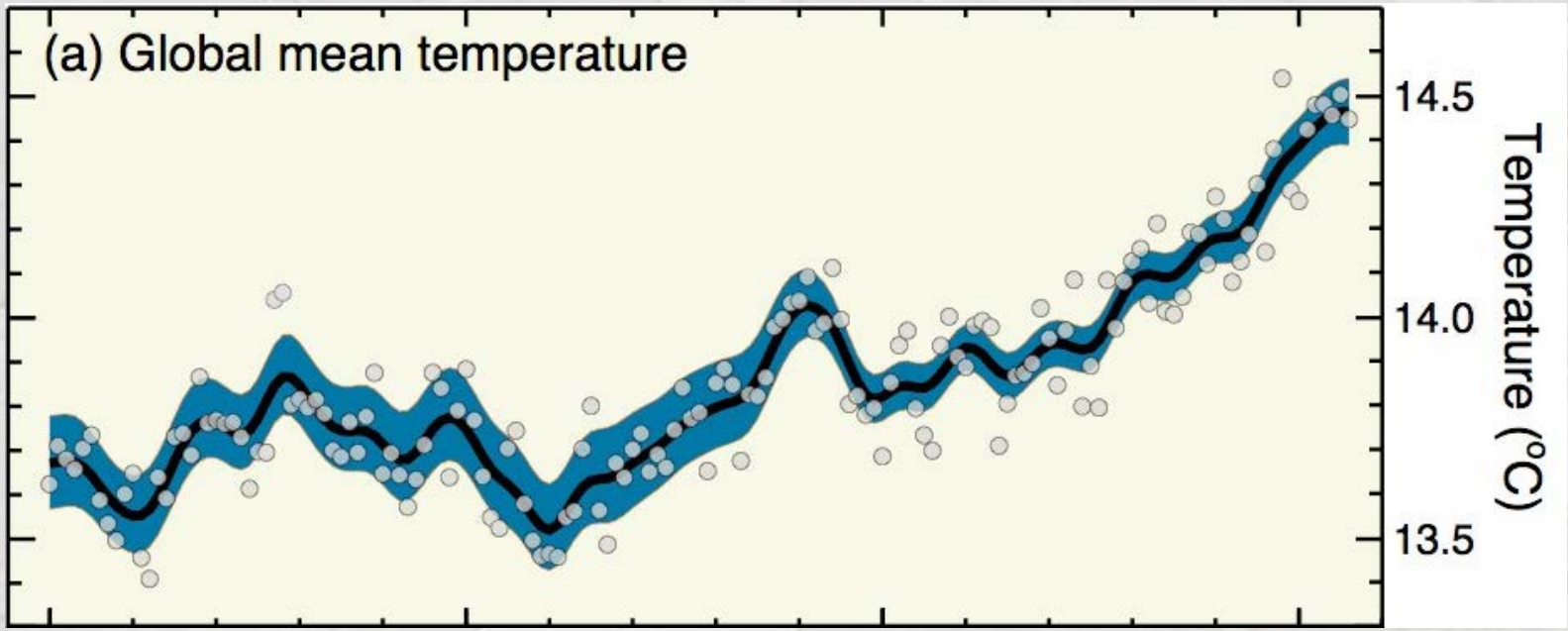
Tree Ring Flow Reconstructions



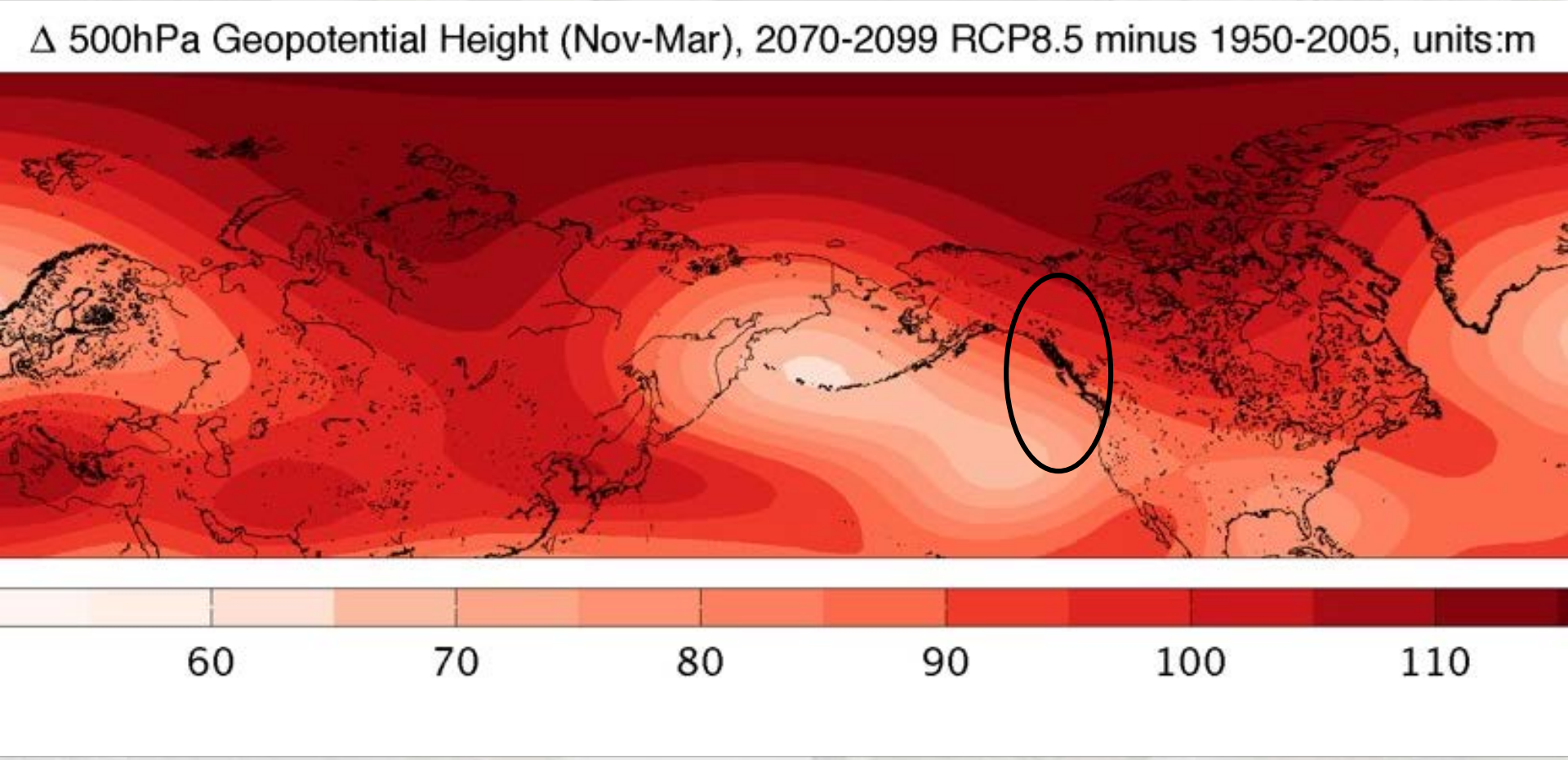
Trends and Future Predictions



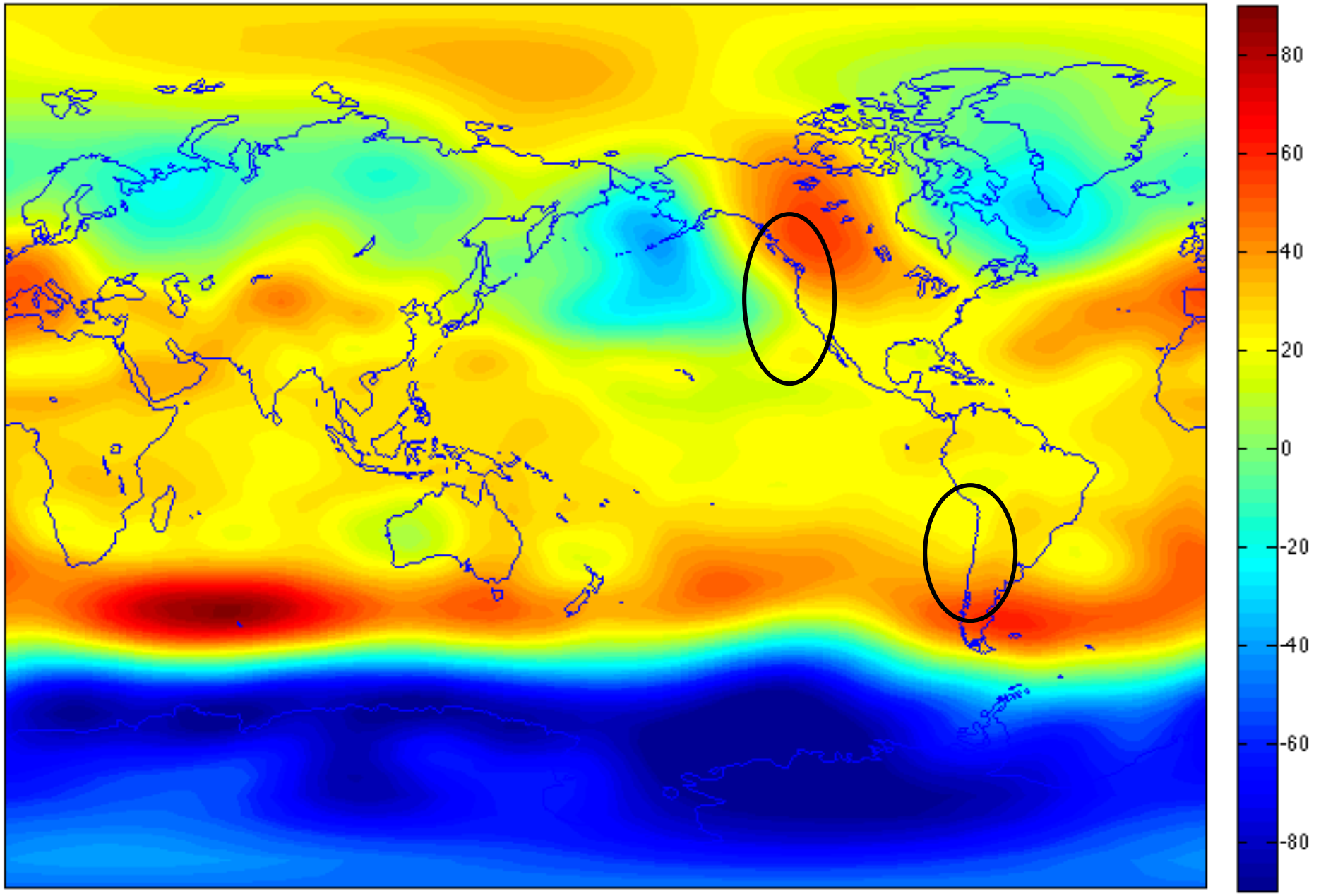
Why would warming slow the westerlies?

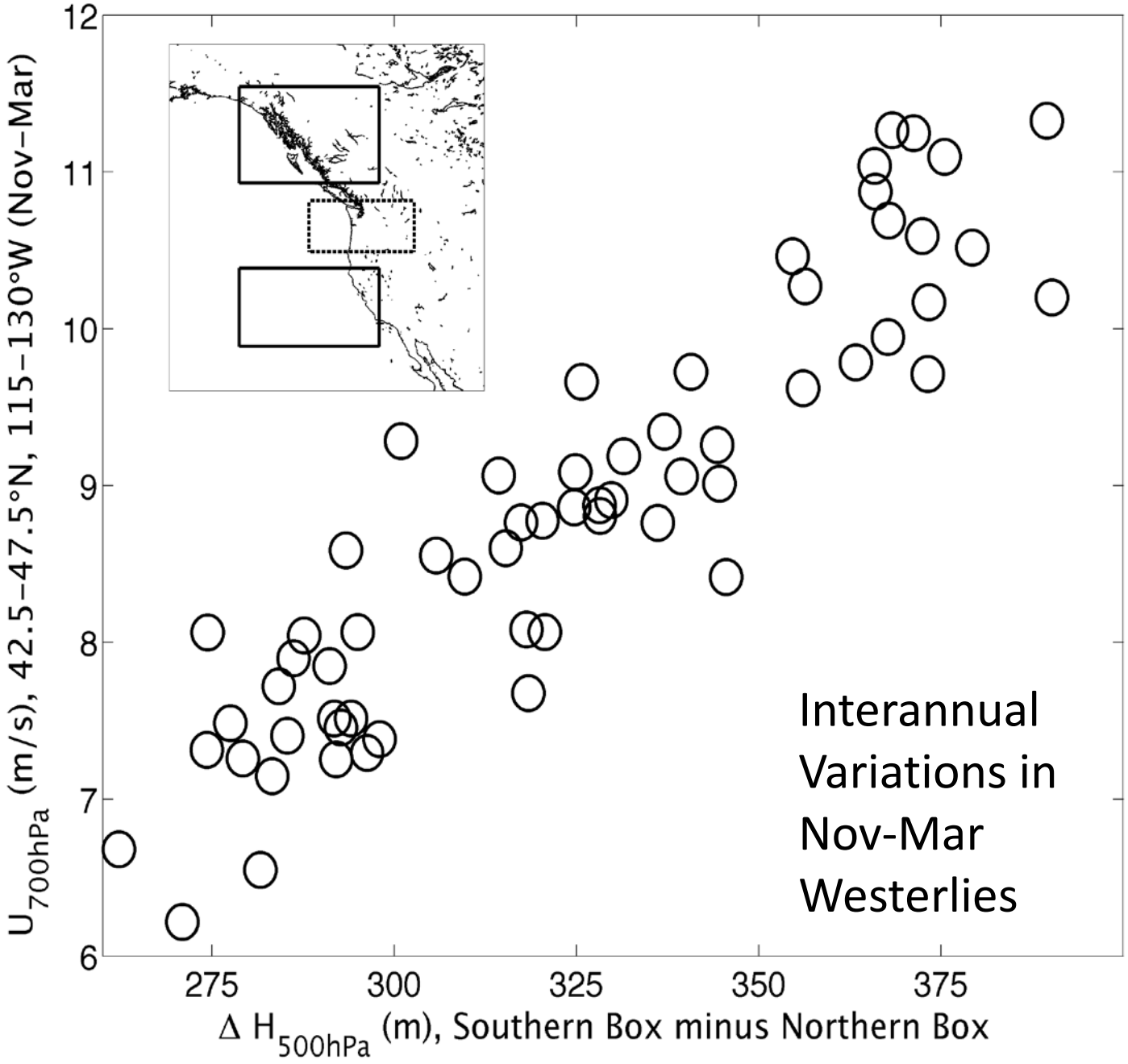


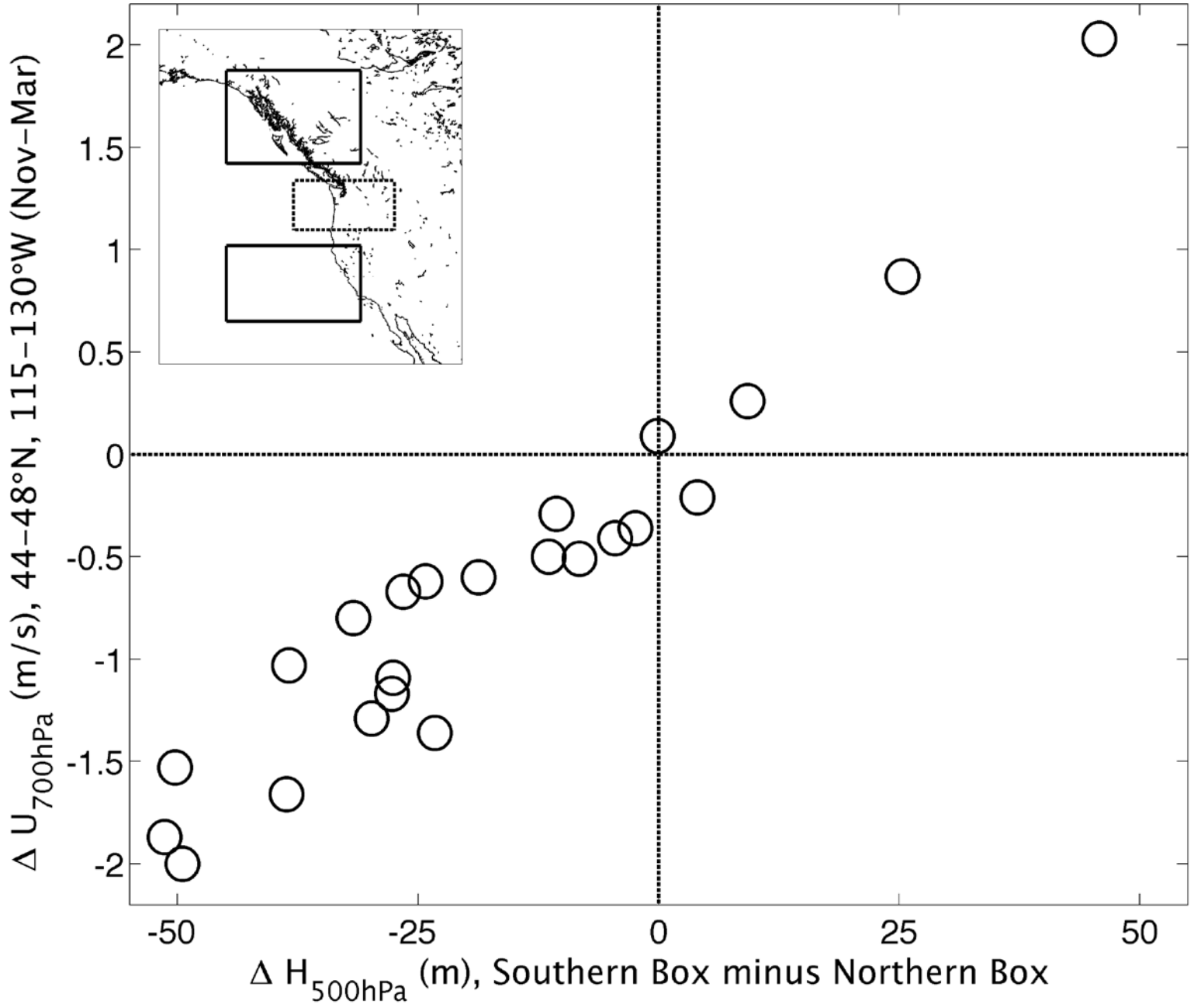
Future Changes in Pressure



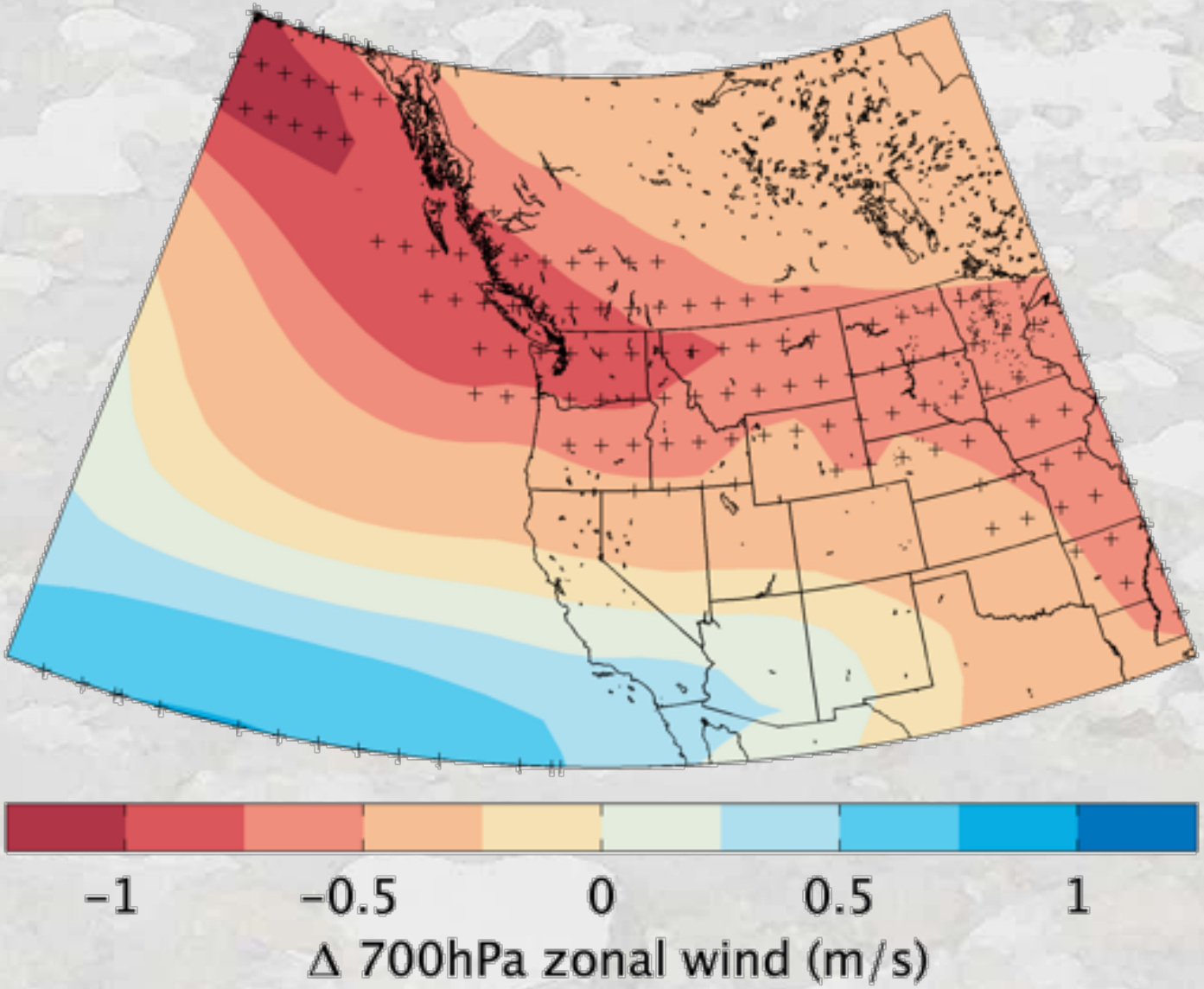
Historical Trends in Nov-Mar 500hPa Height




12
11
10
9
8
7
6
275
300
325
350
375
U_{700hPa} (m/s), 42.5–47.5°N, 115–130°W (Nov–Mar)
ΔH_{500hPa} (m), Southern Box minus Northern Box
Interannual Variations in Nov-Mar Westerlies


2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-50
-25
0
25
50
Δ U700hPa (m/s), 44–48°N, 115–130°W (Nov–Mar)
Δ H500hPa (m), Southern Box minus Northern Box

Future Wind Changes – from GCMs



20 of 24 models show a decline for the region studied!

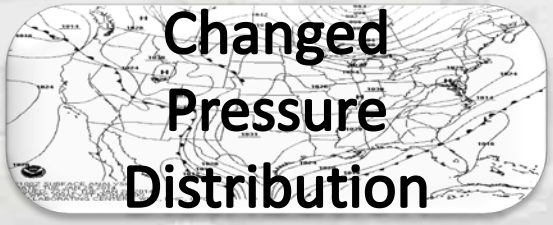
Drivers of PPTN Change

- Dynamic
  - Spreading Hadley Cell
  - Northward shift in jetstream
  - **Changing winds over mountains**
- Thermodynamic
  - Clausius-Clapeyron Relationship
  - Higher Lifting Condensation Level
  - Cloud microphysics

See Seager et al., 2010; Smith and Kirnbaum, 2008

Cascading Changes

Differential Heating

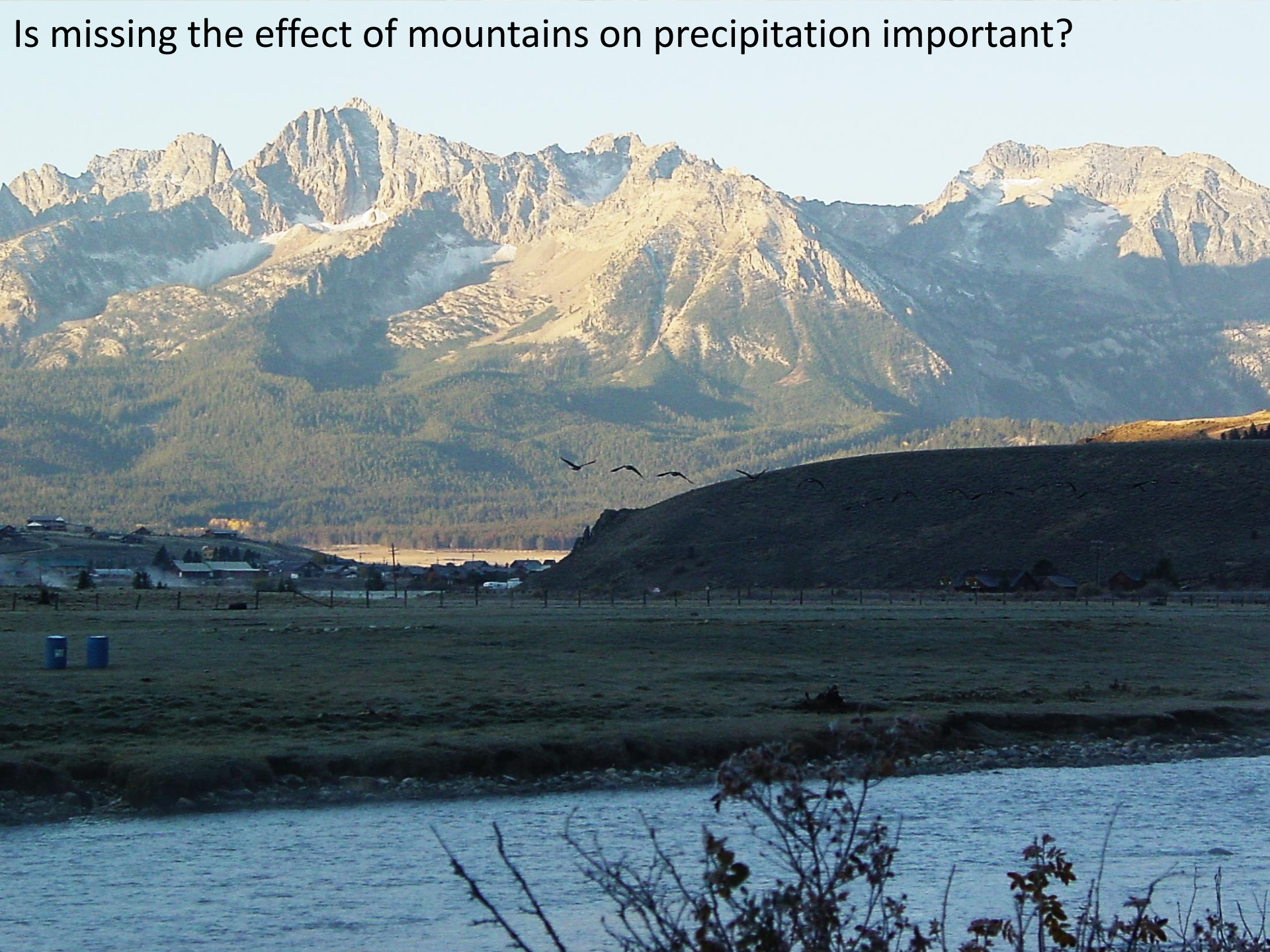


Changed Wind

Changed Mountain Precipitation

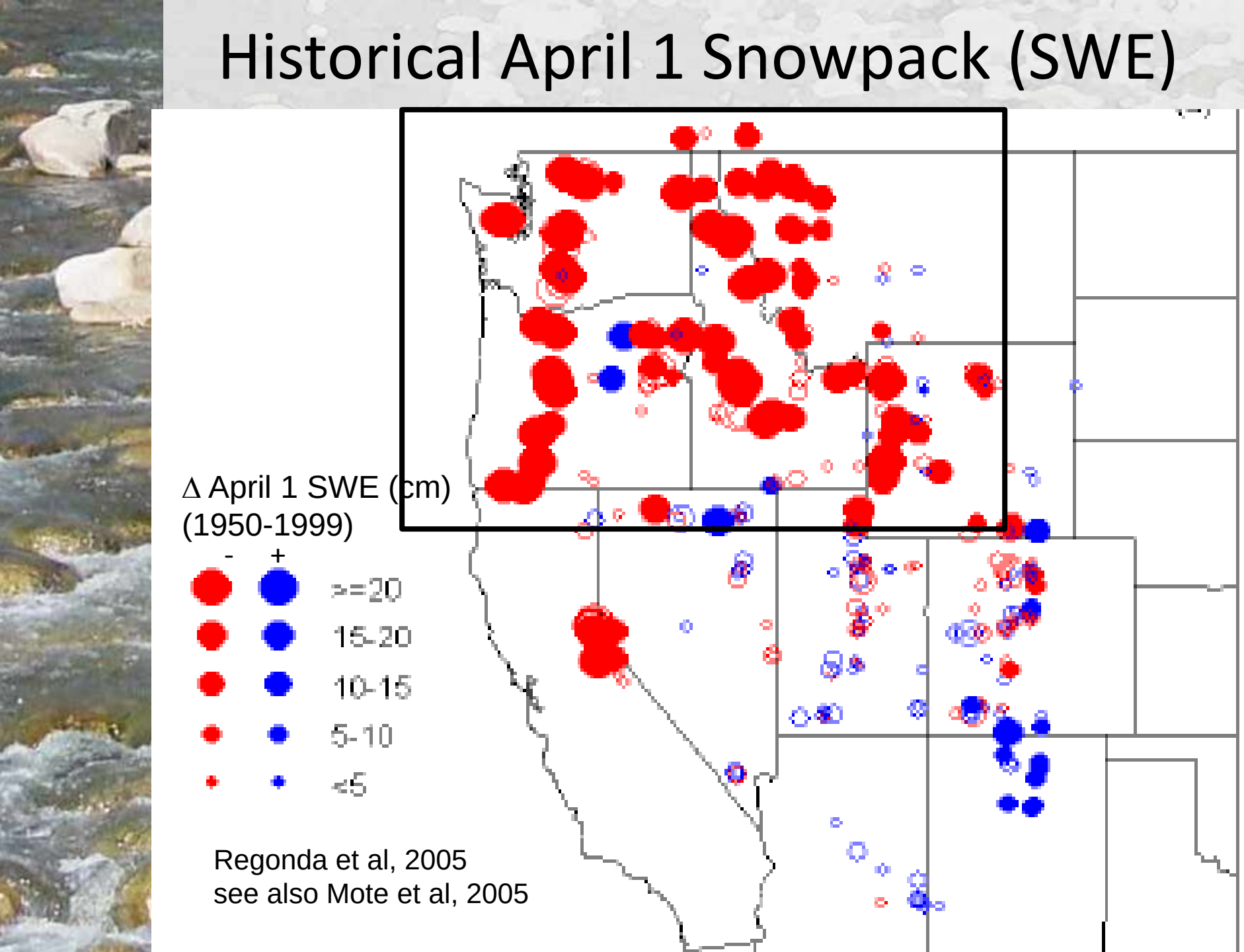
Changed Streamflow

Is missing the effect of mountains on precipitation important?



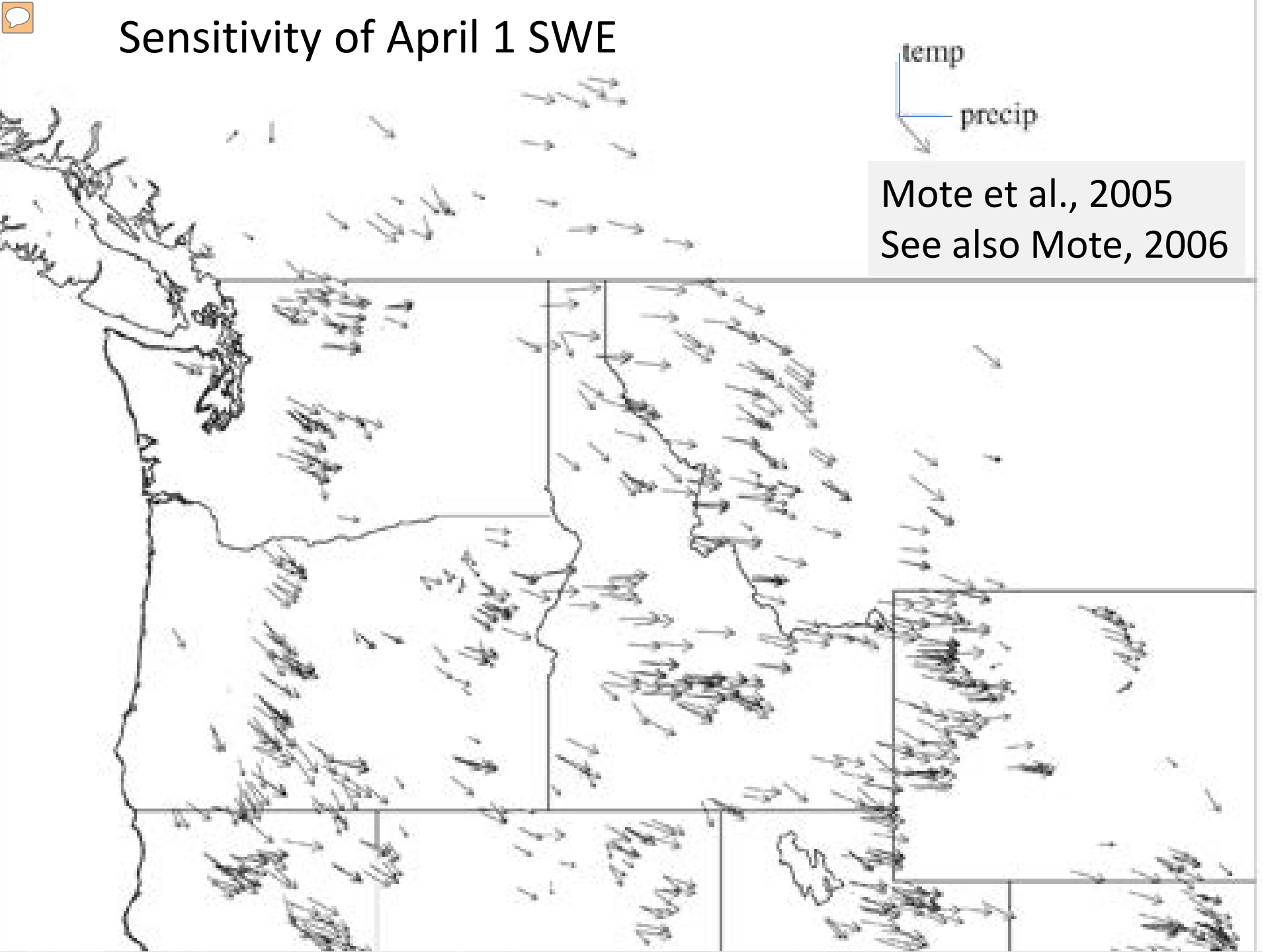
Adaptation Choices

Historical April 1 Snowpack (SWE)



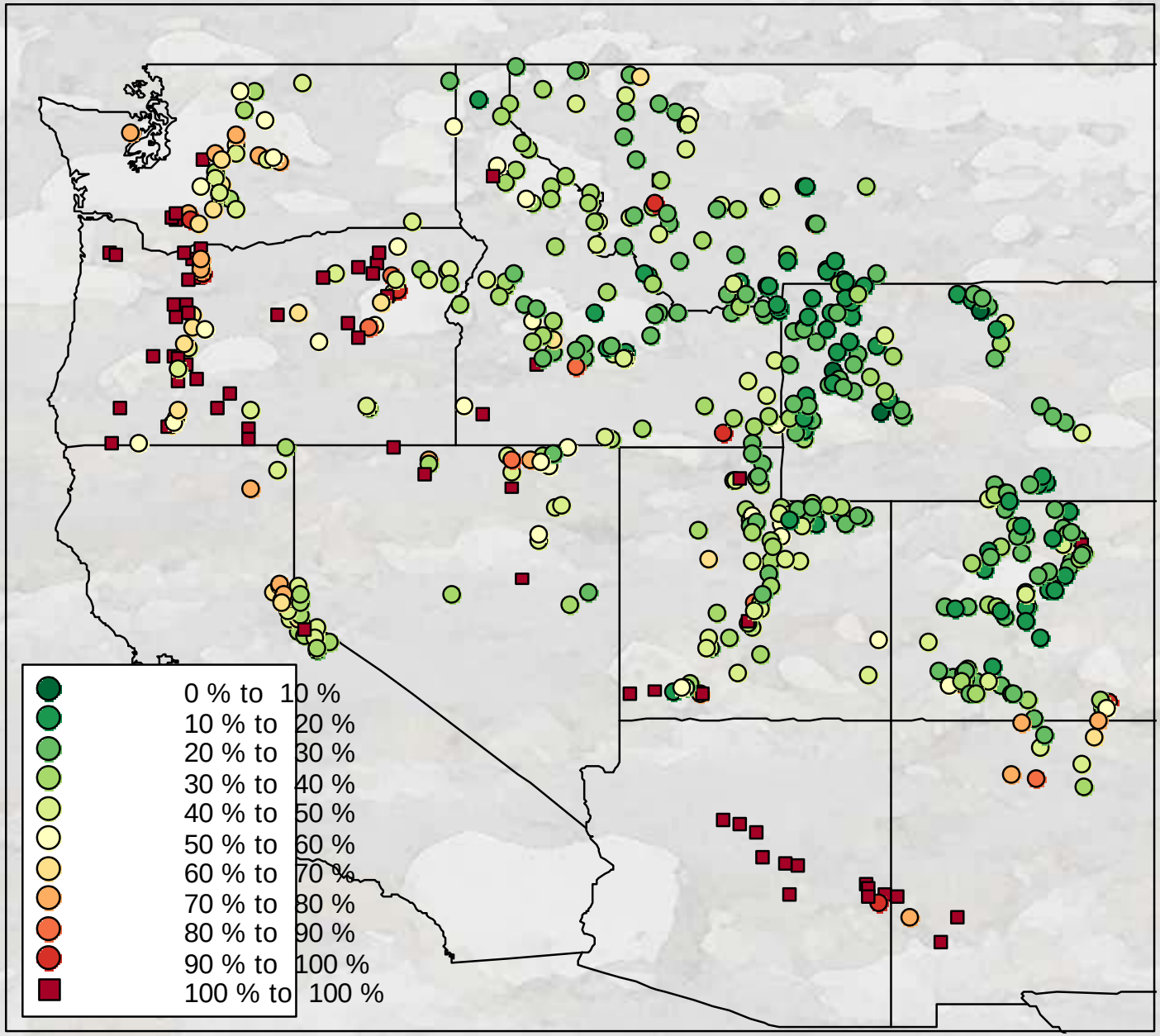
Regonda et al, 2005
see also Mote et al, 2005

Sensitivity of April 1 SWE

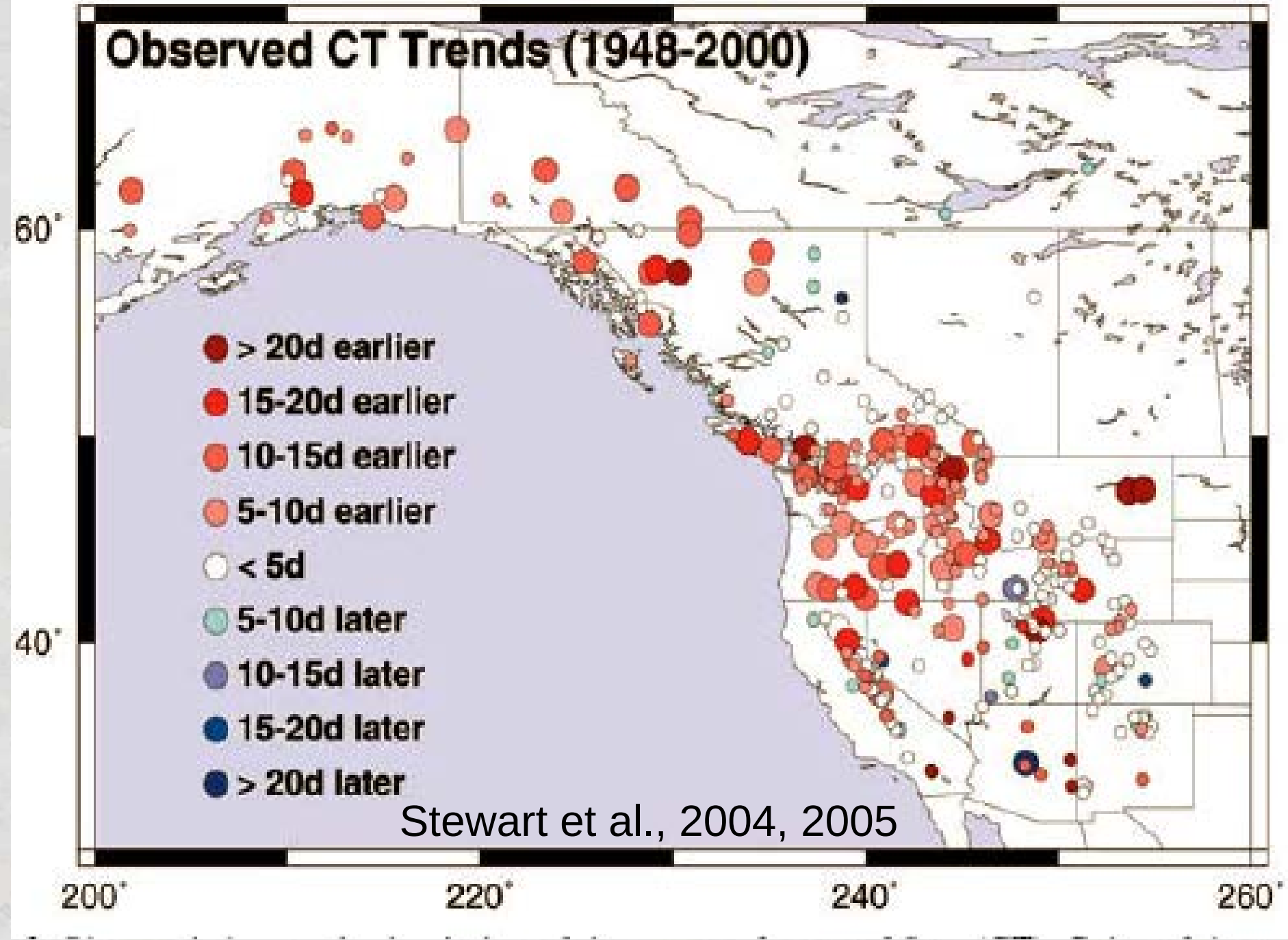


Mote et al., 2005
See also Mote, 2006

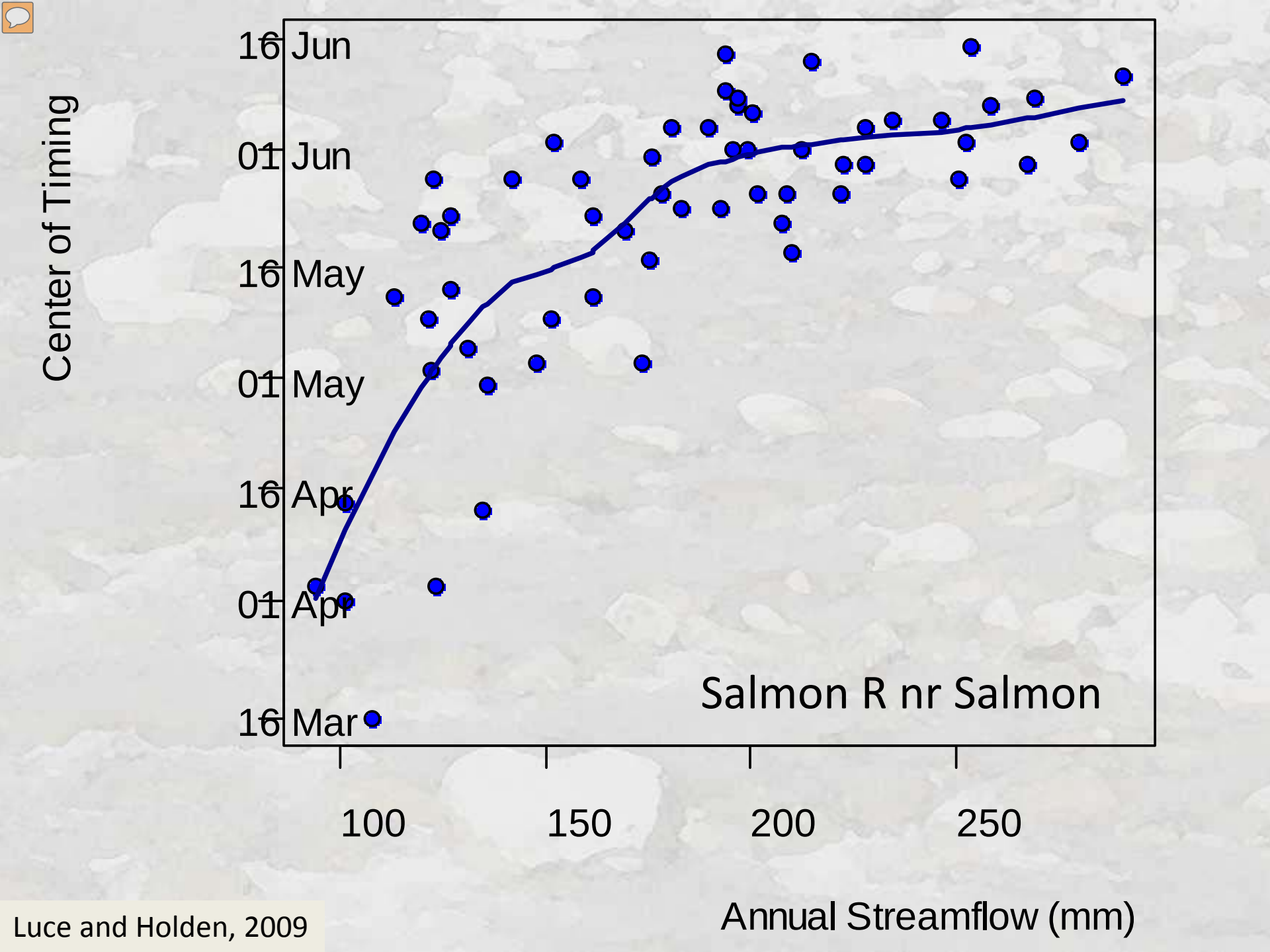
Loss in April 1 SWE with 3°C increase - SNOTEL



Luce et al. (in review)

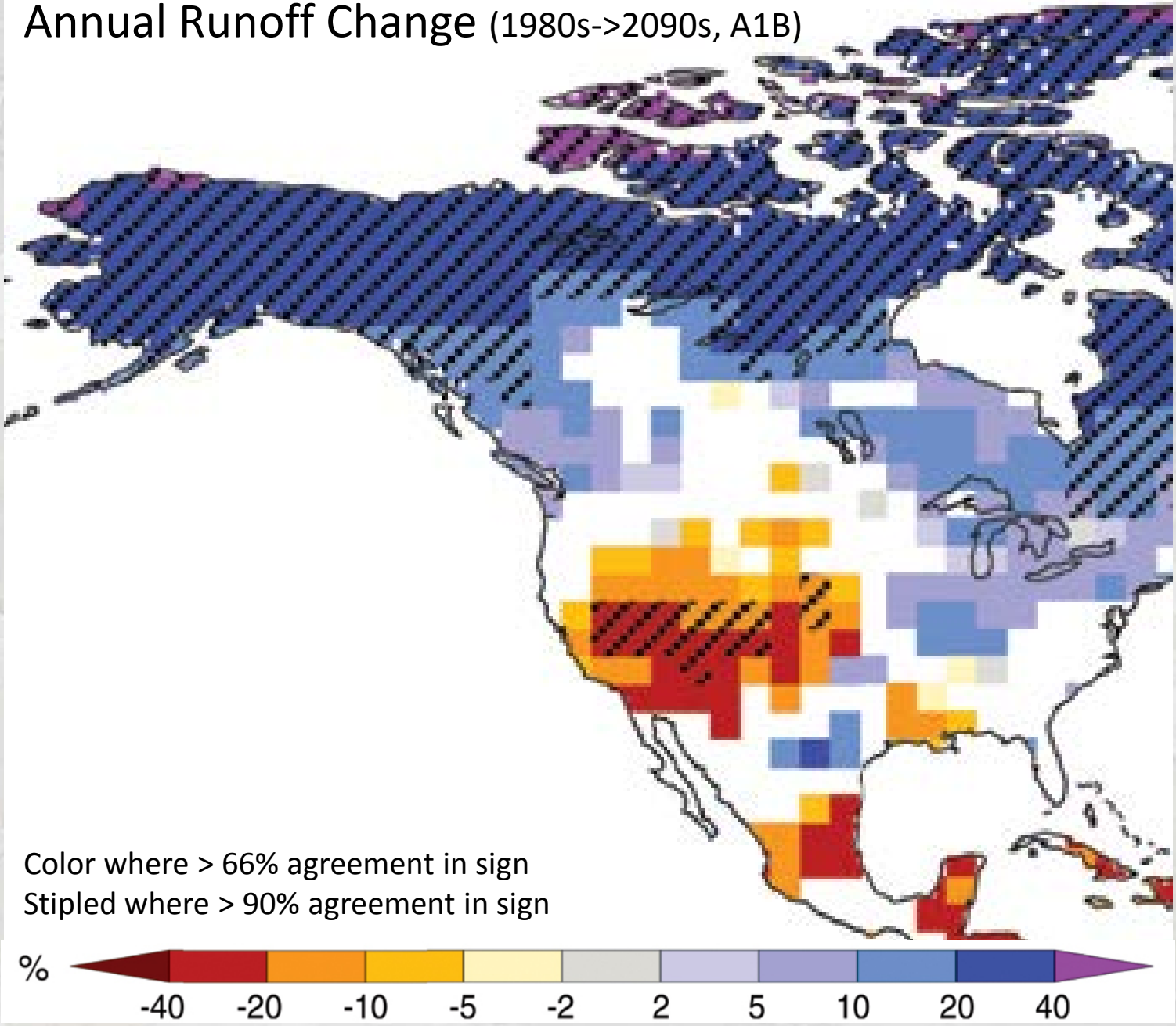


Stewart et al., 2004, 2005



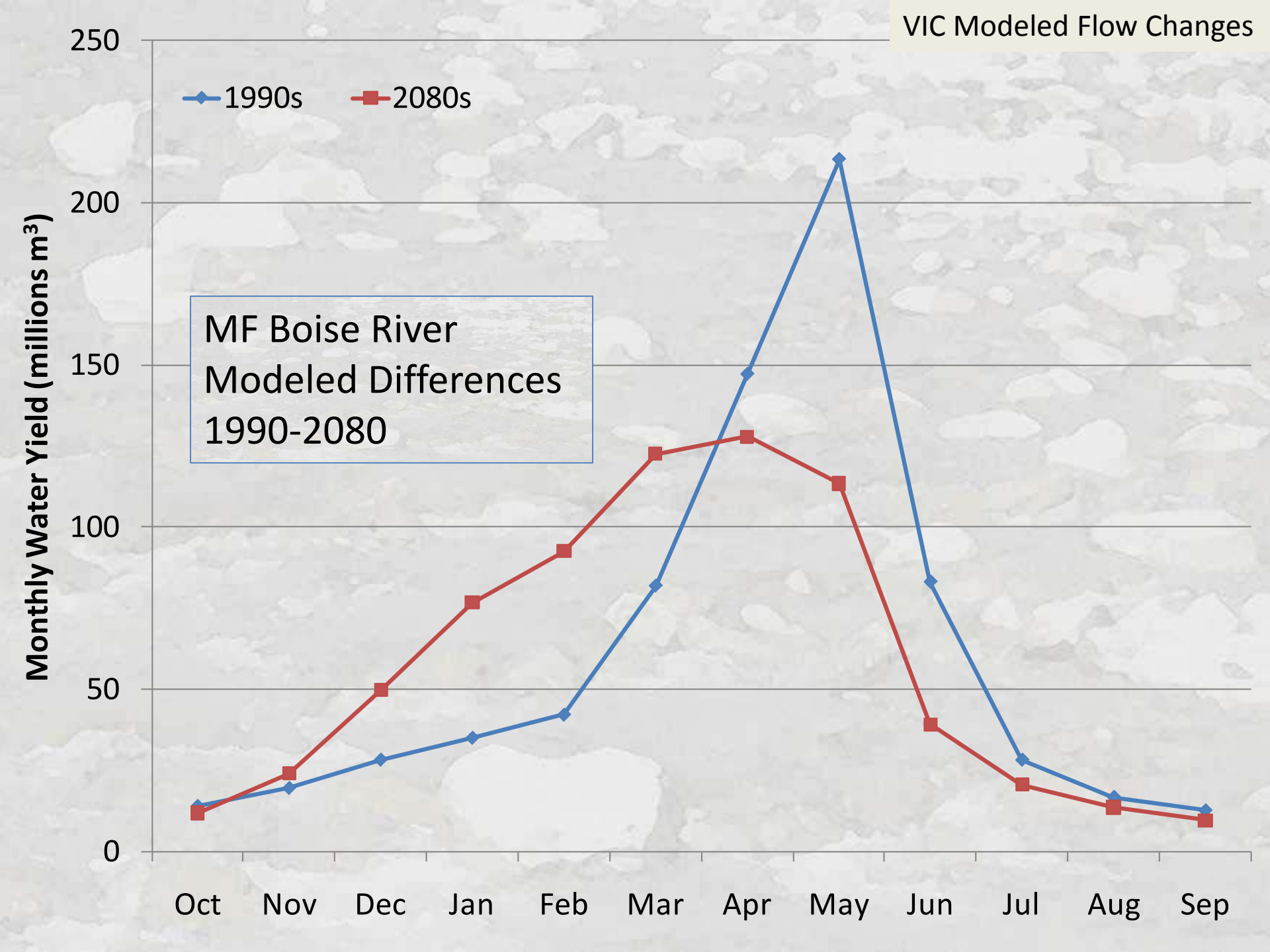
Luce and Holden, 2009

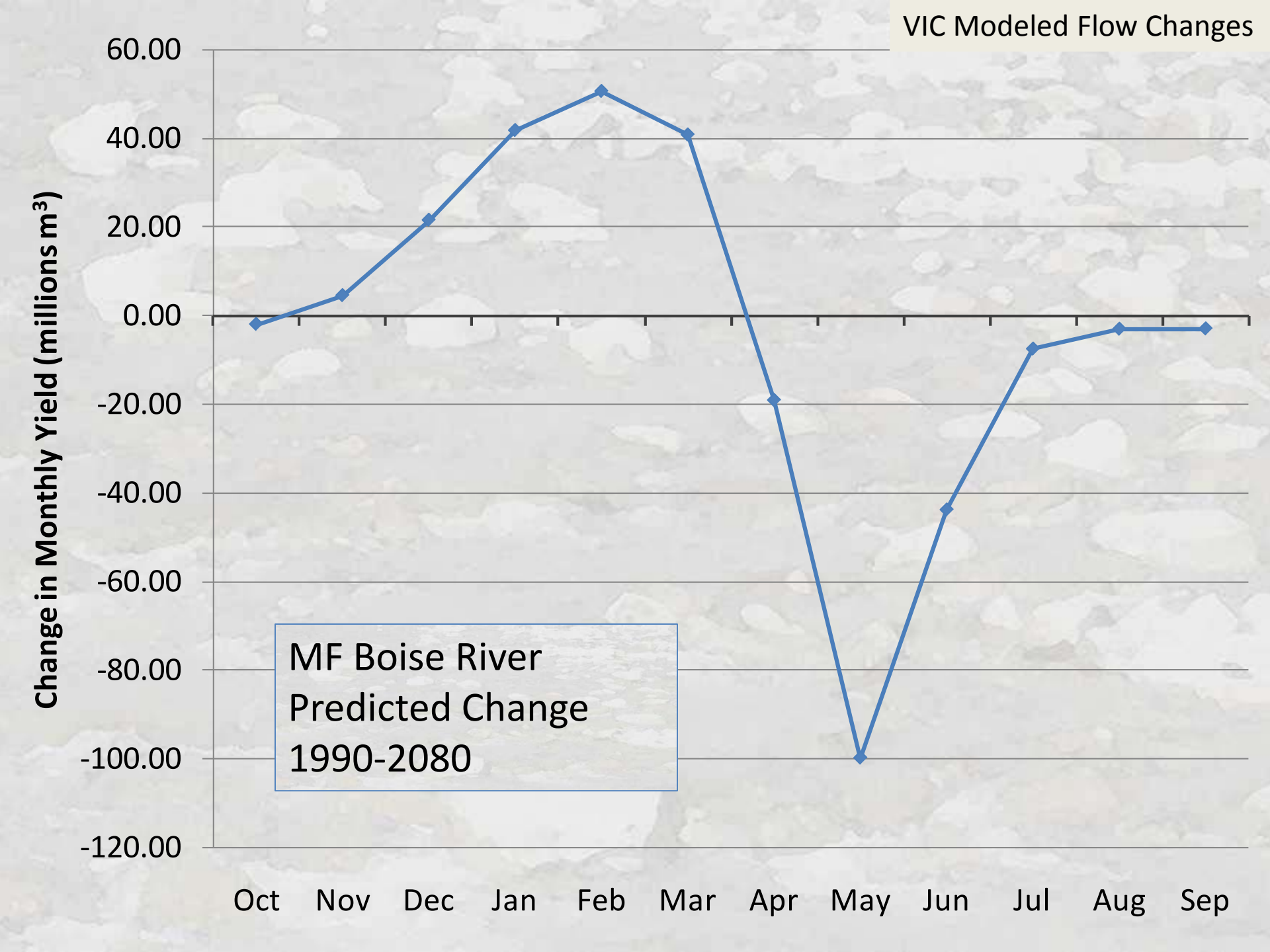
Annual Runoff Change (1980s->2090s, A1B)



IPCC AR4 SYR 3.5

VIC Modeled Flow Changes




VIC Modeled Flow Changes
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
Change in Monthly Yield (millions m³)
MF Boise River
Predicted Change
1990-2080
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

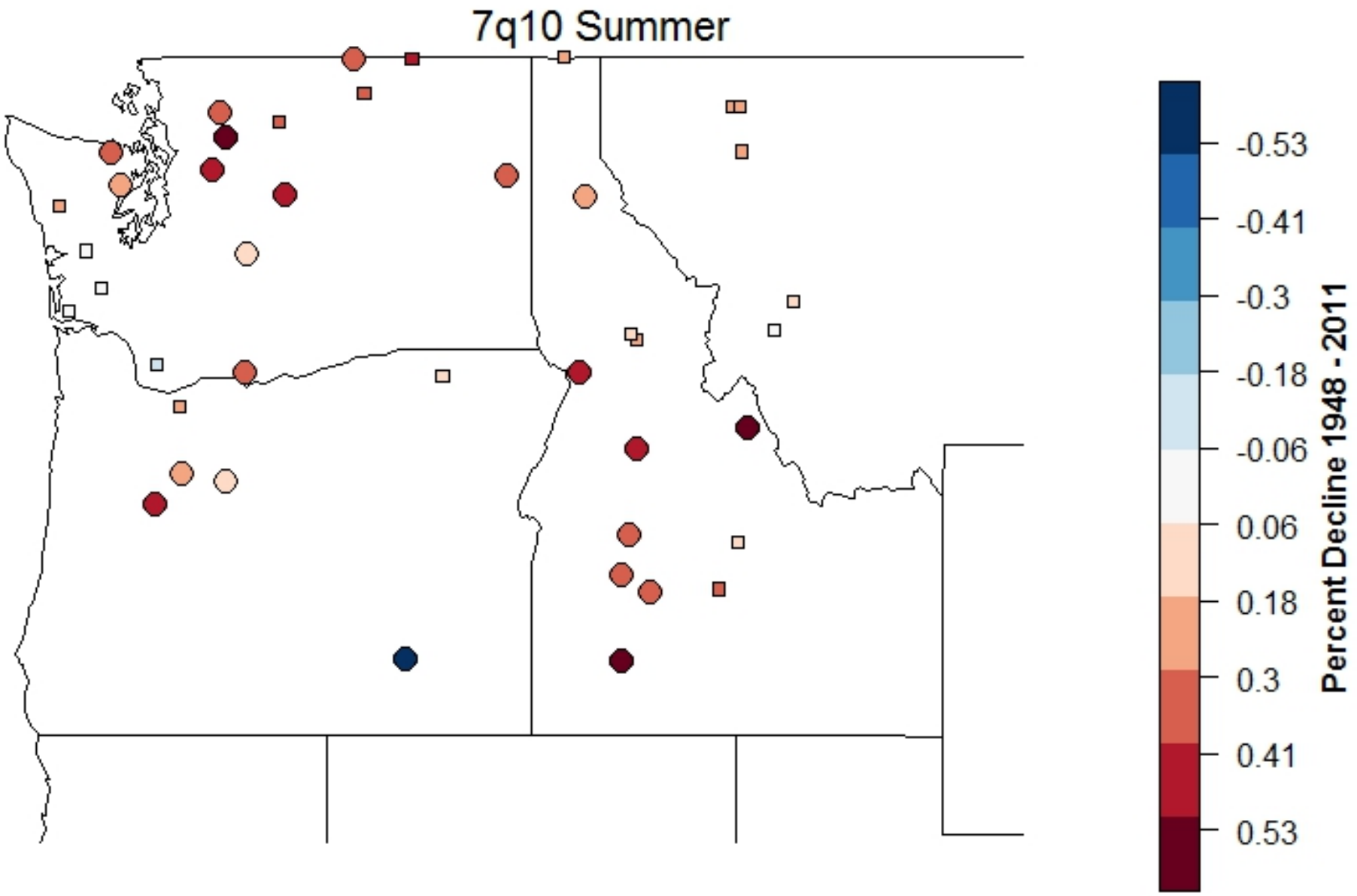
Change in Monthly Yield (millions m³)

60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00

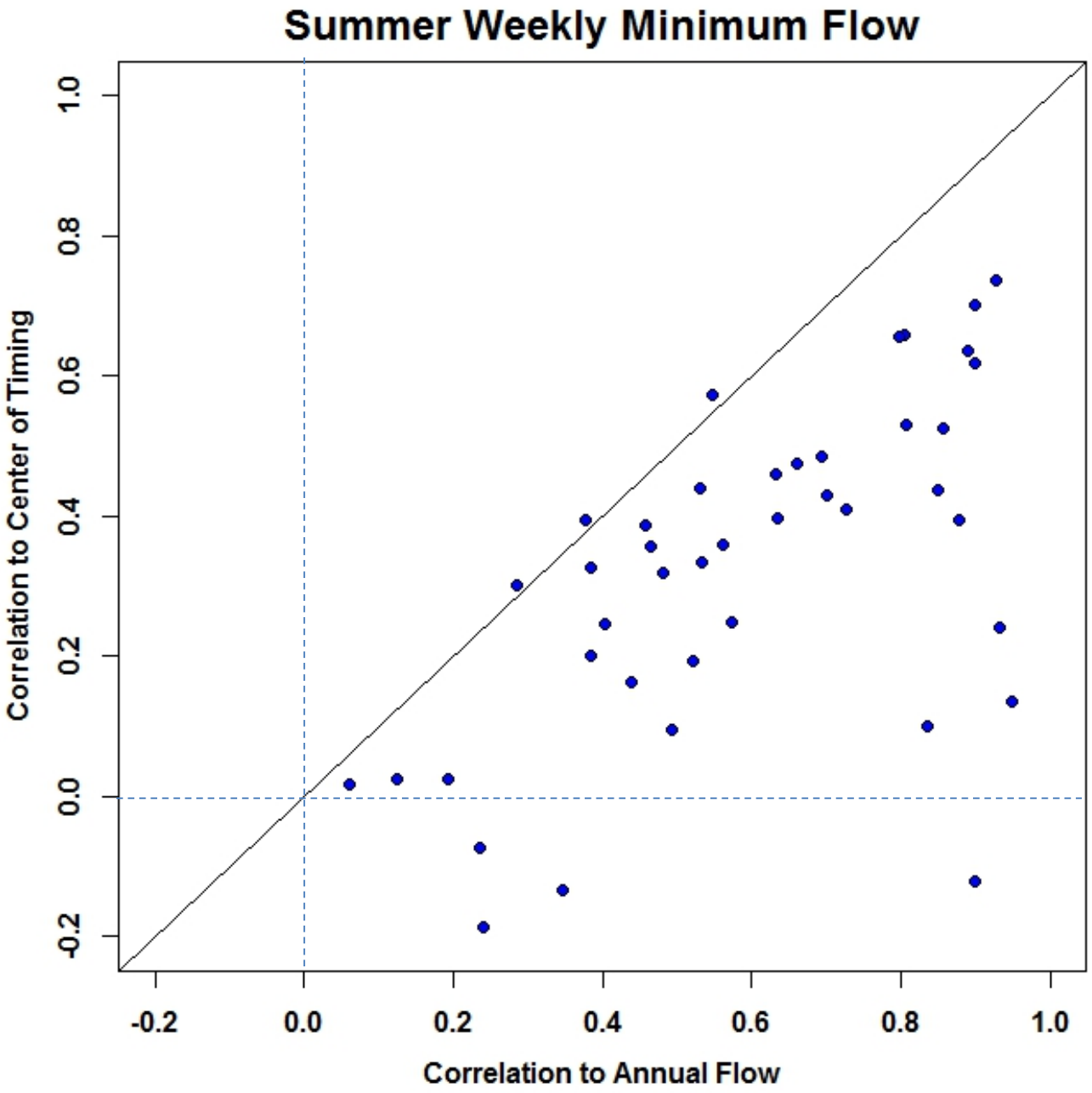
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

Modeled Flow Changes 1990s-2080s

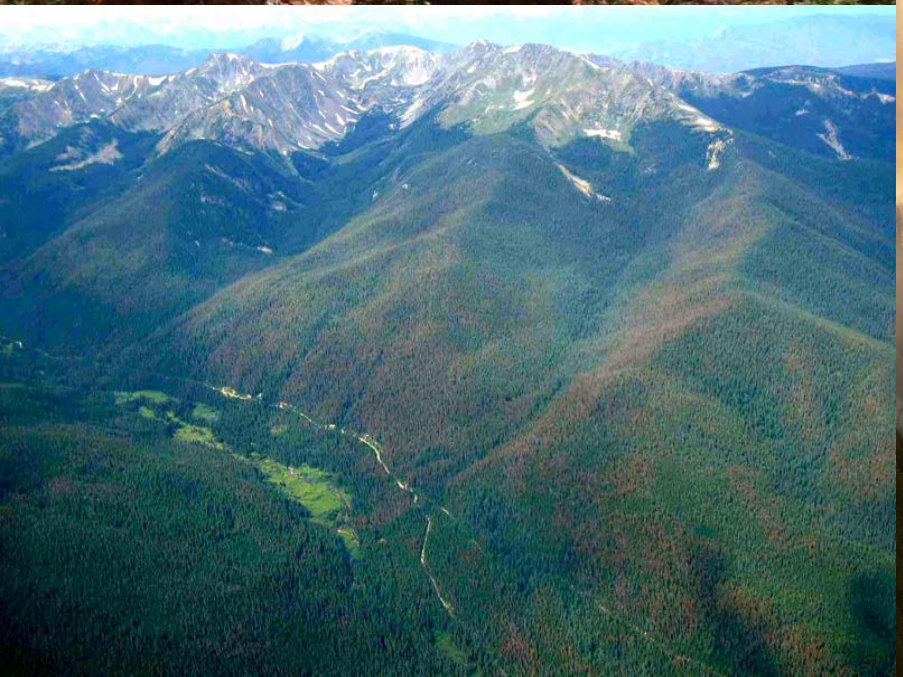
Observed Flow Changes 1950s-1990s



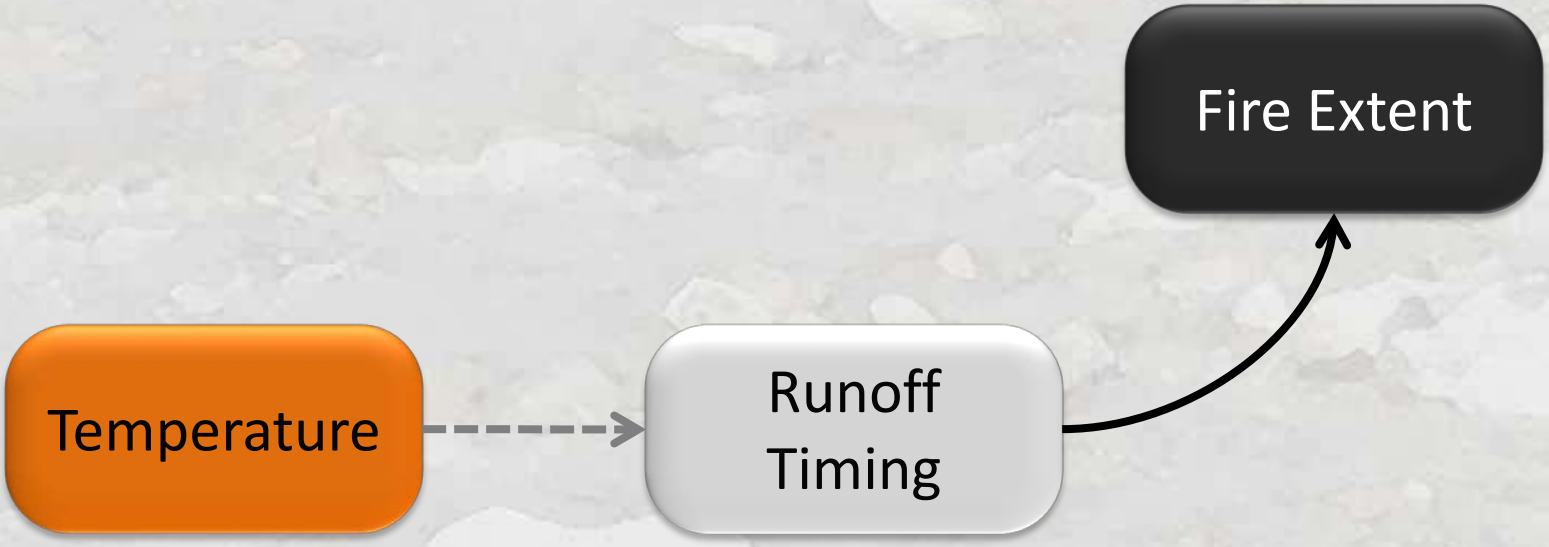
Kormos, in prep



Kormos, in prep

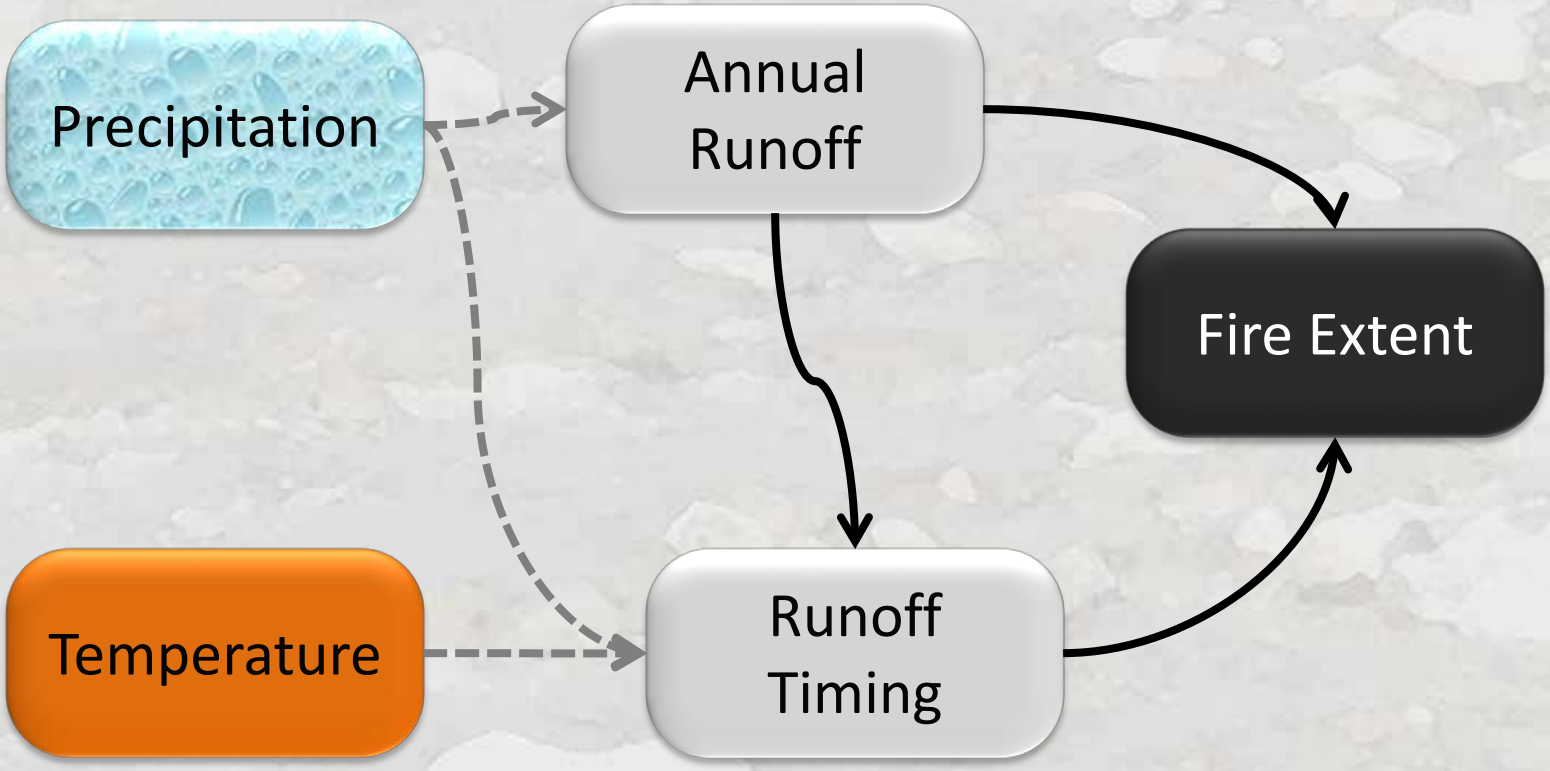


Burned Area Sensitivity



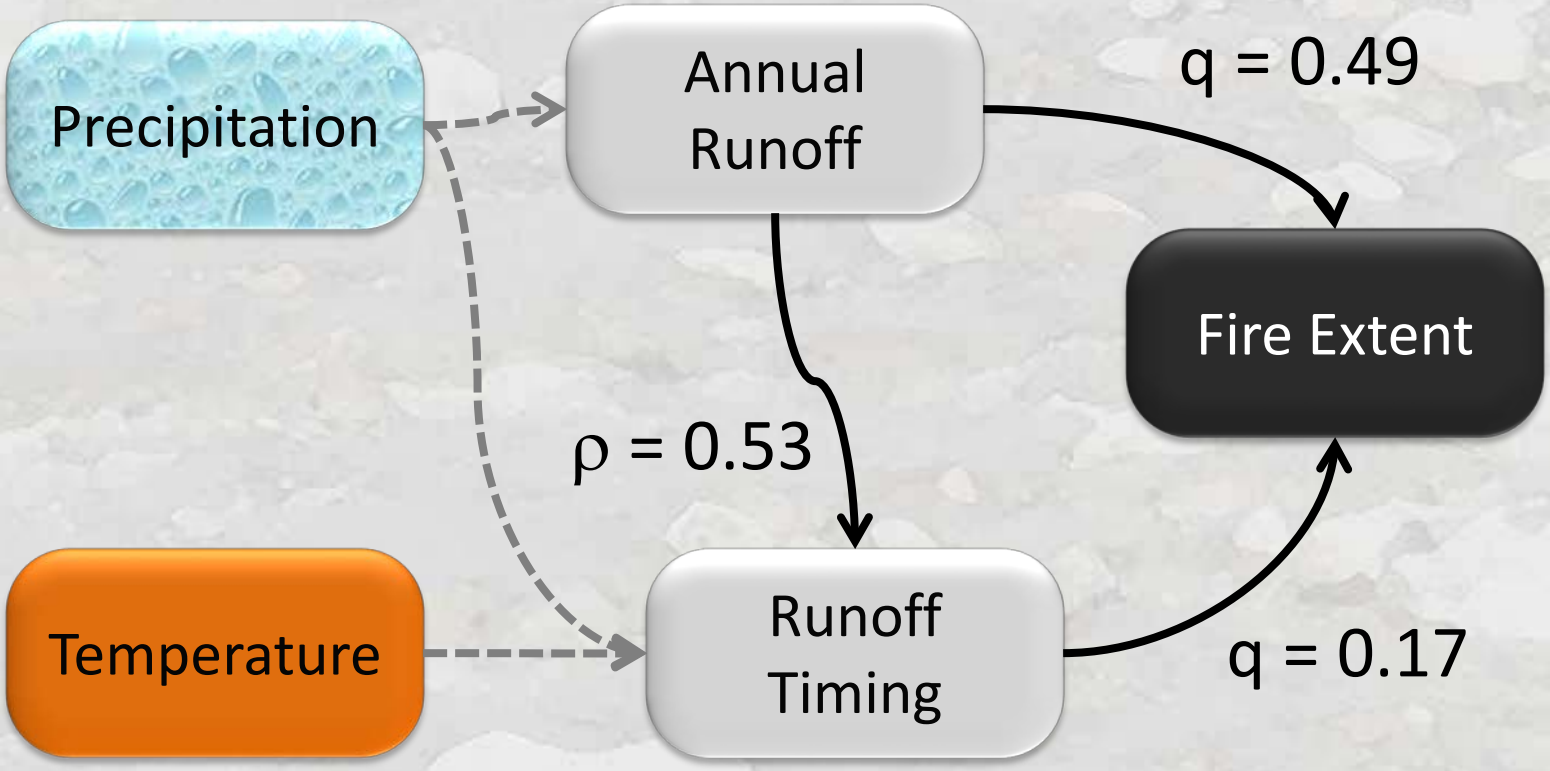
Westerling et al., 2006, 2011

Burned Area Sensitivity

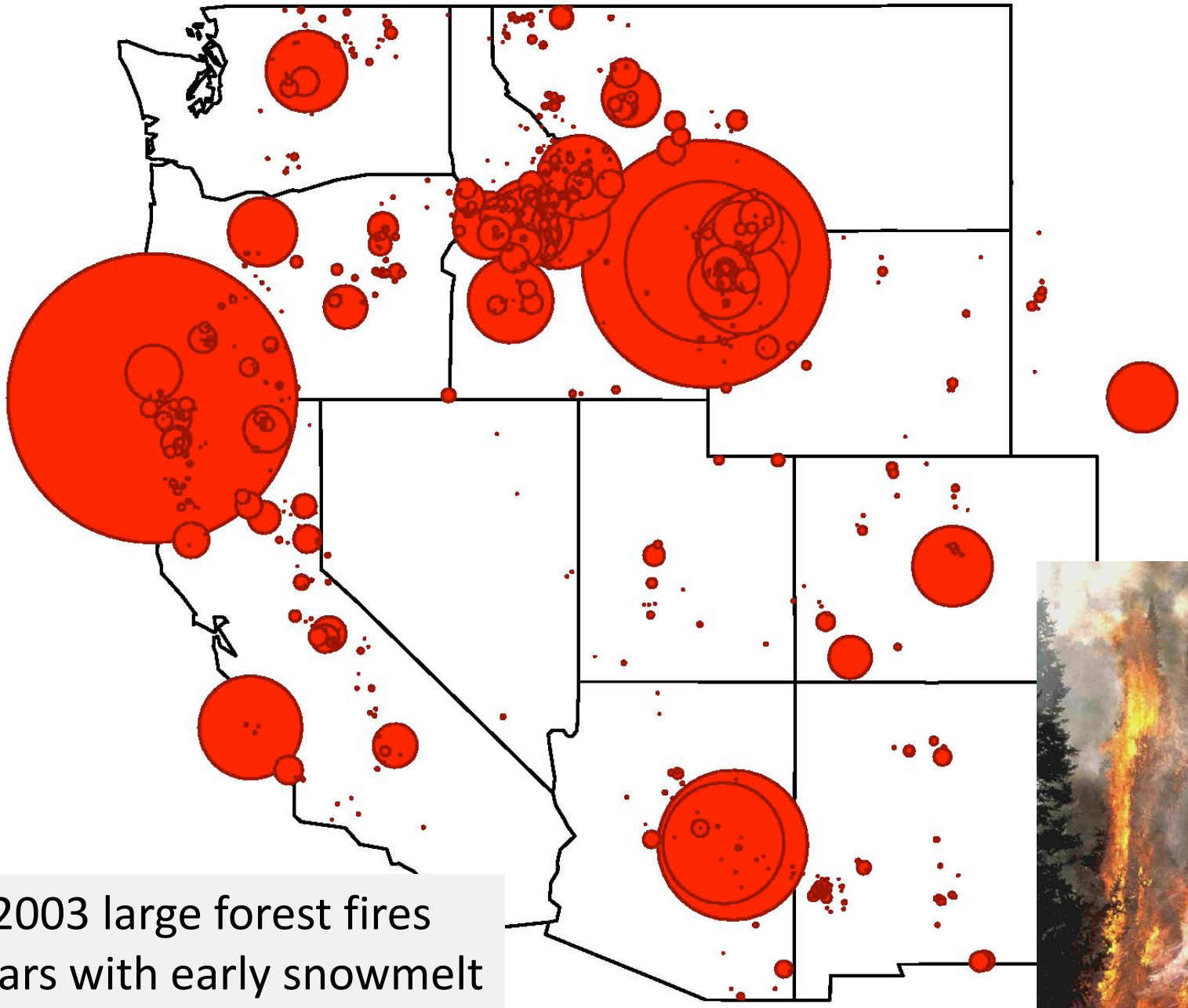


Holden et al., 2012

Burned Area Sensitivity

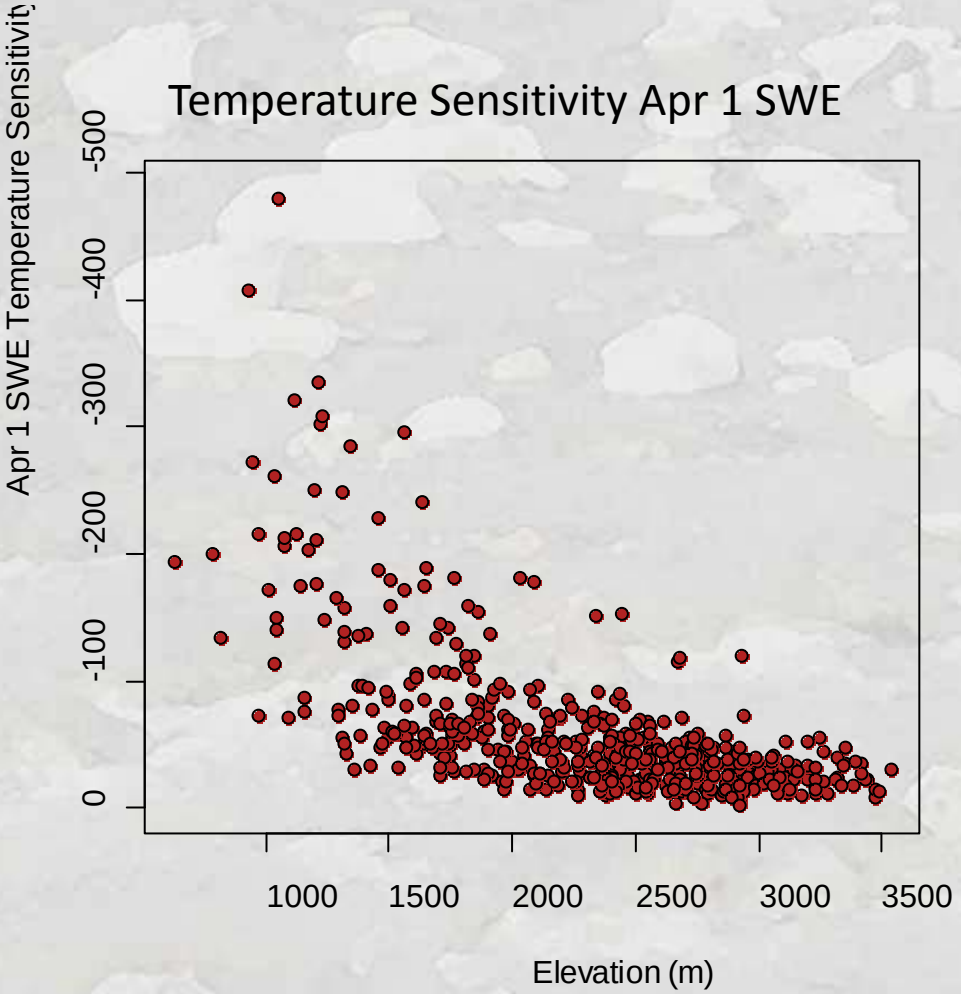


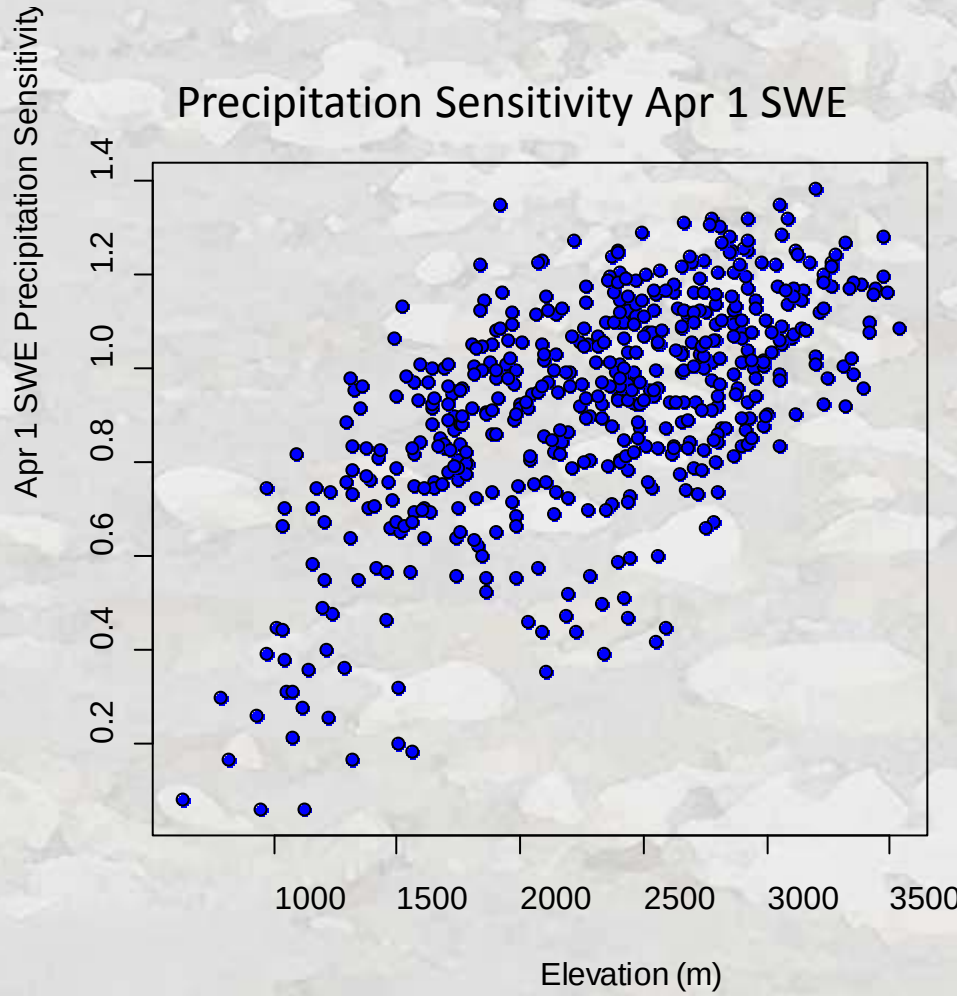
Holden et al., 2012



1972-2003 large forest fires
For years with early snowmelt
Westerling et al, 2006

Fires on National Forests 2001-2007





Luce et al. (in review)

Summary

- Mountain precipitation has declined in Idaho.
- ‘Low’ elevation precipitation has shown no trend over the same period.
- Knowledge of the trend is essential for understanding historical snow and ecology changes and sensitivity.
- Insights from the trend may be informative for assessing future changes in precipitation.