# Causal Influences on Increasing Hydrologic Drought Severity: Northwest U.S.


Charles Luce, US Forest Service Research

Patrick Kormos, NOAA Colorado Basin River Forecast Center

Seth Wenger, University of Georgia

Wouter Berghuijs, University of Bristol & ETH Zurich

# Contrasting Snowmelt Contributions

Quartzville Ck
(rain and a little snow)

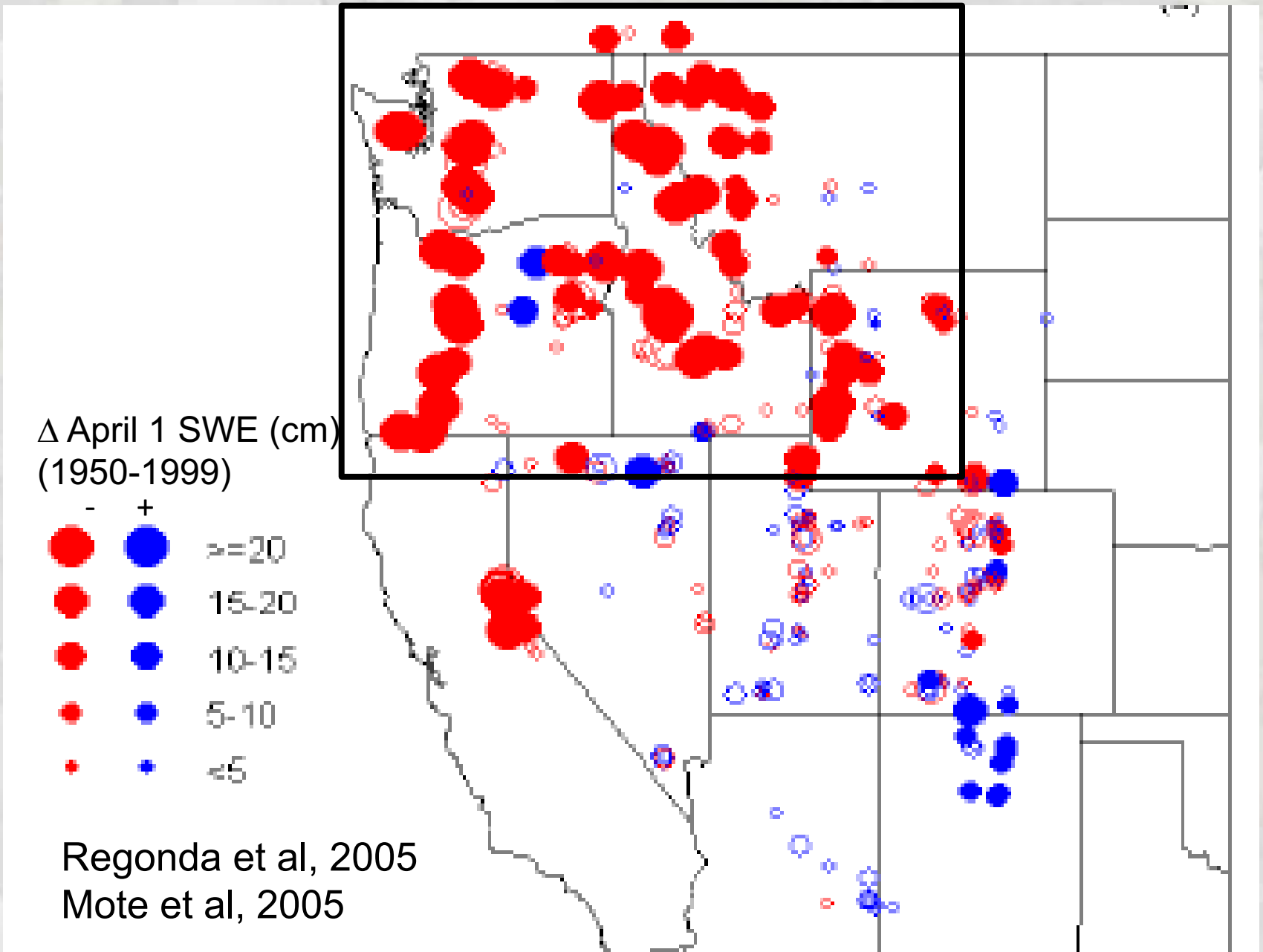
Boise R
(mostly snow)

Flow (cfs)

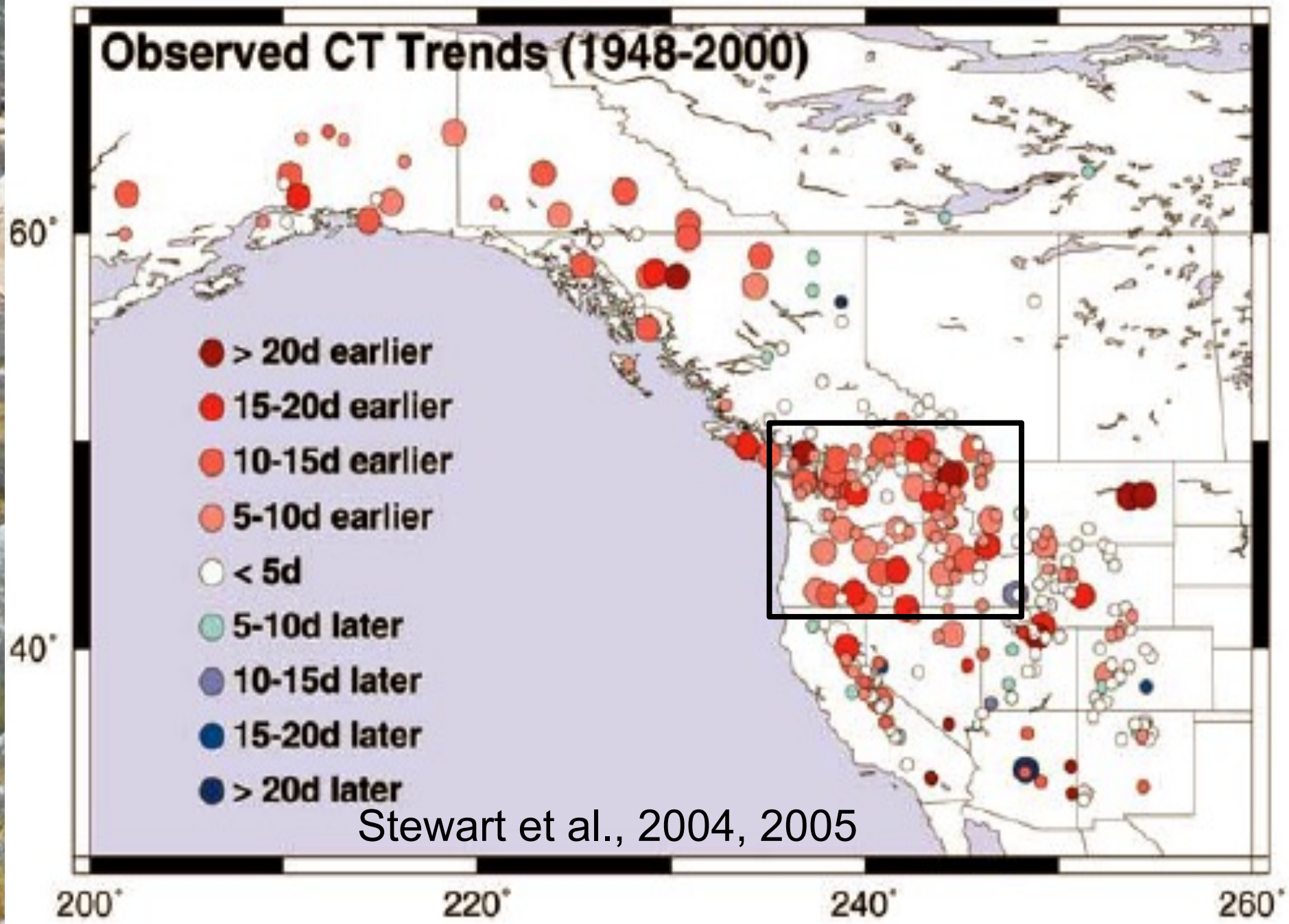
0
2000
4000
6000
8000

Nov
Jan
Mar
May
Jul
Sep

# Decreasing April 1 Snowpack (SWE)




Regonda et al, 2005
Mote et al, 2005




Stewart et al., 2004, 2005

Earlier Streamflow Timing

# Question 1: Is the future already apparent in our low flows, too?

- Climate change hydrologic projections predict:
  - Warmer temperatures, little precipitation change
  - Less snow, more rain
  - Earlier runoff timing
  - Lower low flows

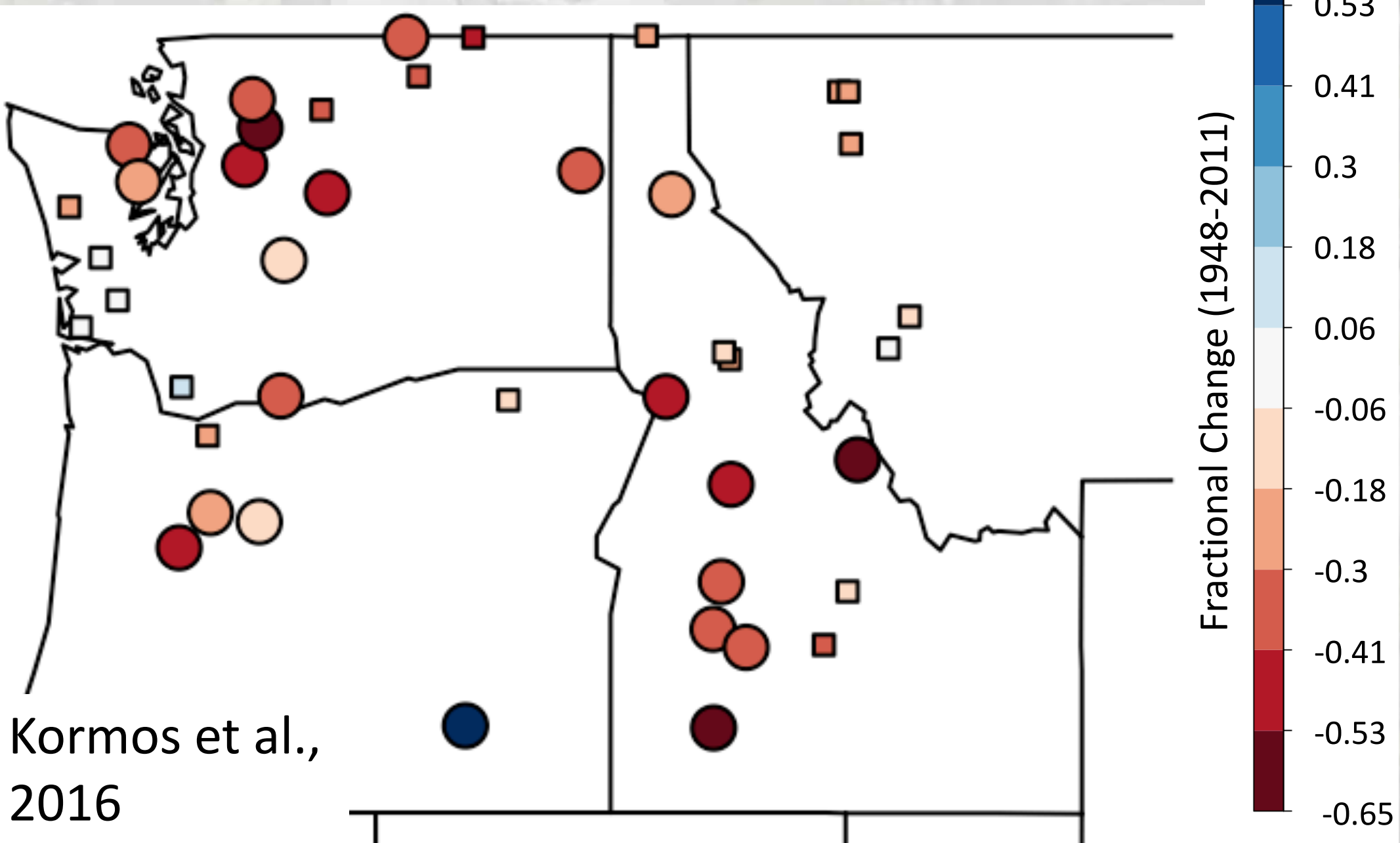
- We have seen less snow
- We have seen earlier timing
- Are we also seeing lower low flows?

# Defining 7Q10

- Minimum 1-week flow
- With probability of occurrence of 0.10

- Constrained June 1 – Nov 15

# 7Q10 Decline: 1948-2011



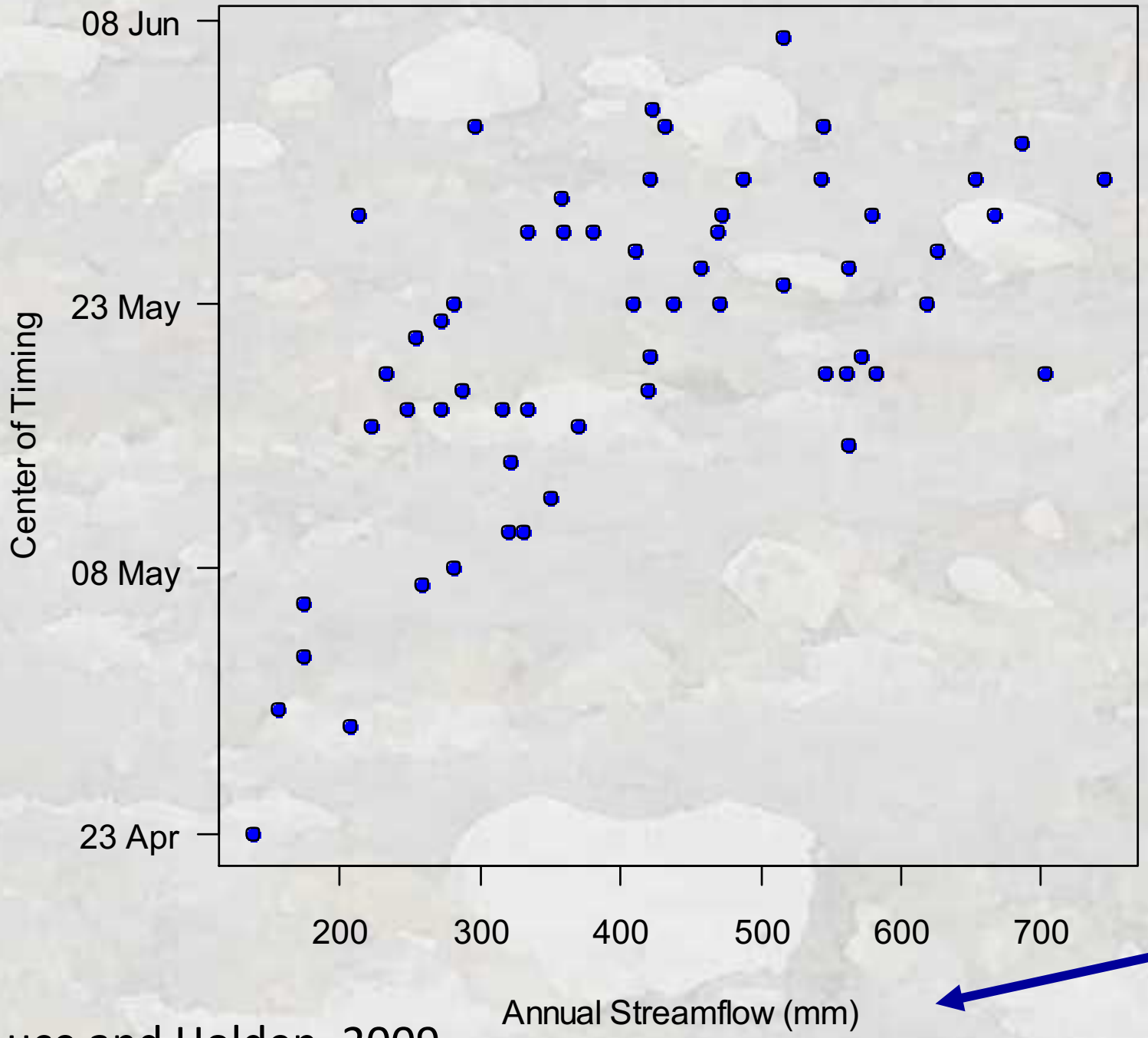

Kormos et al., 2016

# Question 2: Really?

Can we now attribute these lower low-flows to climate change?

*Or phrased alternatively*

Are the declines a consequence of warming temperatures, or … ?

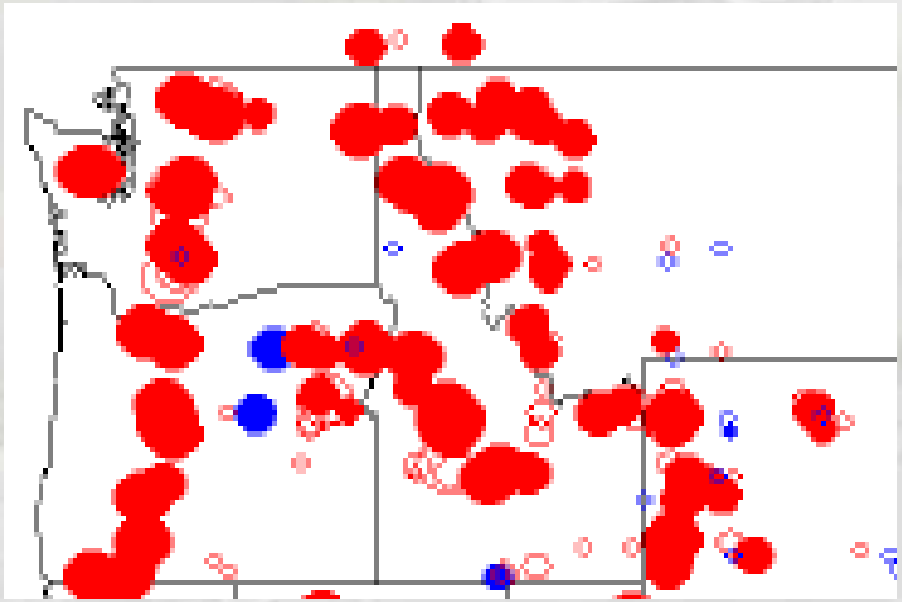



Salmon R. at Salmon

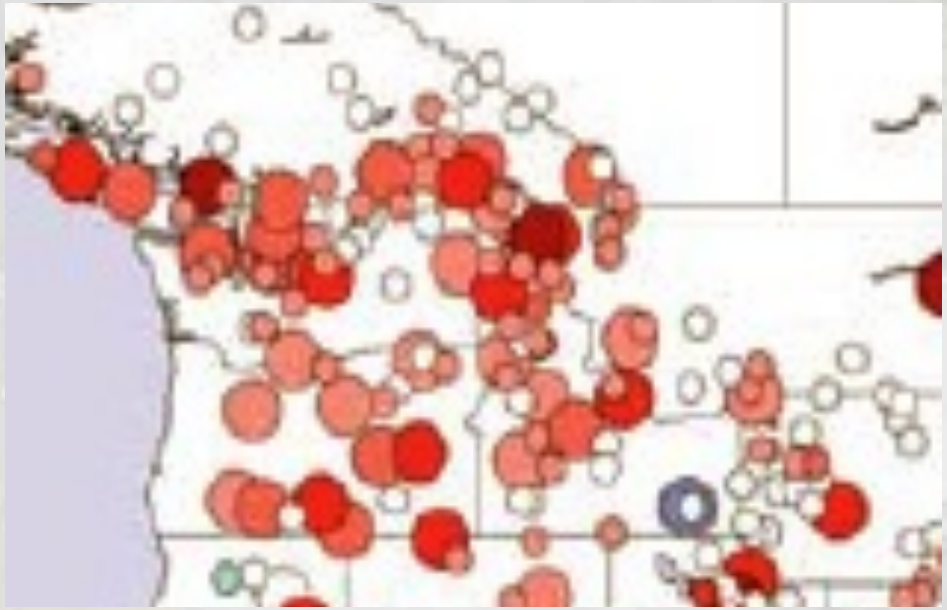
(Strong correlation with precipitation)

Luce and Holden, 2009

# Uniform Effect vs Diverse Sensitivity

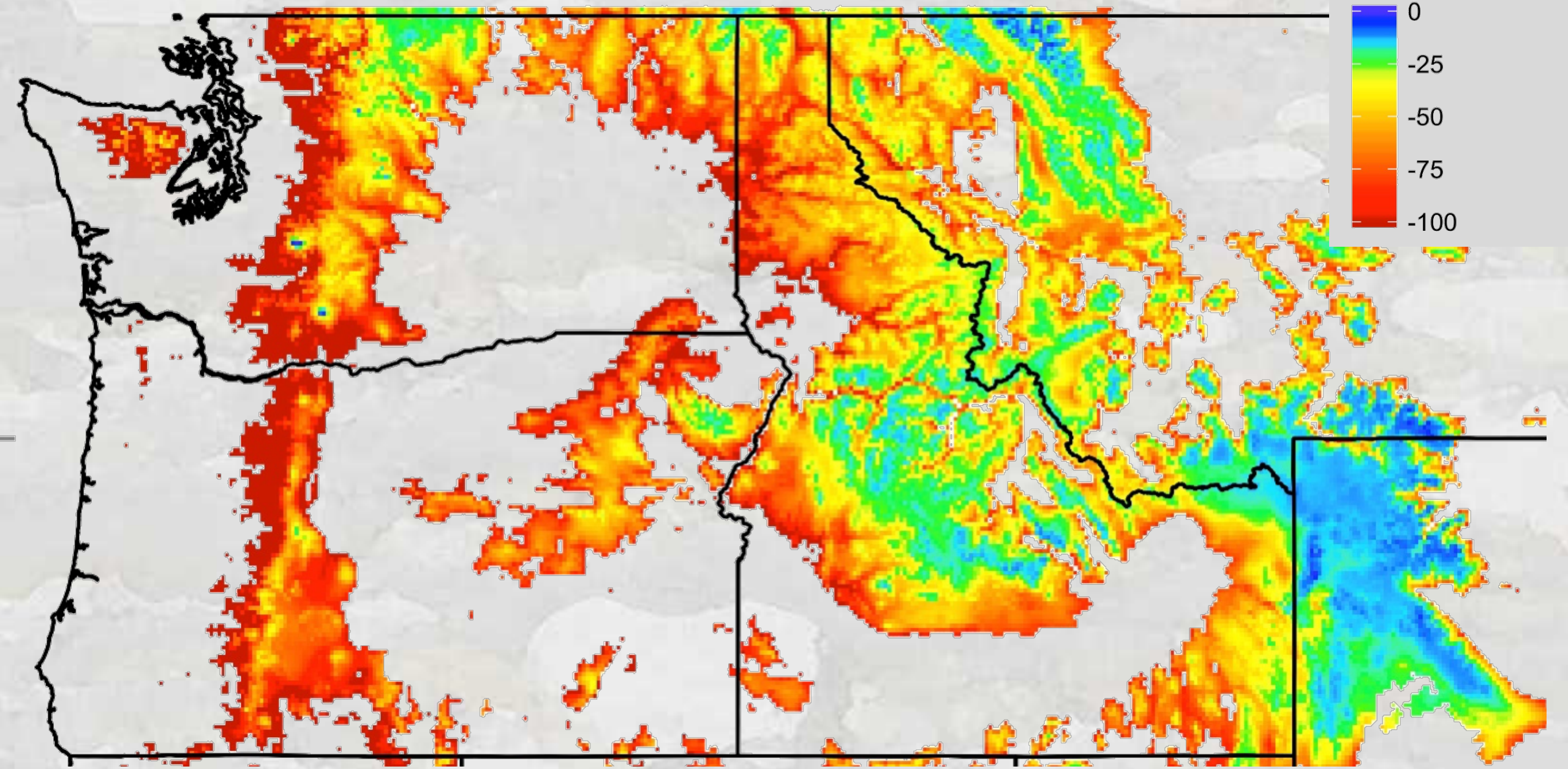


SWE



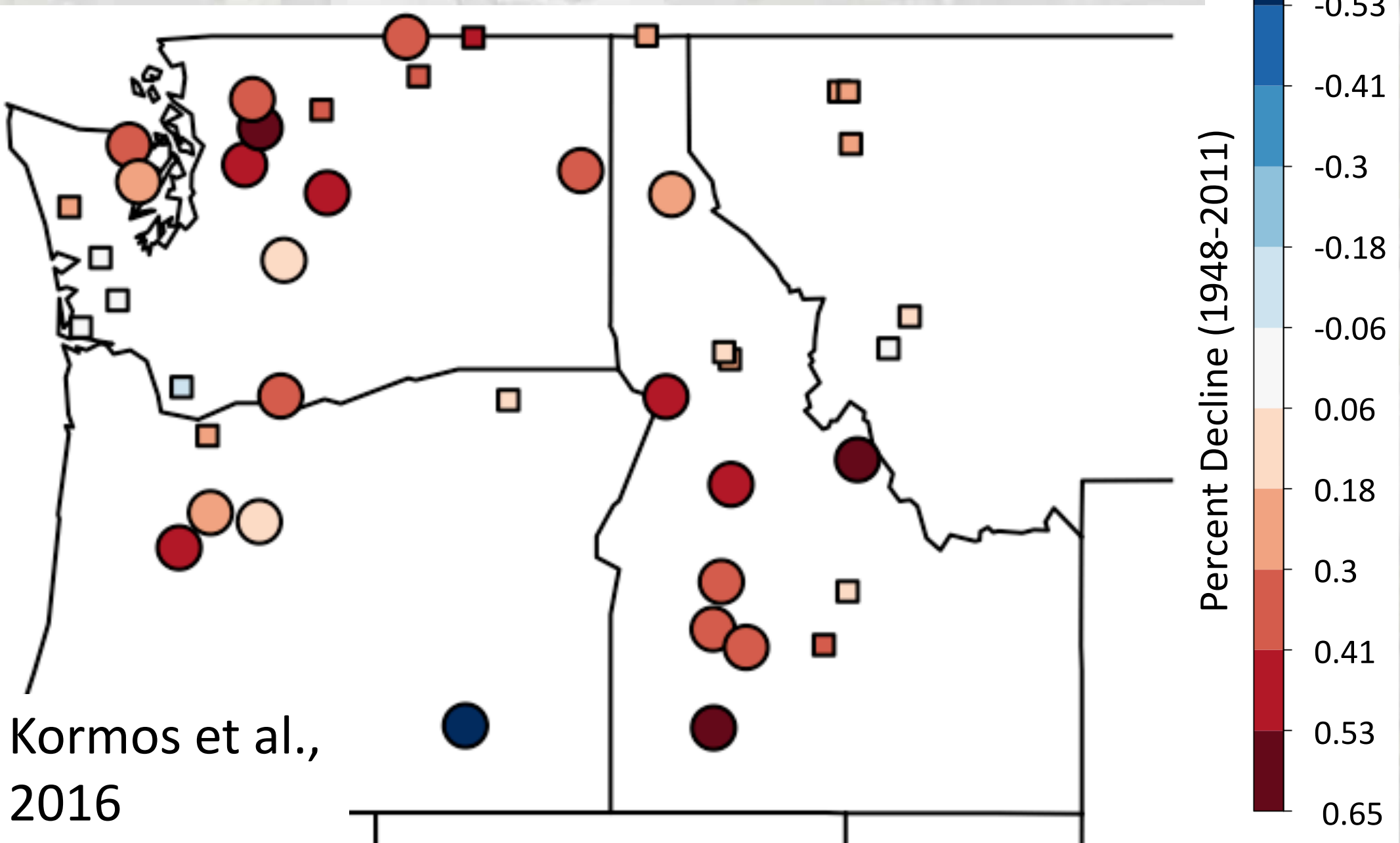
Timing

# April 1 SWE Sensitivity to 3°C Temperature Increase




After Luce et al., 2014 and Lute and Luce, 2017

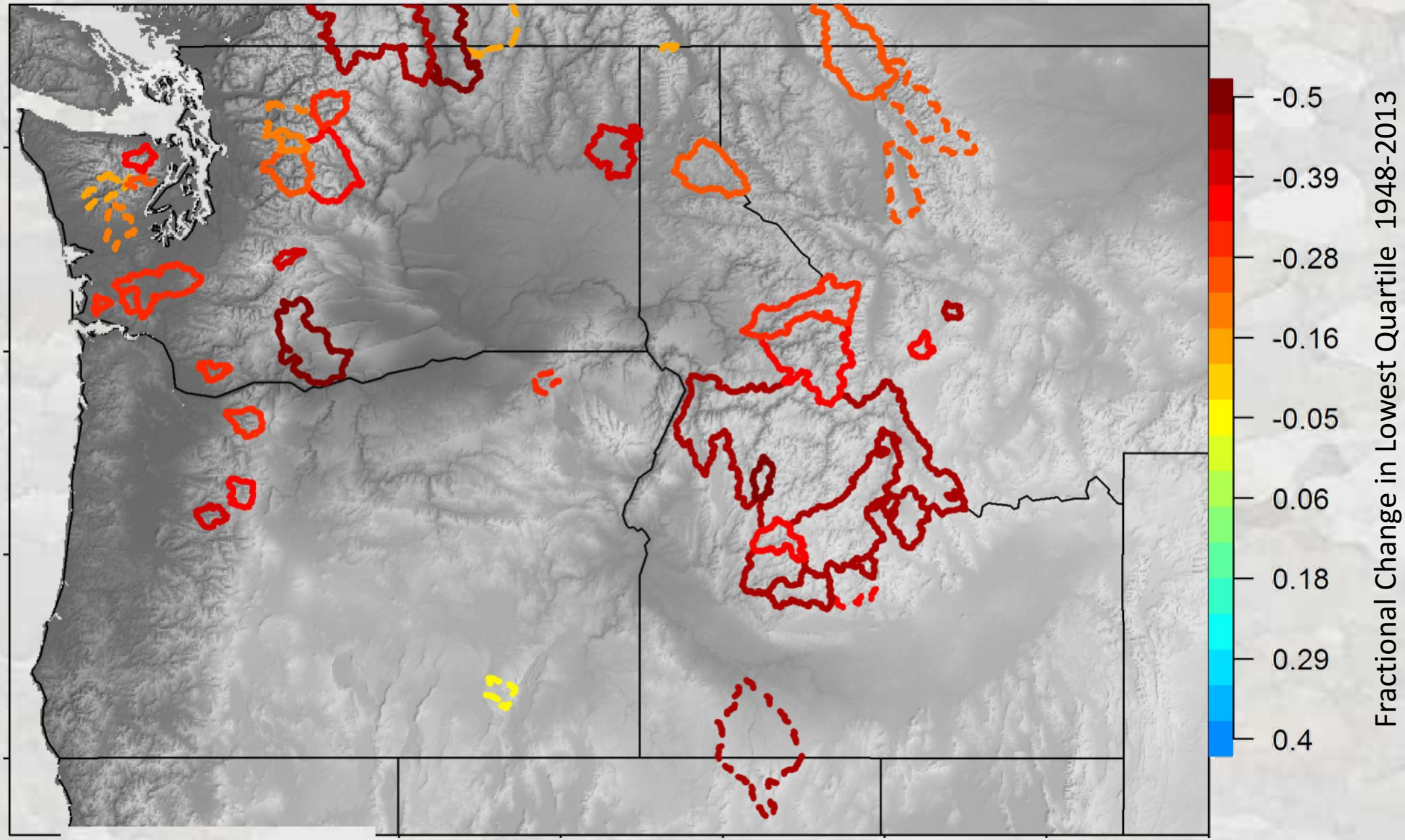
# 7Q10 Decline: 1948-2011



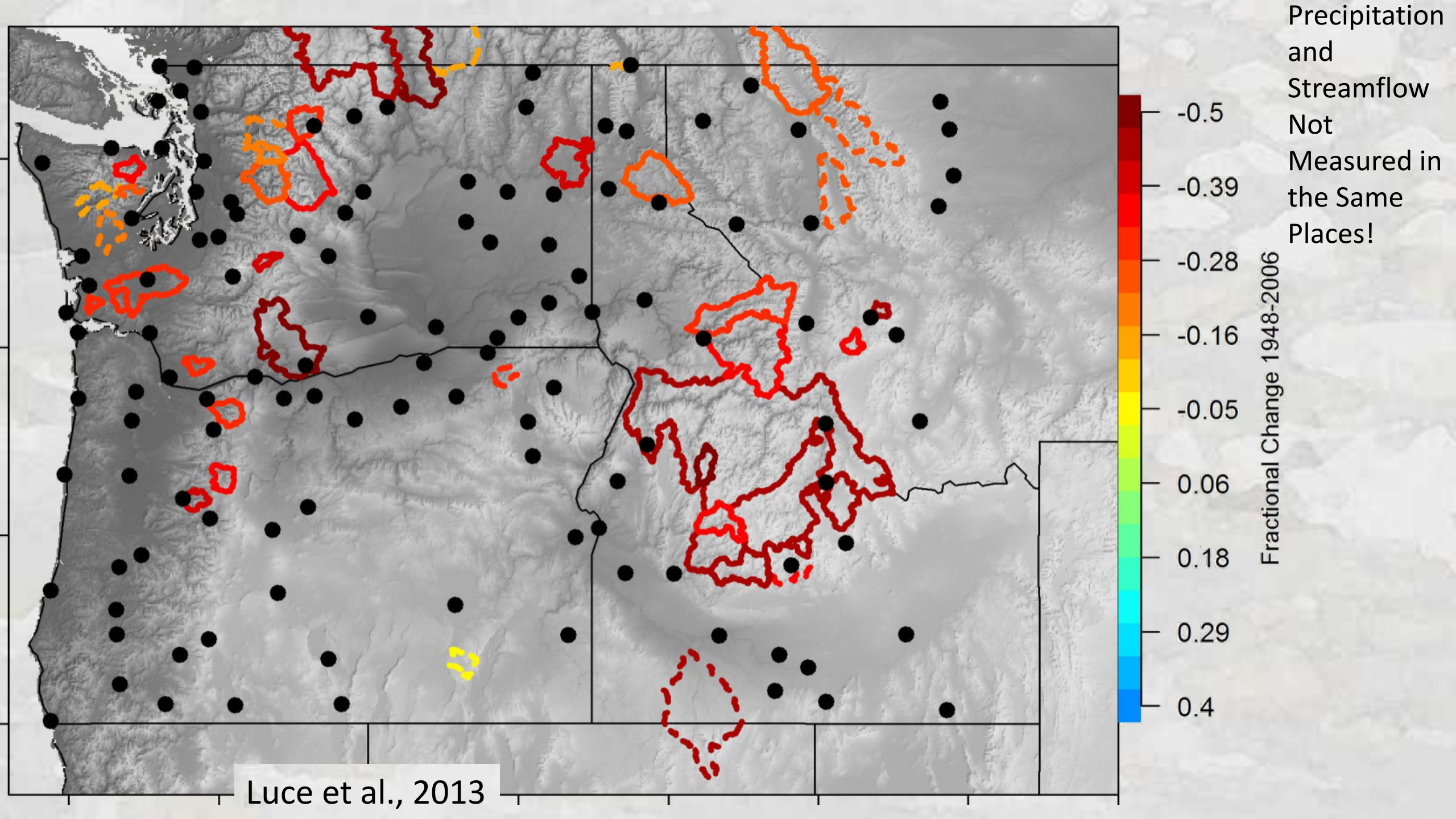

Kormos et al., 2016

# The Plot Twist

# Declines in Annual Runoff from Mountain Basins 1948-2013

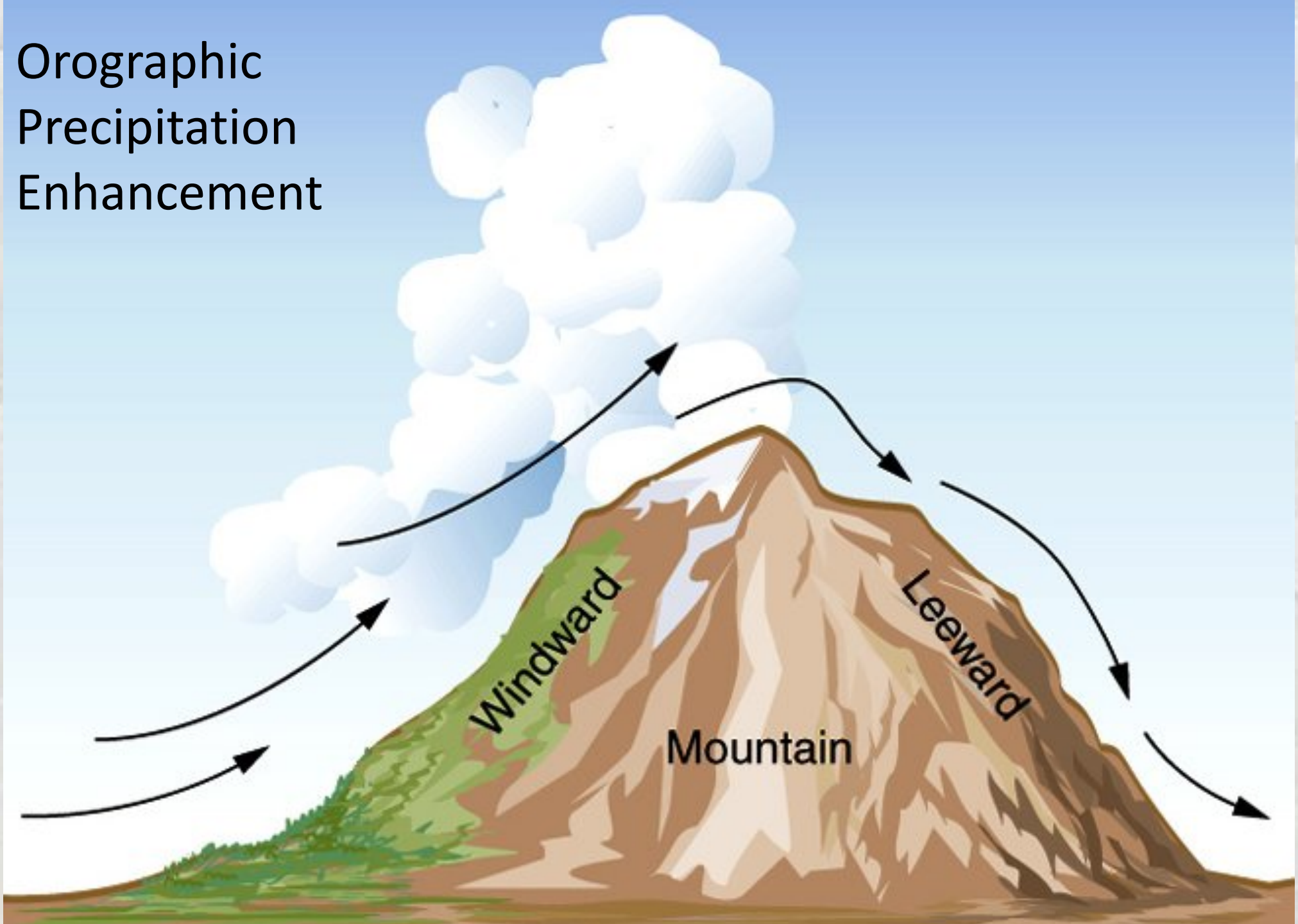


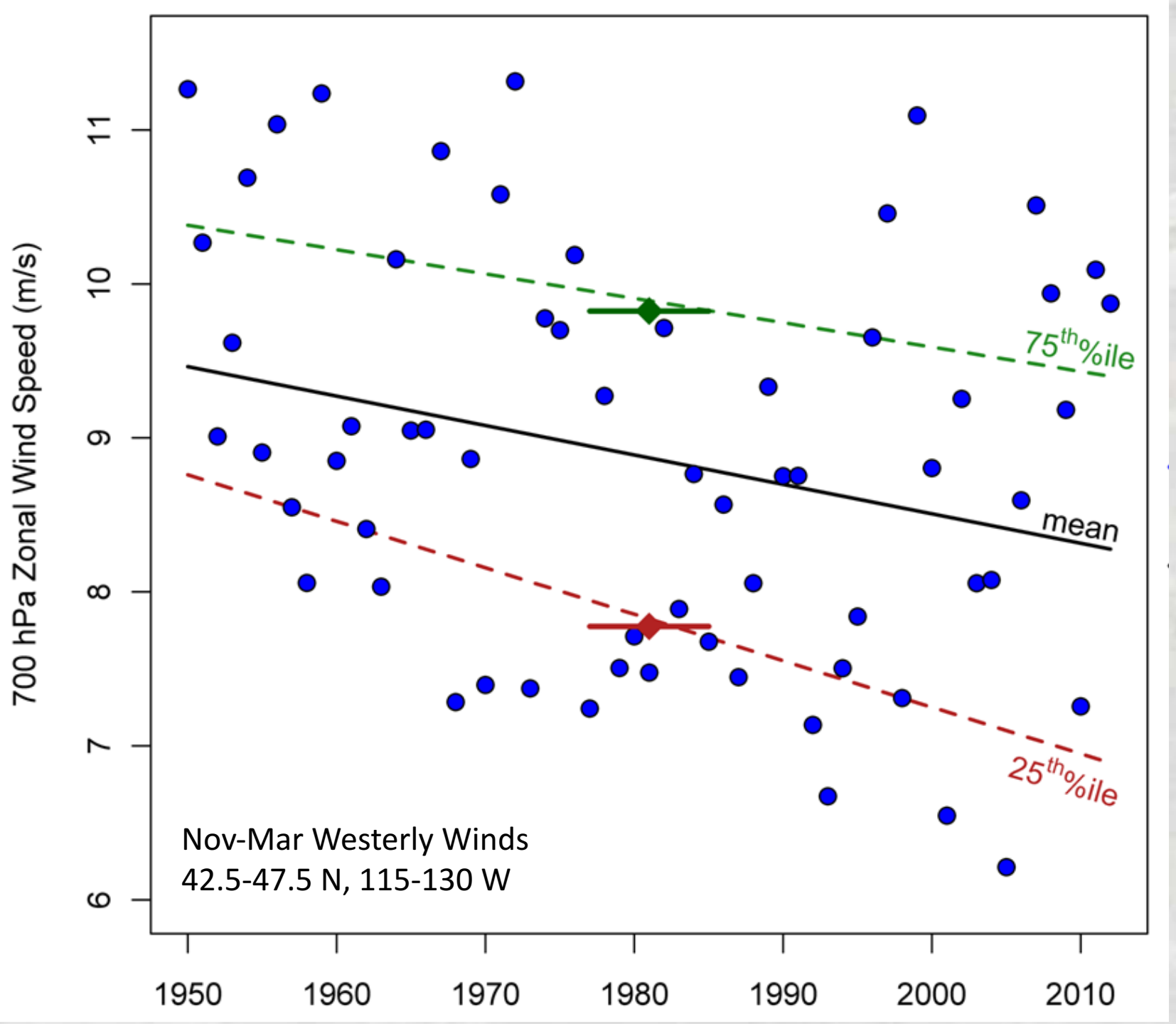

Luce et al., 2013




Precipitation and Streamflow Not Measured in the Same Places!

# Orographic Precipitation Enhancement



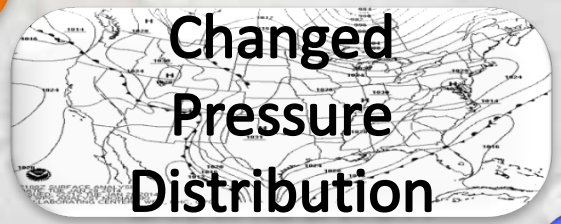



Luce et al., 2013

# The Upshot

Precipitation declined over this period in the mountains

Differential Heating




Changed Wind

Changed Mountain Precipitation

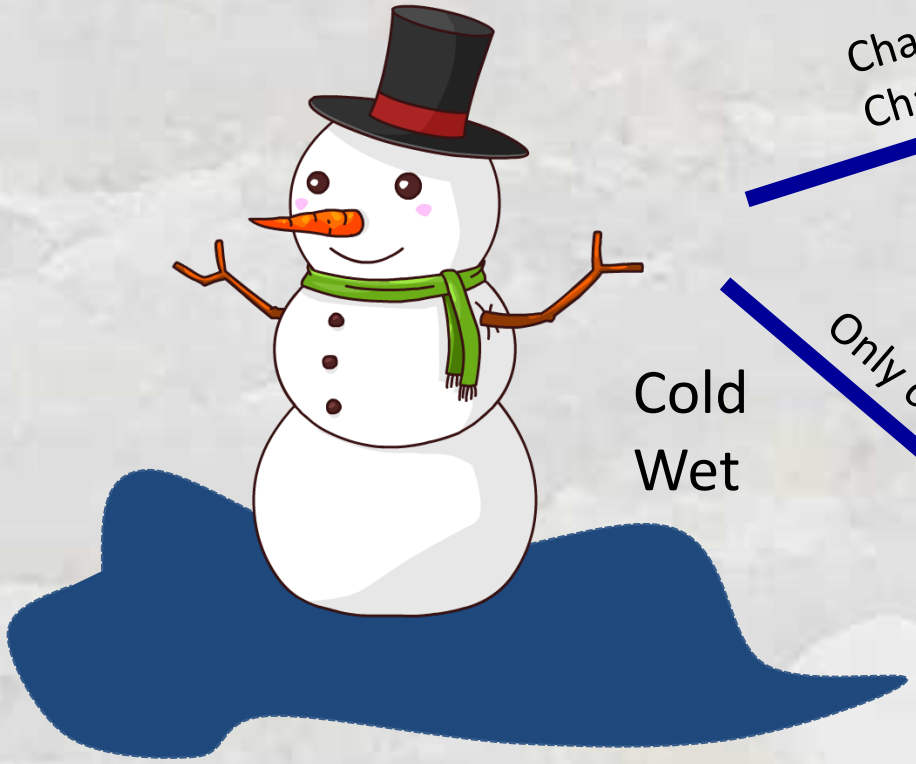
Changed Streamflow

Cascading Changes

Luce, C. H., Abatzoglou, J. T., & Holden, Z. A. (2013). The Missing Mountain Water: Slower Westerlies Decrease Orographic Enhancement in the Pacific Northwest USA. *Science, 342*, 1360-1364

# Two Signals from Streamflow:

- Timing (height of snowman)
- Total Flow (size of puddle)



Cold
Wet

Change timing
Change flow

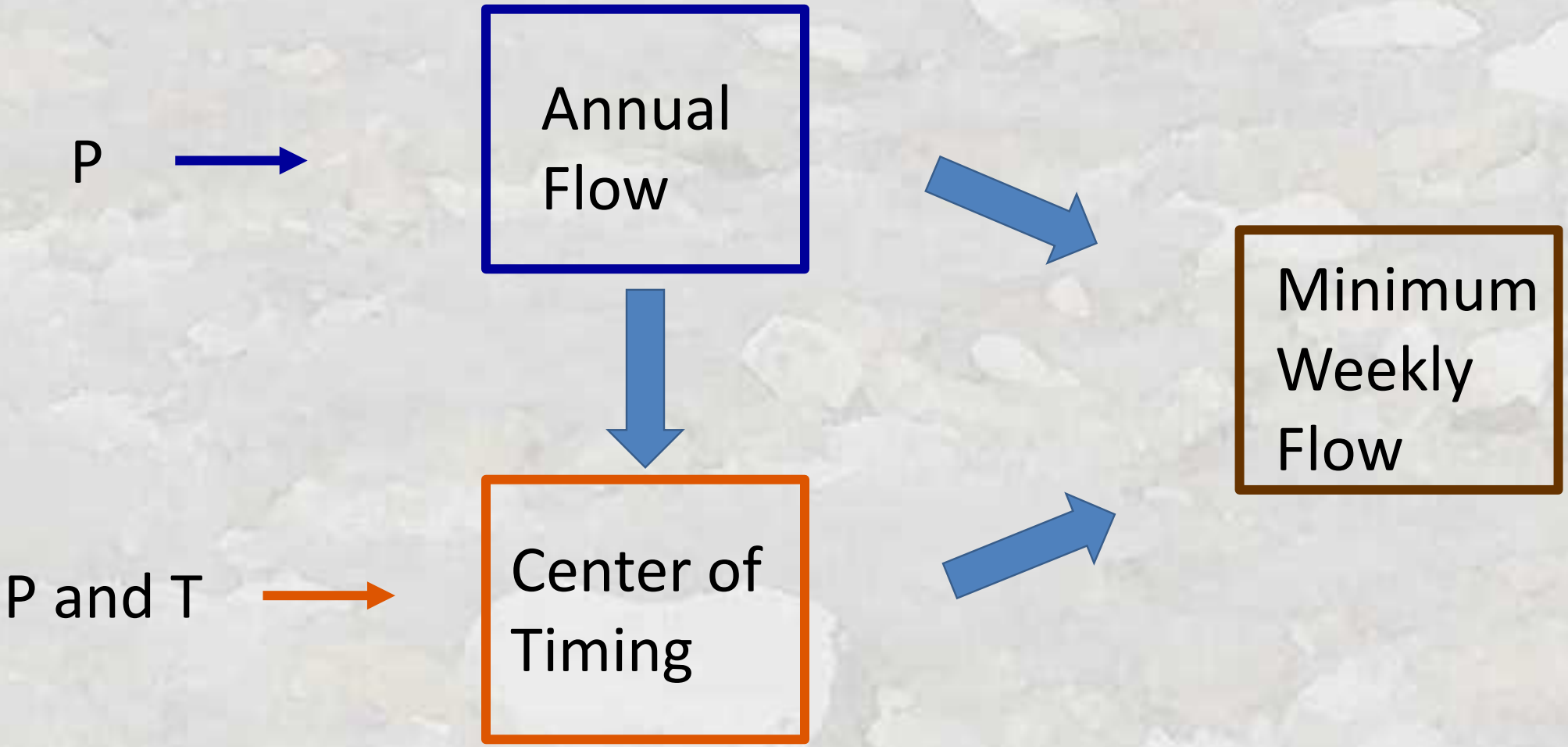
Only change timing

Cold
Dry

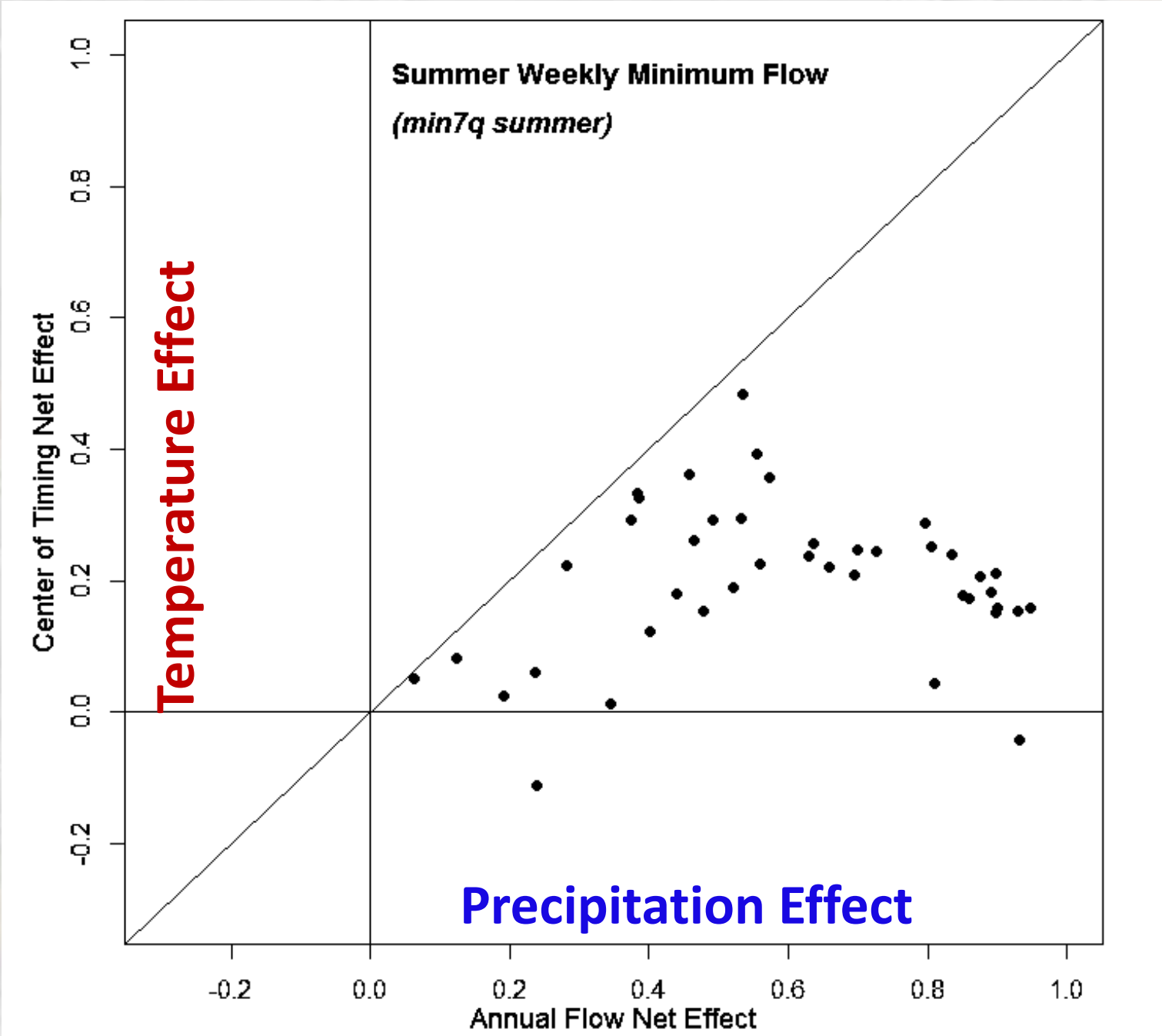
Warm
Dry

Warm
Wet

# Sensitivity Analysis for Minimum Weekly Flow (7Q)



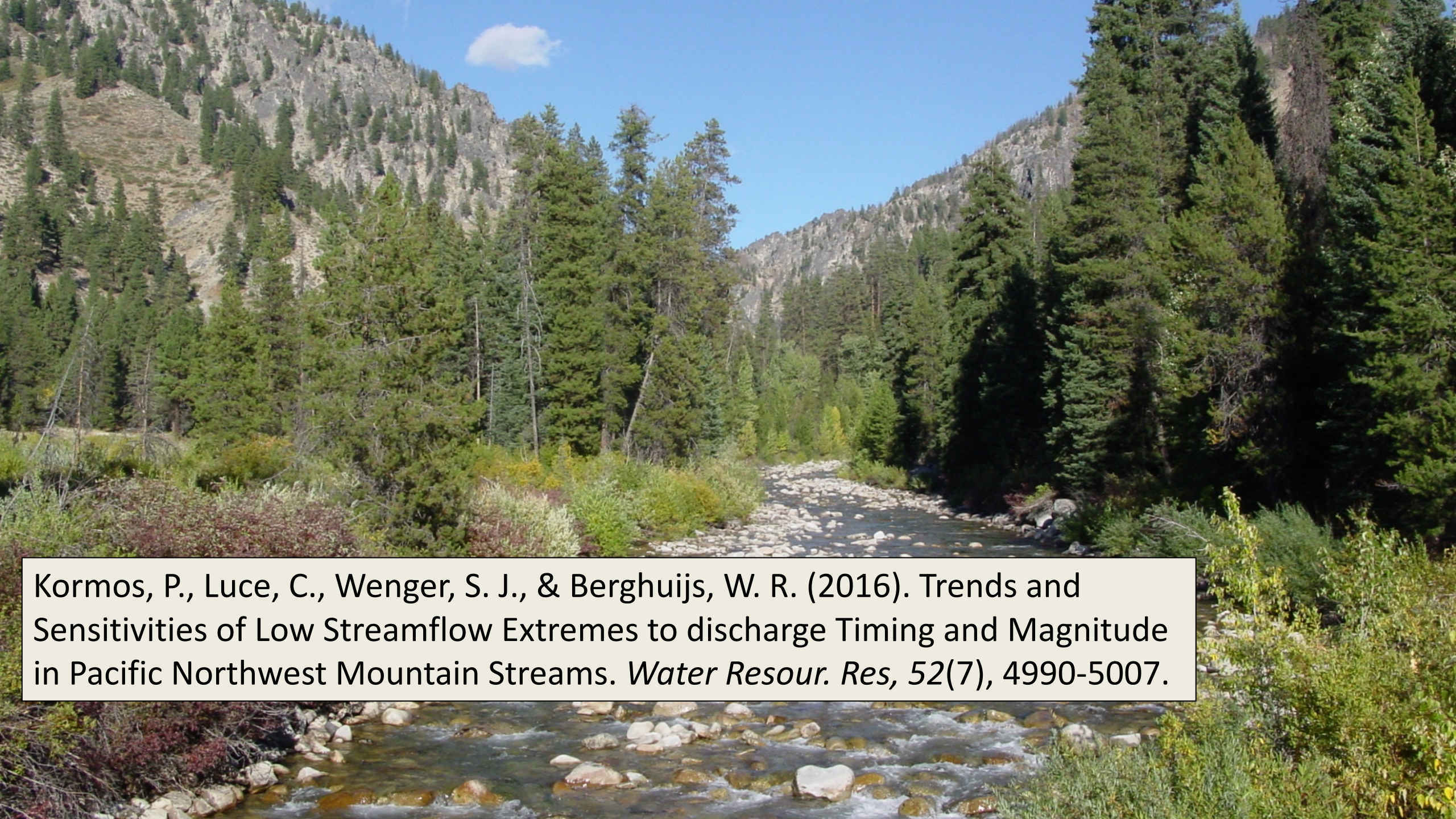
# Low Flow Sensitivity




Kormos et al., 2016

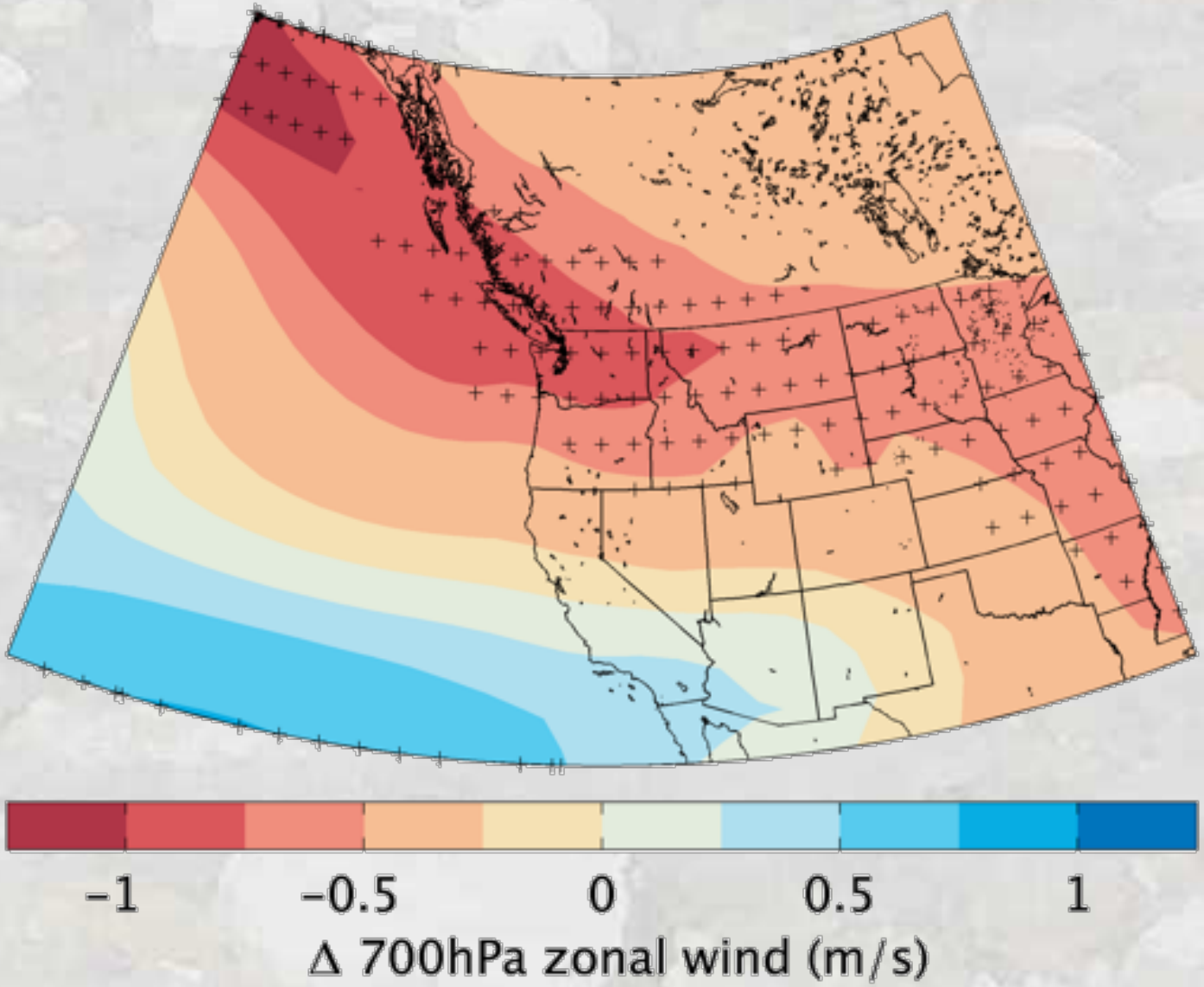
# Summary Thoughts

- Keep alternative paths to a result in mind!!
  - "Sure you have found a solution, but have you found the *only* solution?"
- Trends and Sensitivities are contextual
  - Keep spatial patterns in mind
  - Use them to find testable relationships
- The Case is still under investigation …



Kormos, P., Luce, C., Wenger, S. J., & Berghuijs, W. R. (2016). Trends and Sensitivities of Low Streamflow Extremes to discharge Timing and Magnitude in Pacific Northwest Mountain Streams. *Water Resour. Res, 52*(7), 4990-5007.

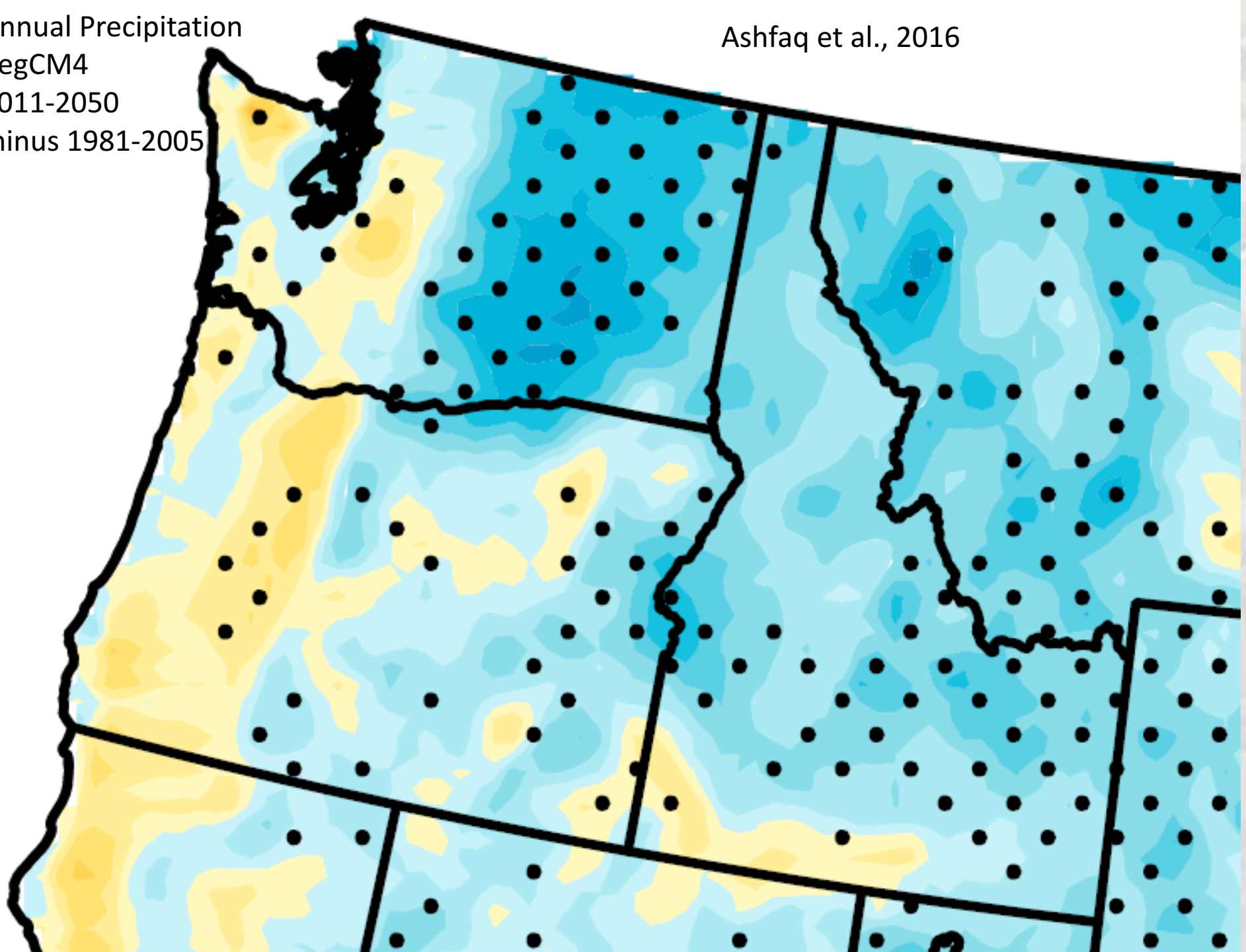
# Future Wind Changes – from GCMs




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

Annual Precipitation
RegCM4
2011-2050
minus 1981-2005

Ashfaq et al., 2016



# Typical Northwest Climate Seasonality