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# *Will the snowpocalypse affect water yields?*

***OR** Interactions Between Hydroclimate and Soil Properties Control the Risk For Altered Hydrologic Partitioning From Changing Snowmelt In the Sierra Nevada*

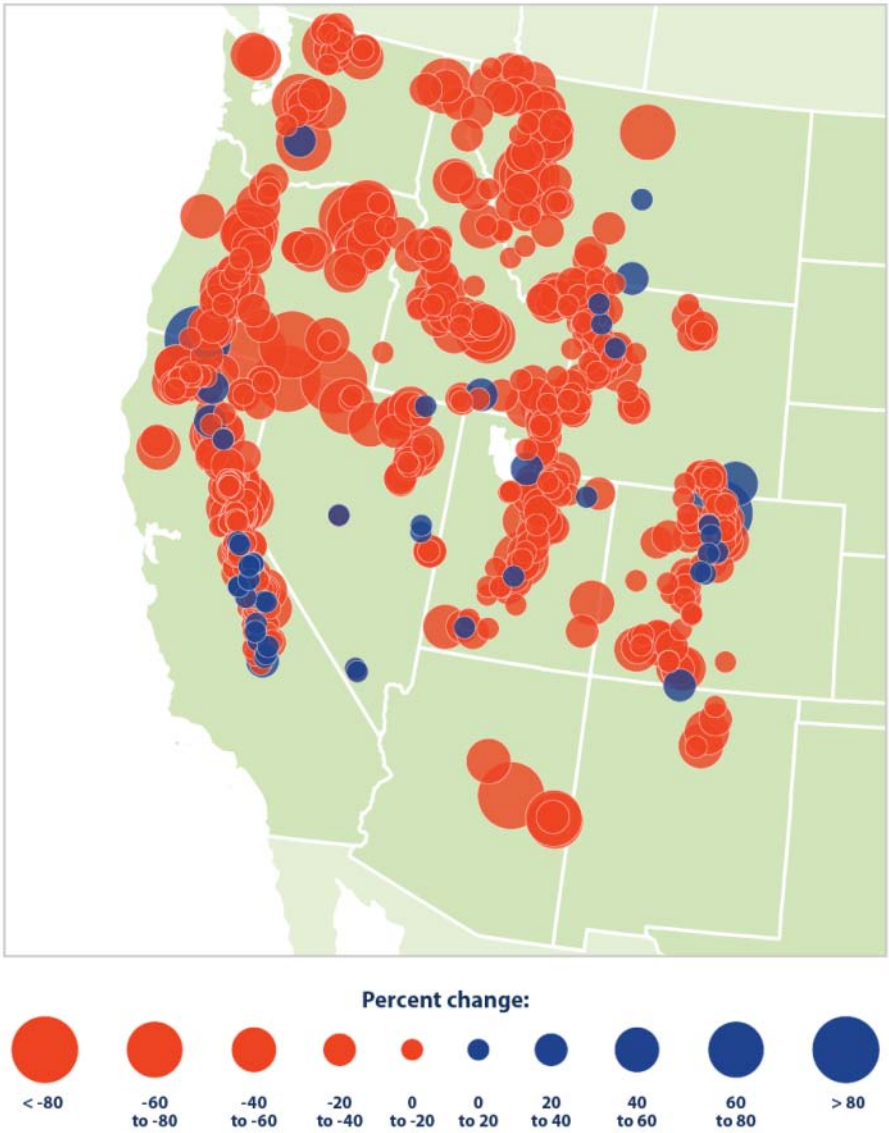
# The three horsemen of the snowpocalypse

**More rain** **Earlier melt/inputs** **Slower melt**

Game of thrones

# Changing snowpack: less accumulation

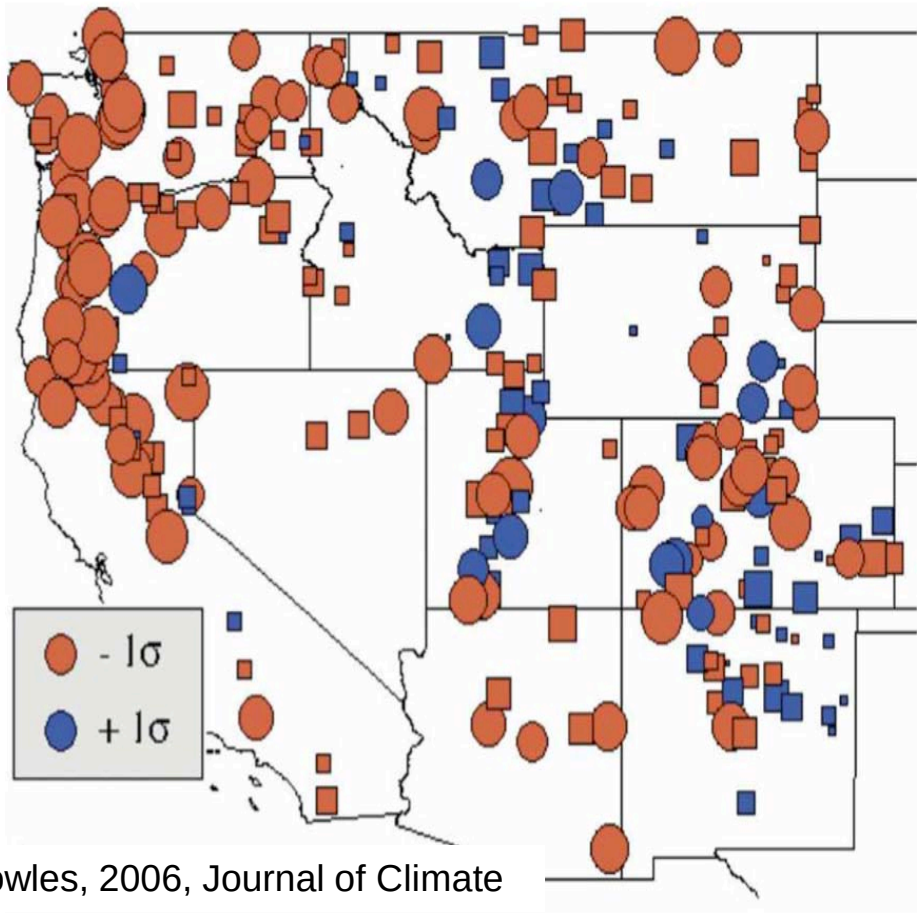
- Less precipitation
- More rain and less snow
- Earlier and/or larger melt
- Increased vapor loss




Mote and Sharp, 2016

# Historical changes from snowfall to rainfall

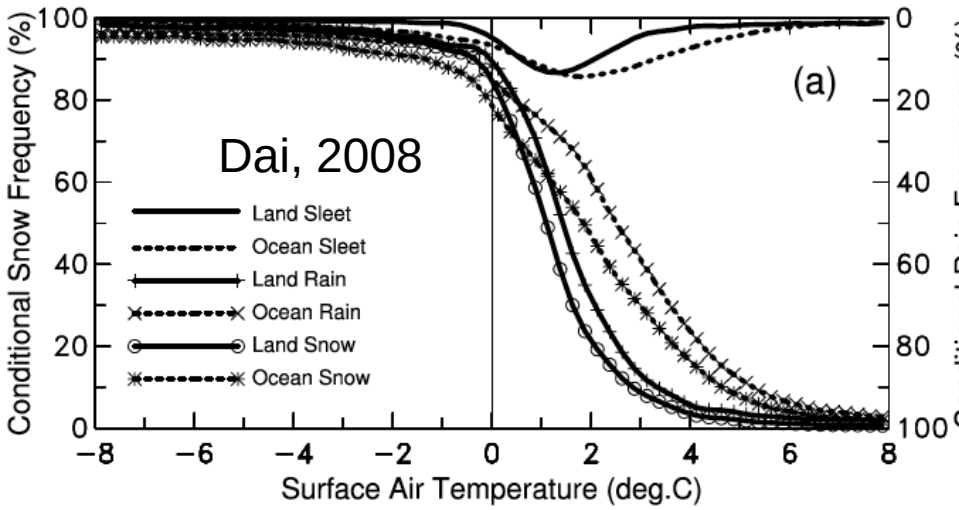
- Warming over the last 50 years has shifted precipitation to be less snow dominated
  - Red: increasing rain
  - Blue: increasing snow

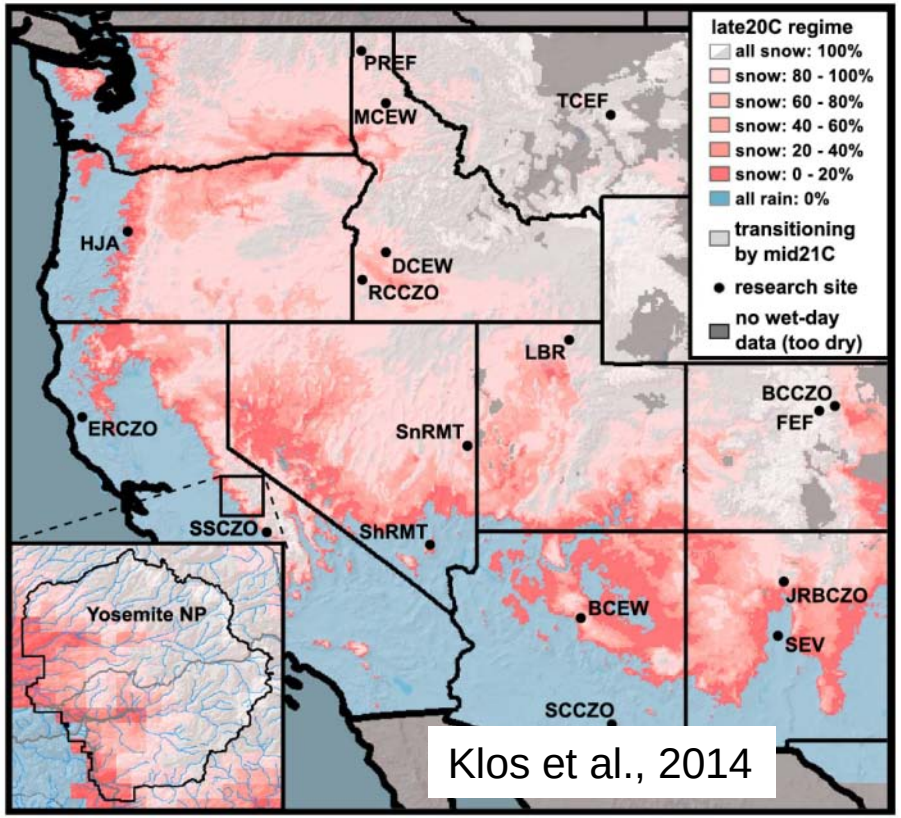



Knowles, 2006, Journal of Climate

# Future trends towards less snowfall

- Future projections are for widespread changes from snow to rain-dominated systems

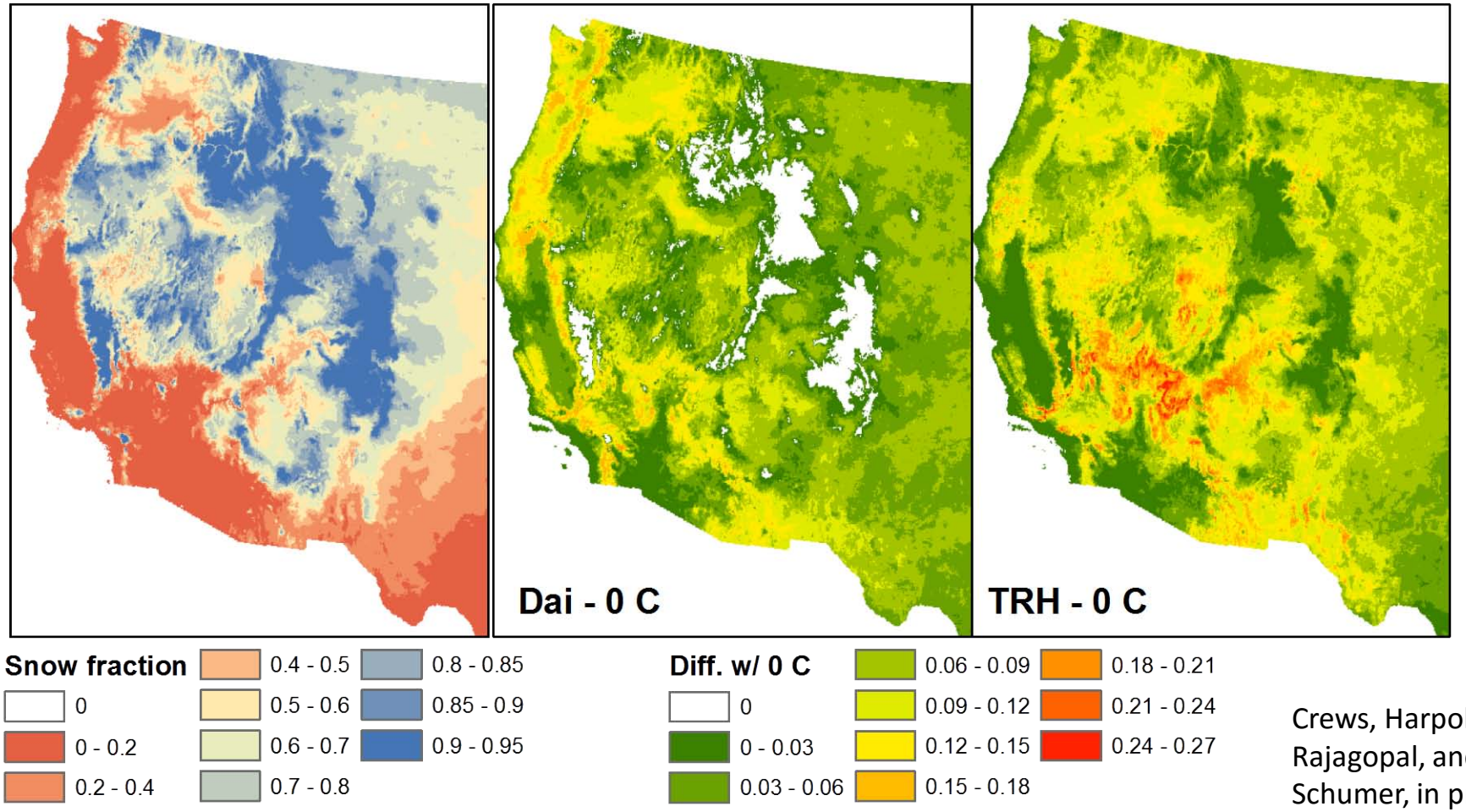



Klos et al., 2014

# Humidity effects on phase

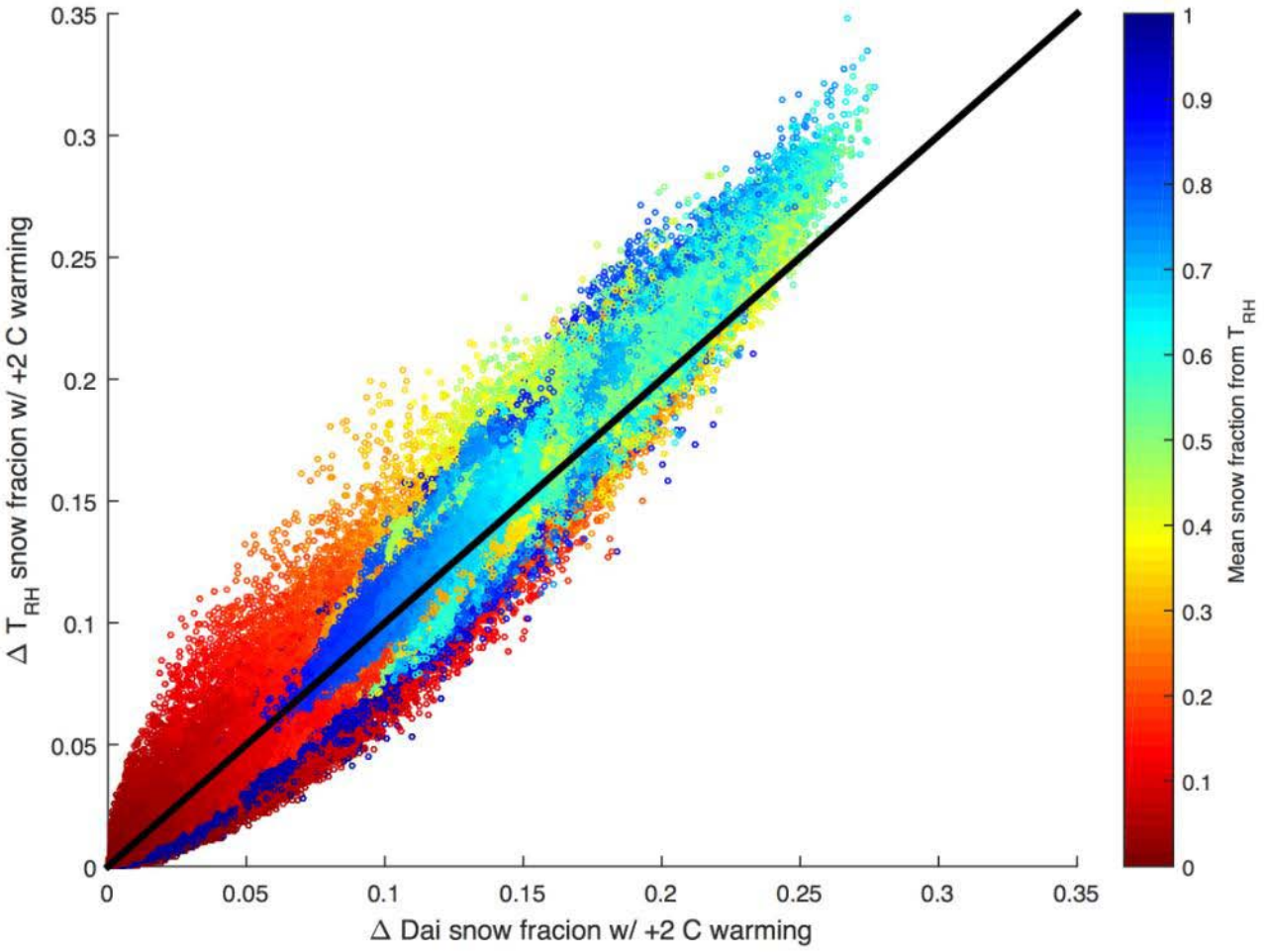
- Latent cooling of hydrometeors in low humidity is not considered in most methods




Crews, Harpold, Rajagopal, and Schumer, in prep

# Prediction of phase change depend on humidity (and temperature)

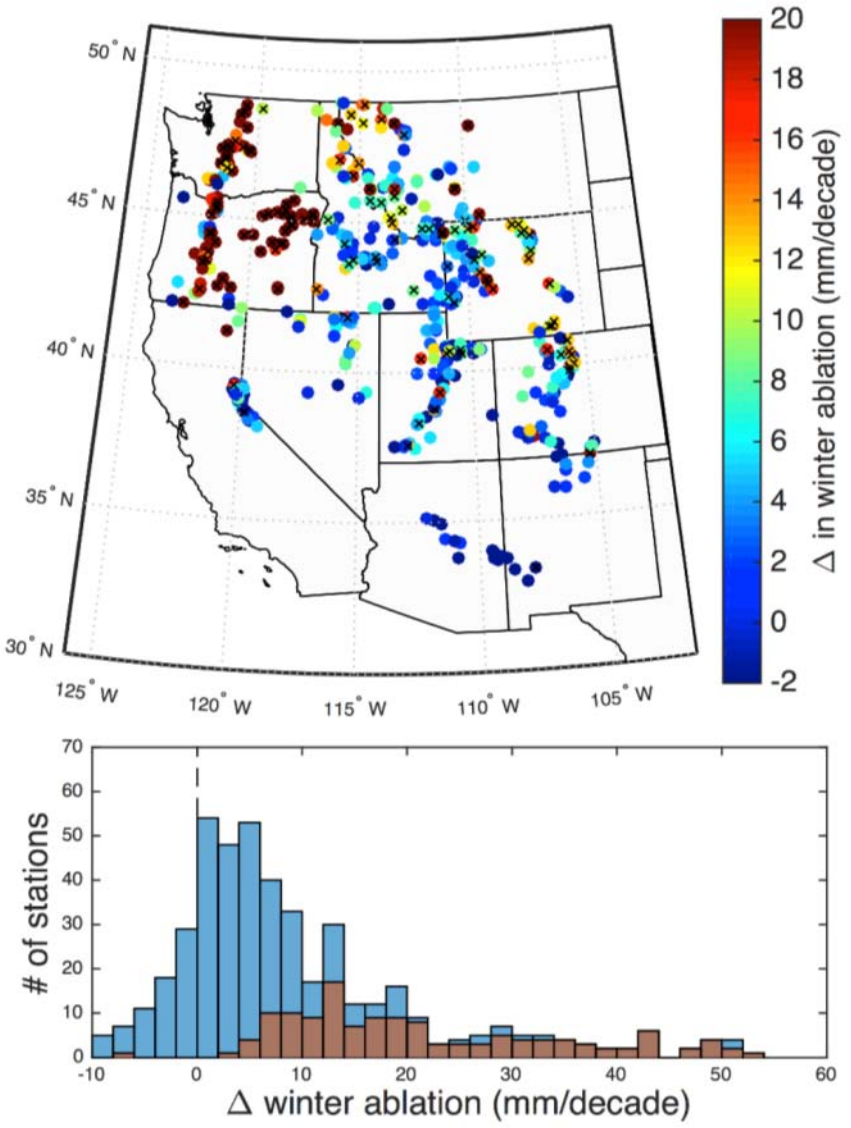
- Humidity changes can overwhelm warming effects
- Future humidity regimes are uncertain




Crews, Harpold, Rajagopal, and Schumer, in prep

# Changing snowpack: winter ablation

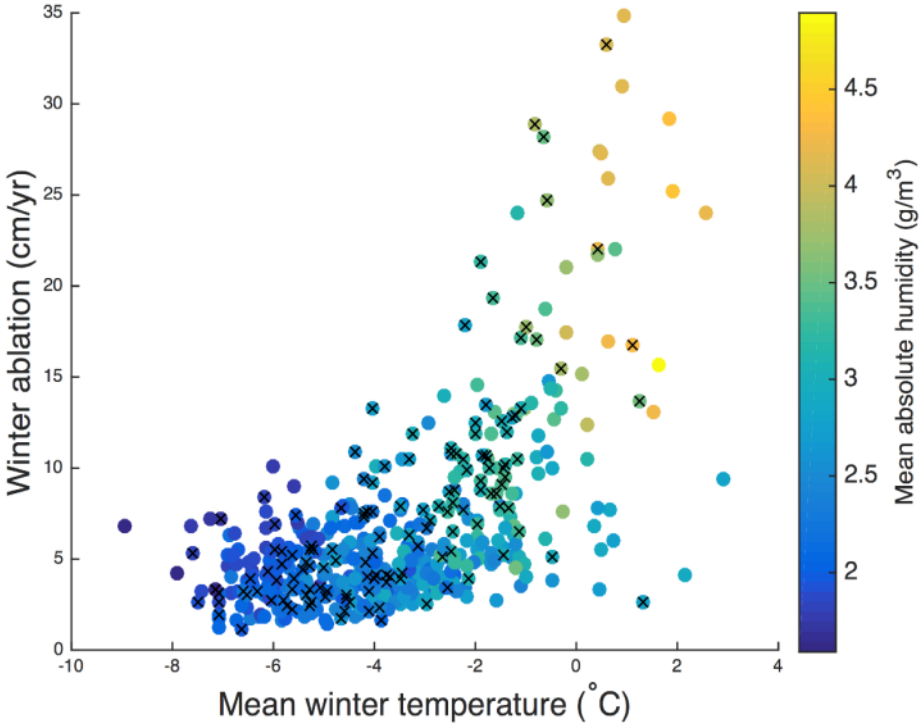
- Ablation (snowpack mass loss) has increased throughout the Western U.S. prior to peak SWE
- Pacific Northwest showed the largest trends winter ablation

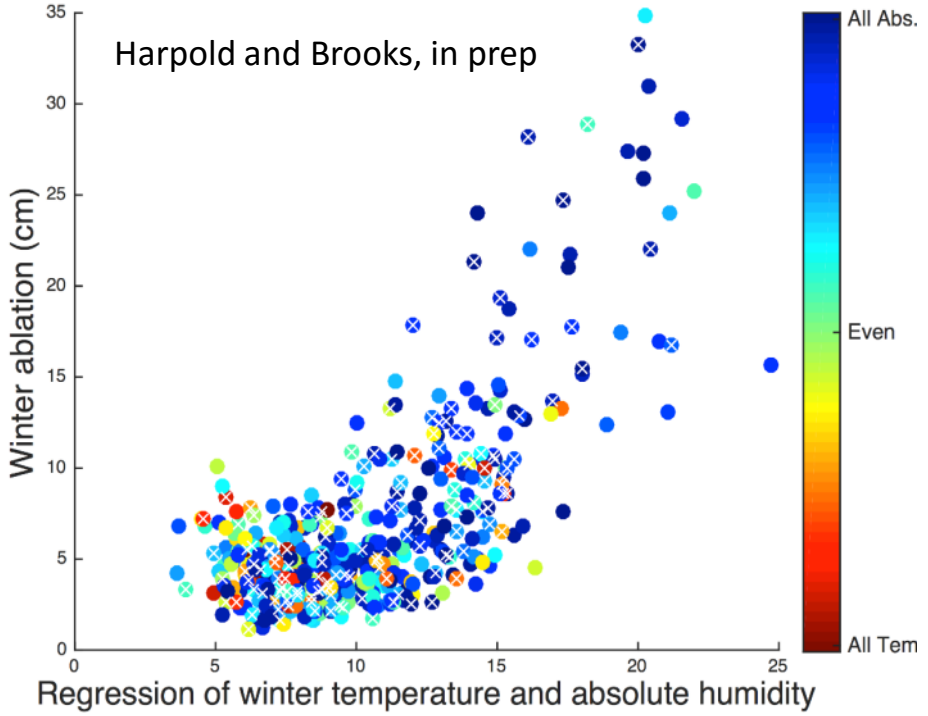



Harpold and Brooks, in prep

# Increased winter ablation

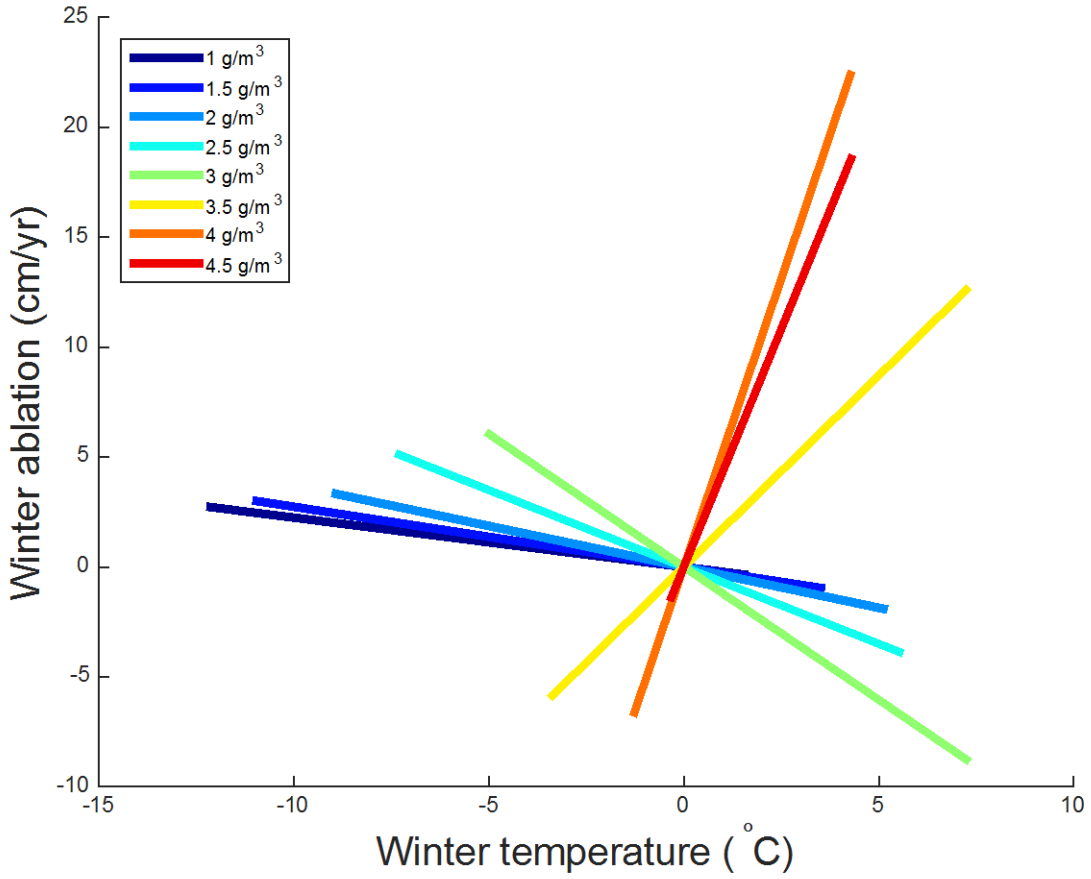
- More ablation in warm and humid areas
- More inter-annual ablation explained by humidity than temperature



# Threats from humidity outweigh temperature change

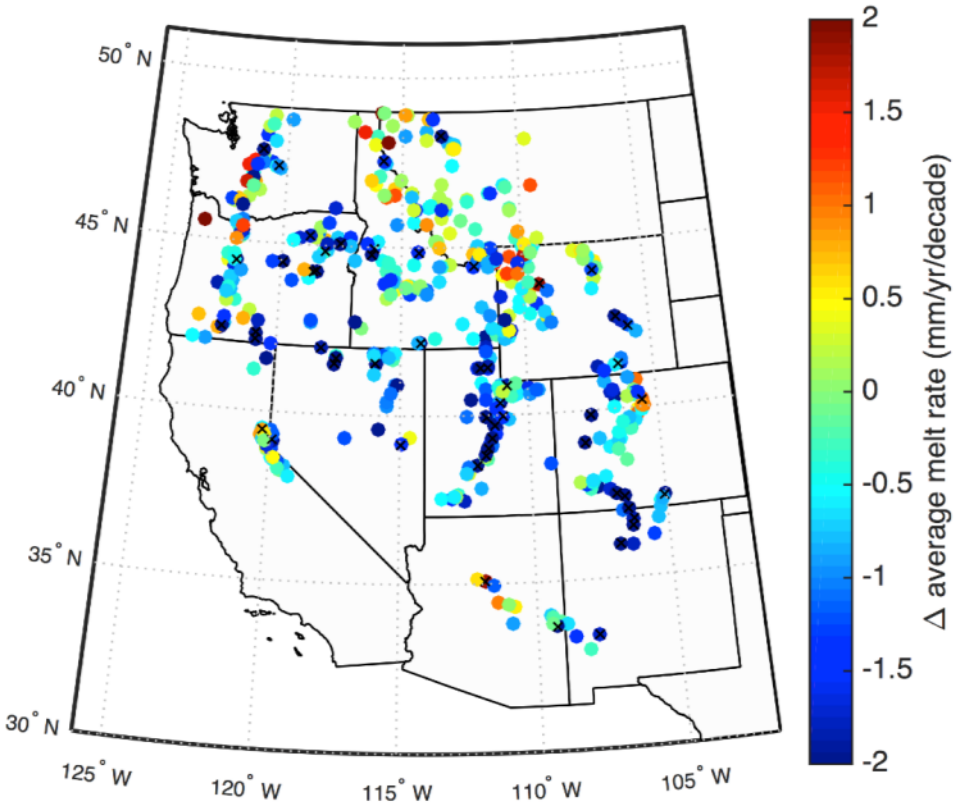
- Temperature has little control on winter ablation
- The effects of warming (sensible heat) small compared to by latent heat

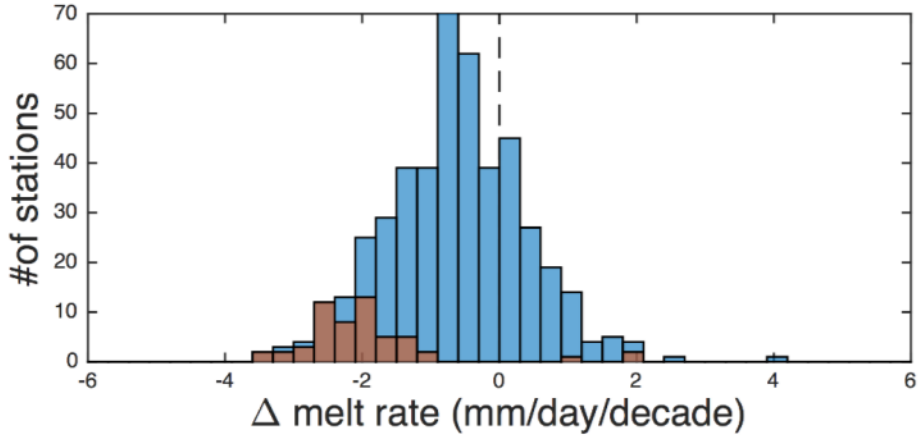



Harpold and Brooks, in prep

# Changing snowpack: slower melt

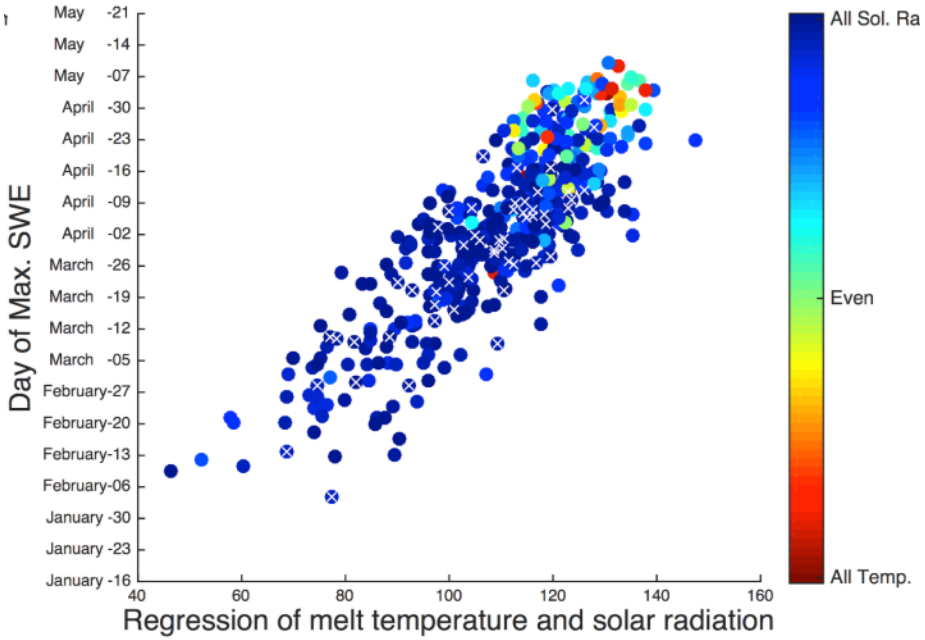
- Snowmelt rates have slowed over 35 years



# Slower snowmelt

- Timing of melt is explained by solar radiation
- Average melt rates explained by solar radiation

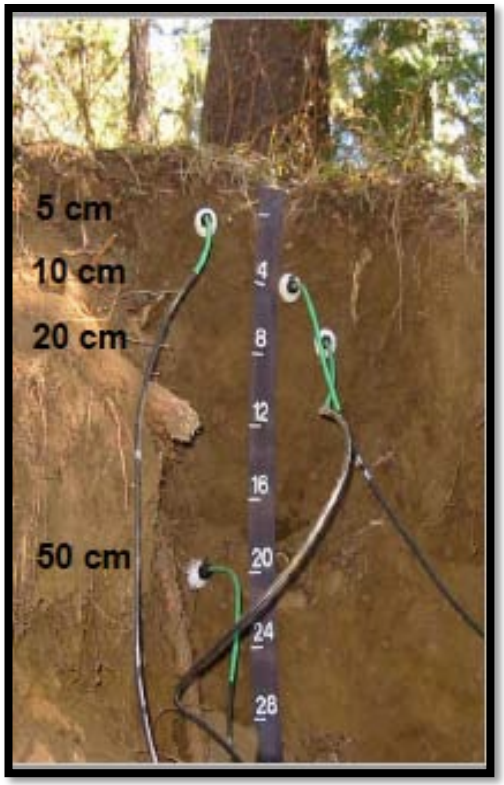


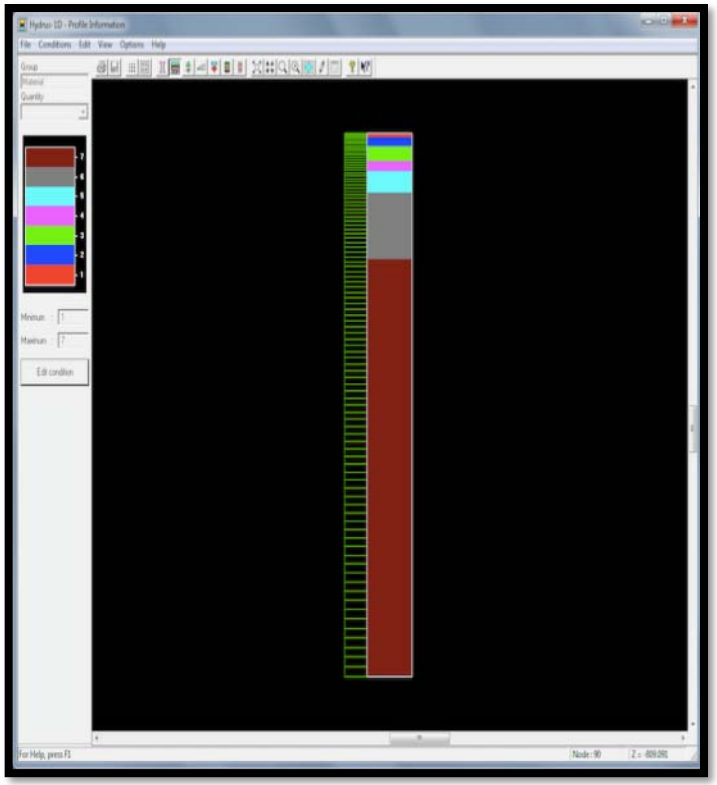
# Does changing snowmelt = changing water yields?

- Will earlier snowmelt deliver less water to streams and aquifers?
- Will changes from snow to rain deliver less water?
- Will slower snowmelt deliver less water to streams and aquifers?

# Lets start simple…1-D modeling

- HYDRUS modeling at SNOTEL sites with measured climate, soil moisture, and soil property data
- How sensitive are fluxes below the root zone (i.e. deep percolation)?

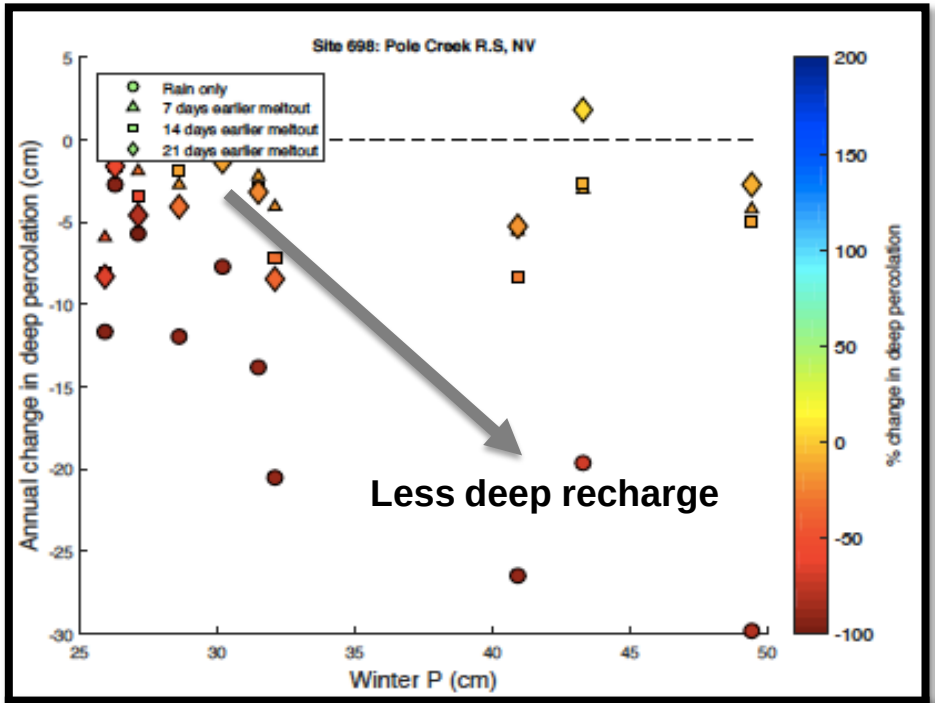



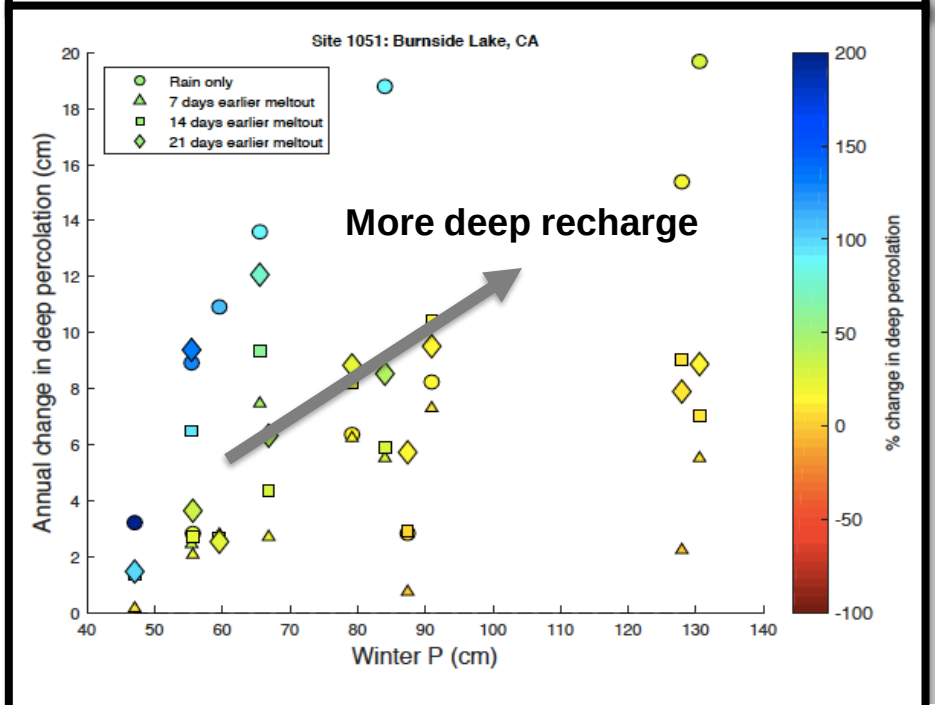



# 1-D experiments

- Scenarios:
  - Rain only
  - PET increase
  - 7, 14, and 21 day earlier snowmelt
- Sensitivity
  - Rooting/soil depth

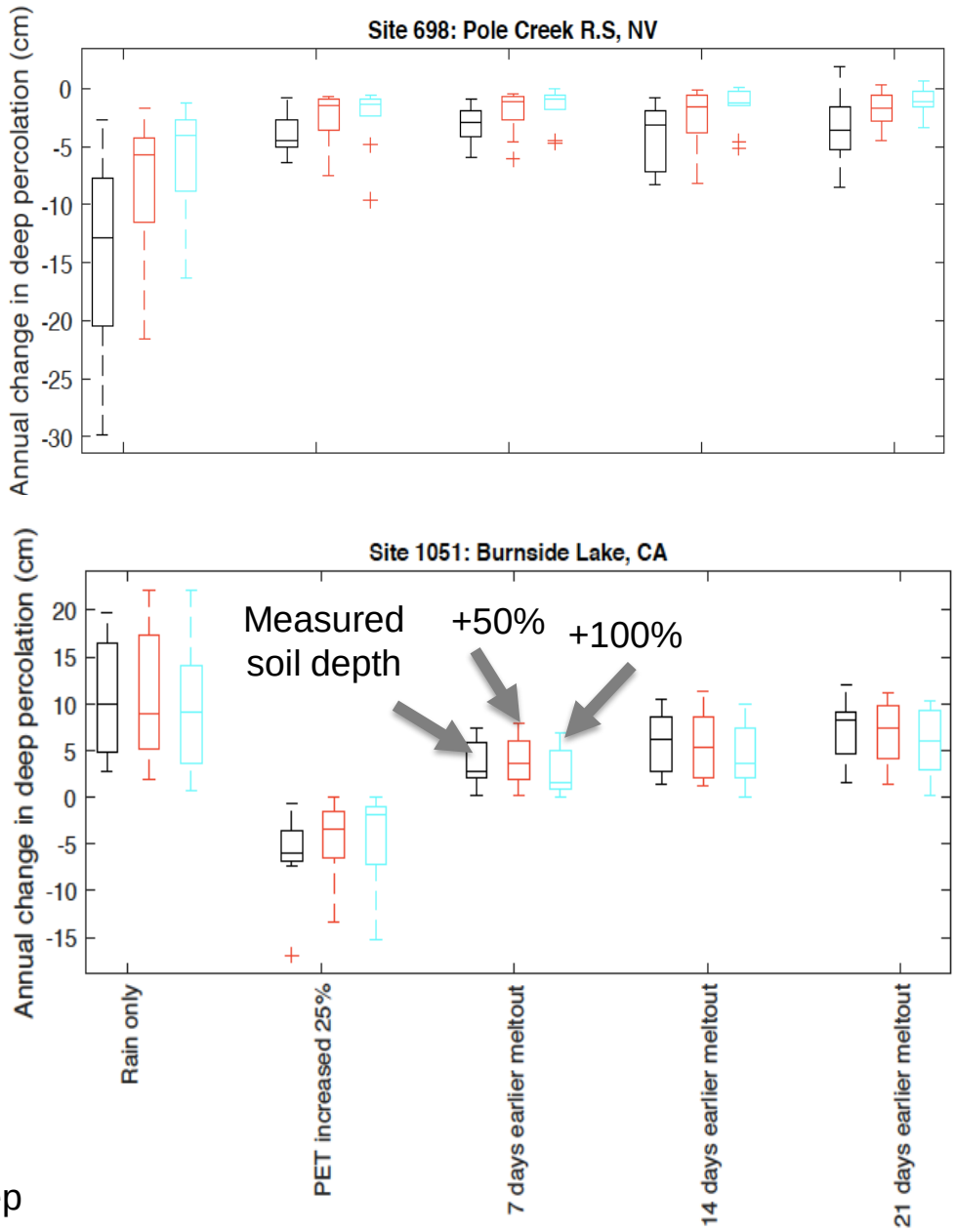
Harpold, Weiss, and Kampf, in prep



# 1-D experiments

- Soil/rooting depth acted to buffer effects of changing snowmelt inputs

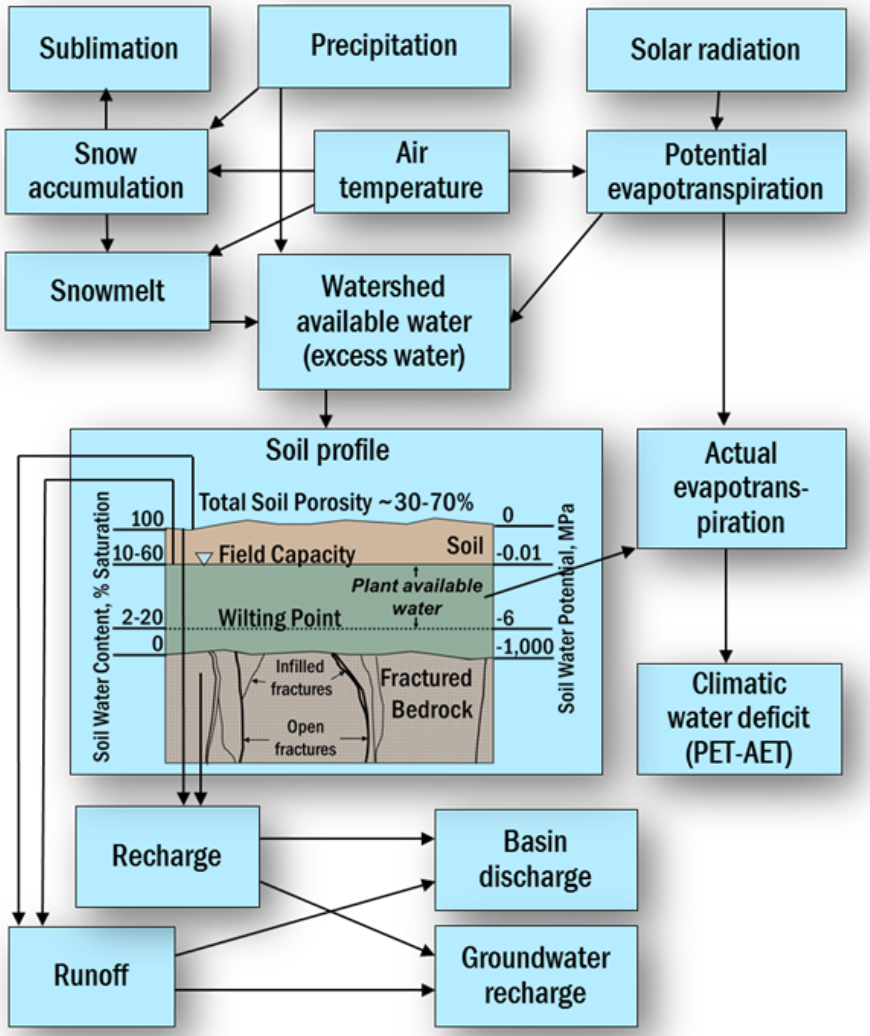



Harpold, Weiss, and Kampf, in prep

# A model experiment changing snow to rain

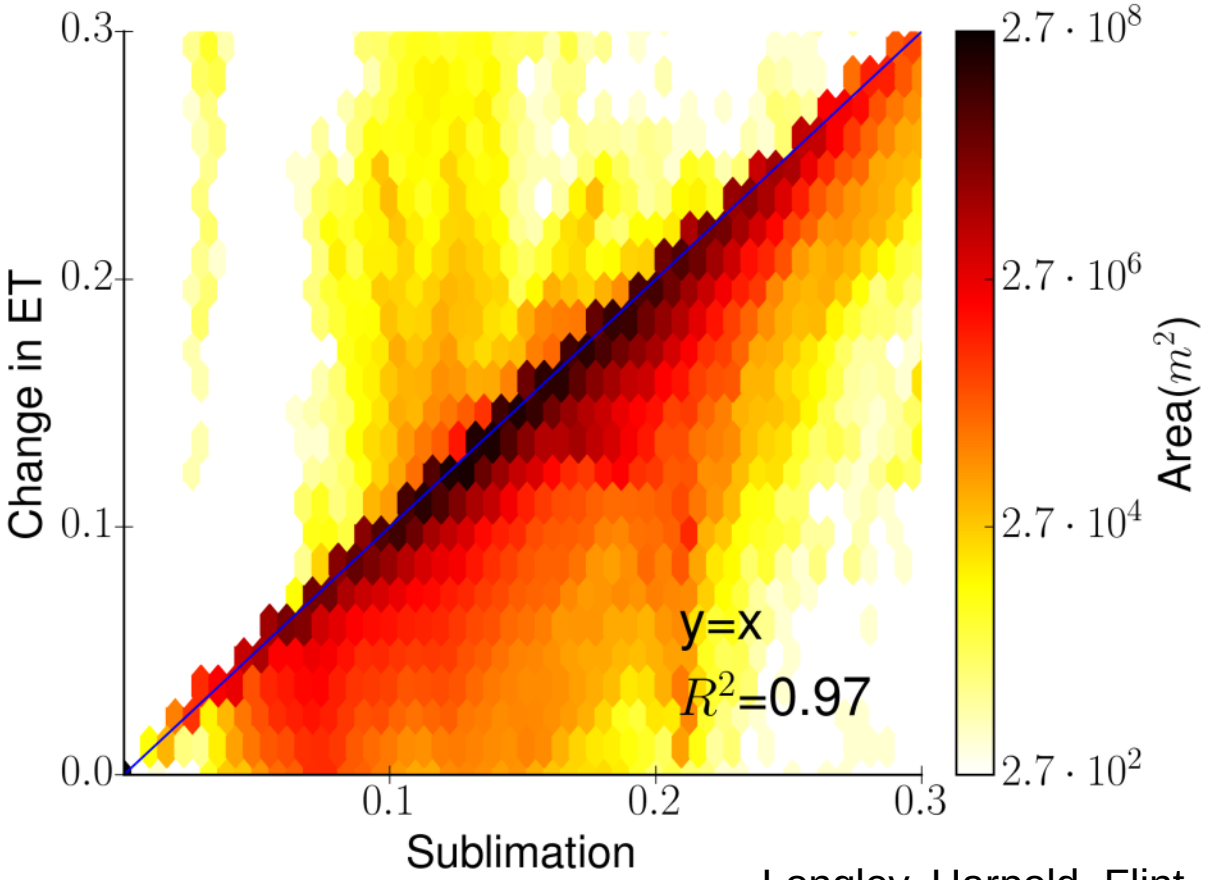
- The BCM model is uniquely suited to answering this question
  - 270 m resolution
  - Subsurface properties highly resolved
  - Monthly time step
  - Large extent

Basin Characterization Model (from Thorne and others, 2012).



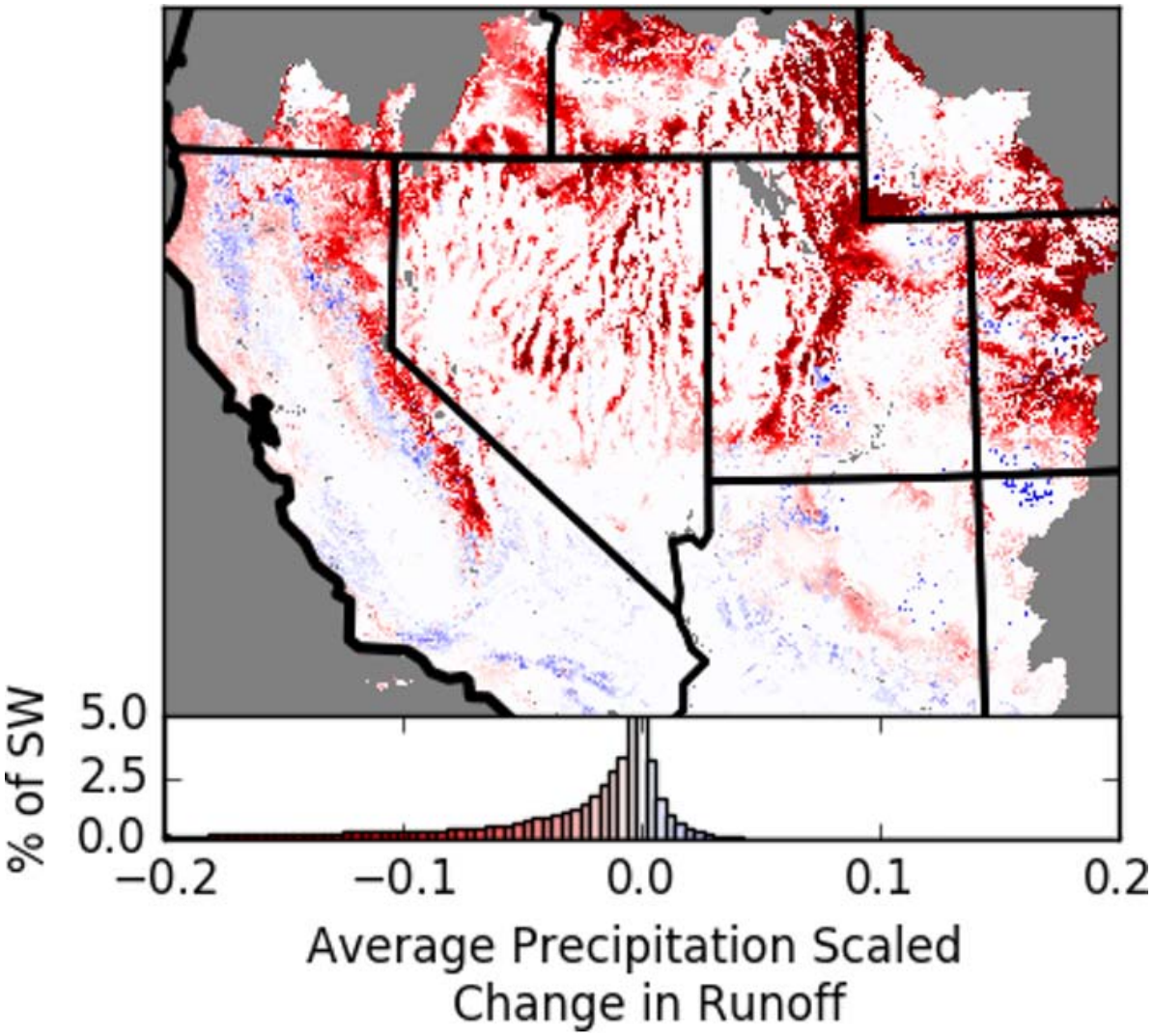
# Snow>Rain: evapotranspiration increases

- In dry regions, sublimation goes to ET
- In wet regions, sublimations to multiple sources




Longley, Harpold, Flint, and Flint, in prep

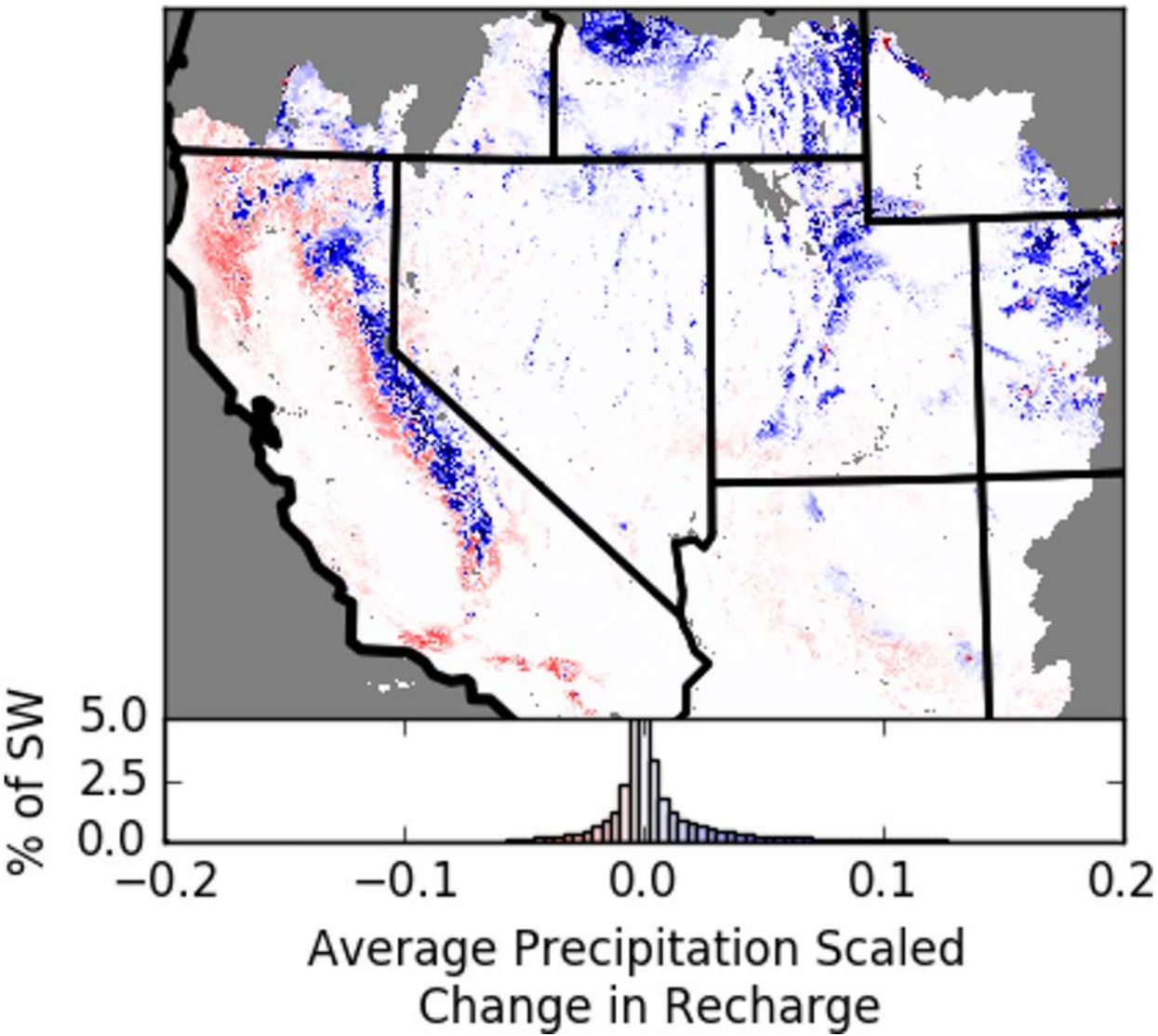
# Snow>Rain: changes in runoff




- Precipitation-scaled runoff (surface and interflow) decreases across most of the West
- Mixed in Sierras!

Longley, Harpold, Flint, and Flint, in prep

# Changes in in-place recharge

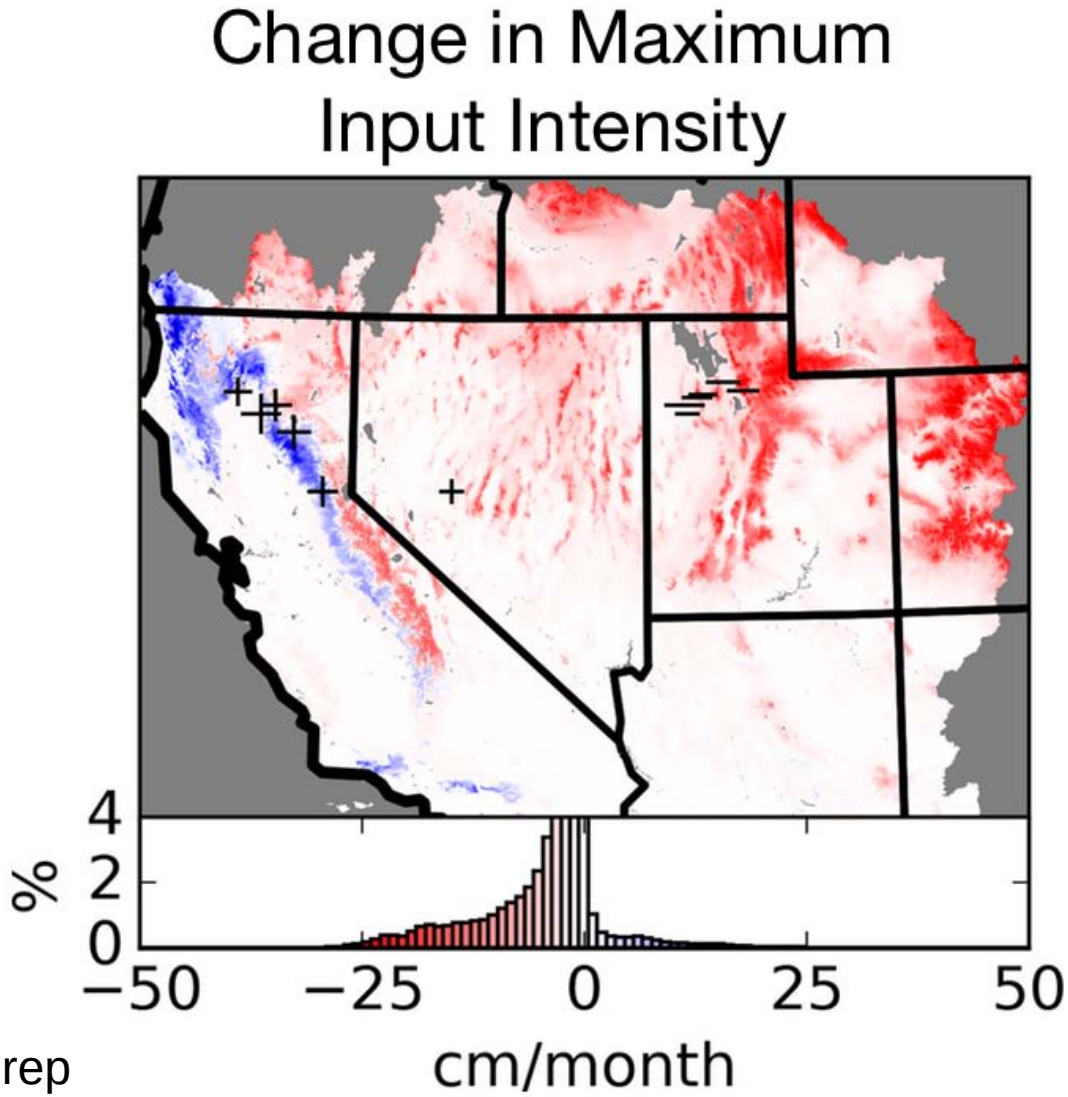



- Groundwater recharge increases across most of the West
- Mixed in the Sierras!

Longley, Harpold, Flint, and Flint, in prep

# Maximum input intensity uneven from snow>rain

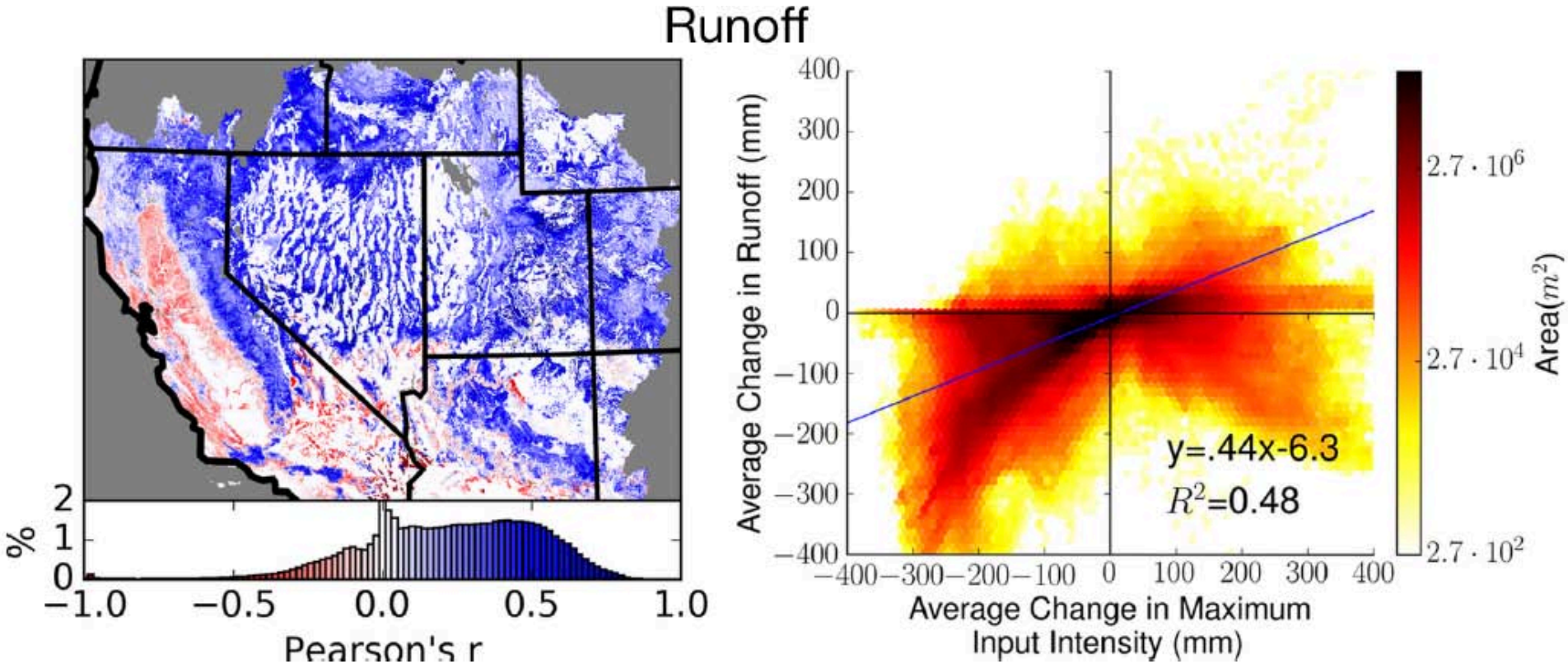
- Most continental areas show decreased in maximum input intensity
- California is the exception!




Longley, Harpold, Flint, and Flint, in prep

# Maximum input intensity

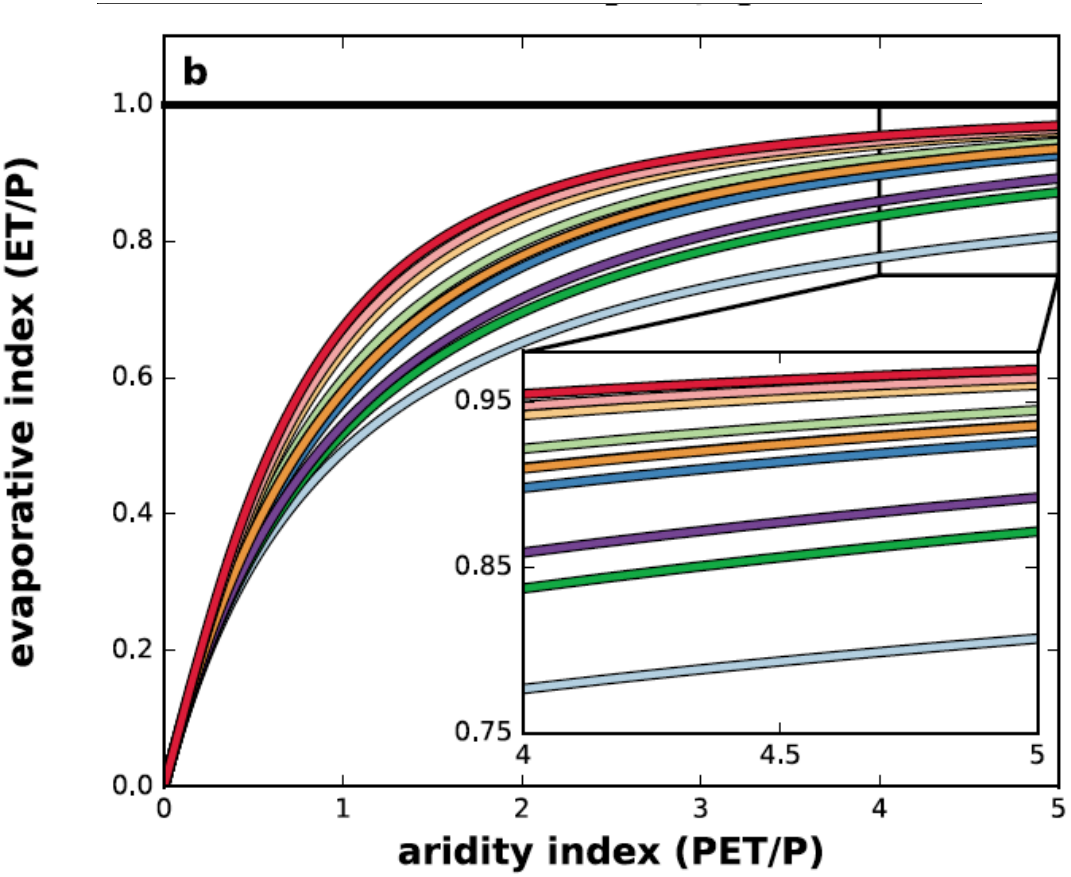
- Positive correlation between higher (lower) input intensity and increase (decrease) in runoff

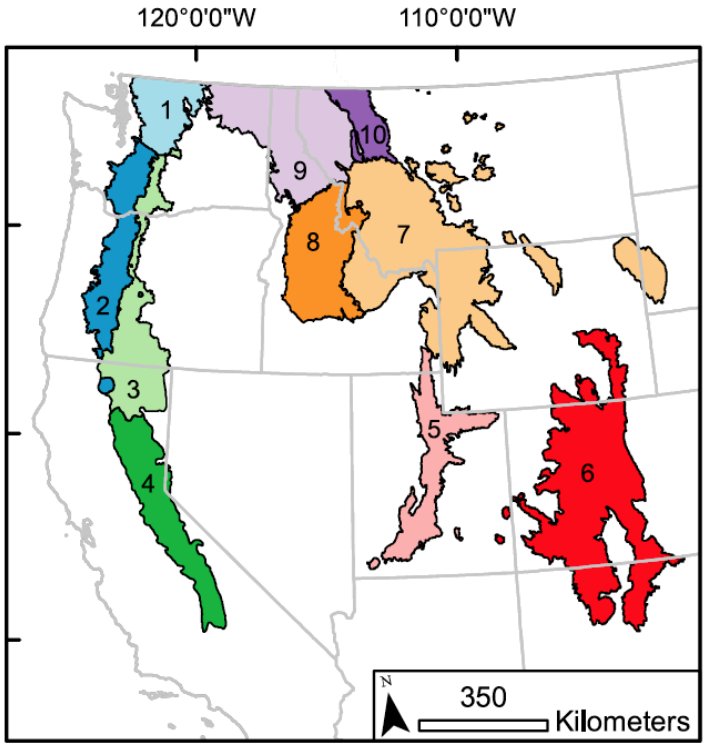



Longley, Harpold, Flint, and Flint, in prep

# Changes in snowmelt rate and streamflow

- VIC model run at 6 km
- Analysis in a Budyko framework



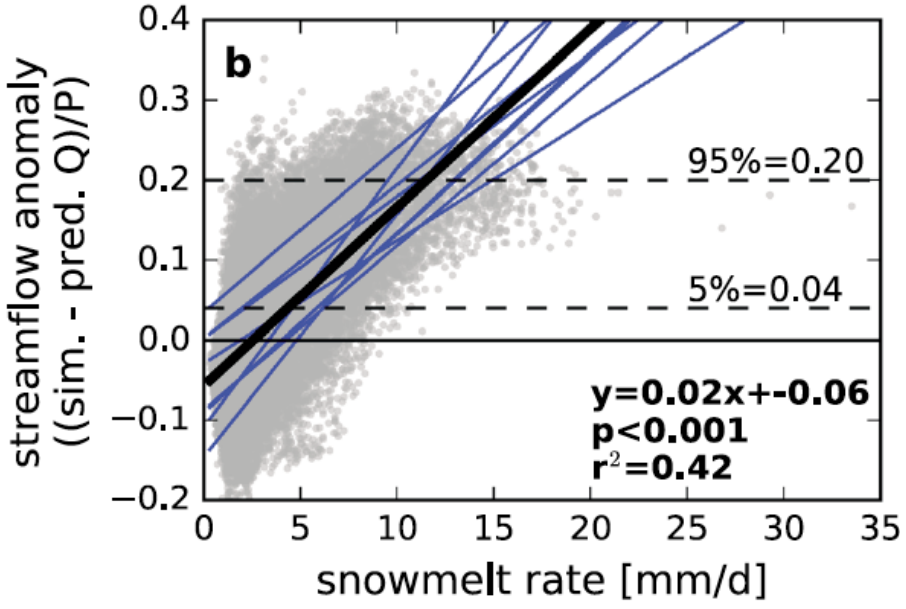



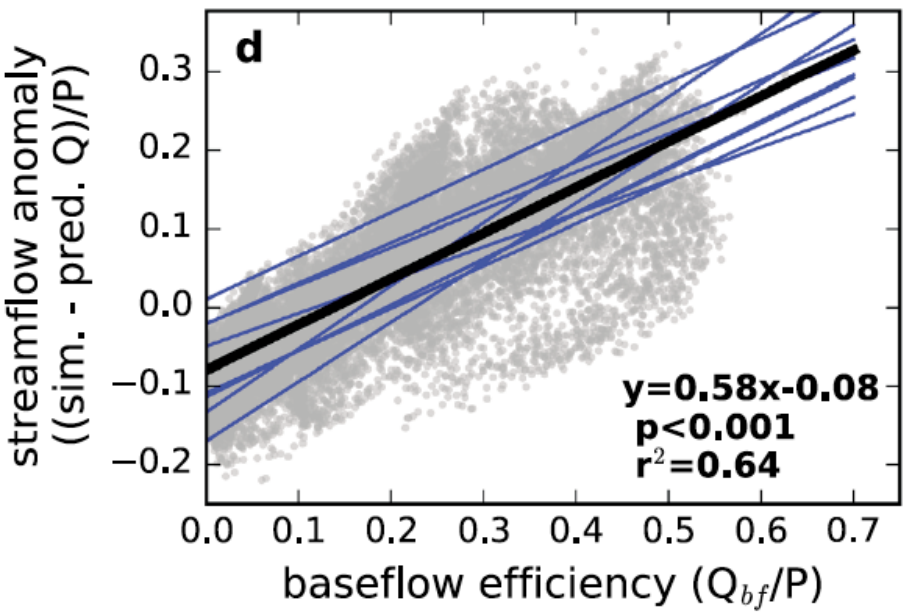

Barnhart et al., 2016

# Changes in snowmelt rate and streamflow

- Streamflow anomaly (difference from Budyko expectation) are higher when:
  - snowmelt rate is higher
  - baseflow generation is higher (more deep percolation)

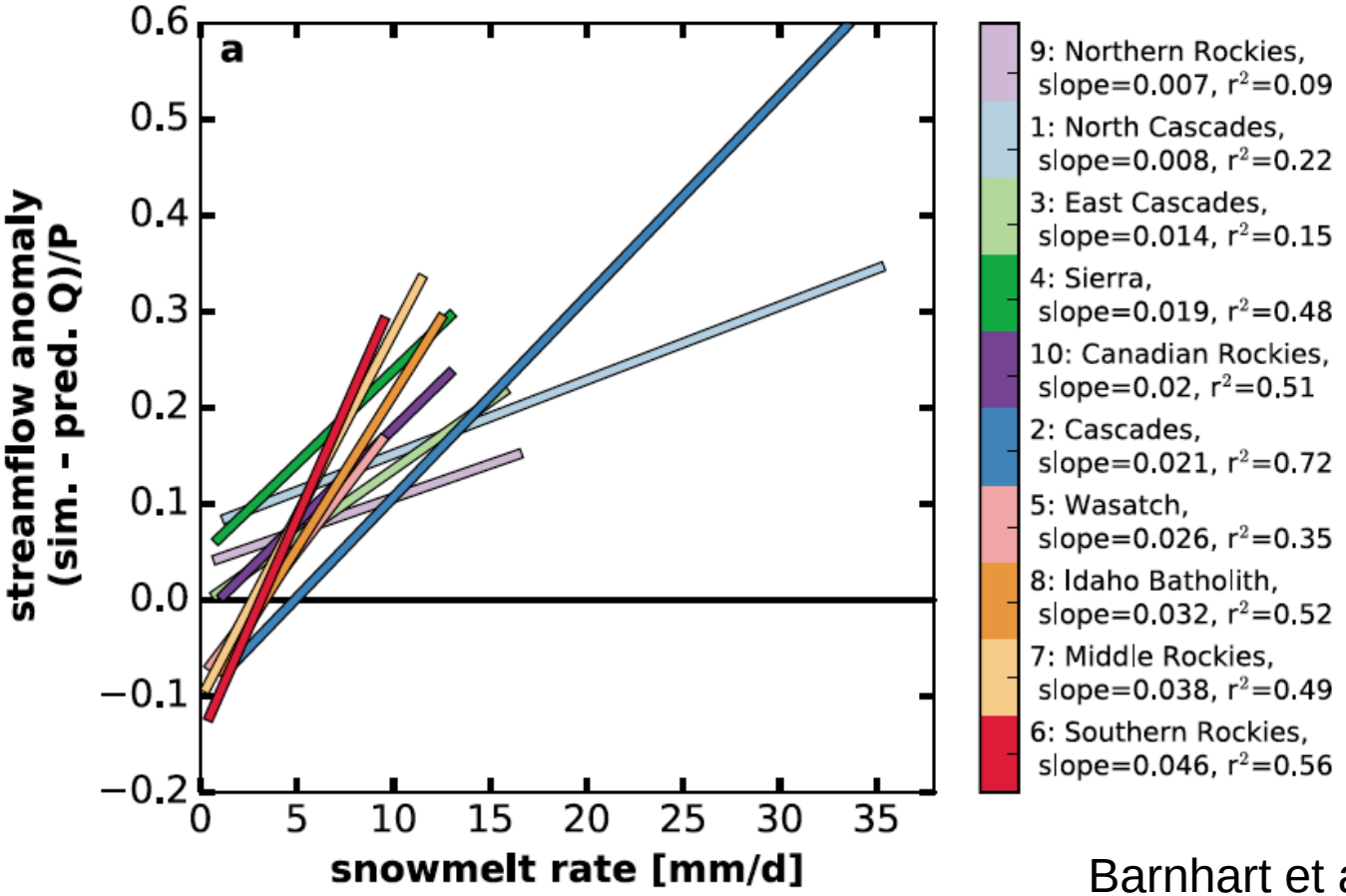
Barnhart et al., 2016



# More efficient streamflow generation when snowmelt rates are high

- Snowmelt rates of 1 cm/day lead to over generation of streamflow by 5-30%




Barnhart et al., 2016

# Will the snowpocalypse affect water yields?

- Change from rain to snow:
  - Generally less runoff
  - Sometimes more recharge
  - California is the exception due to intense winter precipitation
- Earlier water inputs
  - Limited effects on recharge in dry areas
  - Recharge effects dampened by greater storage
- Slower snowmelt
  - Less deep recharge
  - Reduced streamflow