Missouri River Hydroclimatology Overview

(with a little paleohydrology at the end)

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Upper Missouri River Breaks National Monument, MT

Improving Sub-Seasonal to Seasonal (S2S) Precipitation Forecasting

San Diego CA
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Contributions from: Erika Wise (University of North Carolina), Greg Pederson (USGS Northern Rocky Mt Science Center, and graduate students Justin Martin (Montana State U) and Sarah Frederick (University of Arizona)

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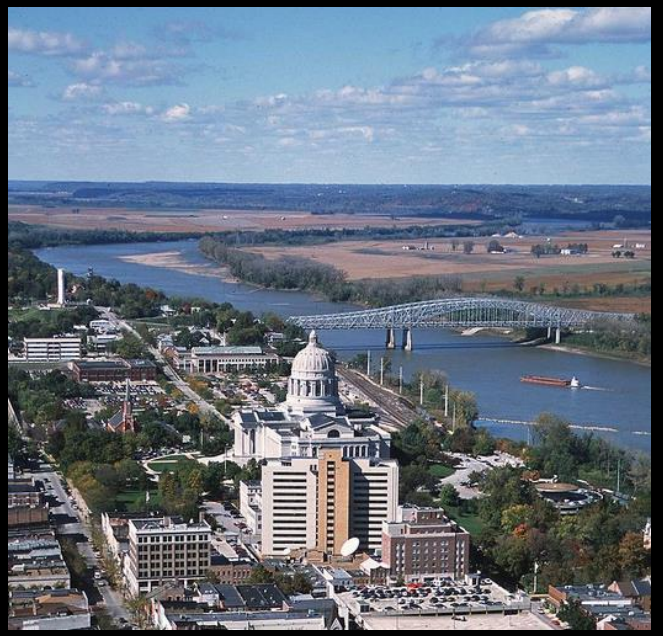
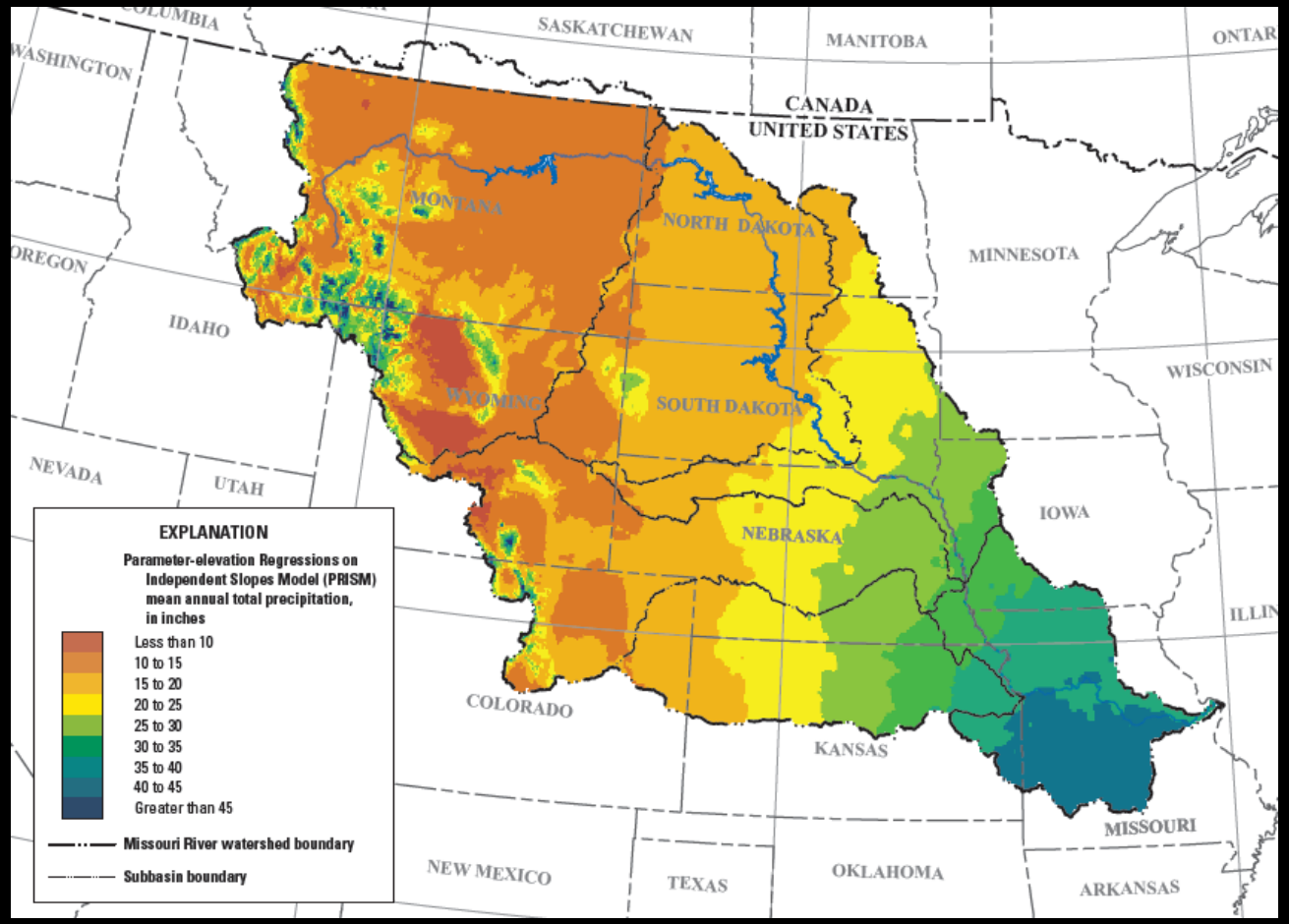
Missouri River

- Length: 2,565 miles (the longest river in the US)
- Watershed size: over 500,000 square miles (the largest watershed within the US)
- Annual yield: 40 million acre-feet (compared to Columbia River's 199 MAF and Colorado's <15 MAF)

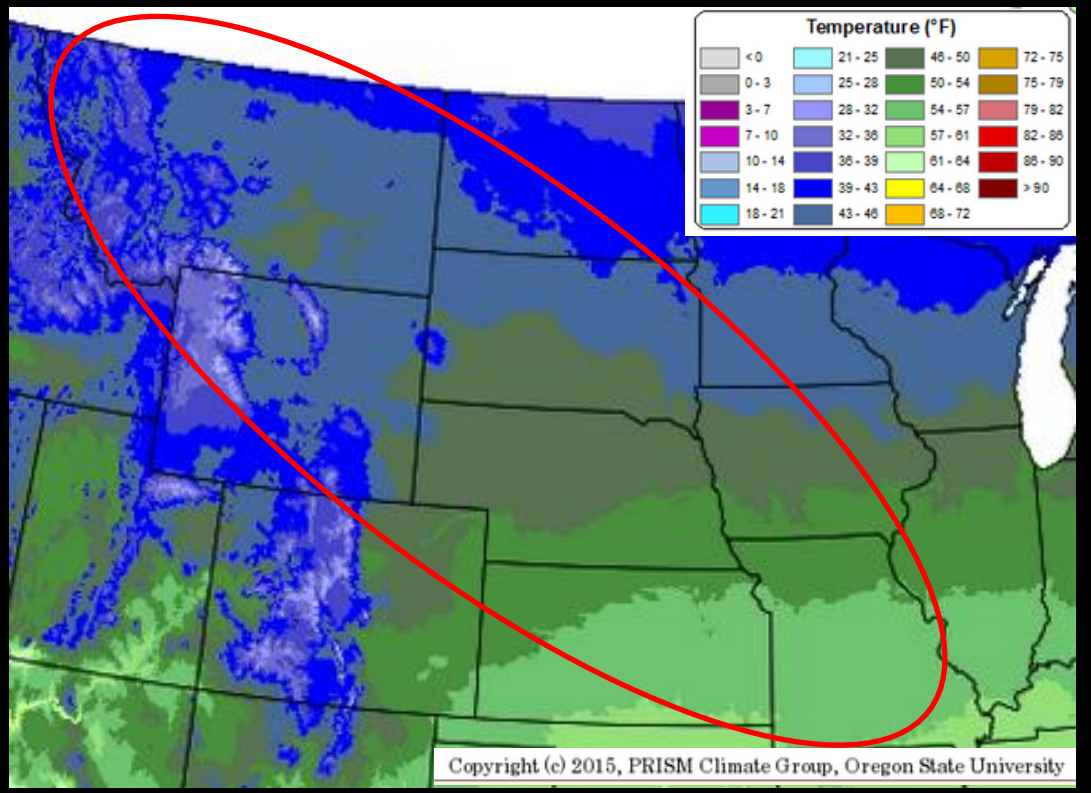
Importance of the basin



Topography, gradients of longitude and latitude influence basin climate



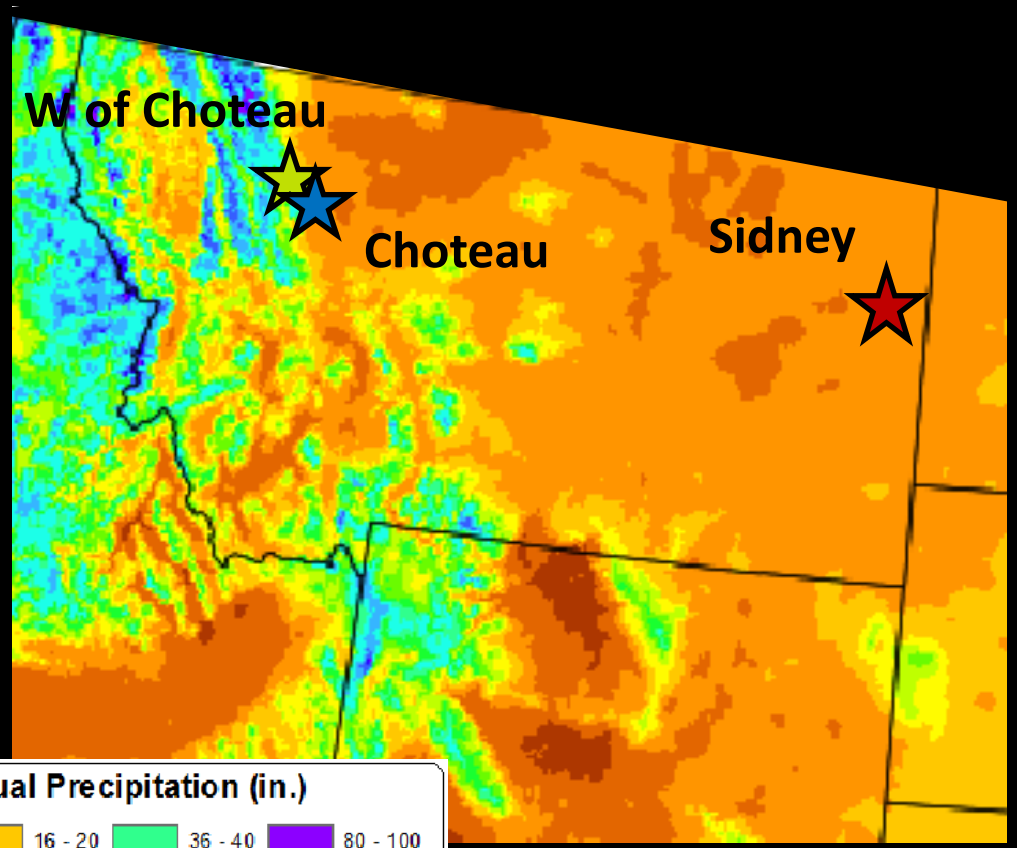
From Norton et al. 2014

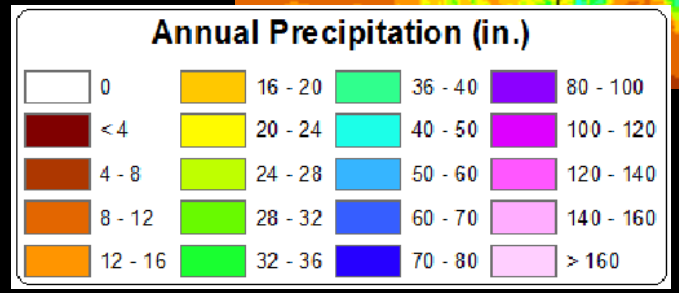


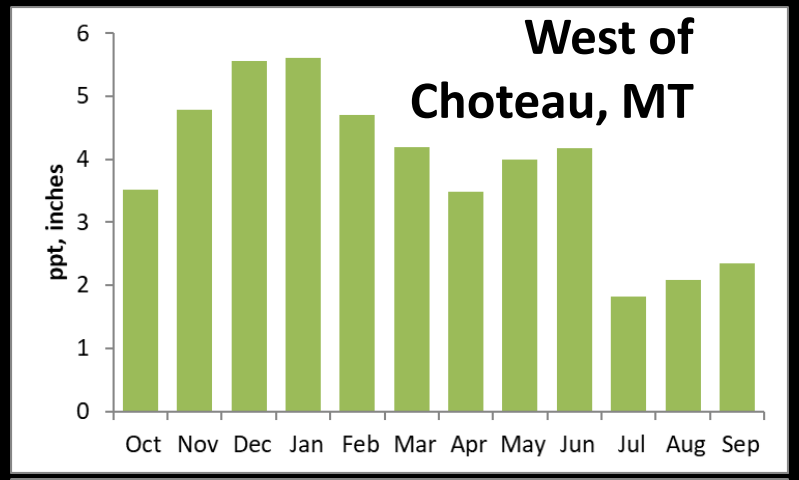
Mean Annual Temperature

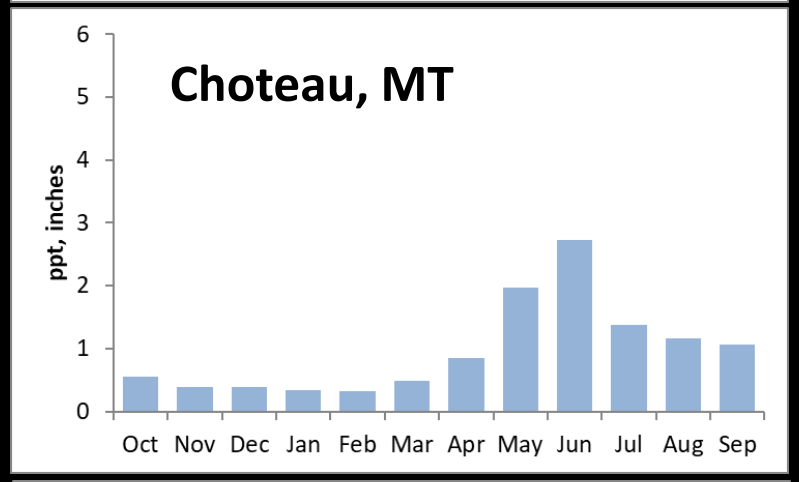
Annual Precipitation Total

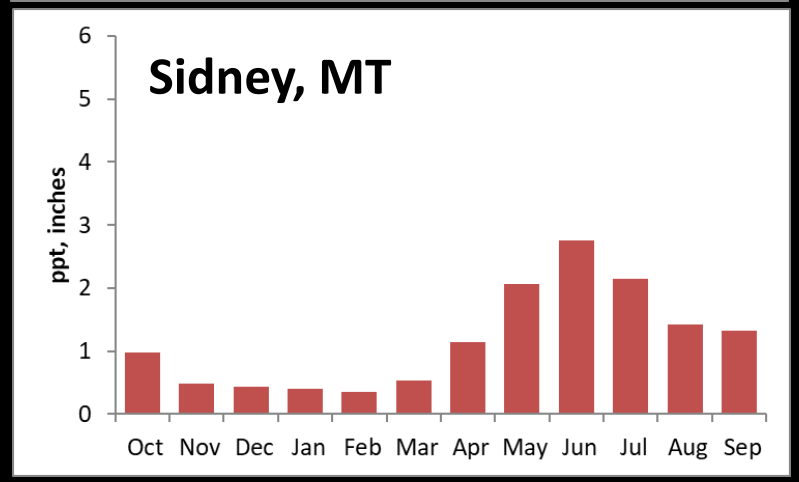
Upper Basin Precipitation Climatology





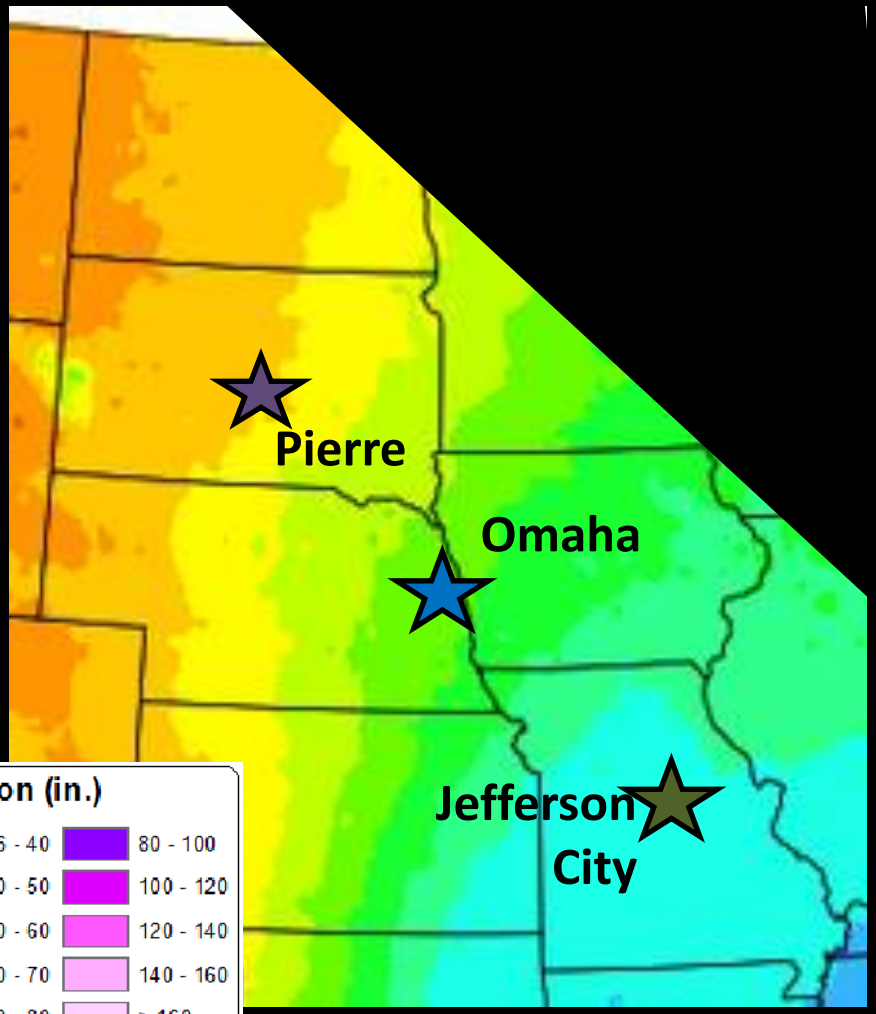


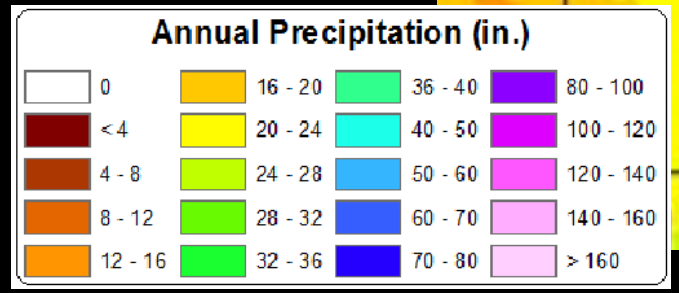


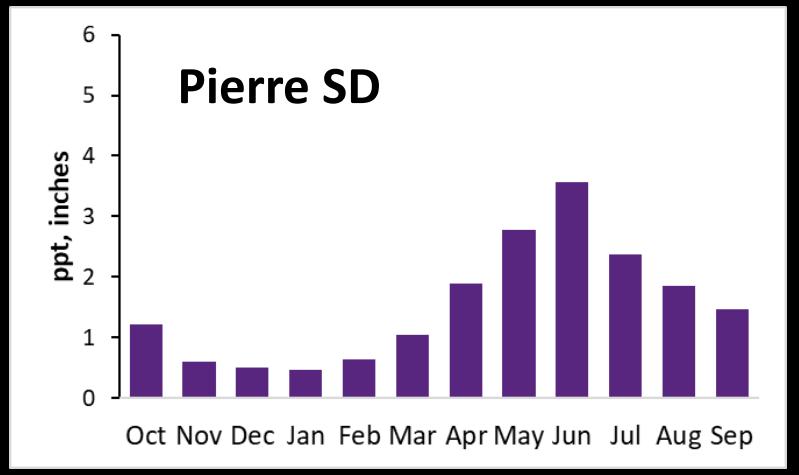


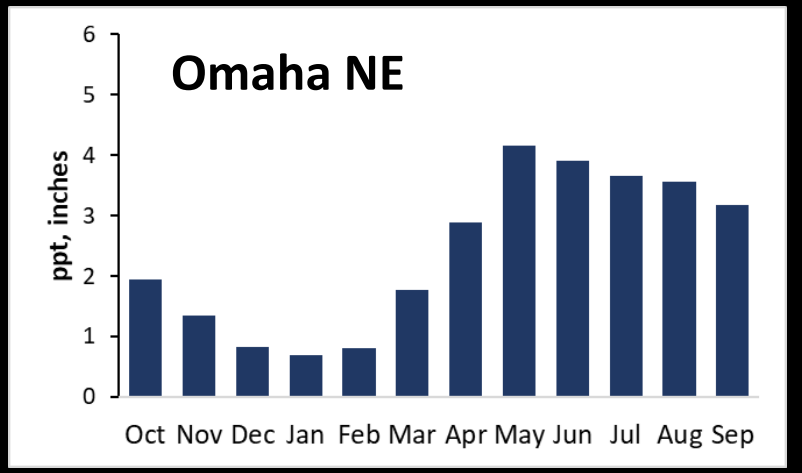
Climate map from PRISM; data from WRCC

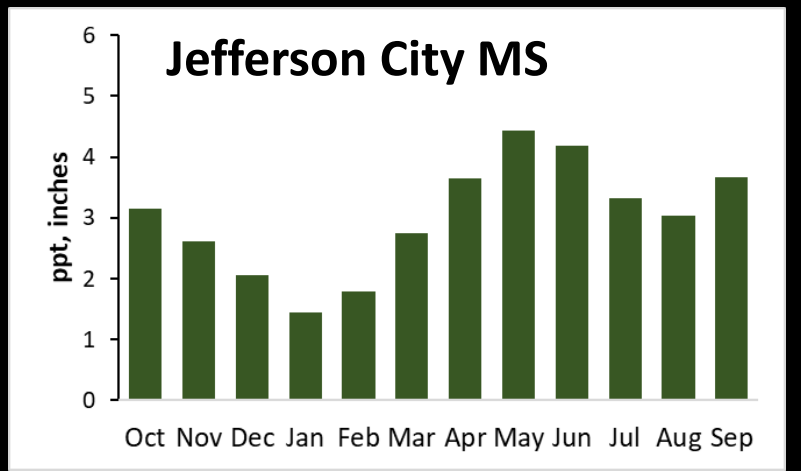
Lower Basin Precipitation Climatology







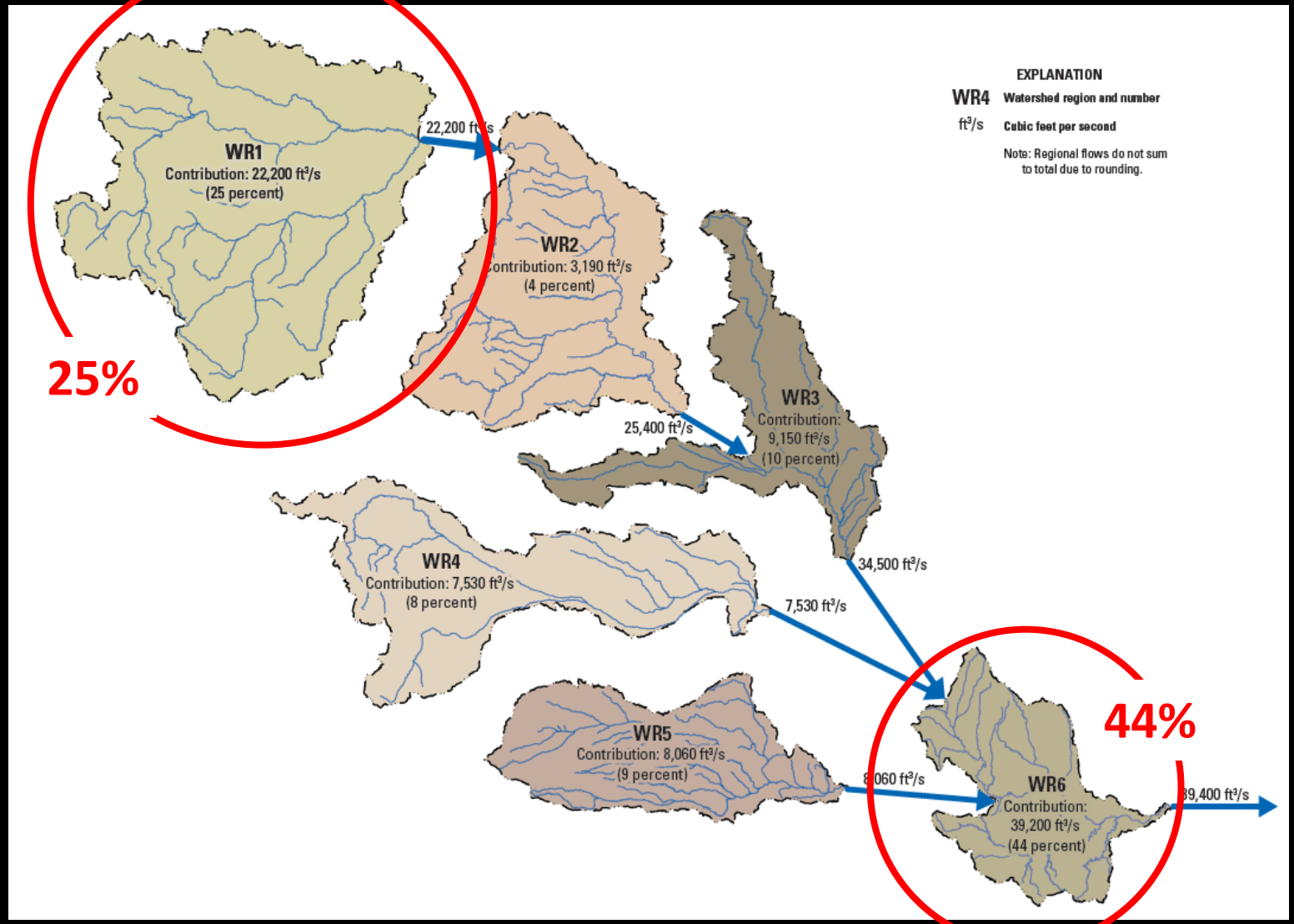




Climate map from PRISM; data from WRCC

2 key source regions for the Missouri River

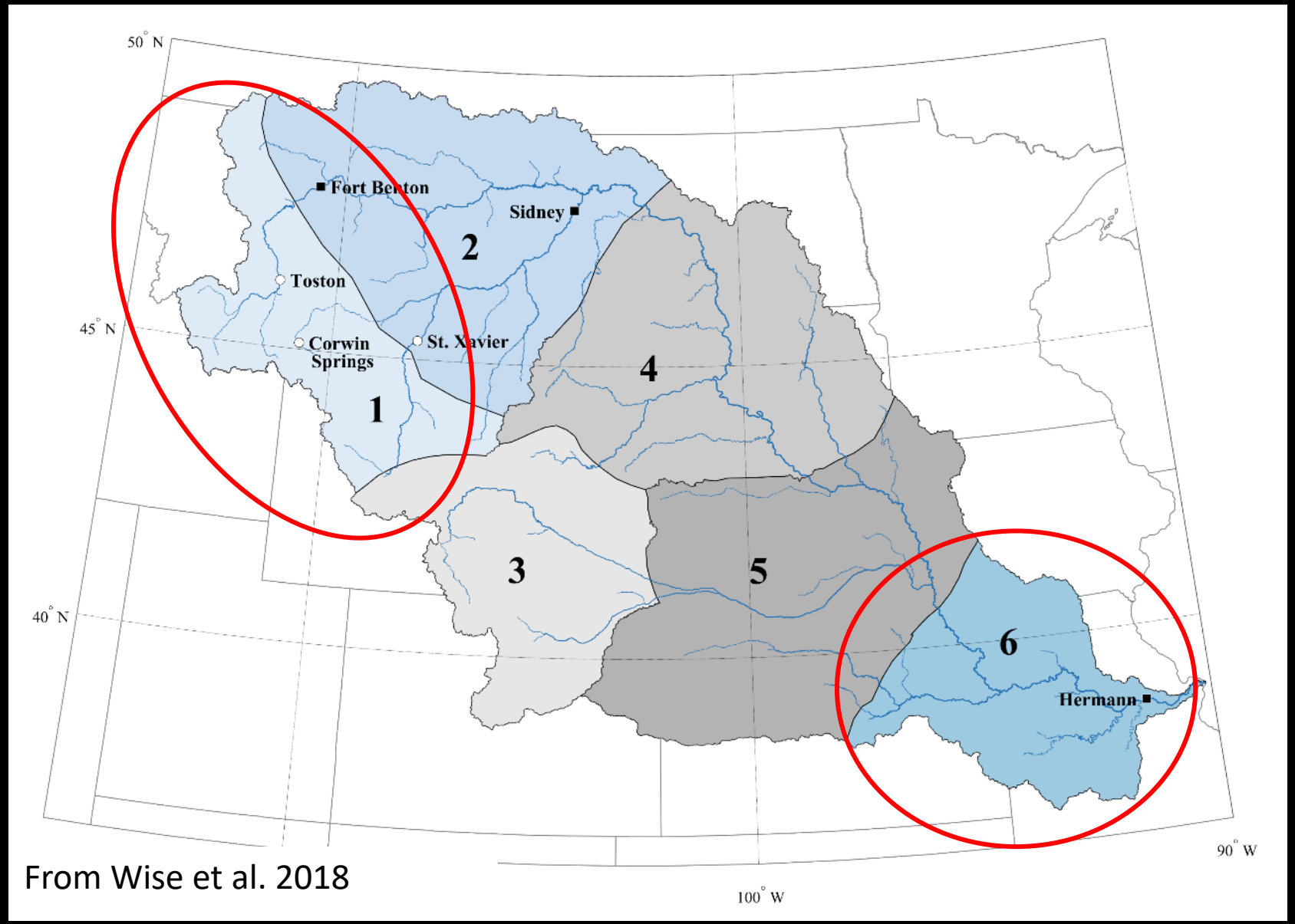
Mean annual contributions of streamflow by watershed region to total mean streamflow



From USGS Scientific Investigations Report 2014–5053
Norton et al. 2014

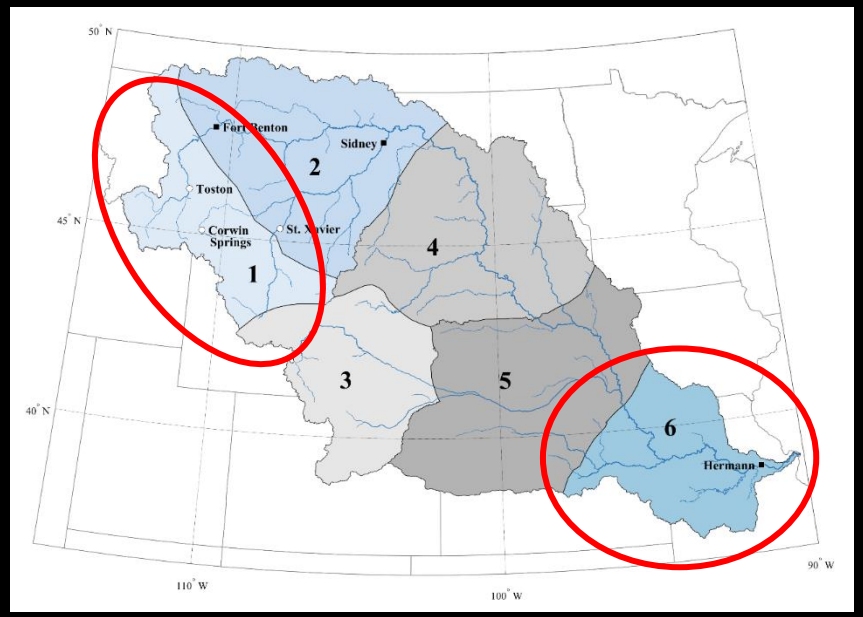
Similar findings in our study:
(Wise et al. 2018)

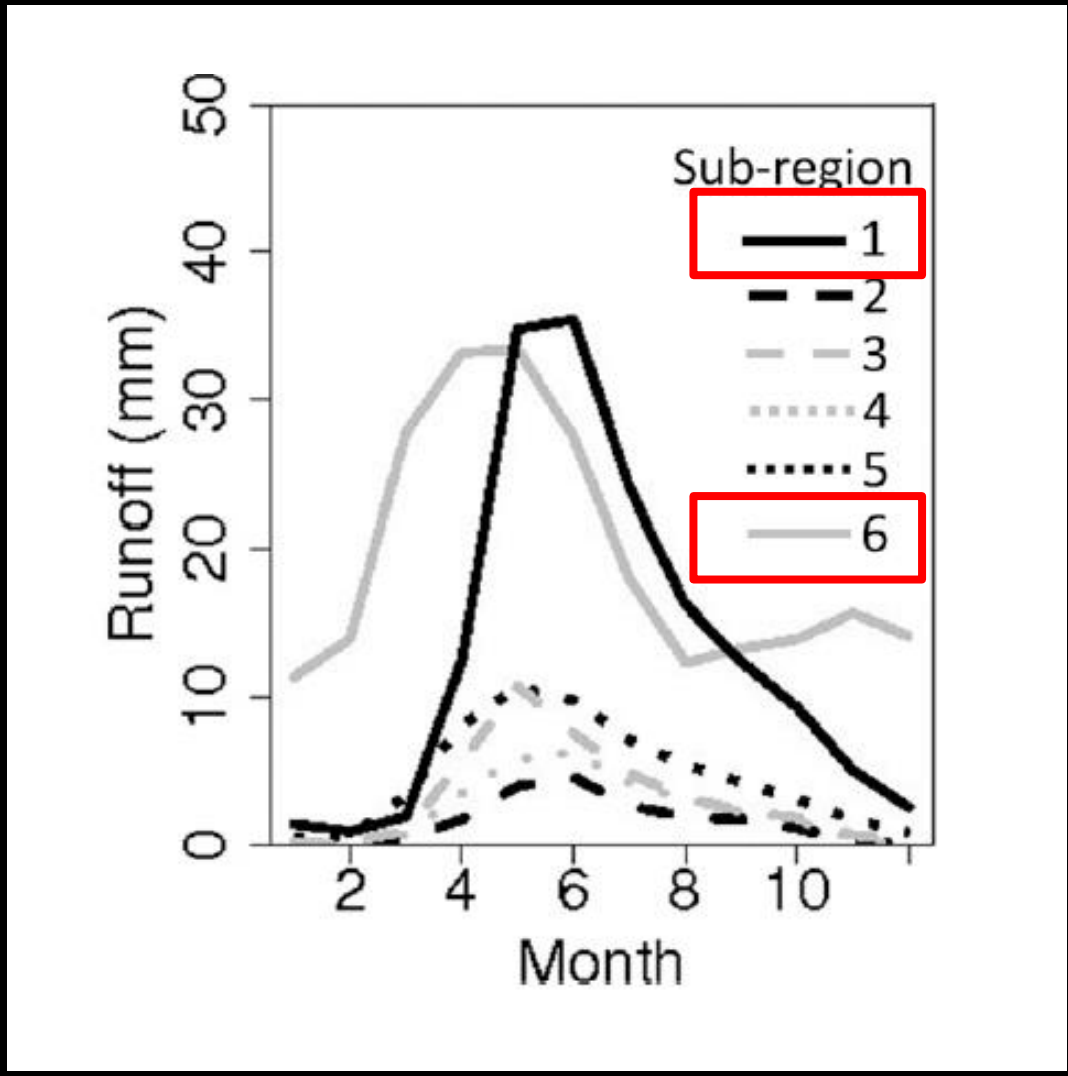
Two main source regions contribute to about 72% of total Missouri River flow



From Wise et al. 2018

Missouri River basin sub-regions: mean monthly runoff





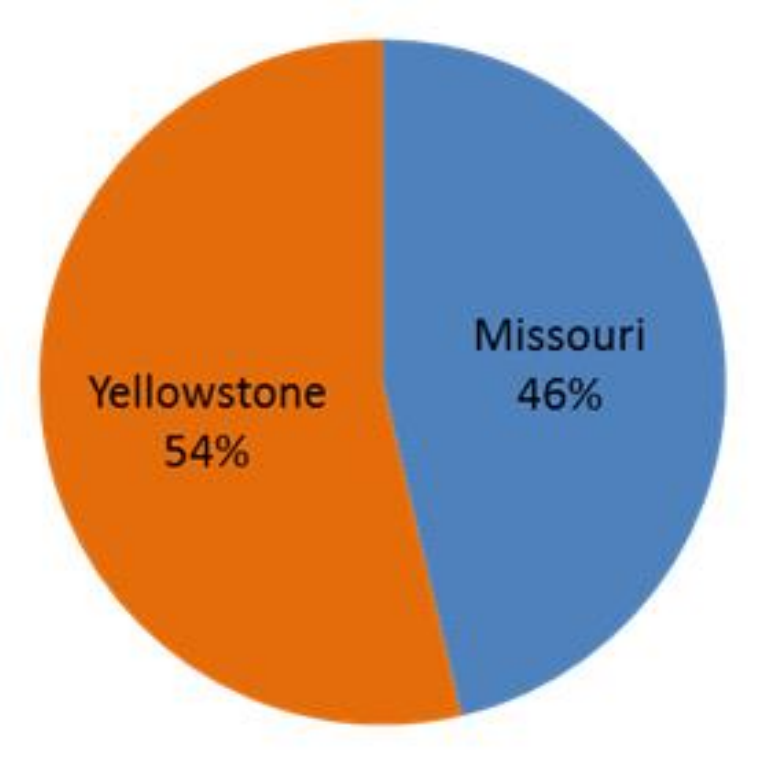
Mean monthly runoff (mm) for each subregion

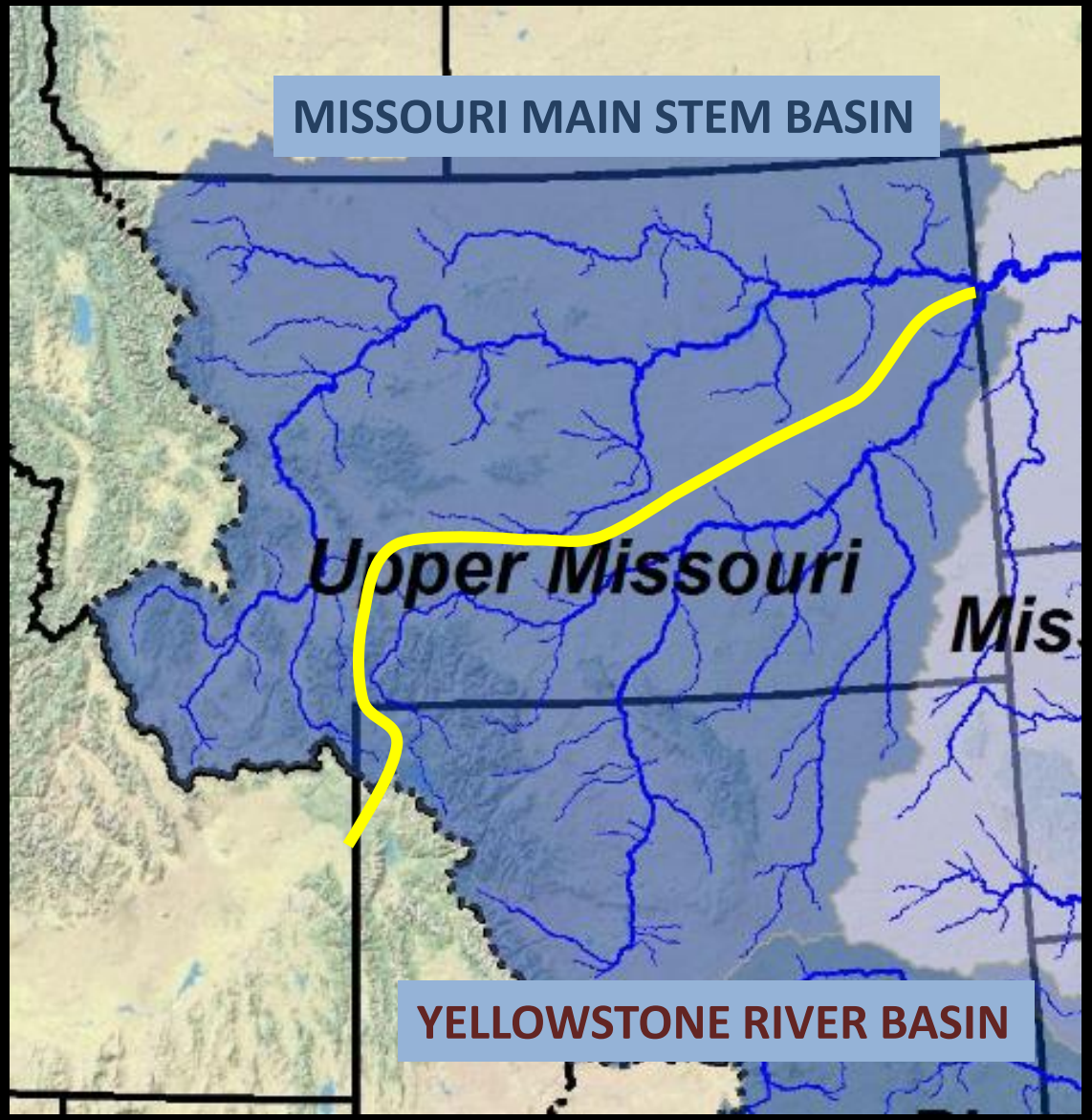
Upper Missouri River basin

UMRB flow = ~28% of total MRB flow

Upper Missouri River basin

Yellowstone (54%) and Missouri main stem (46%) are the 2 main sub-basins in the UMRB

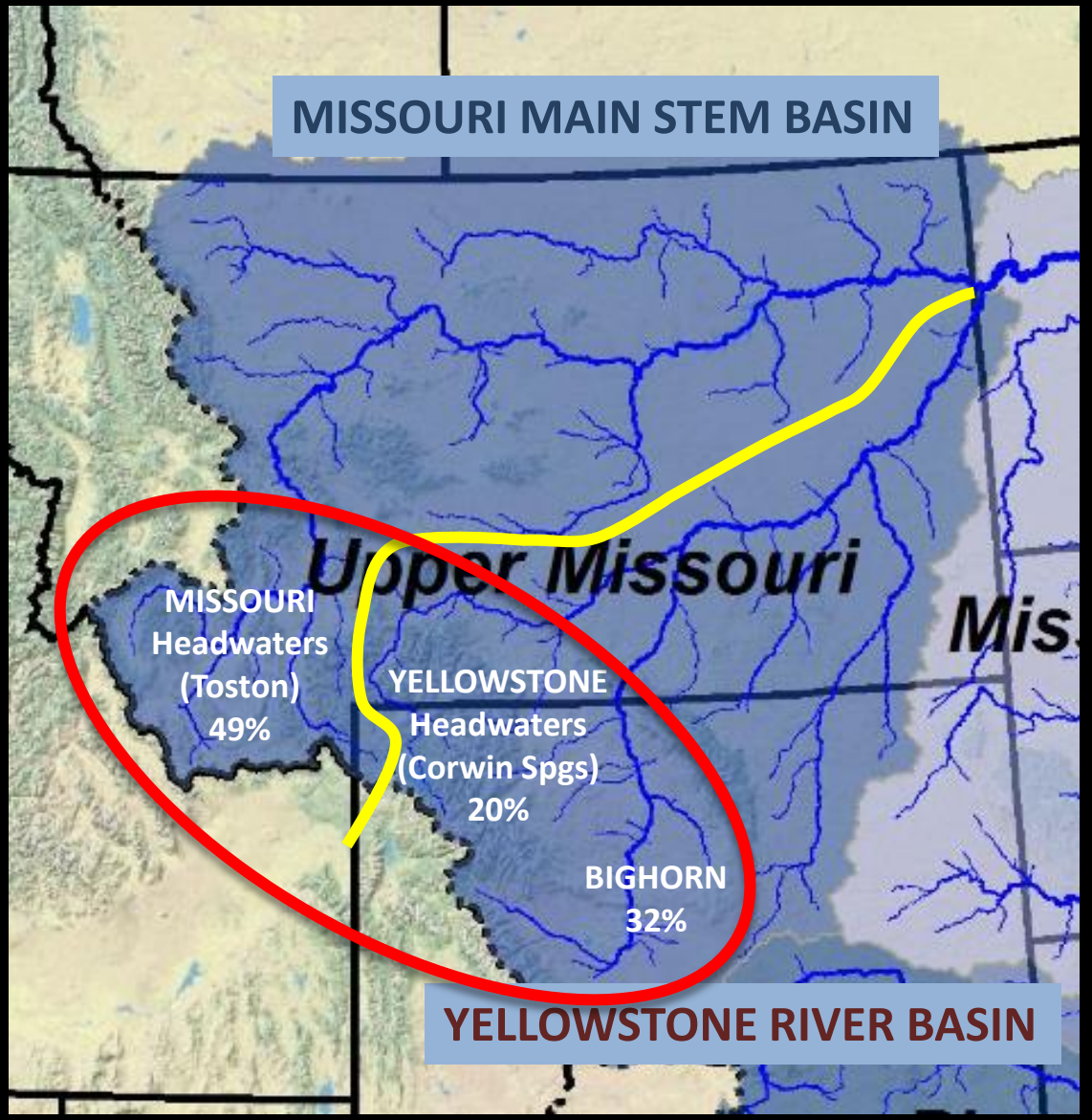




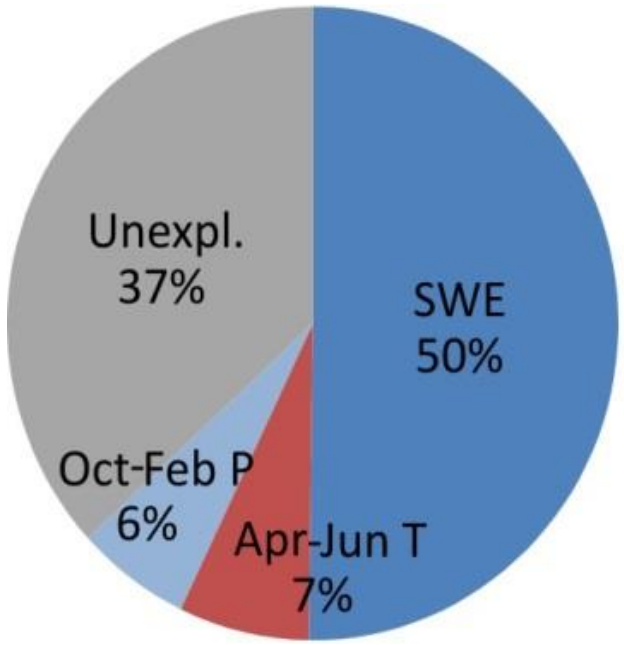
The Importance of the Headwaters:

3 headwaters gages account for 51% of total UMRB flows.

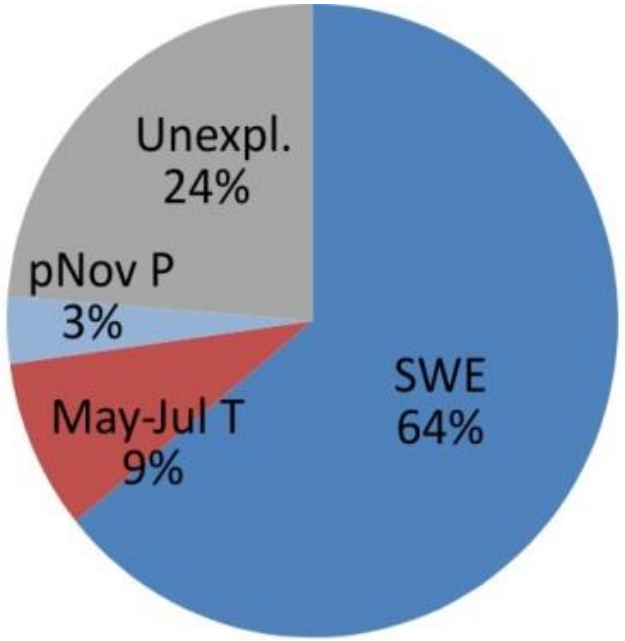
- Missouri at Toston
- Yellowstone at Corwin Spgs
- Bighorn nr St. Xavier



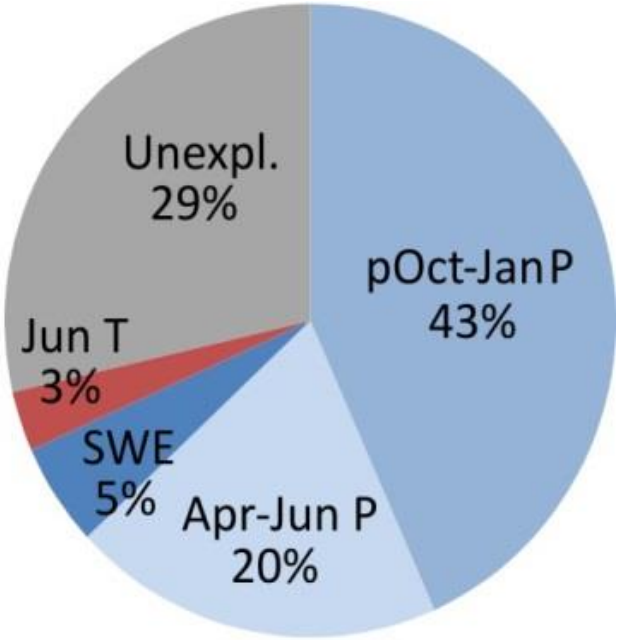
Major climatic factors influencing Missouri River Headwaters streamflow



Missouri R. @ Toston



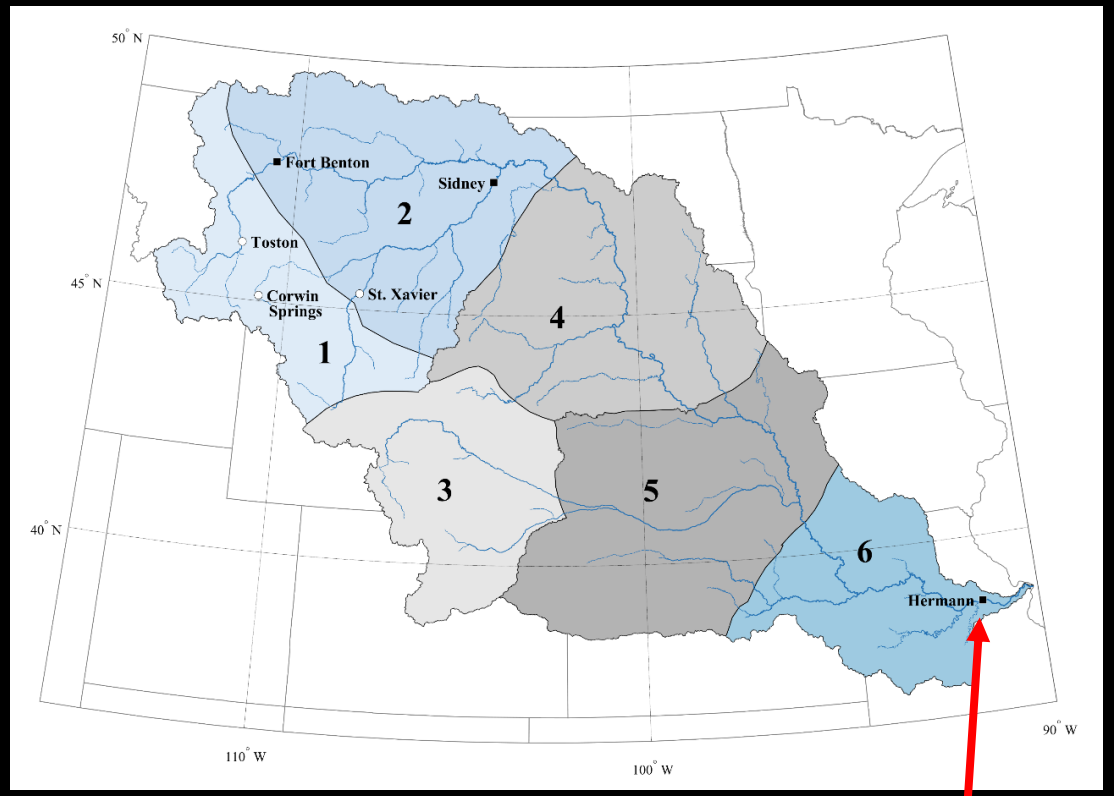
Yellowstone R. @ Corwin Spgs



Bighorn R @ St. Xavier

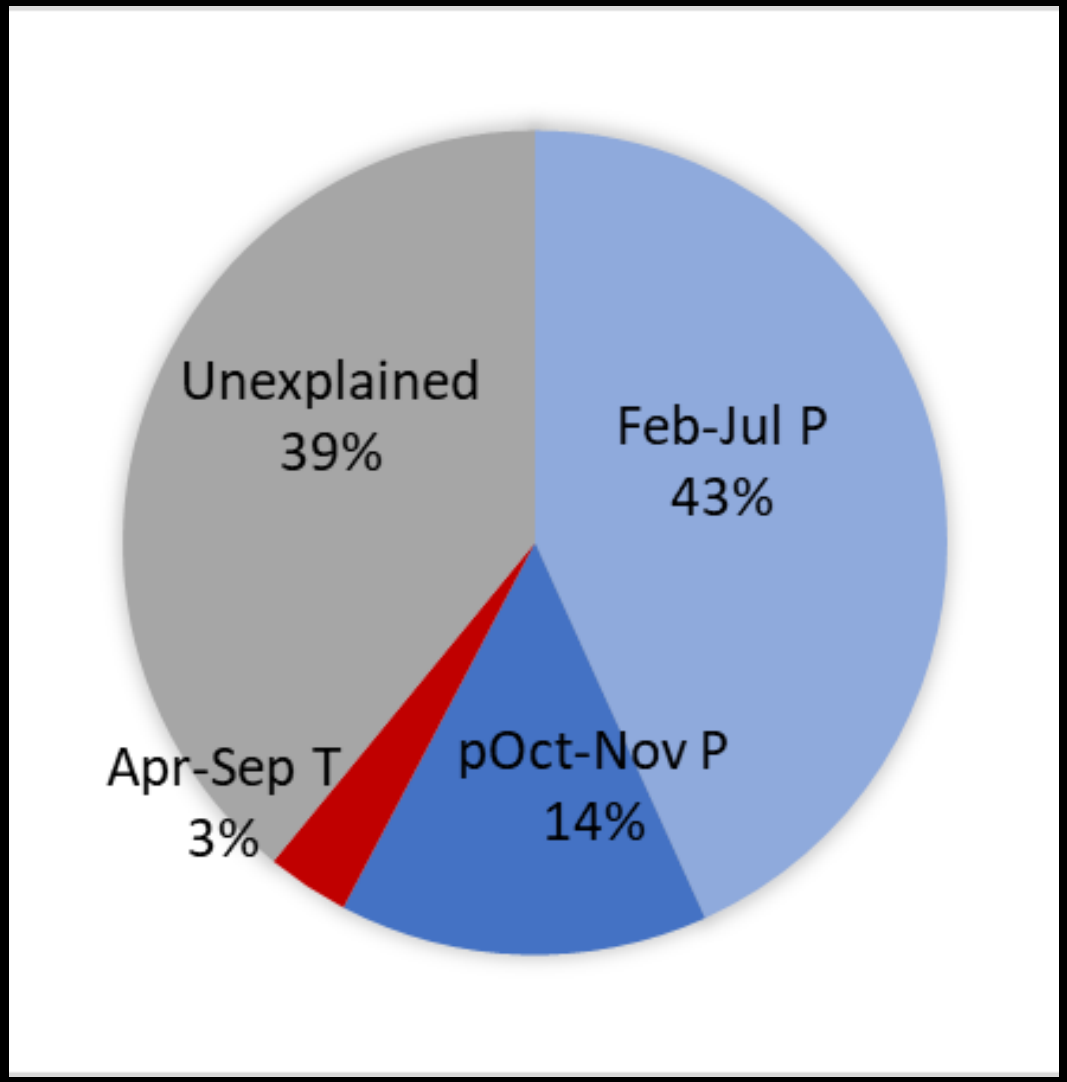
Lower Missouri River basin

LMRB flow = 44% of total MRB flow



Gage at Hermann, MO

Major climatic factors influencing lower Missouri River streamflow



Summary of climate variables most important for Missouri River streamflow

Upper Missouri (region 1)

Main stem and Yellowstone

- April 1 SWE
- Spring temperatures
- *Prior fall/early winter precipitation*

Bighorn

- Early winter precipitation
- Spring precipitation
- *April 1 SWE*
- *Spring temperatures*

Lower Missouri (region 6)

- Feb-July precipitation
- Prior fall precipitation
- *April – September temperatures*

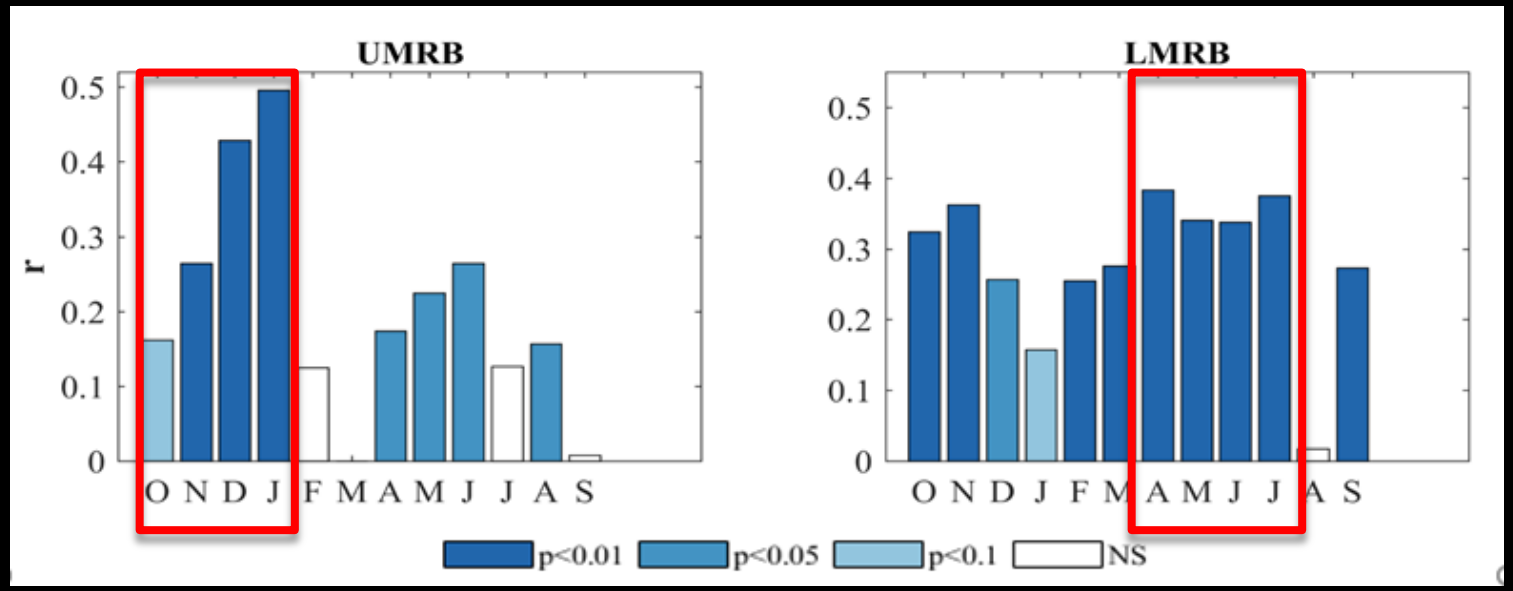
Seasonal circulation patterns associated with Missouri River streamflow

Circulation analysis

- 500 mb GPH
- Sea surface temperatures (SSTs)

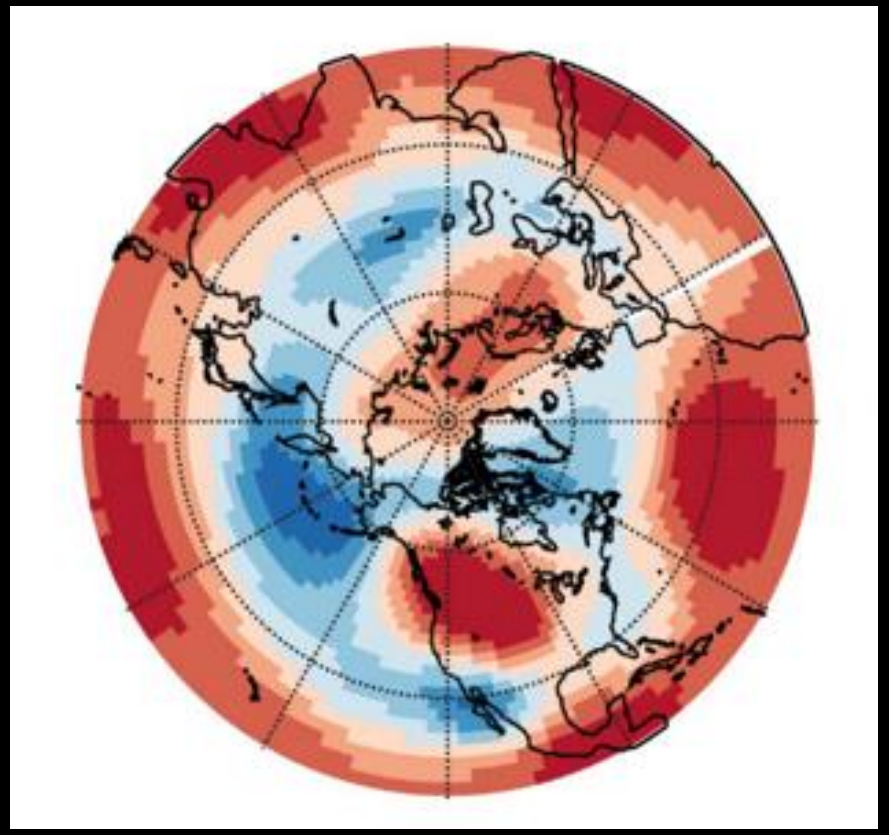
during months when precipitation is associated with upper and lower Missouri River flows

- Upper: October -January
- Lower: April - July

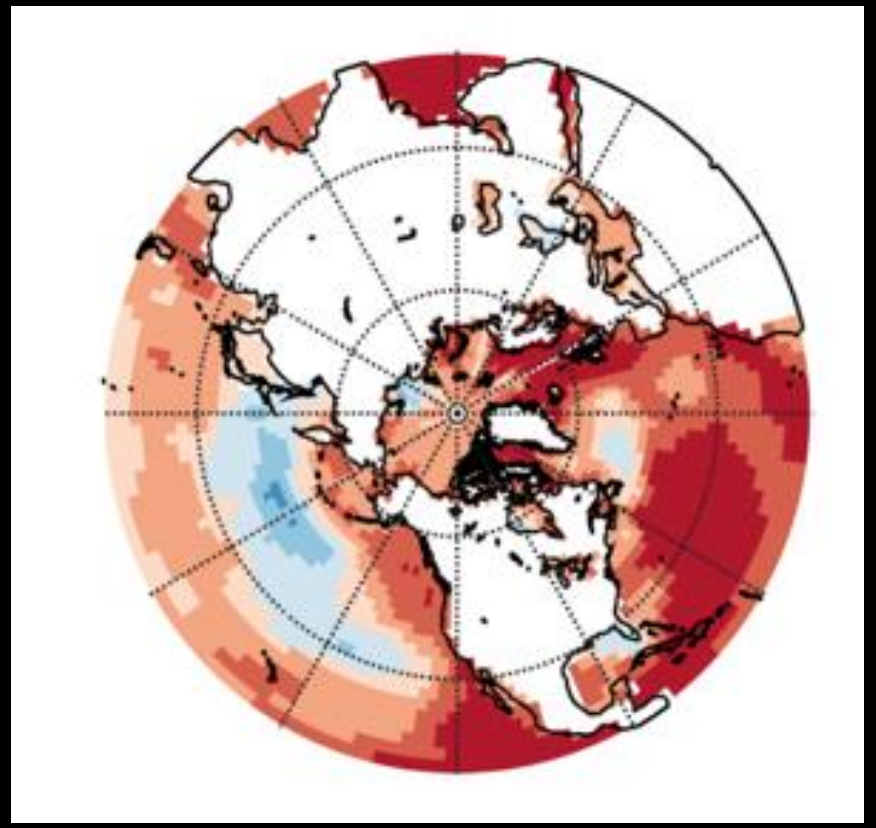


Annual upper basin flow and October-January patterns

500mb GPH

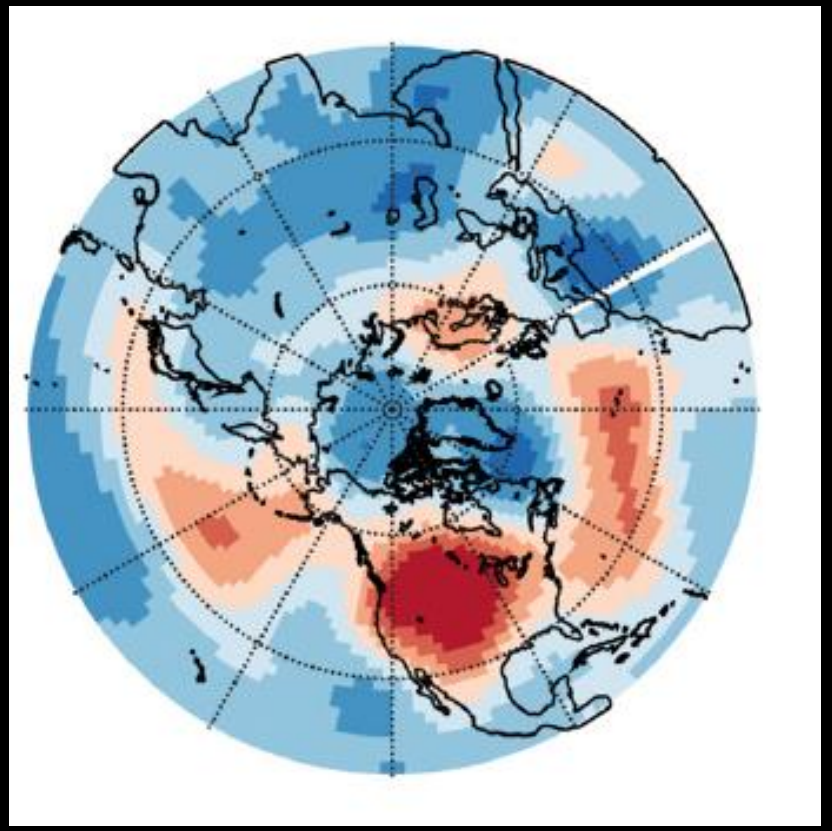


SSTs

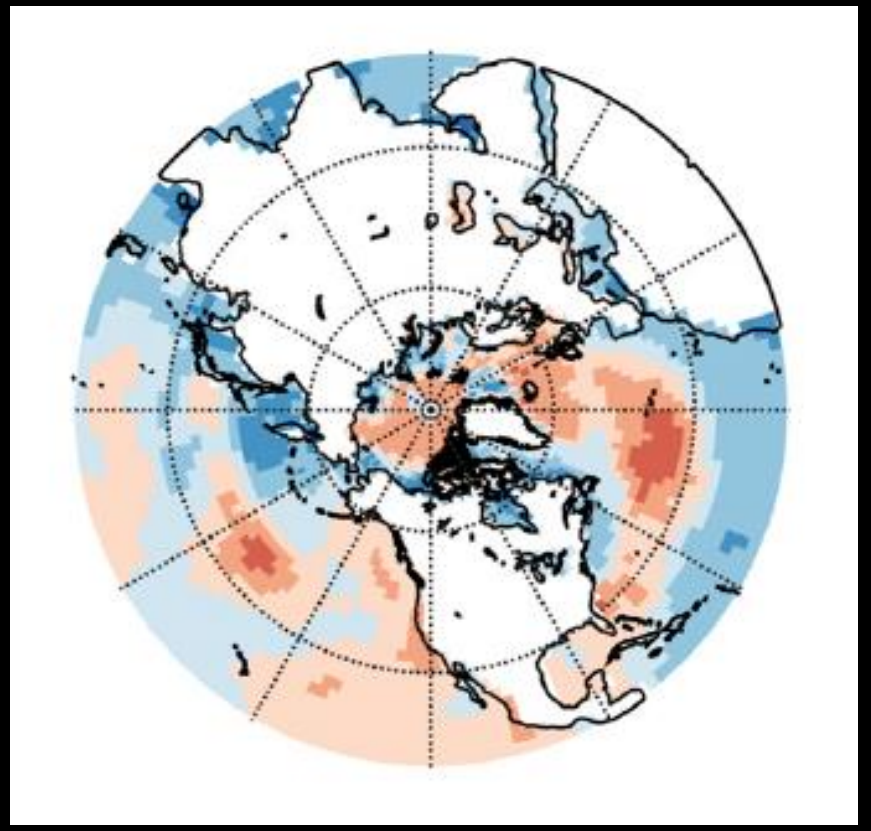


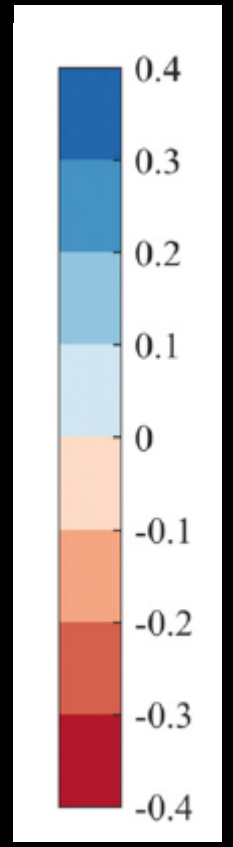
Annual lower basin flow and April-July patterns

500mb GPH



SSTs





Summary of Upper Basin Hydroclimate:

- Accounts for ~28% of total flow; over half of that comes from high headwaters
- High headwaters basin flows are strongly related to April 1 SWE
- Other/related season controls on upper basin flow: early winter precipitation; spring precipitation secondarily; spring temperatures
- Winter (Oct-Jan) circulation associated with water year flow:
  - Pacific North America (PNA)-type 500 mb pattern
  - Weaker ENSO-like SST signature

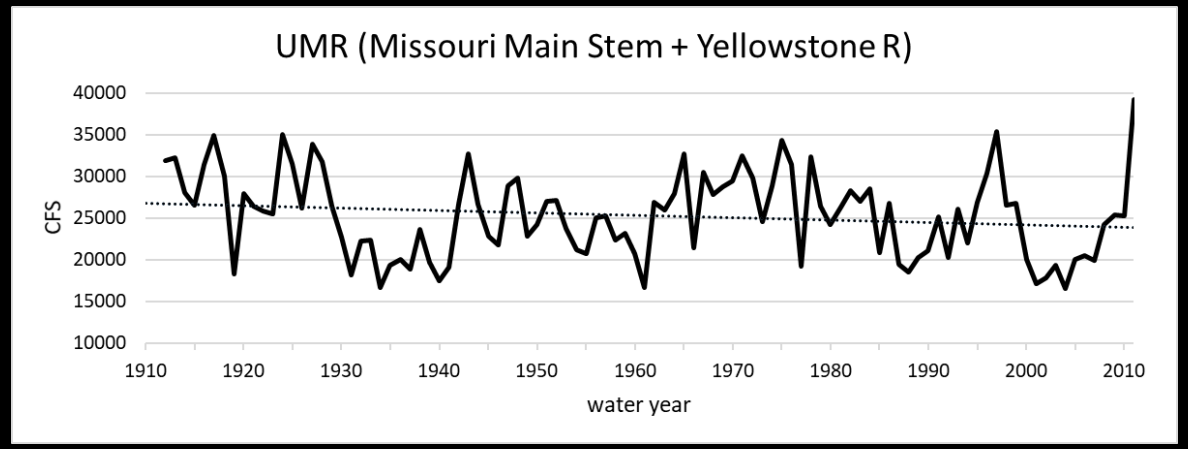
Summary of Lower Basin Hydroclimate:

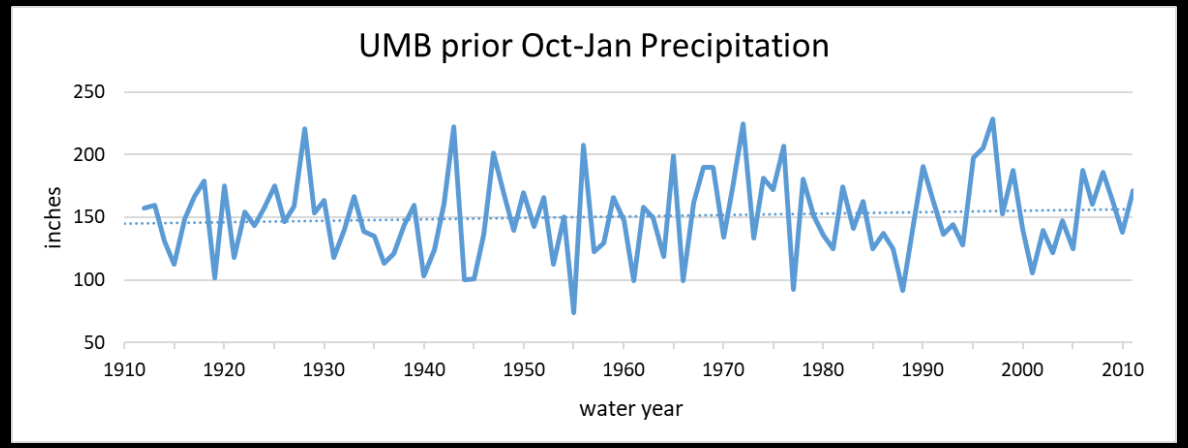
- Missouri R. flow at its mouth originates in large part from local climate

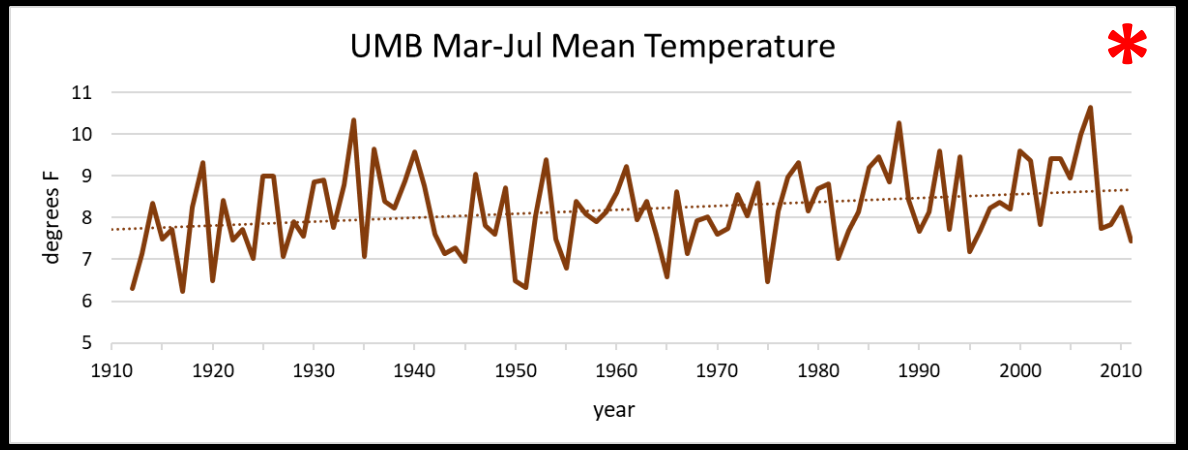
- Spring/early summer (April-July) is the most important precipitation season, but prior fall is also important

- Spring/summer circulation associated with water year flow:
  - Large 500 mb pressure center over central North American
  - Atlantic SSTs suggest influence of Atlantic Multidecadal Oscillation (AMO)

Trends in streamflow and key climate variables for Missouri River streamflow, 1912-2011







Upper Missouri River basin (Main stem + Yellowstone)

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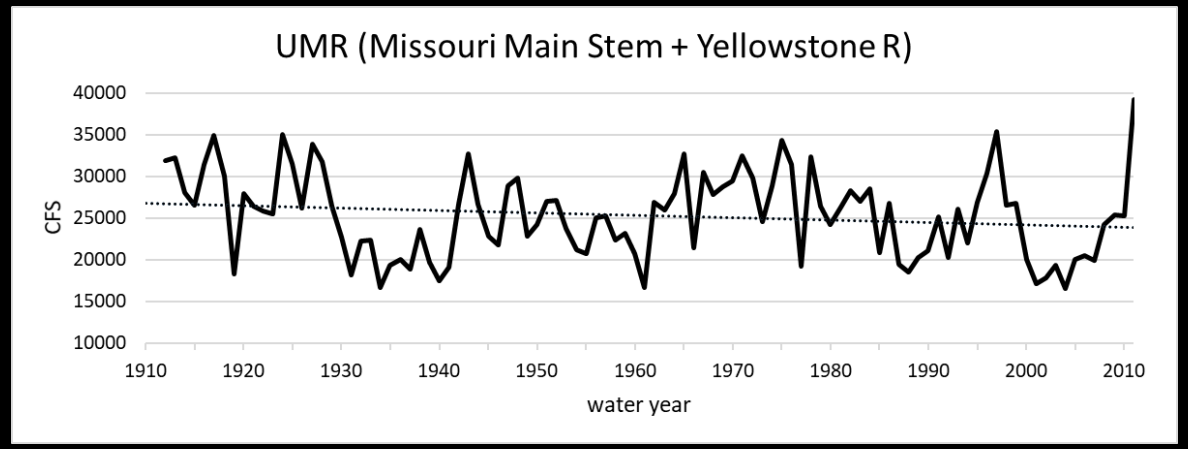
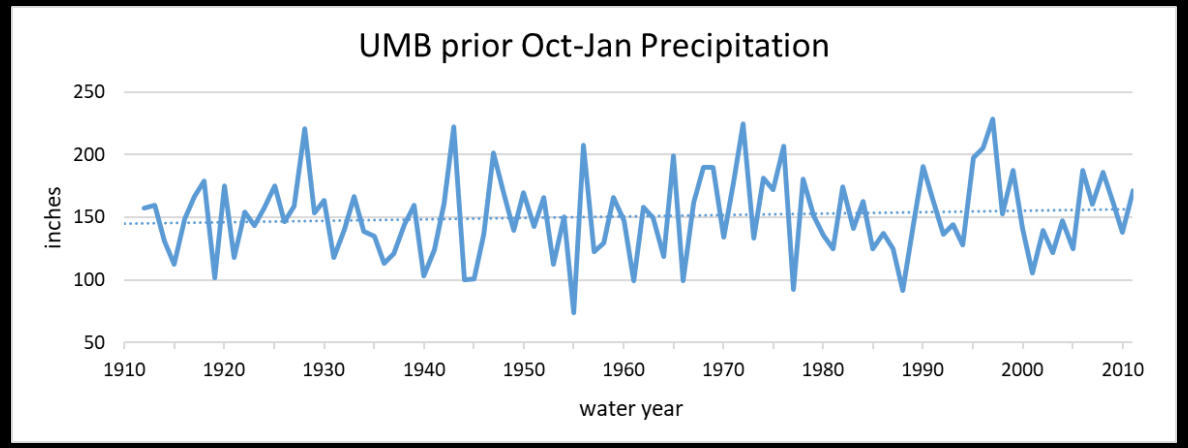
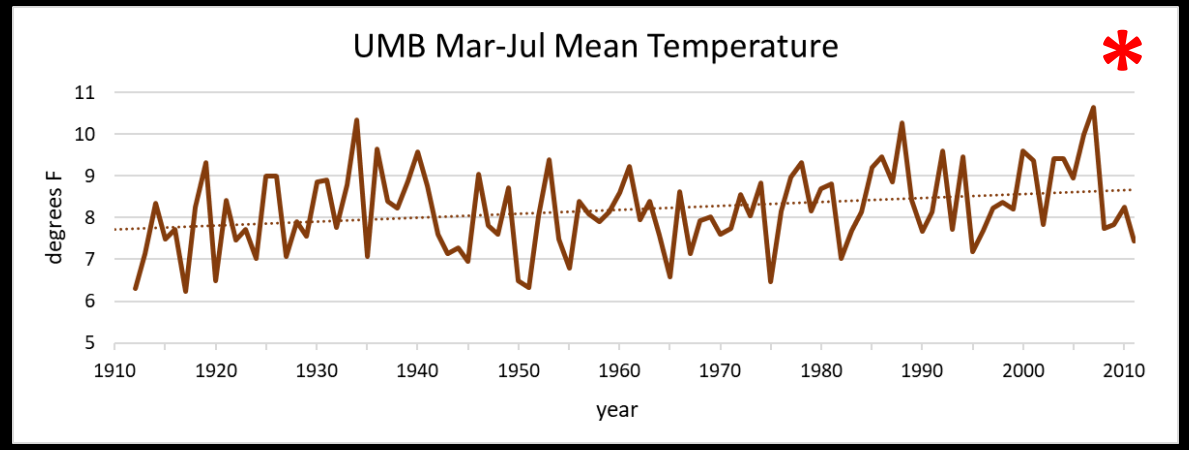
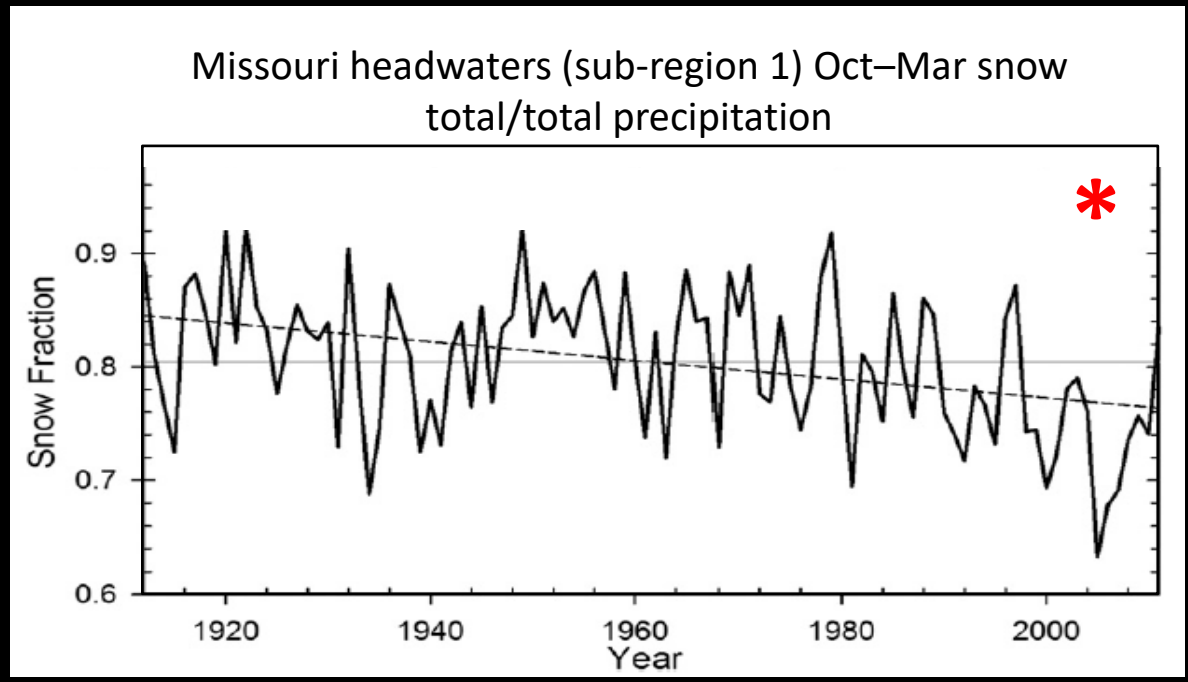


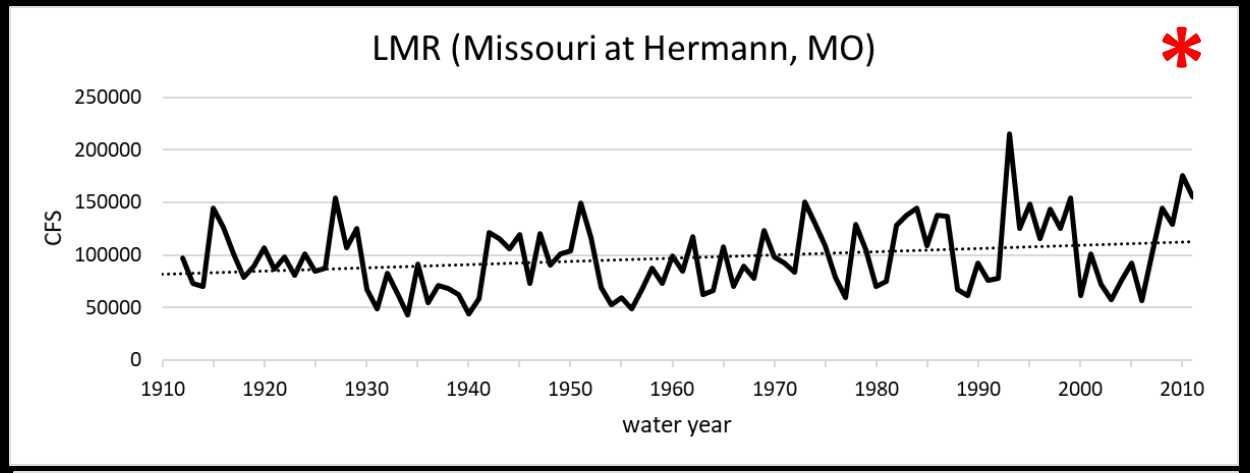


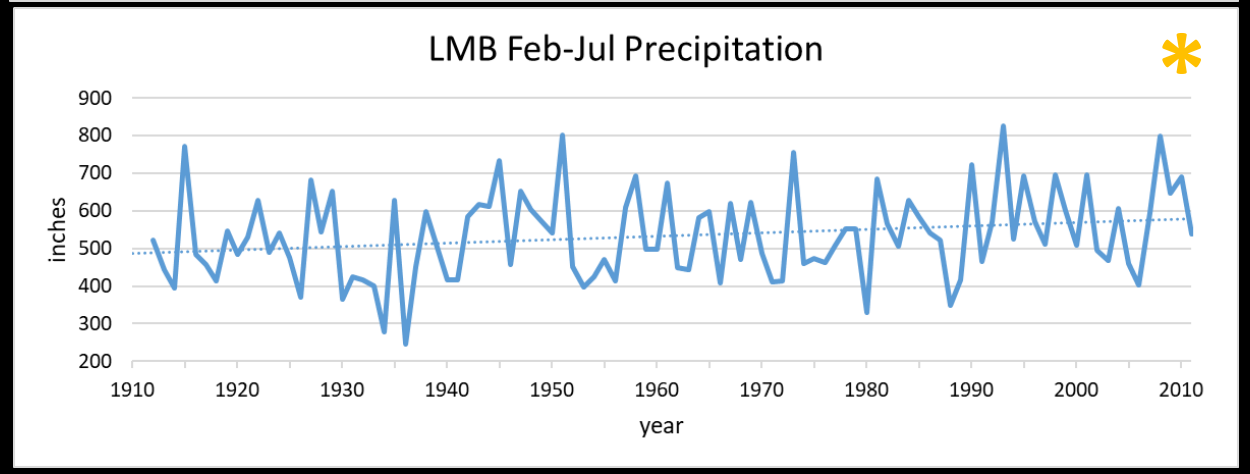


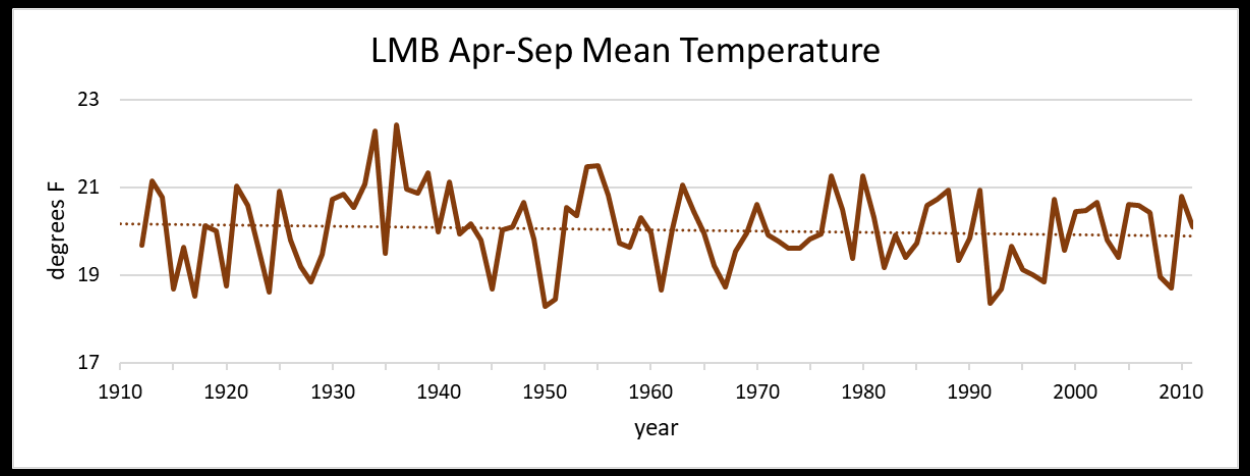


* = trend is significant $p < 0.01$

Lower Missouri River Basin (region 6)







* = trend is significant p < 0.01

* = trend is significant p < 0.05

Summary of trends

Upper Missouri

- ↓ Fraction of winter precipitation that falls as snow
- ↑ March-July temperatures

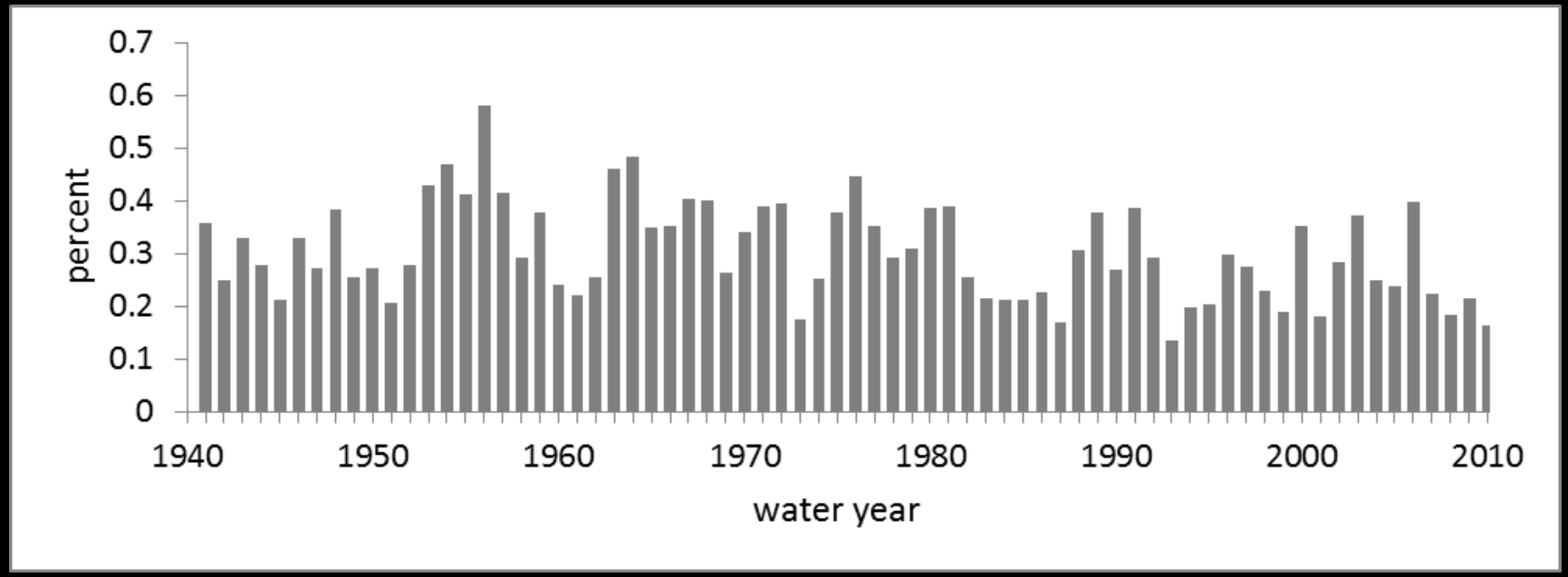
Lower Missouri

- ↑ Water year streamflow
- ↑ February-July precipitation

Contribution of upper basin flow to total Missouri River flow

Percent of total Missouri River basin flow accounted for by upper basin flow, 1941-2010

- Contribution has varied from 14% to 58%



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Total Missouri R. flow = Hermann MO gage

Percent of total Missouri River basin flow accounted for by upper basin flow, 1941-2010

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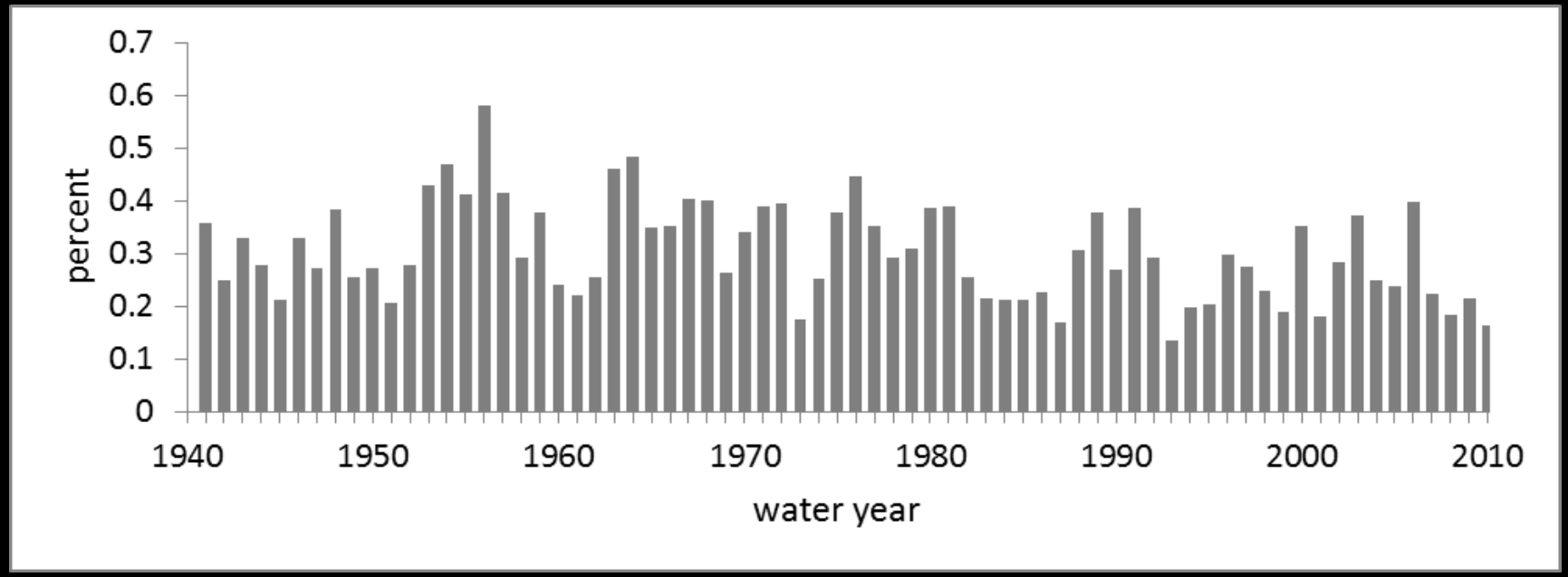
- Contribution has decreased over time (significant at $p < 0.01$)



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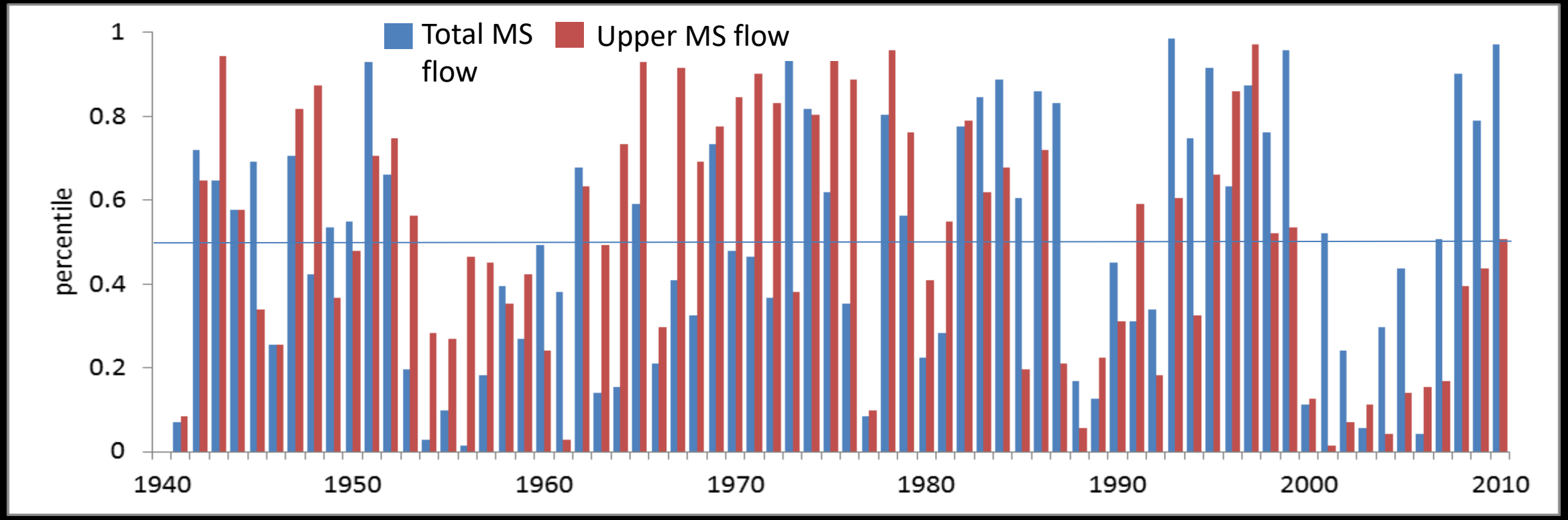
Upper versus lower basin flows, in percentile, 1941-2010

Changes in relative flow volume over time



Upper Basin Contribution Summary:

- Changes in contribution of the upper basin flow likely reflect increases in flow in the lower basin, due to increases in late winter/spring/summer precipitation

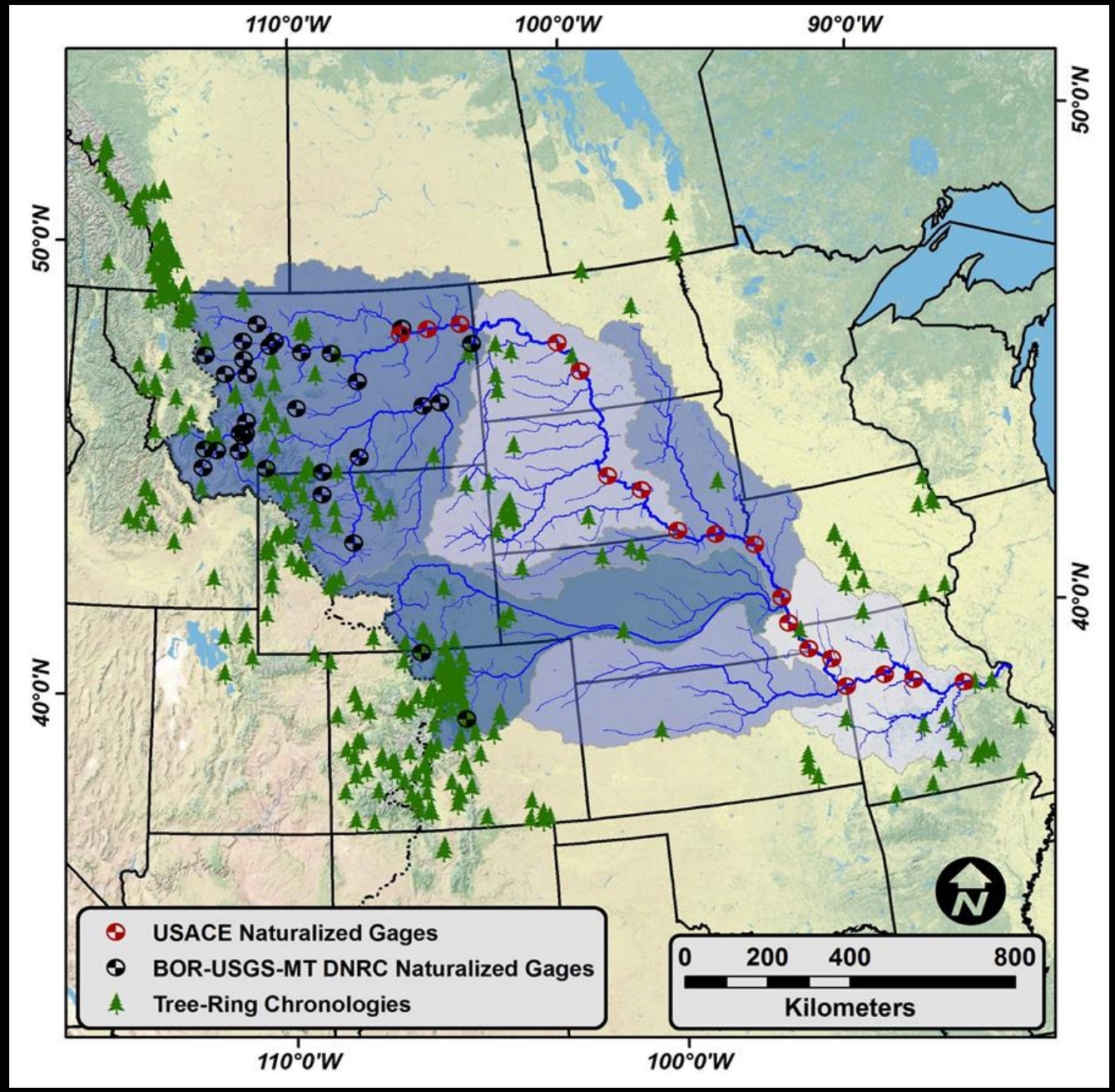
- Changes in relative flow volume indicate the upper basin flows were relatively greater during the 1950s and 1960s droughts, but less, relative to lower basin flows, since 2001.

  Is this change a result of the increasing spring/summer temperatures in the upper basin, along with a reduction of snow fraction? Likely to continue in the future?

A Paleo Perspective on Upper Missouri River Basin Hydroclimate

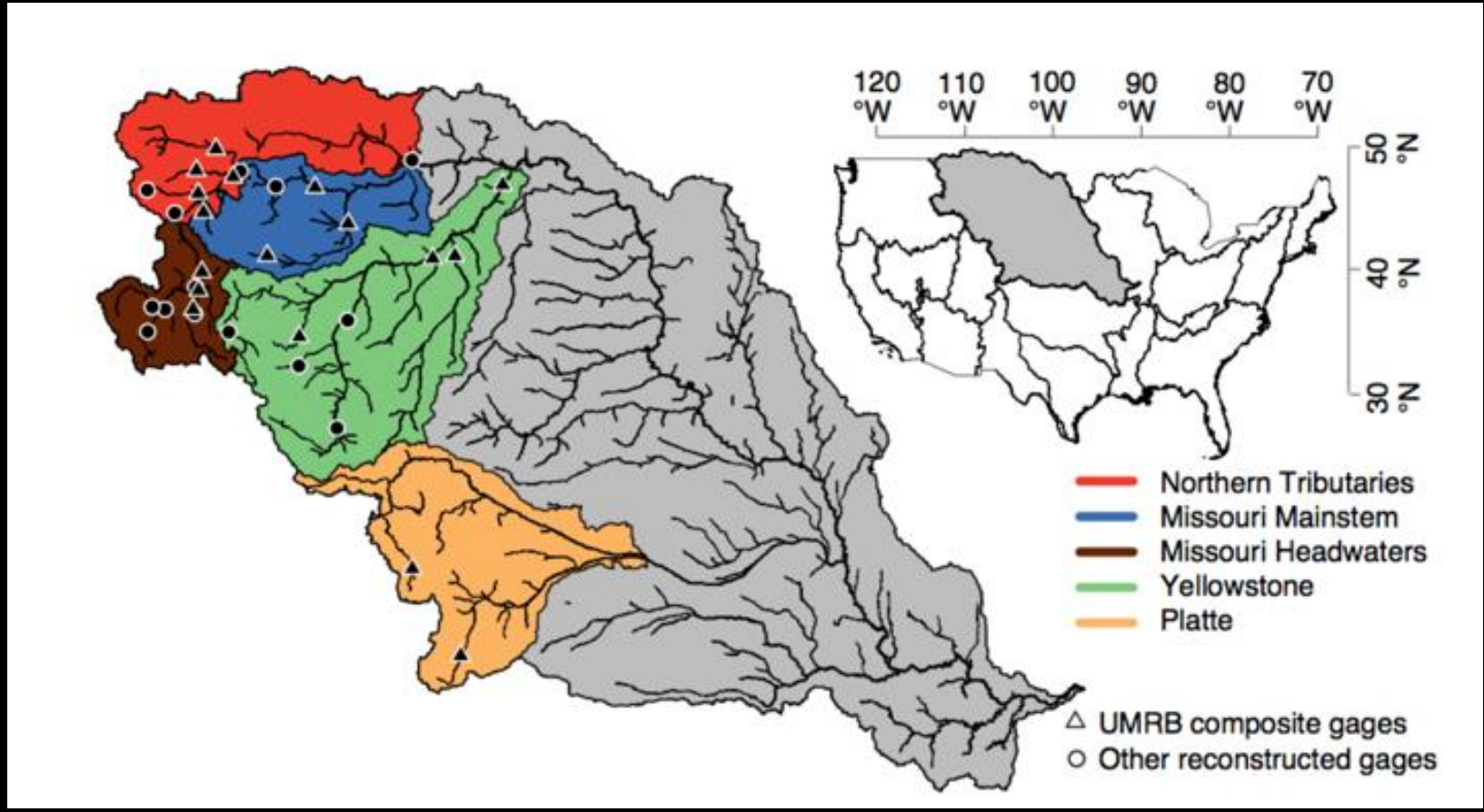
Tree-ring chronologies and gages with estimated natural flows for Missouri River basin reconstructions

(this project focused on the upper basin)



Martin et al. in prep.

Sub-basins of the upper Missouri River basin, gage locations for which annual flow reconstructions were generated



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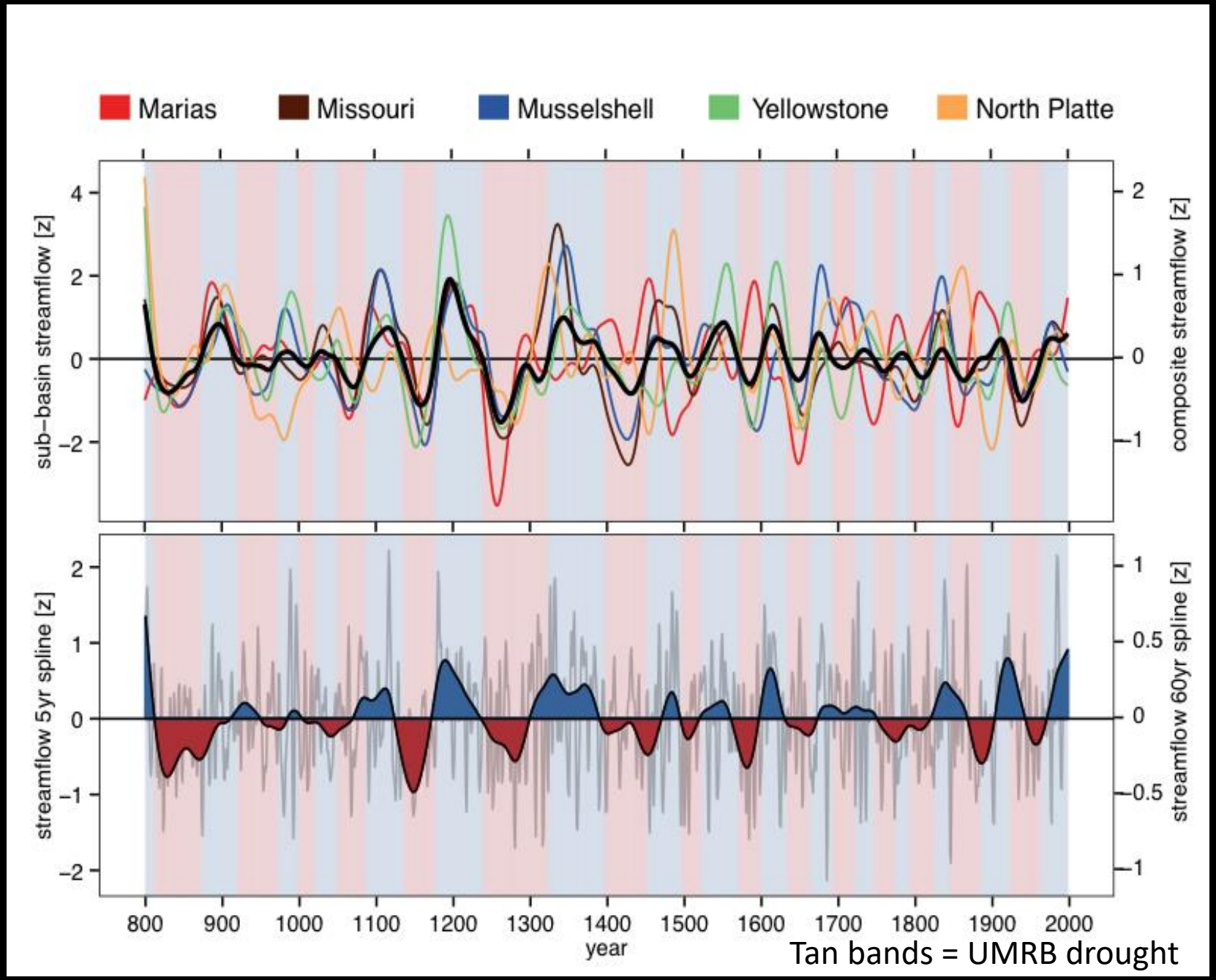
Reconstructed Upper Missouri River Streamflow Sub-basins and Basin Average, 800-2010



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   - Late winter/spring/early summer in the Lower basin (Atlantic SSTs)
4. Different trends in climate in the Upper and Lower basins may be reducing the contribution of the Upper basin to total basin streamflow
5. In terms of relative streamflow volume, the contribution from the Upper basin appears to be decreasing

Synthesis of key points

1. Two main source regions for the Missouri River basin: the upper basin (main stem + Yellowstone) and the watershed region directly above the mouth.
2. In the Upper basin, the high headwaters are particularly important
3. The key seasonal precipitation contributions to Missouri streamflow
   - Snow in the Upper basin (wintertime PNA pattern)
   - Late winter/spring/early summer in the Lower basin (Atlantic SSTs)
4. Different trends in climate in the Upper and Lower basins may be reducing the contribution of the Upper basin to total basin streamflow
5. In terms of relative streamflow volume, the contribution from the Upper basin appears to be decreasing
6. Tree-ring reconstructions of streamflow provide information on long-term variability over the basin and on multidecadal+ time scales.

For more information on instrumental data analysis, see:

Wise, E.K., C.A. Woodhouse, G.J. McCabe, G.T. Pederson, and J-M. St. Jacques. 2018. **Hydroclimatology of the Missouri River basin**. *Journal of Hydrometeorology*, 19, 161-182, doi: 10.1175/JHM-D-17-0155.1

Publications on Missouri River reconstructions coming soon:

Frederick, S.E. and C.A. Woodhouse. *Submitted*. **A multi-century perspective on the relative influence of seasonal precipitation on streamflow in the Missouri River headwaters.** *Water Resources Research*

Martin, J., Pederson, G.T., Woodhouse, C.A., Cook, E.R, McGuire, M., Broman, D., Lanini, J., et al. , *in prep* 2018., **Upper Missouri River Basin Streamflow Reconstructions for Drought Adaptation and Water Management Planning**, *Quaternary Science Reviews*

Ravindranath, A., et al. *In Review*. **Streamflow Reconstruction in the Upper Missouri River Basin Using a Novel Bayesian Network Model**. *Water Resources Research*

Data

- Estimated natural flows, for key gages: Missouri River at Ft. Benton, Yellowstone River at Sidney (UMRB), Missouri River at Hermann (LMRB), 1912-2011
- PRISM gridded monthly total precipitation and average temperature
- Snowpack data (April 1 SWE) for the MS headwaters, Yellowstone headwaters and entire MRB headwaters, 1936-2011
- Northern Hemisphere 500mb heights
- NOAA Extended Reconstructed SSTs