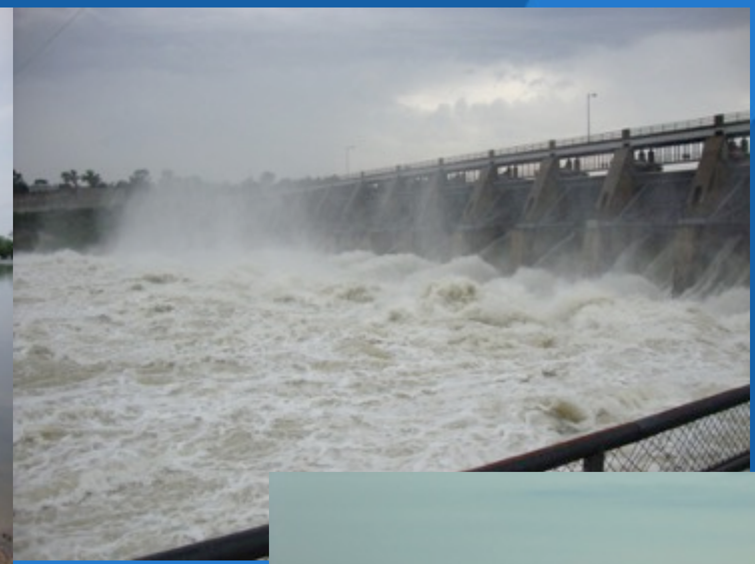
Climate Study: Recent Findings for the Missouri Basin

Interstate 29 underwater: Missouri River flooding in Omaha, NE June 2011.
Photo by Larry Geiger. [https://franceshunter.wordpress.com/2011/06/20/great-missouri-river-flood-of-2011/]

Upper Missouri Basin NIDIS Workshop

Doug Kluck
With major contributions from Ben Livneh, Martin Hoerling, Jon Eischeid, Robert Webb, Andrew Badger

The Missouri Basin had a bit of an extreme event in 2011



Missouri Basin Climate Research

- **Climate Assessment Report: Causes for Hydrologic Extremes in the Upper Missouri Basin**

- **Seasonal Precipitation Forecasts Over the Missouri Basin**

- **Climate Assessment Report: Understanding and Explaining Climate Extremes in the Missouri River Basin Associated with the 2011 Flooding**

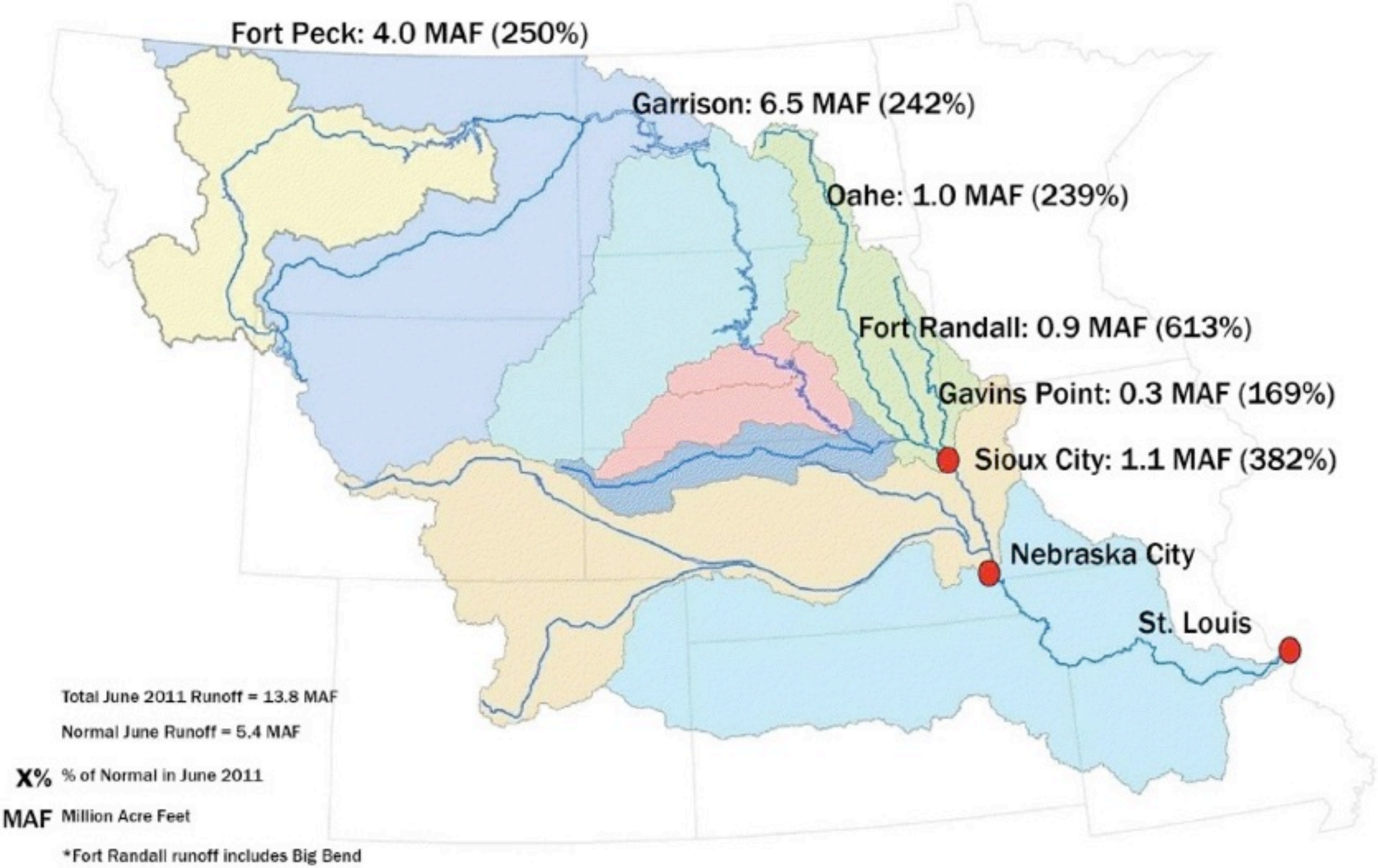
- **Explaining Climate Extremes: An Assessment of the 2011 Missouri River Basin Flood**

https://www.drought.gov/drought/dews/missouri-river-basin/reports-assessments-and-outlooks

US Army Corps of Engineers
BUILDING STRONG

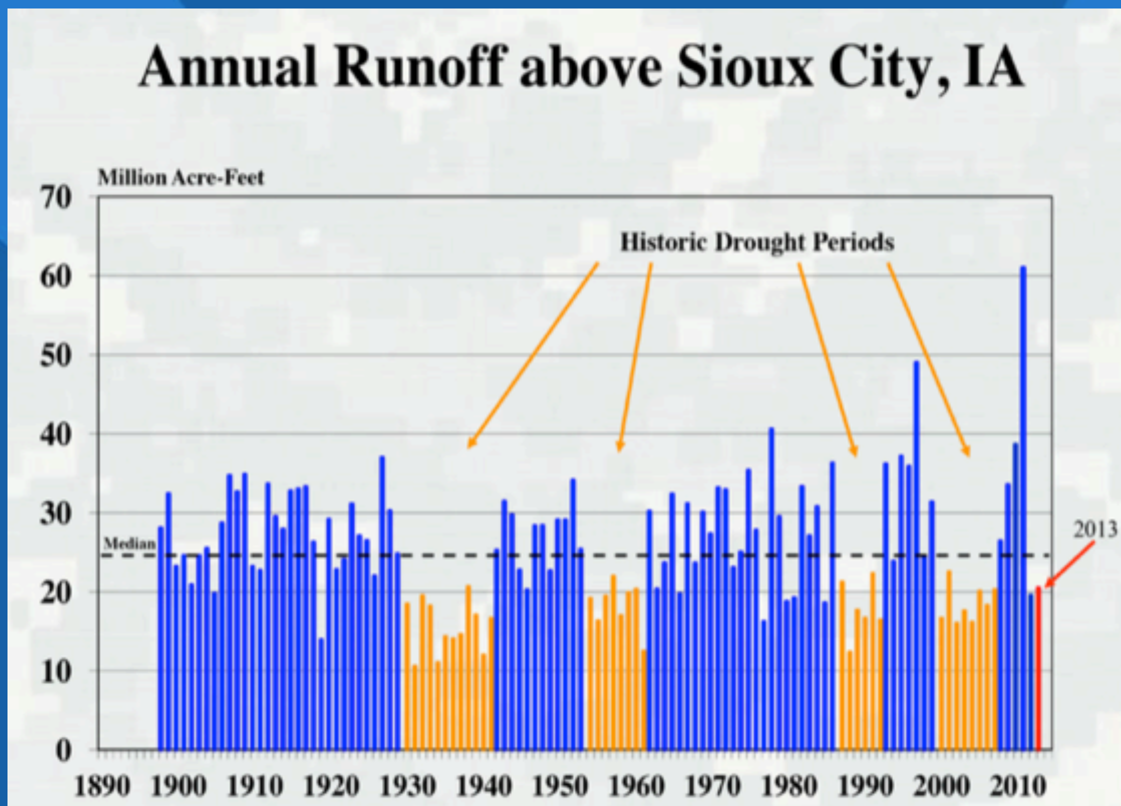
Missouri River Basin

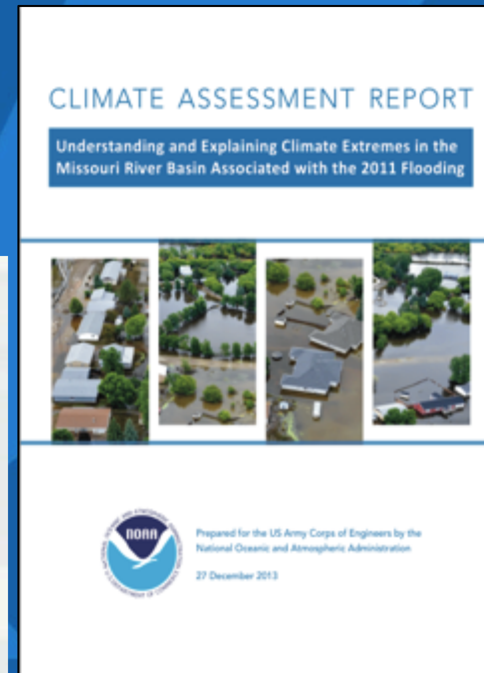
June 2011 Runoff



Attribution of Missouri Basin Climate Variability

- 2011 prompted NOAA investigation into drivers
- Recent variability in annual flows emerged





Regimes of persistent low flows, denoted by orange bars, denote hydrologic droughts within the basin. Horizontal line shows the historical median value. Data source is USACE.

Explaining Climate Extremes

An Assessment of the 2011 Missouri River Basin Flood

In early 2011, the Missouri River Basin experienced devastating flooding, which caused significant property loss and threatened thousands of lives. January-May was the wettest recorded in the region since 1895, and the annual runoff above Sioux City, Iowa surpassed the previous record.

Researchers from the National Oceanic and Atmospheric Administration (NOAA) pursued a scientific study on the meteorological causes for the flood event with hopes to better understand its causes and assess its predictability. An assessment report has been completed, following peer review, and below are highlighted the major scientific findings.

The Missouri River Basin, the Missouri River, and the main U.S. Army Corps of Engineers reservoirs. The Upper (Lower) Basin is the region generally located in a west-east line above (below) Gavins Point near Sioux City Iowa. (Image courtesy Missouri Department of Natural Resources)

Major Findings

The factors immediately responsible for flooding were found to be a sequence of events that included:

- Pre-existing wet conditions – a particularly cold and wet 2010-2011 winter that led to unusually high snow pack, and
- Record-setting rains in late spring

The late spring rains were almost certainly the most critical in the meteorological sequence for understanding the historic proportion of Missouri Basin flooding.

The wintertime cold and wet conditions were shown to be consistent with those occurring in the upper Missouri Basin during La Niña events, and in this sense NOAA's La Niña Advisory issued on 5 August 2010 provided early warning for these types of winter conditions. However, La Niña in general, and the particular ocean conditions in 2011 specifically, were found not to materially alter the risks for a wet spring in the upper Missouri Basin.

The report suggests that neither the NOAA La Niña Alert Status nor subsequent exact knowledge of the details of the ocean conditions could have forewarned of extreme heavy spring rains.

61 million acre-feet (maf) of runoff above Sioux City, Iowa beat the prior record by 12 maf

The analyses in the report indicate that the record-setting amount of water from the Upper Missouri Basin could not have been anticipated before the heavy spring rains set in, and it could almost certainly not have been anticipated at long seasonal (6-9 month) lead times.

Conclusions

The report found that the record flooding was consistent with the physical response of basin runoff to a sequence of naturally occurring climate conditions, the majority of which resulted from random atmospheric variations, which could not have been predicted with current scientific knowledge. Due to the unusual sequence of extreme weather events, a flood of this magnitude was a rare occurrence, and a comparable event has low probability for recurring in the immediate future.

A caveat to the conclusion that the flooding was the result of a sequence of naturally occurring climate conditions is the fact that annual flow in the Upper Missouri Basin has been more volatile in recent decades compared to prior decades dating to 1898. Specifically:

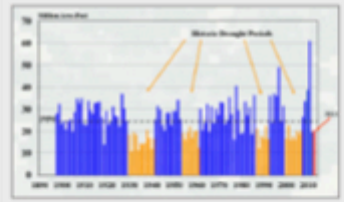
- Nine of the ten highest annual runoffs in the Missouri Basin historical record were found to have occurred after 1970, and
- Year-to-year variability of annual runoff has increased dramatically in recent decades principally due to an increase in high flow events.

The report does not address the underlying cause for post-1970 increase in the frequency of high runoffs events, but recommends further investigation of possible factors in order to better inform decision makers on the risks for future severe flooding events in the Missouri River Basin.

Given these events and the hydrology of the Missouri Basin, it was reasonable to expect that the subsequent 2012 year would also be susceptible to flooding. The previous five years had experienced above-average annual precipitation in the upper basin, resulting in progressively higher annual runoff from 2008-2011. However, the observed 2012 annual runoff in the Missouri Basin was below normal. The climate conditions themselves had not changed much between 2011 and 2012, and the concentrations of human-caused greenhouse gases were basically the same.

The fate of 2012 Missouri River runoff was apparently not set by the pre-existing conditions of 2011 anymore than pre-existing conditions determined the fate of 2011. Instead, in both 2011 and 2012 annual runoff depended primarily on meteorological factors, which abruptly returned the basin from flooding conditions in 2011 to drought conditions in 2012. The similar large-scale climate conditions of 2011 and 2012 serve as a lesson on the power of short-term variations in weather to cause contrasting impacts on the Missouri River Basin's annual runoff.

Annual Runoff above Sioux City, Iowa



Time series of the annual Missouri River runoff (million acre-feet) above Sioux City, Iowa for 1898-2012. The 2013 value (red bar) is a preliminary estimate. Regimes of persistent low flows, denoted by orange bars, denote hydrologic droughts within the basin. Horizontal line shows the historical median value. Data source is USACE.

The historical ranking of regional precipitation for annual 2010 conditions (top), and for the subsequent January-May 2011 conditions (bottom). Over the Missouri River Basin region, 2010 ranked 5th wettest since 1895, whereas the subsequent 5-month period January-May 2011 ranked as the historical wettest since 1895. Note the dramatic contrast between conditions in the Missouri Basin versus those immediately south. Data source is NOAA.

For more information, contact:

Robert.S.Webb@noaa.gov, or
Martin.Hoerling@noaa.gov
NOAA Earth System Research Laboratory
325 Broadway, Boulder, Colorado 80305

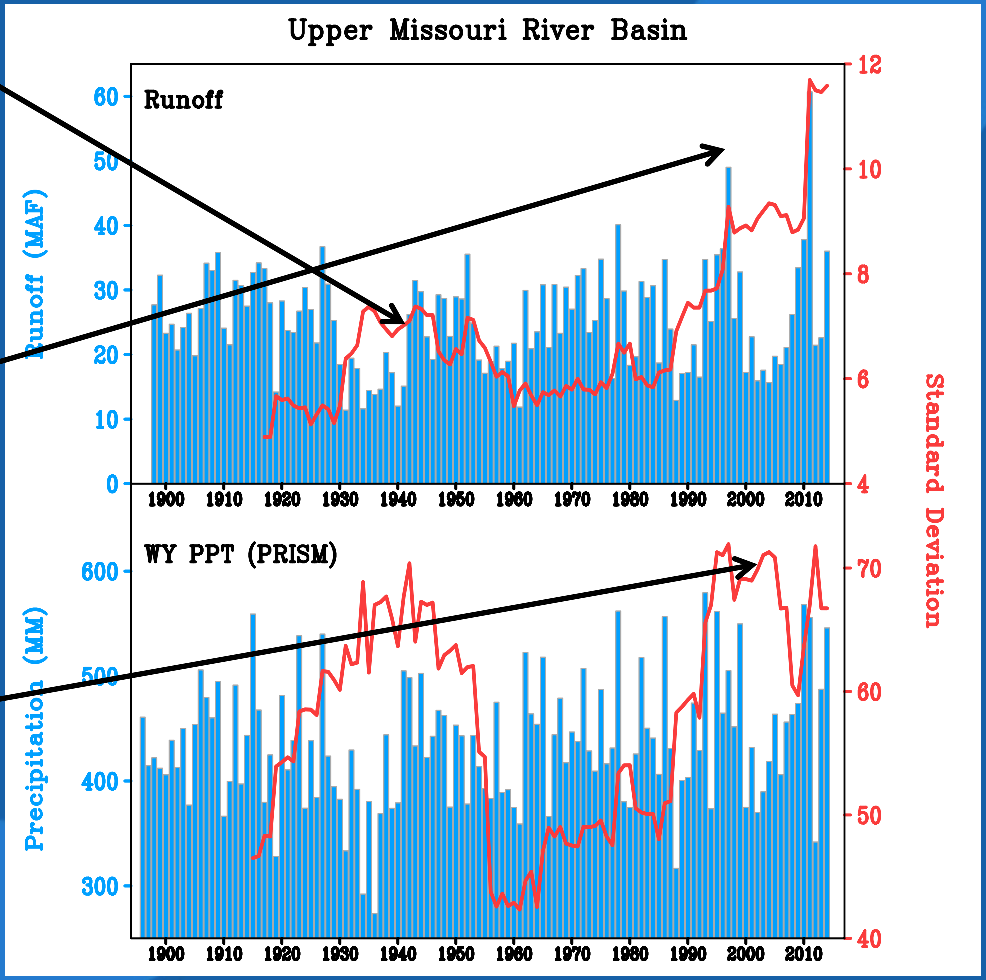
Funding for this project was provided by U.S. Army Corps of Engineers (USACE)

Visit us online at:
www.esrl.noaa.gov/psd/csi/

Red line: inter-annual standard deviation (20-yr moving window)

Runoff exhibits increasing inter-annual variability since 1975

Areal precipitation variability **increasing not nearly as dramatic over last 40 years**

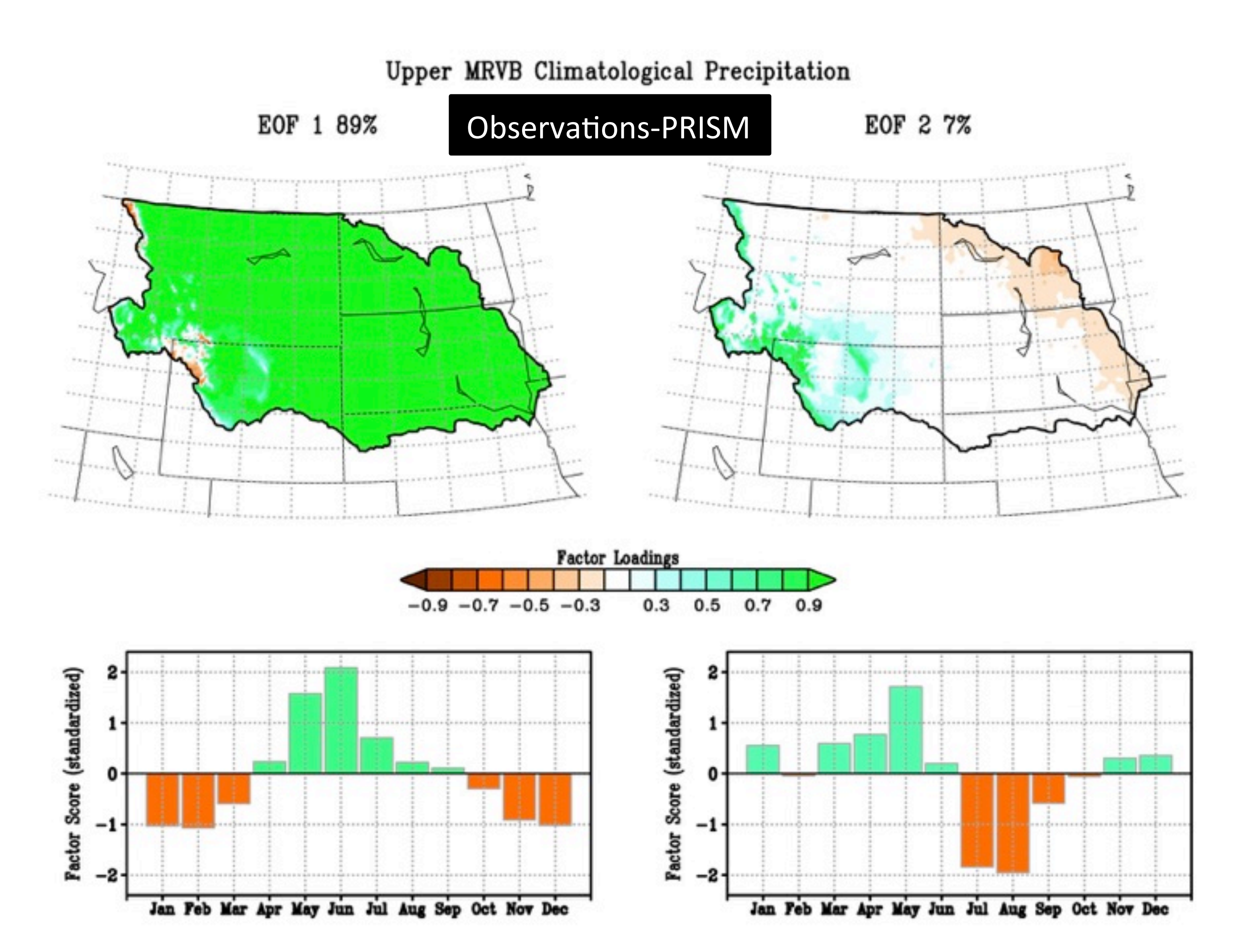


What is the mechanism behind this disparity?

- Changes in **precipitation intensity**
- Changes in **seasonality**
- Changes in **antecedent moisture**

Runoff source: USACE; Precipitation source: PRISM; image: image from: NOAA Climate Assessment Report; prepared for USACE Dec 2013 [http://www.esrl.noaa.gov/psd/csi/factsheets/pdf/noaa-mrb-climate-assessment-report.pdf]

Seasonality and Regionality of Runoff Sources in the Upper MRB



Observational Analysis of Change in the Missouri River Basin

Observed Discharge from UMRB:

- During the 117 years of record-keeping (1898-2014)---
    - the 4 highest flow years have occurred in the last 40 years (1975-2014)
    - 10 of the highest 13 runoff years in the UMRB have occurred in the last 40 years
    - 9% increase in average annual flow in last 40-yrs compared to prior 77 year average
    - doubling of the coefficient of variability in last 20yrs compared to first 20yrs

Explaining Hydrologic Extremes in the Upper Missouri River Basin

Background

Nine of the ten largest flood events in the Upper Missouri River Basin (UMRB) since records began in 1898 have occurred since 1970. Dry years have also continued to occur, analogous to low runoff years of the Dustbowl era. As a result, yearly volatility in runoff has become much more extreme since 1970, due mainly to changes in the character of high runoff events.

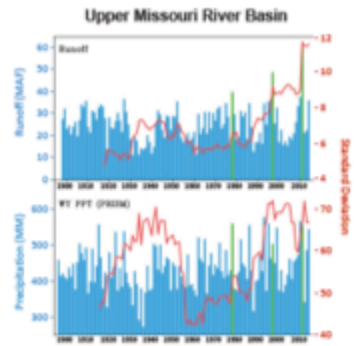
Researchers from the National Oceanic and Atmospheric Administration (NOAA) and the University of Colorado's Cooperative Institute for Research in Environmental Sciences (CIRES) have studied the physical causes for the recent increase of high annual runoff in the UMRB and present their findings in a new assessment report.

Major Findings

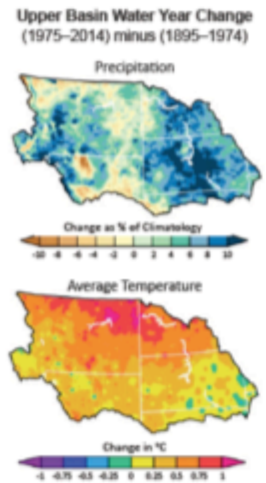
The increased frequency of high annual runoff events in the last 40-year period, as measured by naturalized runoff at Sioux City, Iowa, resulted mainly from the land surface response to increased precipitation falling over the UMRB. Runoff production was shown to be especially sensitive to two features of observed meteorological changes during 1975-2014 (relative to 1895-1974):

- A seasonal wetting that saw the largest percentage increases (+12%) occur during the cold season (October-March).
- A regional wetting that saw the strongest wet trends occur over South Dakota and the eastern one-third of the upper basin (up to +20%).

Using historical meteorological data and land surface models, the report paints a picture of an upper basin that is inefficient at converting annual precipitation to runoff. A runoff coefficient of only about 8% indicates that less than 1/10th of the annual precipitation falling over the upper basin is realized as runoff at Sioux City, Iowa. This low runoff efficiency is unique compared to other parts of the country, where for example runoff efficiencies can be as high as 50% or greater in the humid East and Pacific Northwest. UMRB efficiency is higher in the cold season, and thus the greater increase in precipitation at that time of year led to an amplified runoff response. Land model experiments demonstrate an acute runoff sensitivity to soil moisture conditions over eastern portions of the upper basin, especially in the reach from Gavins Point to Sioux City. Higher soil moisture conditions due to wetting in the last 40 years over that mostly unregulated sub-basin have appreciably enhanced its contribution to the upper basin's overall runoff production.



Time series of water-year (1 October-30 September) UMRB runoff (million acre-feet) above Sioux City, Iowa for 1898-2014 (top), and water-year precipitation average for the upper basin above Sioux City (mm; bottom). Green bars highlight the three highest runoff years in the record. A measure of the year-to-year volatility is shown in the red curves that plot standard deviation of water-year values for 20-yr moving windows. Runoff at Sioux City from USACE; precipitation is PRISM.



The observed change in water-year (1 October-30 September) precipitation (% of climatology, top), and average surface air temperature (°C, bottom). Changes are calculated by differencing the 40-yr average (1975-2014) from the 80-yr average (1895-1974). Data source is PRISM.

Conclusions

The report demonstrates a strong physical connection between the increased frequency of high annual runoff events in the UMRB and the increase in precipitation falling over the upper basin. Each of the nine highest annual runoff years since 1975 were abnormally wet years. A concentration of wetting during the cold season has been key, leading to higher soil moisture conditions that further acted to increase efficiency in runoff production. The upper basin has warmed, which may have slightly reduced runoff efficiency, though this effect has been far eclipsed by the increased precipitation.

The cause for these changes in meteorological conditions was also briefly explored in the report. Most of the magnitude in observed precipitation increases, and hence much of the runoff increases, occurred via natural variations in the region's climate. The warming trend, by contrast, was consistent with an emergent signal of human-induced climate change.

Wetter and warmer conditions in the UMRB are anticipated in the future due to human-induced climate change. Under an aggressive emissions scenario, the upper basin is expected to warm by about 6°C by the end of the 21st century. It is currently unclear whether the impact of such unprecedented warming on future upper basin runoff will dominate over precipitation changes, or even over the typical natural precipitation variability. Further investigation is required on how annual runoff efficiency will change and whether year-to-year runoff volatility will increase.

In the immediate future, runoff variations including extreme high and low runoff years, will continue to be dominated by natural variability in the upper basin. The report indicates that predictions of such variability will benefit from improved soil moisture monitoring, whose antecedent land surface states were found to correlate with subsequent annual runoff. However, the direct effects of precipitation will continue to prevail in driving runoff variability. Overall, improved outlooks for annual runoff and likelihood of flooding will benefit most substantively from improvements in precipitation predictions at monthly, seasonal and longer time scales.

For more information, contact:
Ben.Livneh@colorado.edu, or
Martin.Hoerling@noaa.gov
NOAA Earth System Research Laboratory
325 Broadway, Boulder, Colorado 80305

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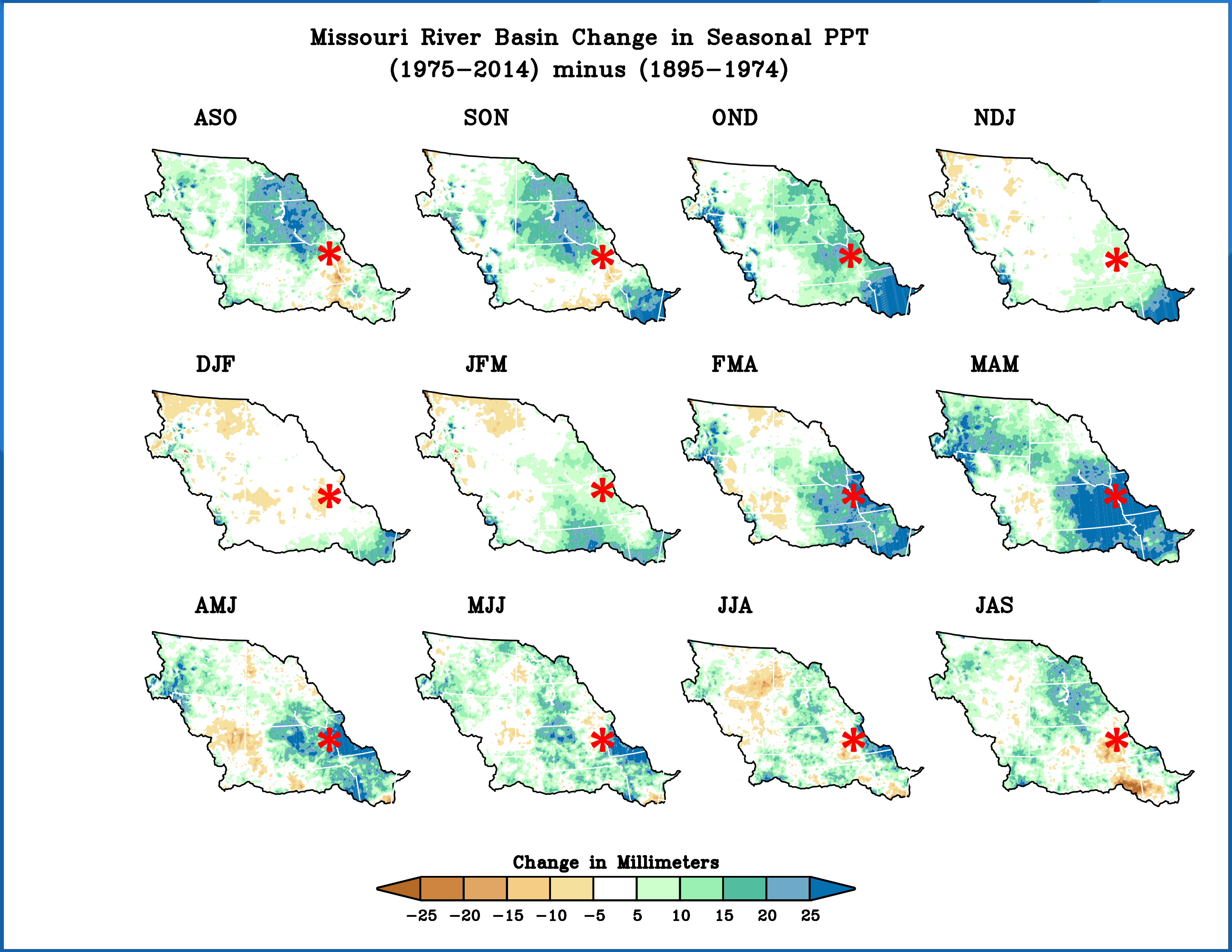
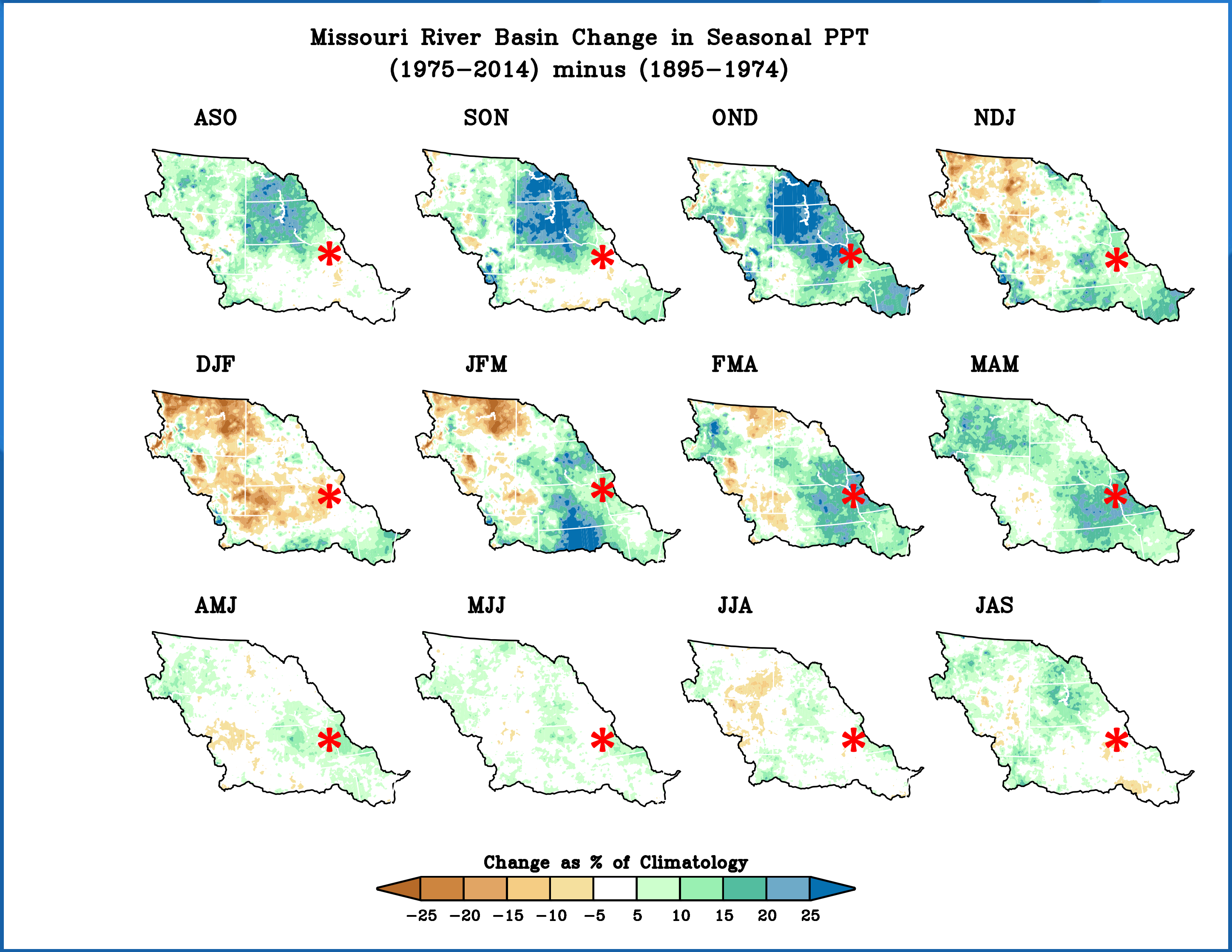
CIRES

Observed Change in Seasonal Precipitation



Observed Change in Seasonal Precipitation (% Climo)



Summary of Station-Based Analysis for *Cold Season*

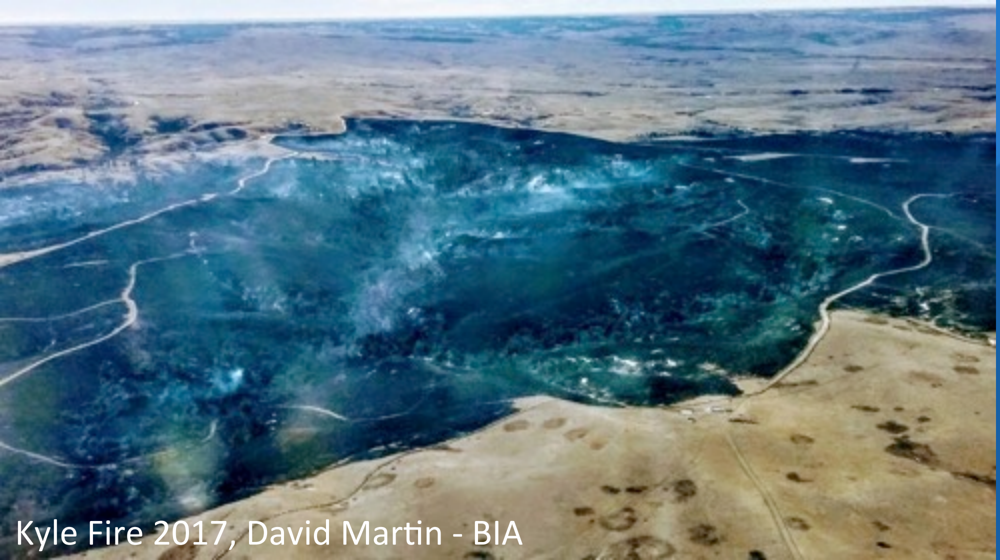
- Mean pcpn has increased in the UMRB (1975-2014) vs (1901-2014) at most stations, except western Montana
- Frequency of very heavy rain days has increased, is aligned with mean pcpn change
- A greater proportion of seasonal pcpn total is now contributed by very heavy rain day.

Summary of Station-Based Analysis for Warm Season

- Mean pcpn has increased in the UMRB (1975-2014) vs (1901-2014) at most stations
- Frequency of very heavy rain days has increased, in aligned with mean pcpn change
- Most stations show little change in proportion of seasonal pcpn contributed by very heavy rain day except a few stations just above Sioux City.

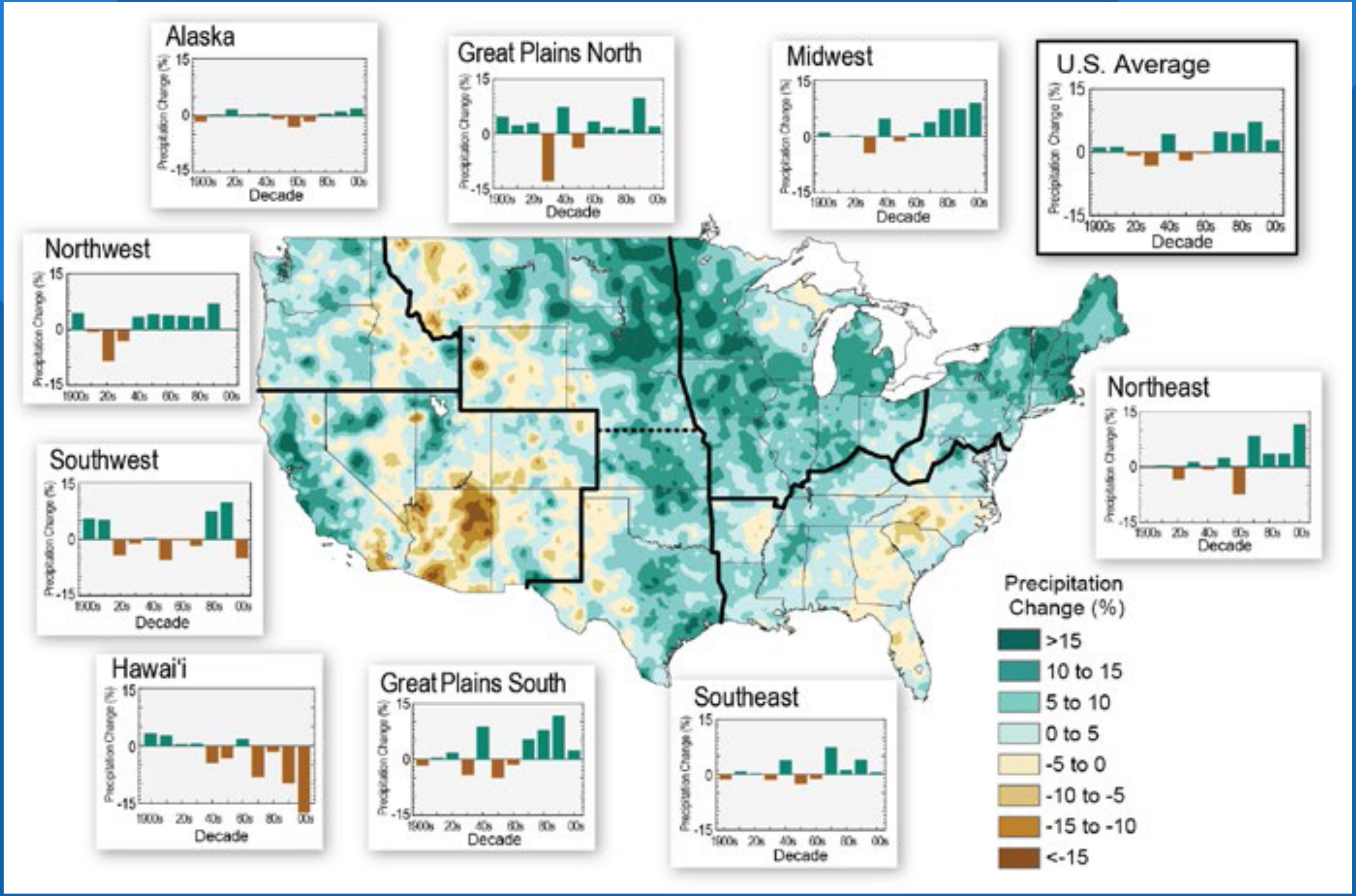
Food for Thought

Kyle Fire 2017, David Martin - BIA



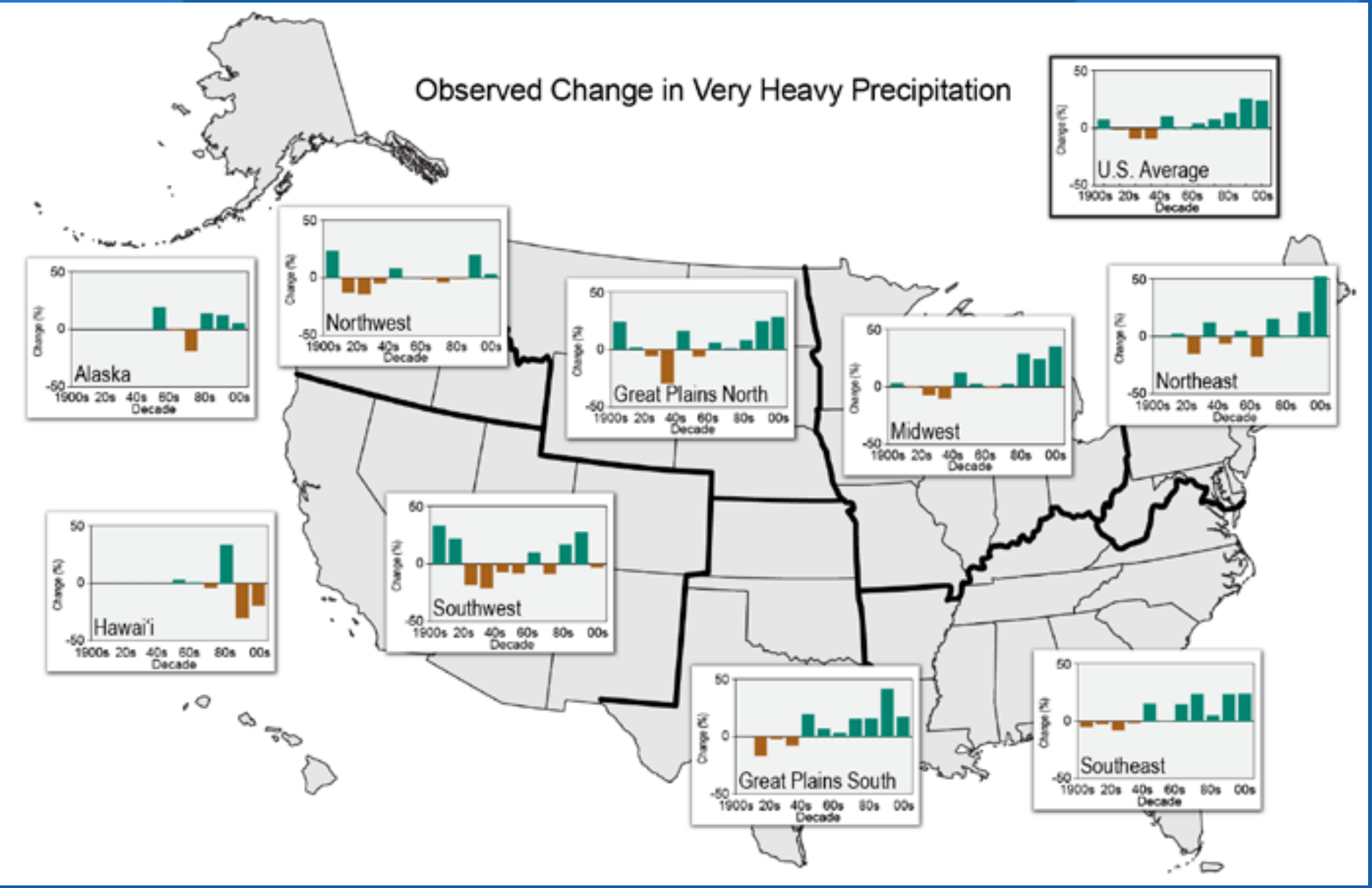
Kyle Fire 2017, David Martin - BIA

Precipitation Trends

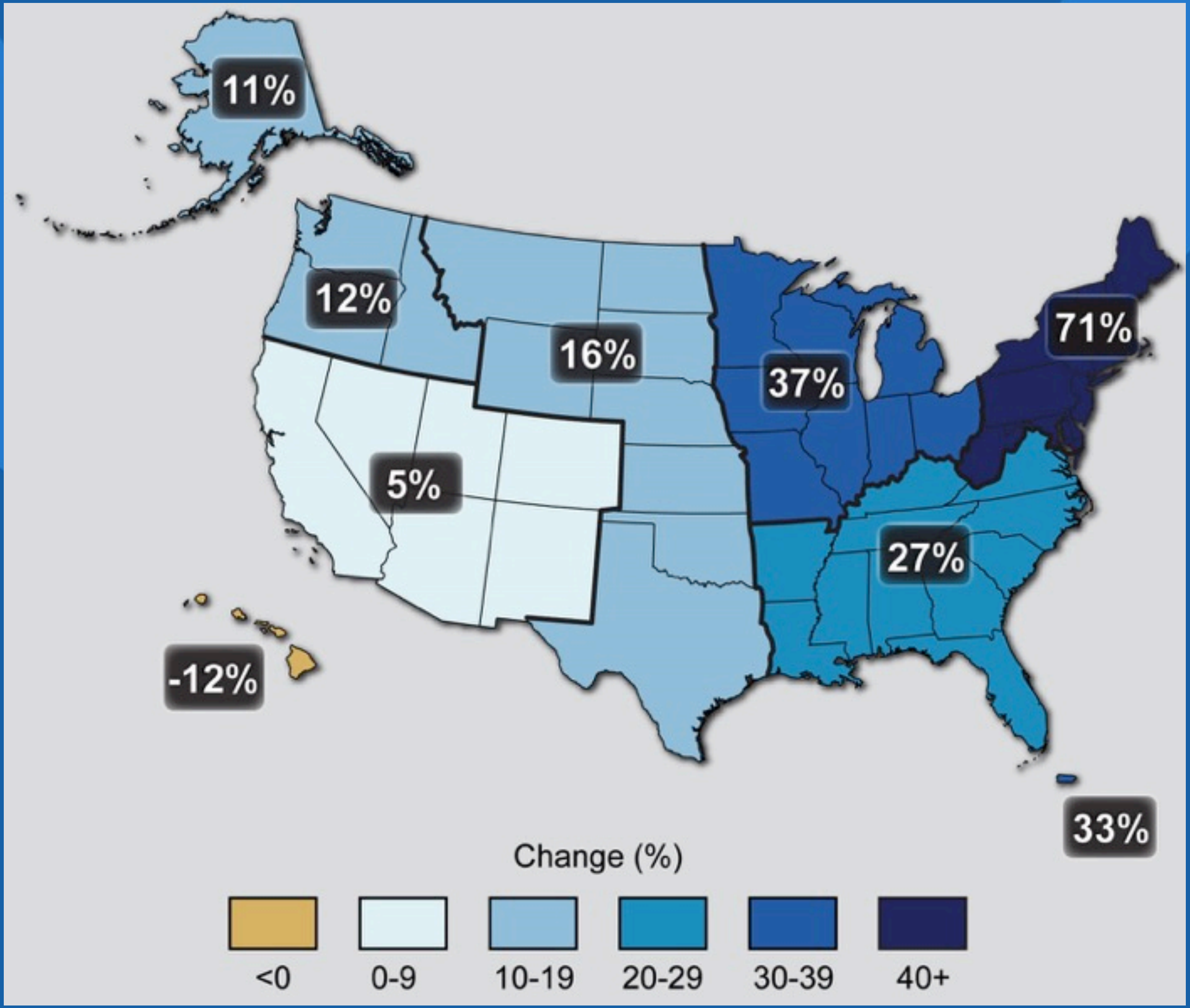


http://nca2014.globalchange.gov/

Observed Change in Very Heavy Precipitation



Observed Change in Very Heavy Precipitation



Source: National Climate Assessment - http://nca2014.globalchange.gov/

Trends in Flood Magnitude

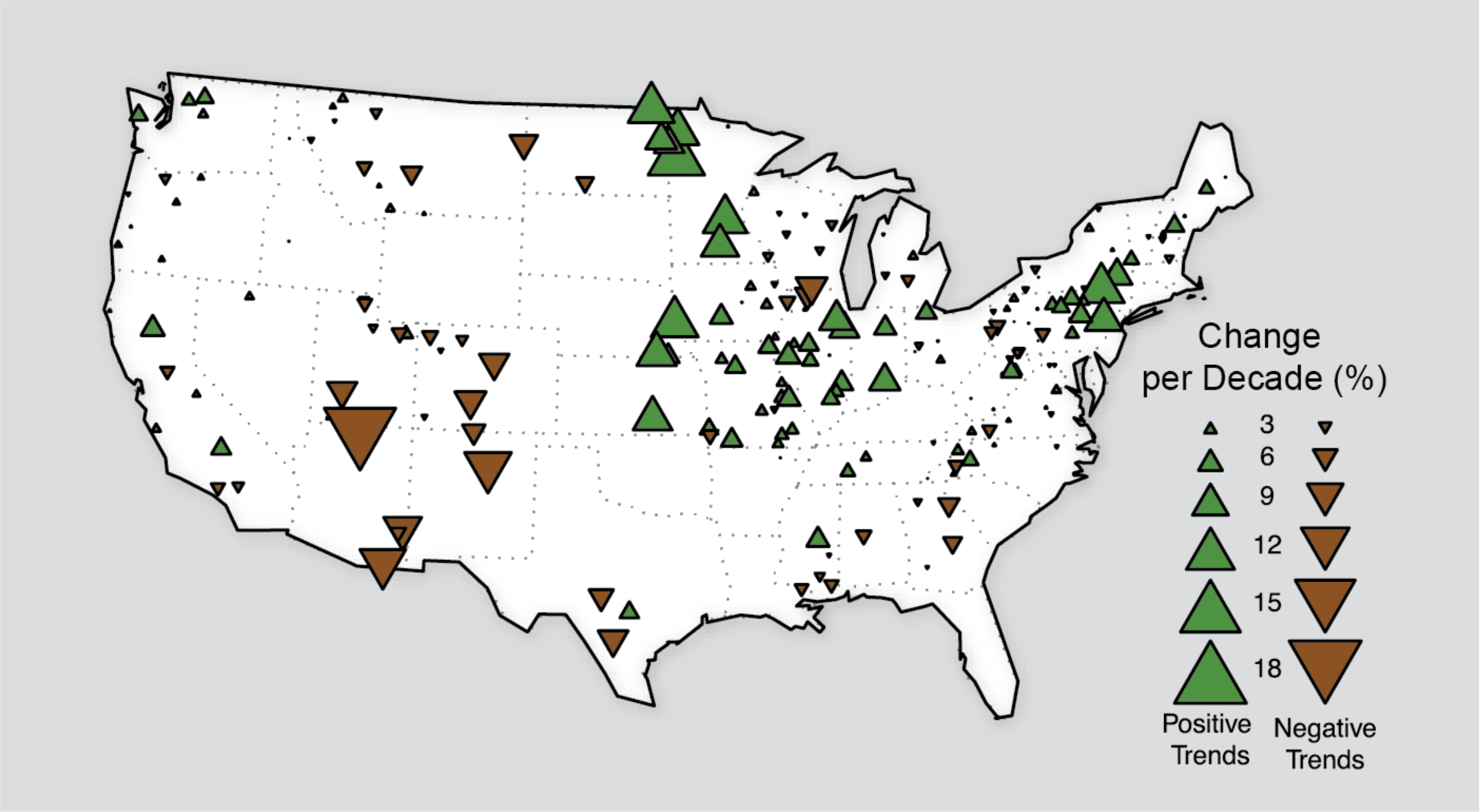
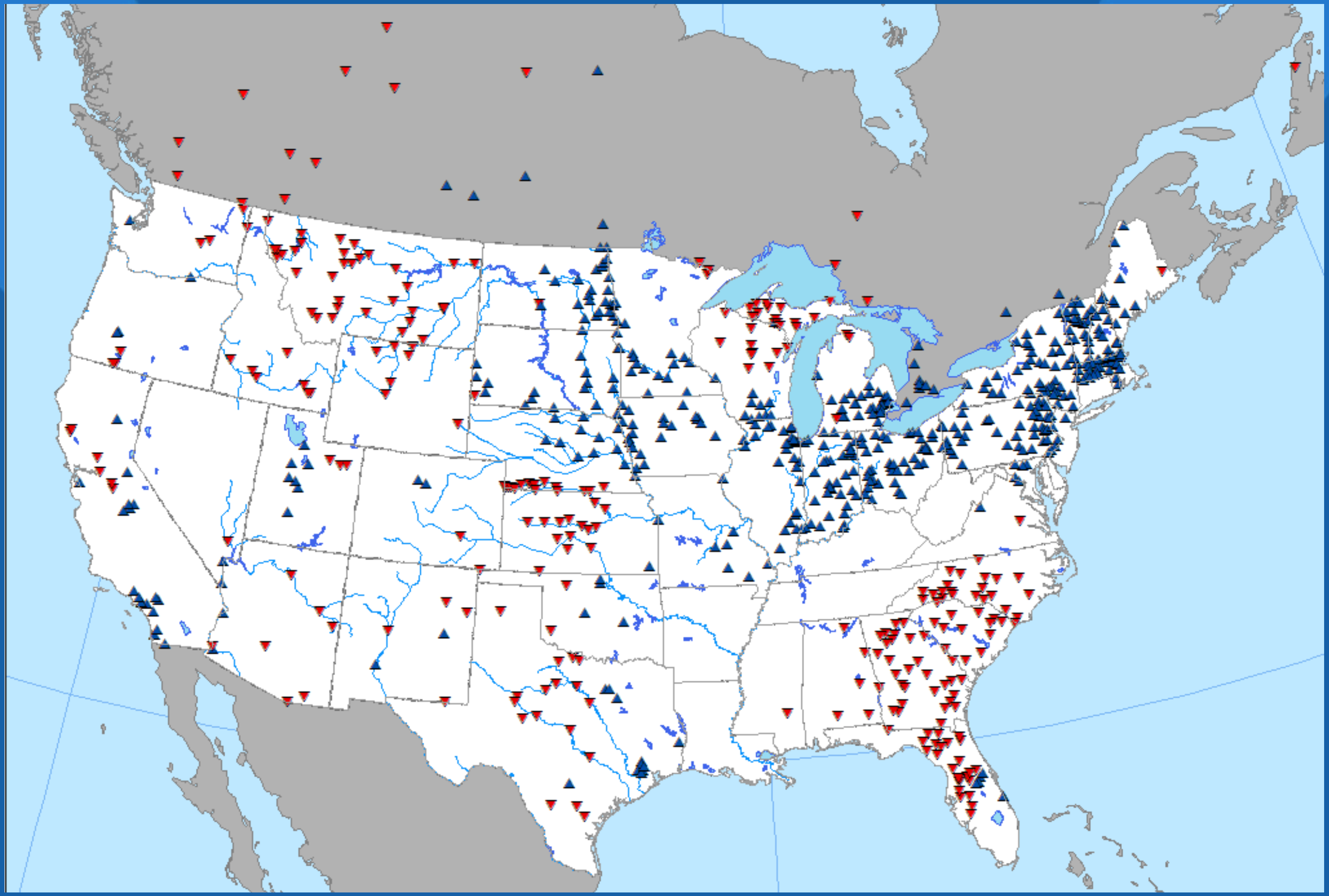
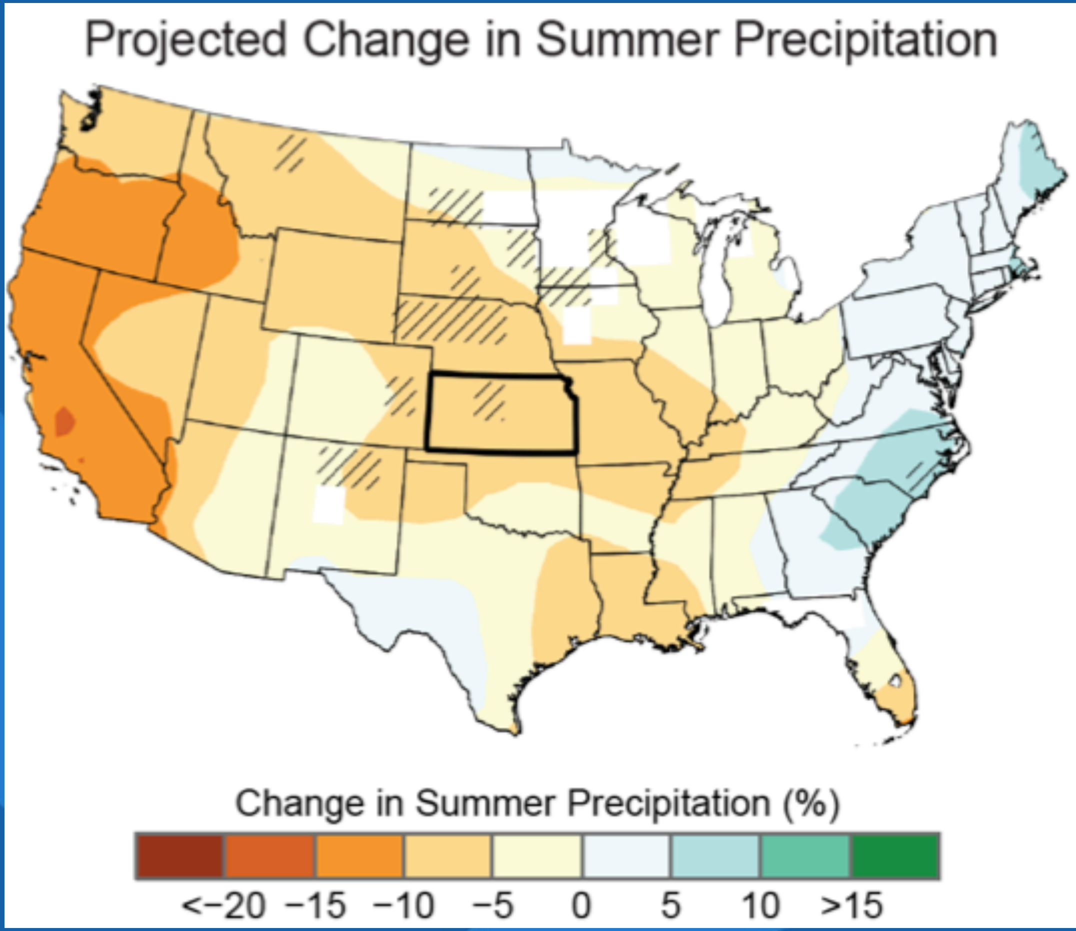


Figure source: Peterson et al. 2013

Streamflow trends (*p*=0.10) for stations with continuous records 1960-2012



Preliminary Information – subject to revision. Not for citation



Change in Summer Precipitation (%) Projected Change Precipitation

Figure 7: Projected change in summer precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Summer precipitation is projected to decrease in the range of 5%–10% by 2050, although the changes are statistically significant only in the central part of the state. Source: CICS-NC, NOAA NCEI, and NEMAC.

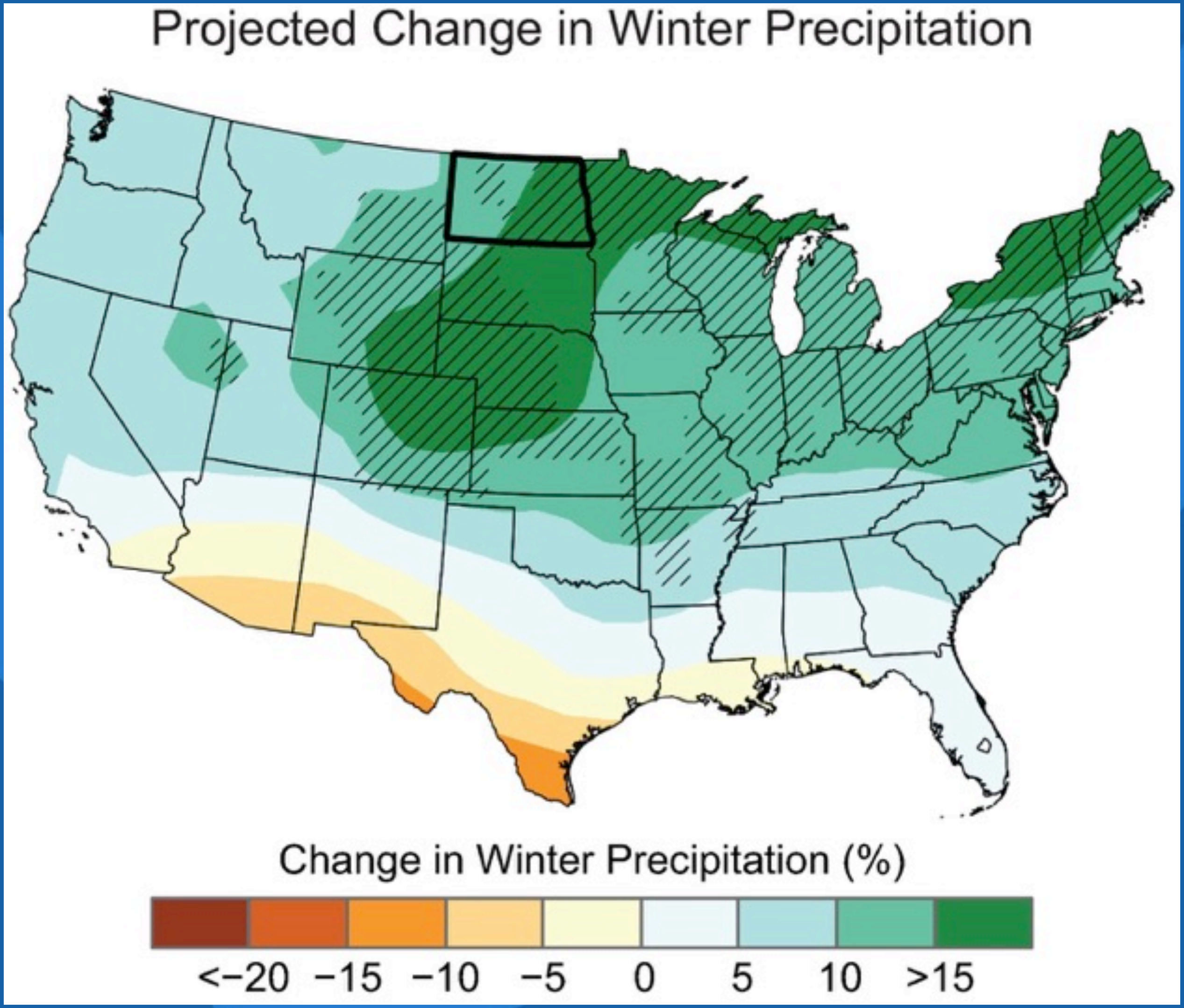


Figure 7: Projected changes in winter precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. Hatching represents areas where the majority of climate models indicate a statistically significant change. Colorado is part of a large area of projected increases in winter precipitation across the northern United States. Source: CICS-NC, NOAA NCEI, and NEMAC.

Thank You