Climate/Drought in the Missouri River Basin

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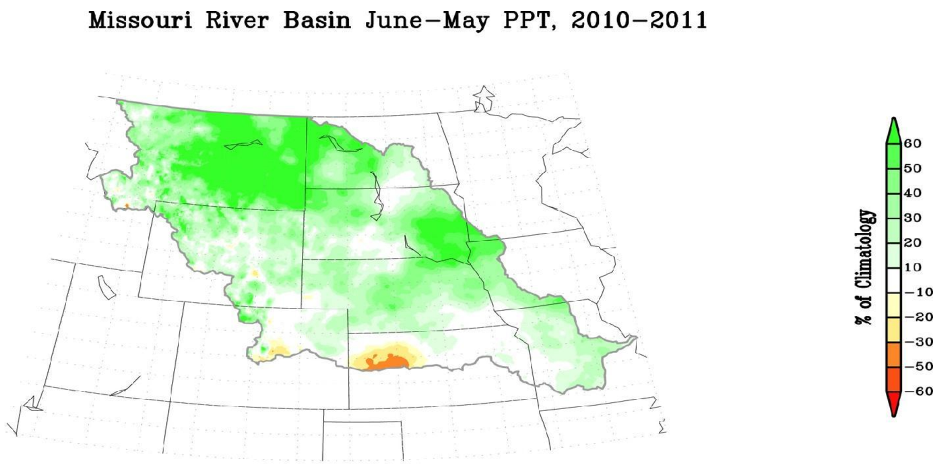

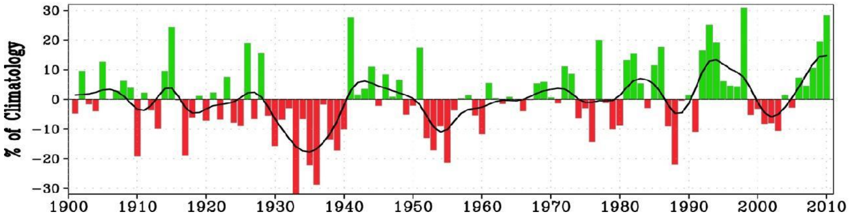

AMERICAN ASSOCIATION OF STATE CLIMATOLOGISTS

South Dakota State University
College of Agriculture and Biological Sciences

South Dakota Climate and Weather

Outline

- Climate in general
- Current Climate Changes
- Future Changes
- Climate Extremes

SOUTH DAKOTA STATE UNIVERSITY

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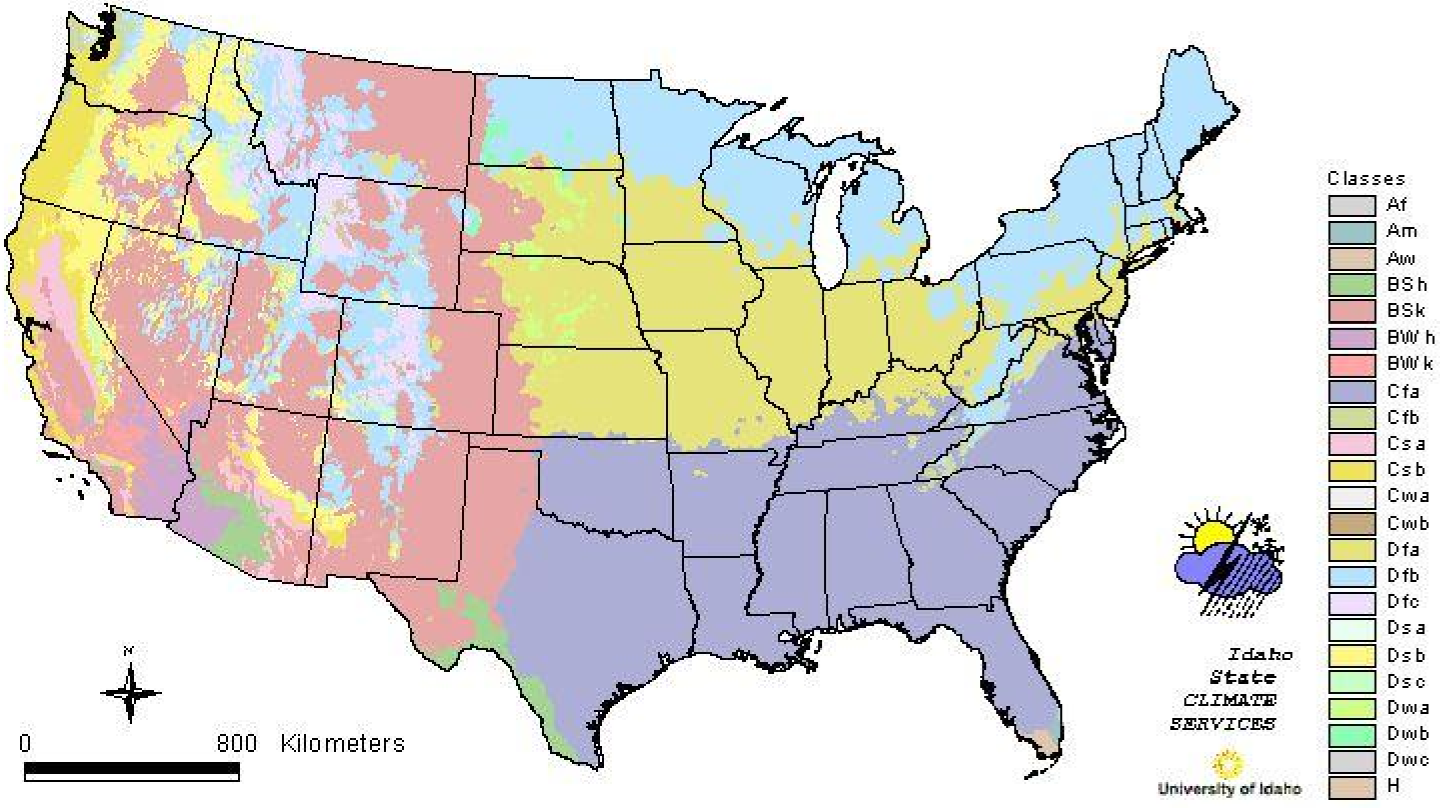
http://www.stateclimate.org

CLIMATE

Köppen Climate Classification for the Conterminous United States



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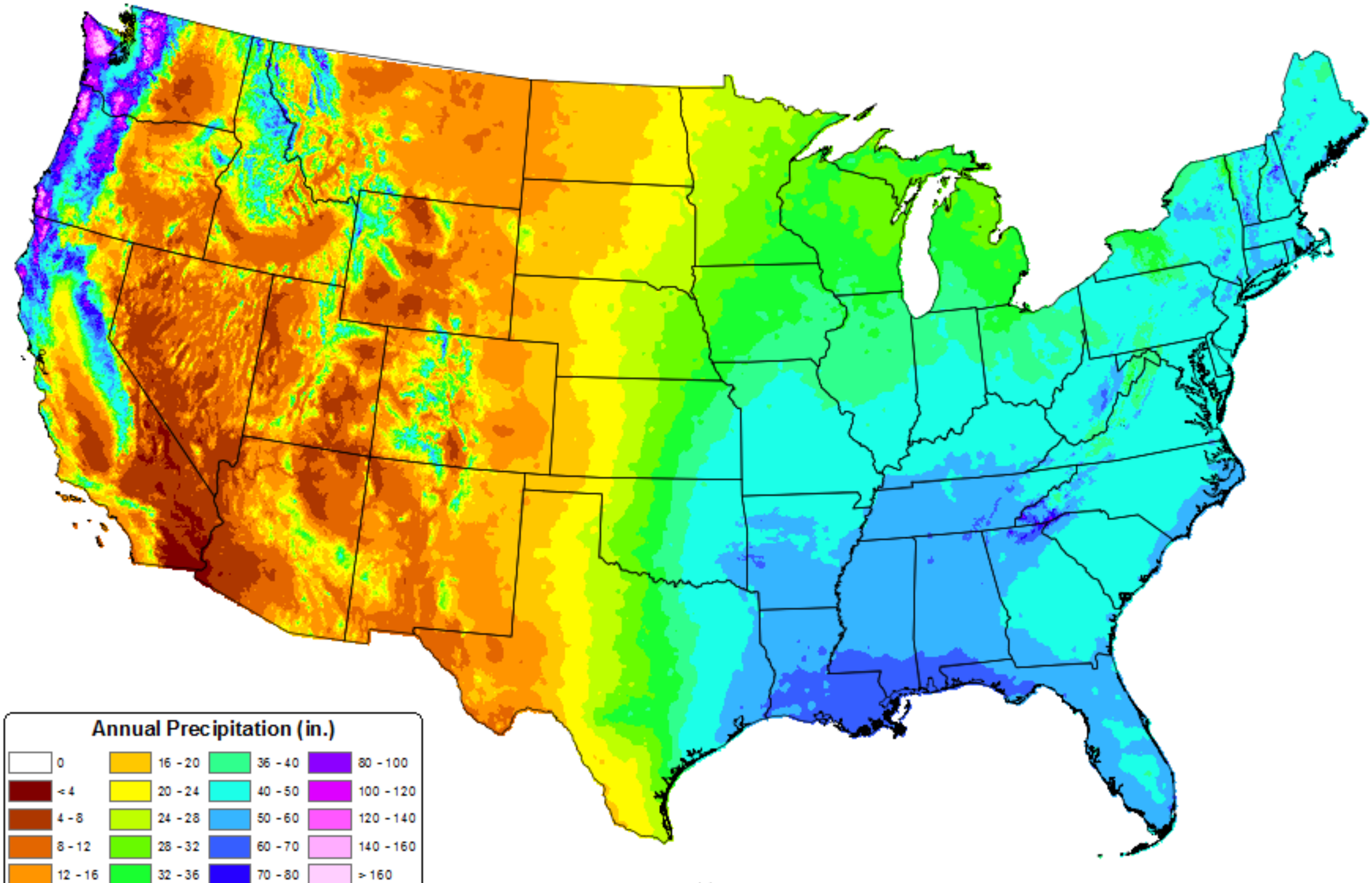
30-yr Normal Precipitation: Annual

Period: 1981-2010



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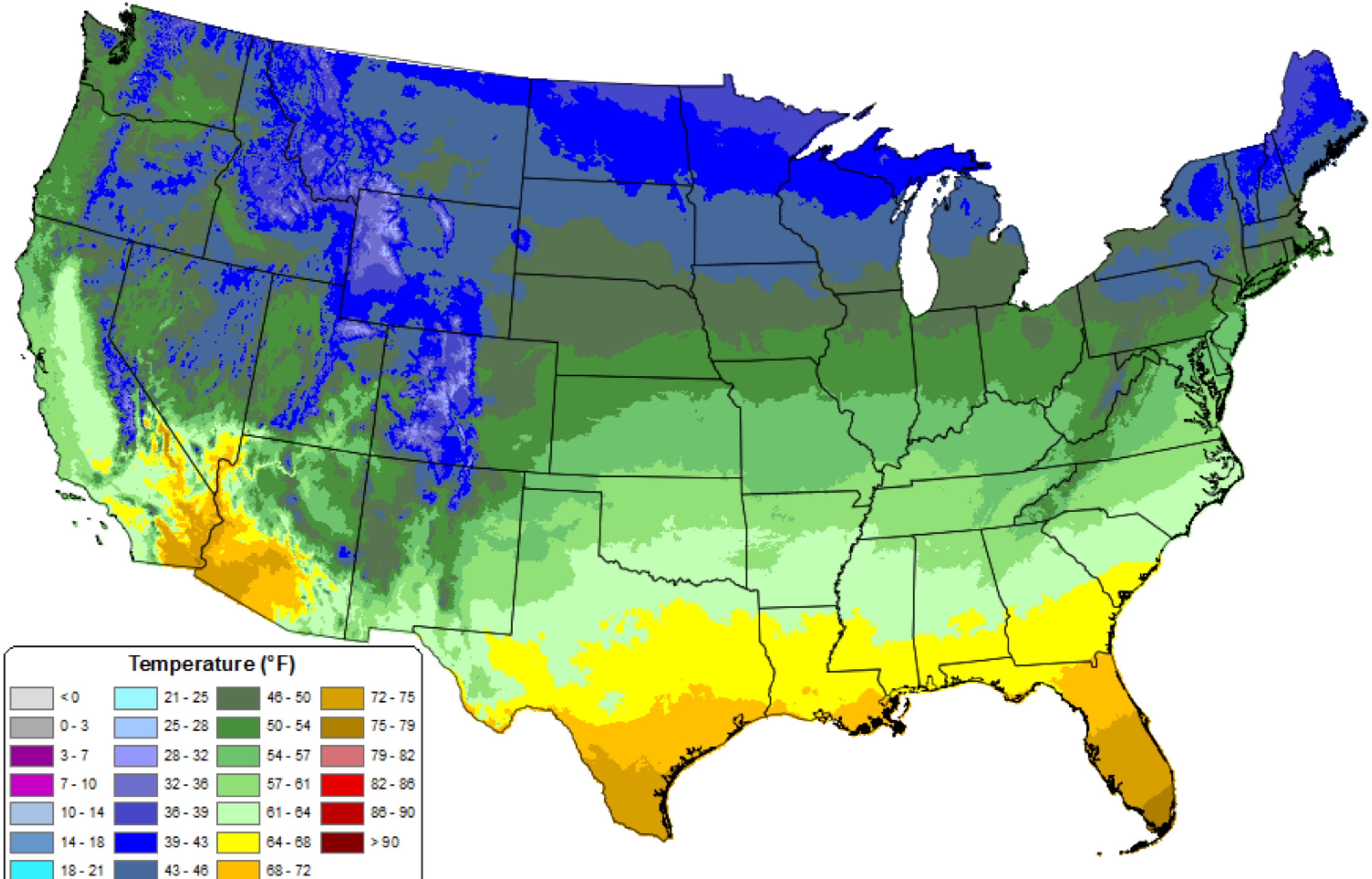
30-yr Normal Mean Temperature: Annual

Period: 1981-2010



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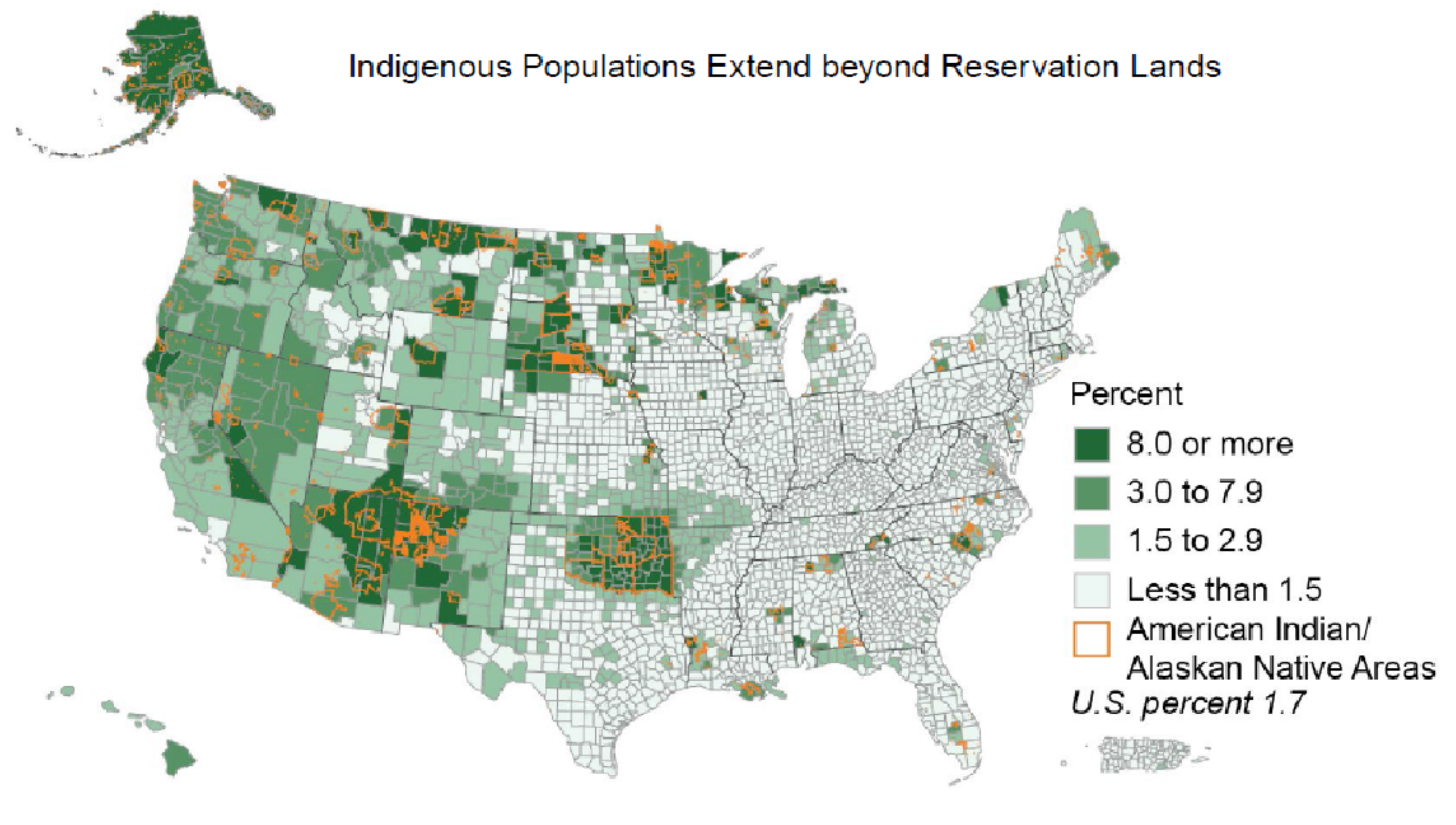
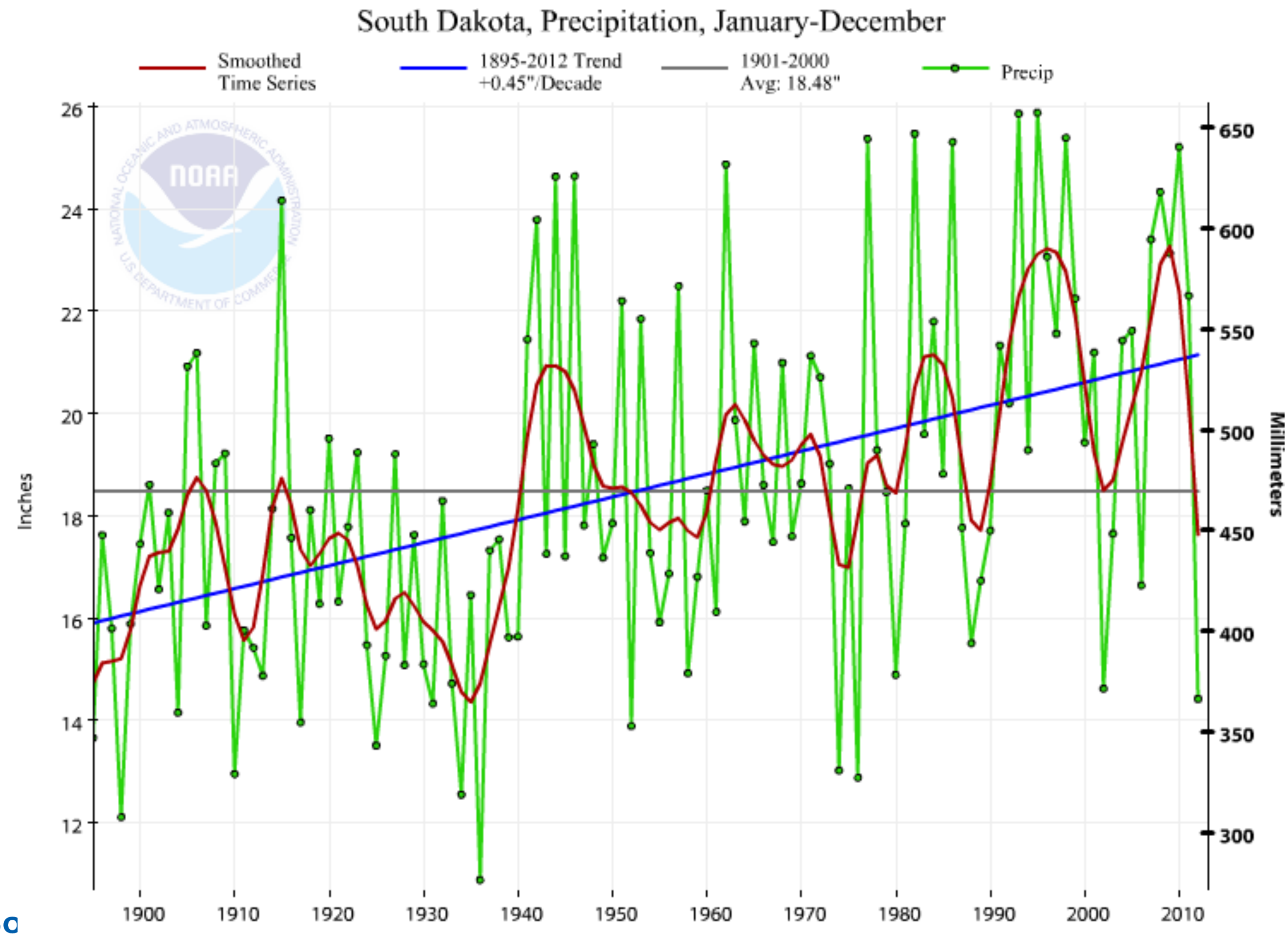
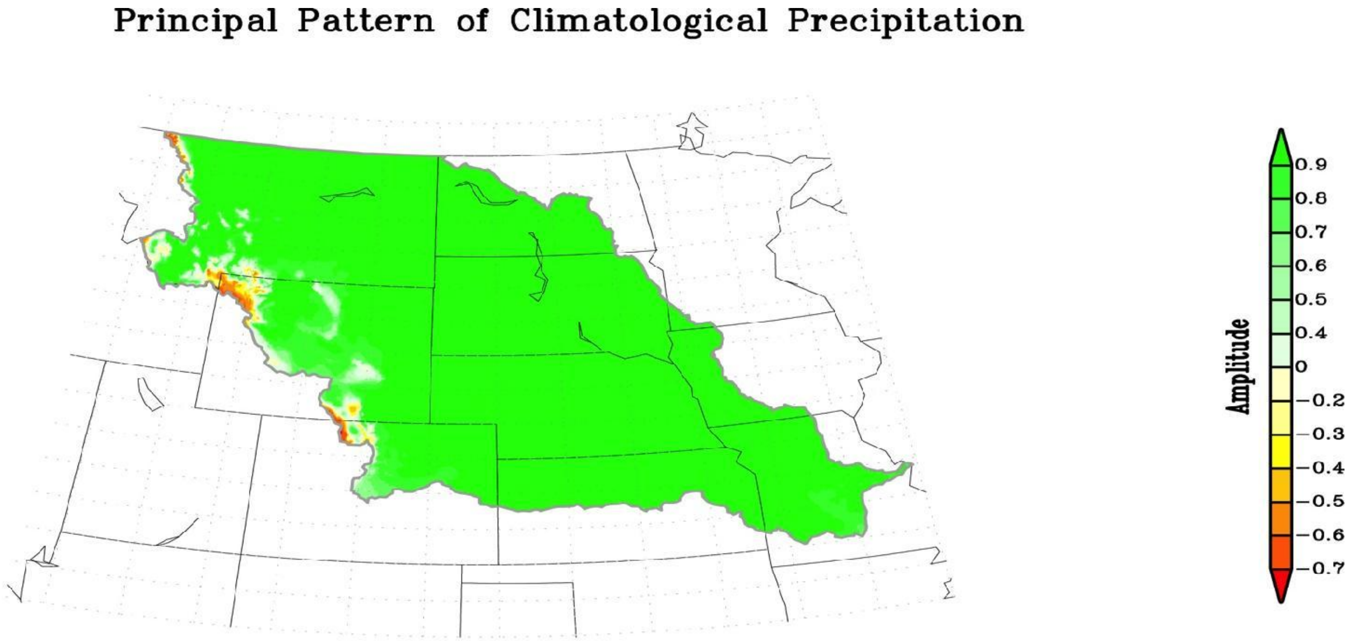


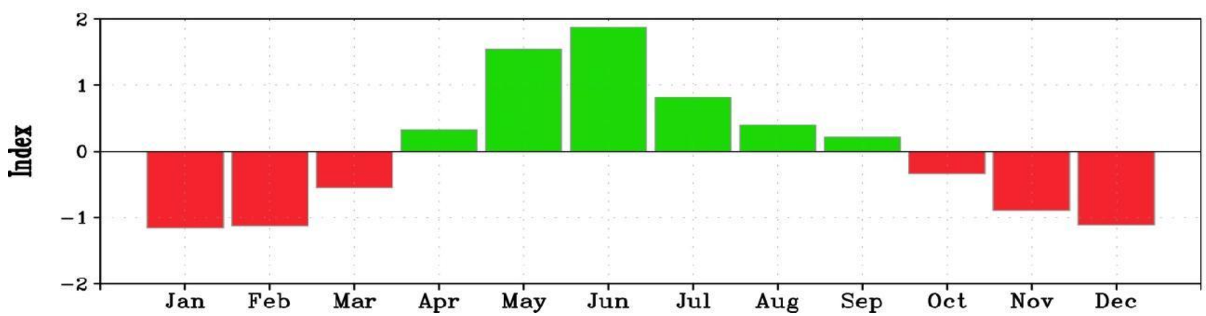
Figure 12.1. Census data show that American Indian and Alaska Native populations are concentrated around, but are not limited to, reservation lands like the Hopi and Navajo in Arizona and New Mexico, the Choctaw, Chickasaw, and Cherokee in Oklahoma, and various Sioux tribes in the Dakotas and Montana. Not depicted in this graphic is the proportion of Native Americans who live off-reservation and in and around urban centers (such as Chicago, Minneapolis, Denver, Albuquerque, and Los Angeles) yet still maintain strong family ties to their tribes, tribal lands, and cultural resources. (Figure source: Norriset al. 2012[5]).

Climate is not static



Seasonality of Precipitation
Spring is the Missouri Basin's Rainy Season

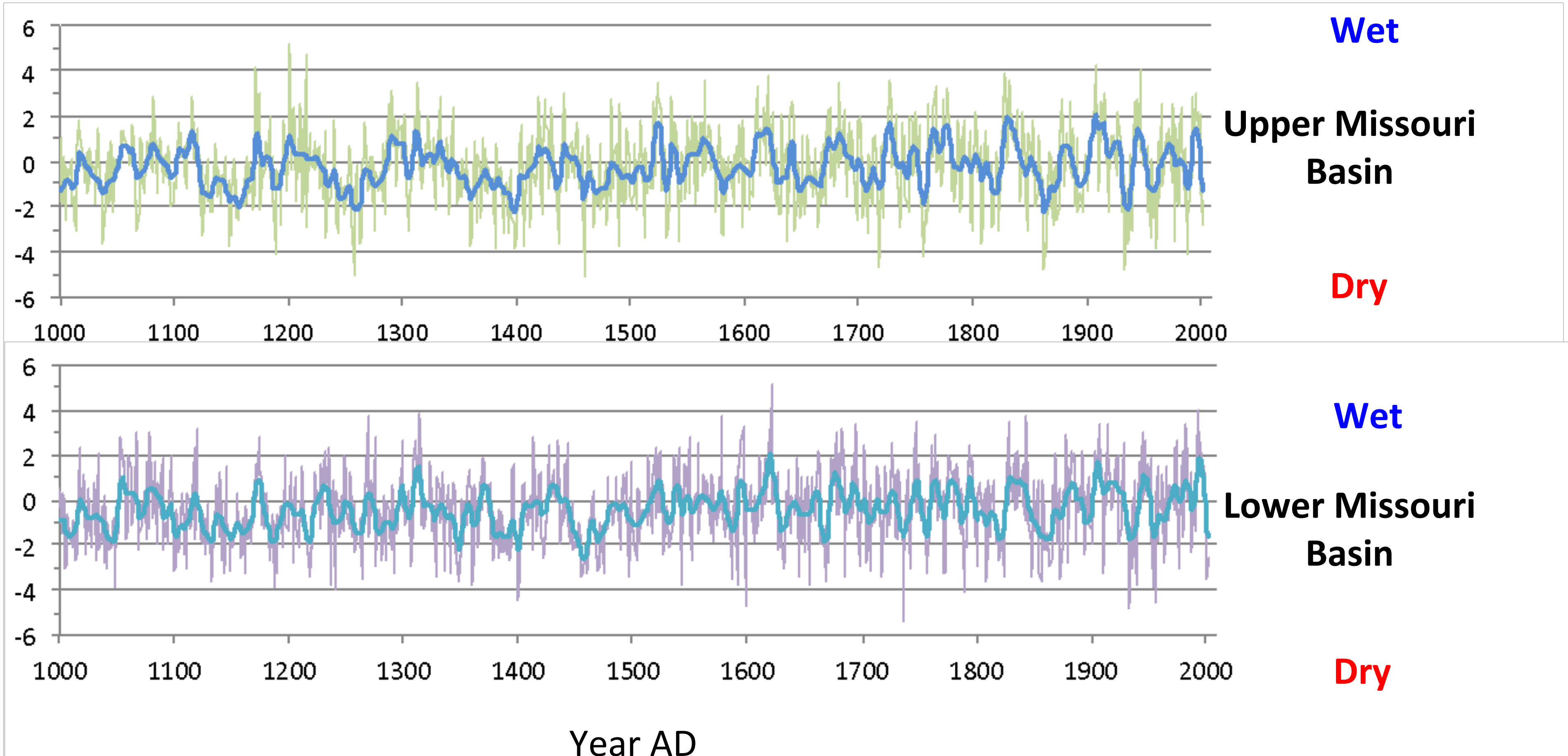




But, severe Missouri River floods often stem from the <u>combination</u> of a prolonged wet period, rapid snowmelt, and heavy spring rains.

Paleoclimate Perspective

Tree ring reconstructions of Palmer Drought Severity Index (PDSI)



Interannual and decadal climate variability resulting in shifts between wet and dry conditions common over the last 1000 years

Cook, E.R., et al. (2008)

Data from NOAA National Climatic Data Center

Climate variability in the Missouri Basin

- ENSO
- PDO
- AO/NAO
- TAG
- WPWP
- Local conditions
- Climate change
- Others

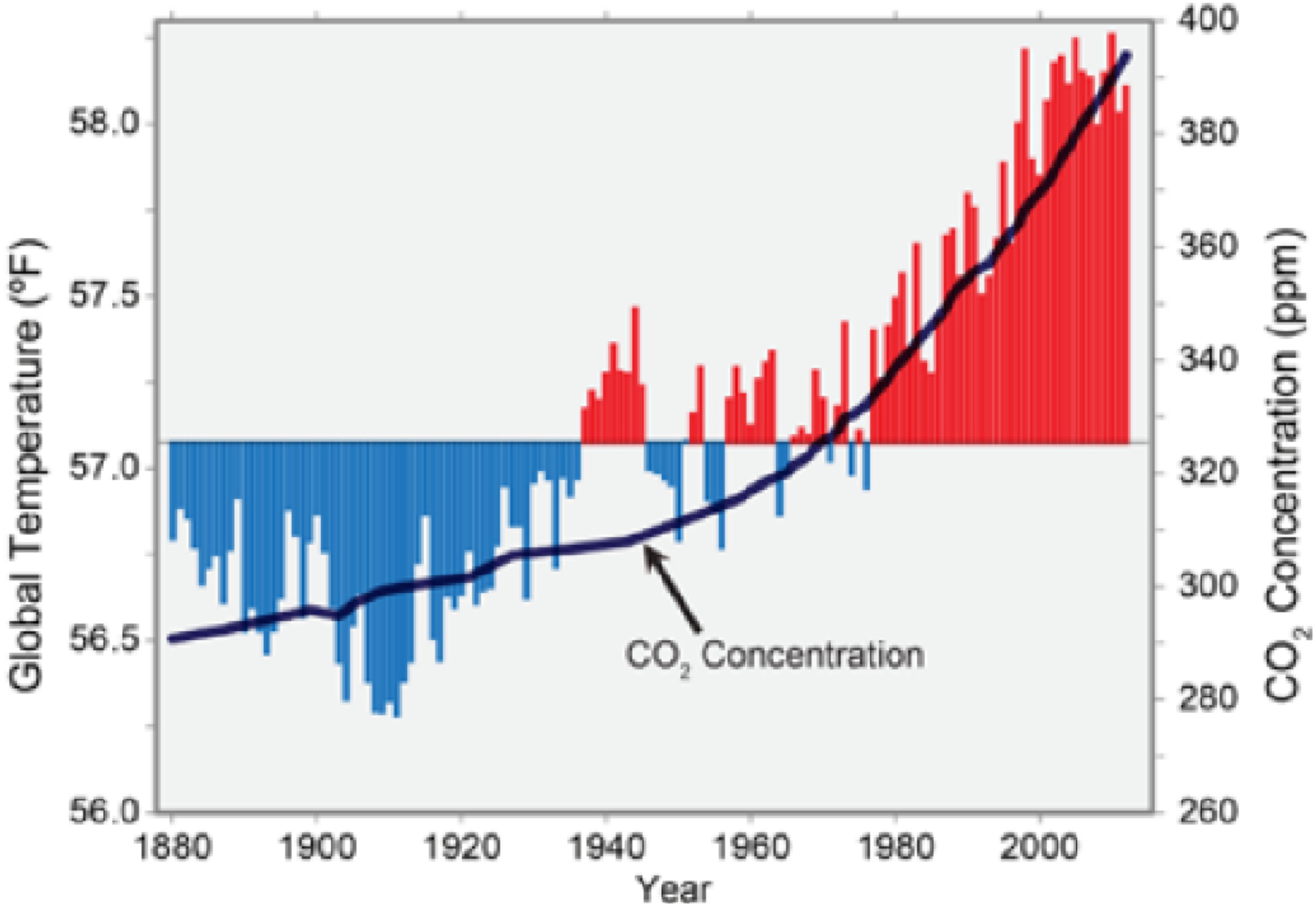
- Note – much of the variability is still unexplained

CLIMATE CHANGES

Derived from

- http://nca2014.globalchange.gov/

Global Temperature and Carbon Dioxide



Observed U.S. Temperature Change

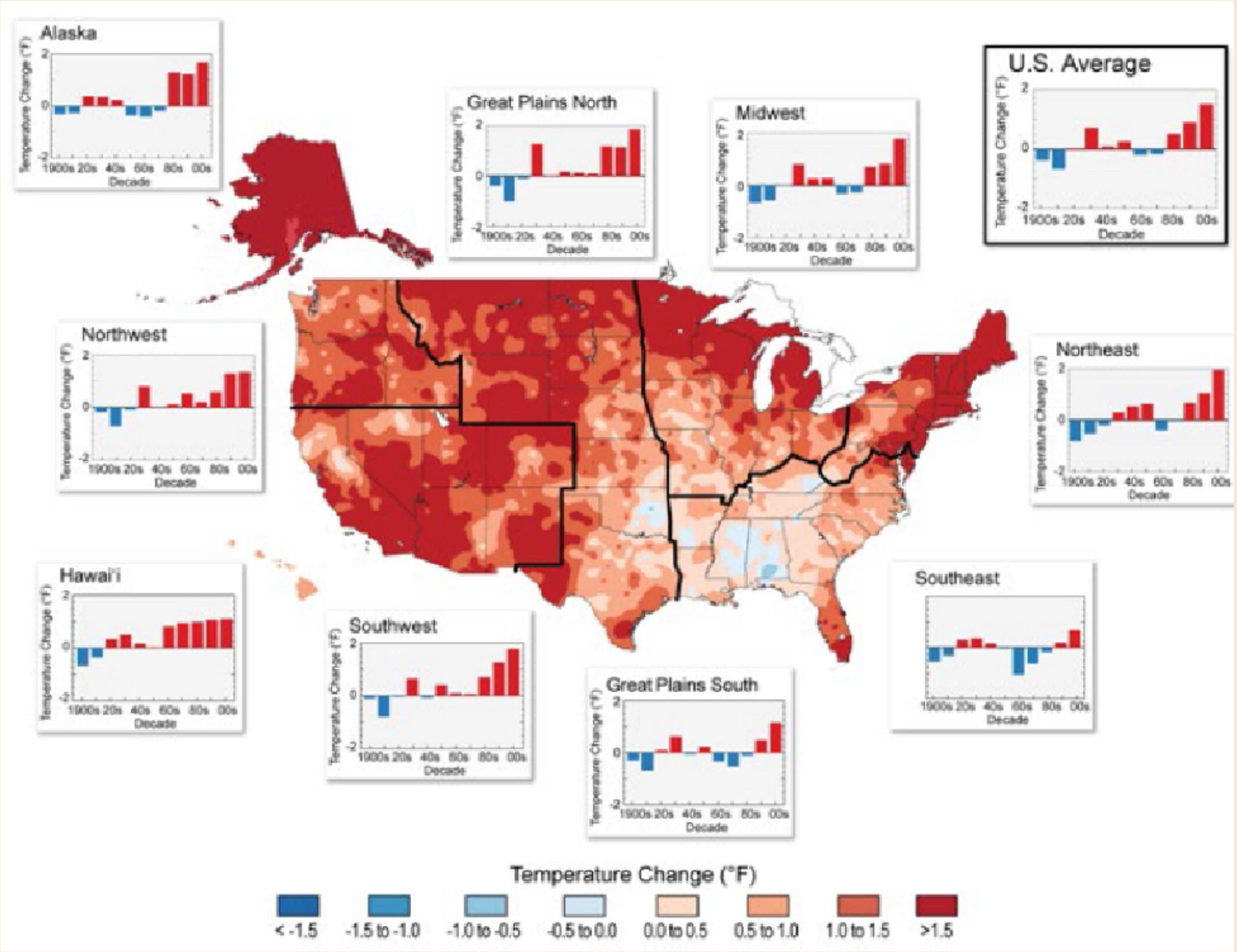


Figure 2.7. The colors on the map show temperature changes over the past 22 years (1991-2012) compared to the 1901-1960 average, and compared to the 1951-1980 average for Alaska and Hawai'i. The bars on the graphs show the average temperature changes by decade for 1901-2012 (relative to the 1901-1960 average) for each region. The far right bar in each graph (2000s decade) includes 2011 and 2012. The period from 2001 to 2012 was warmer than any previous decade in every region. (Figure source: NOAA NCDC / CICS-NC).

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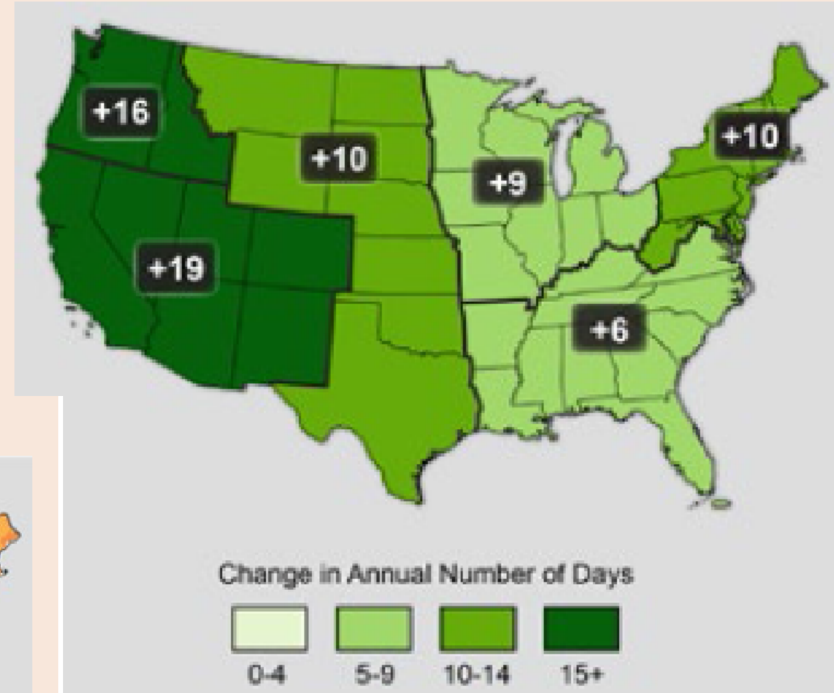
Observed Increase in Frost-Free Season Length



e 2.10. The frost-free season length, defined as the between the last occurrence of 32°F in the spring e first occurrence of 32°F in the fall, has increased in J.S. region during 1991-2012 relative to 1901-1960. ses in frost-free season length correspond to similar ses in growing season length. (Figure source: NOAA / CICS-NC).

Projected Changes in Frost-Free Season Length

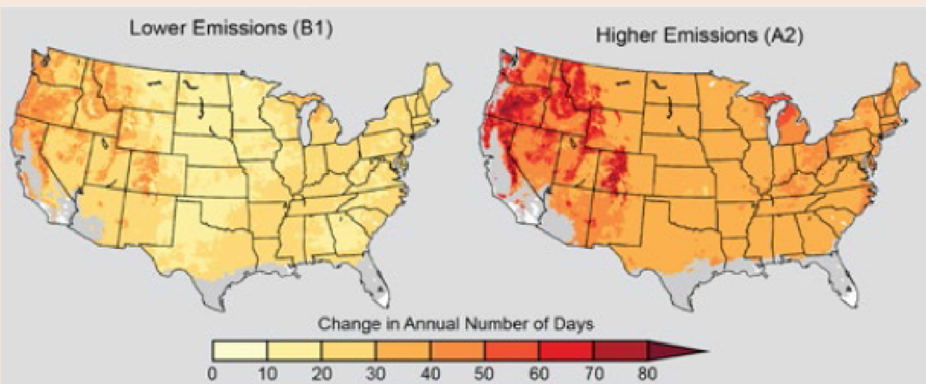


Figure 2.11. The maps show projected increases in frost-free season length for the last three decades of this century (2070-2099 as compared to 1971-2000) under two emissions scenarios, one in which heat-trapping gas emissions continue to grow (A2) and one in which emissions peak in 2050 (B1). Increases in the frost-free season correspond to similar increases in the growing season. White areas are projected to experience no freezes for 2070-2099, and gray areas are projected to experience more than 10 frost-free years during the same period. (Figure source: NOAA NCDC / CICS-NC).

Observed U.S. Precipitation Change

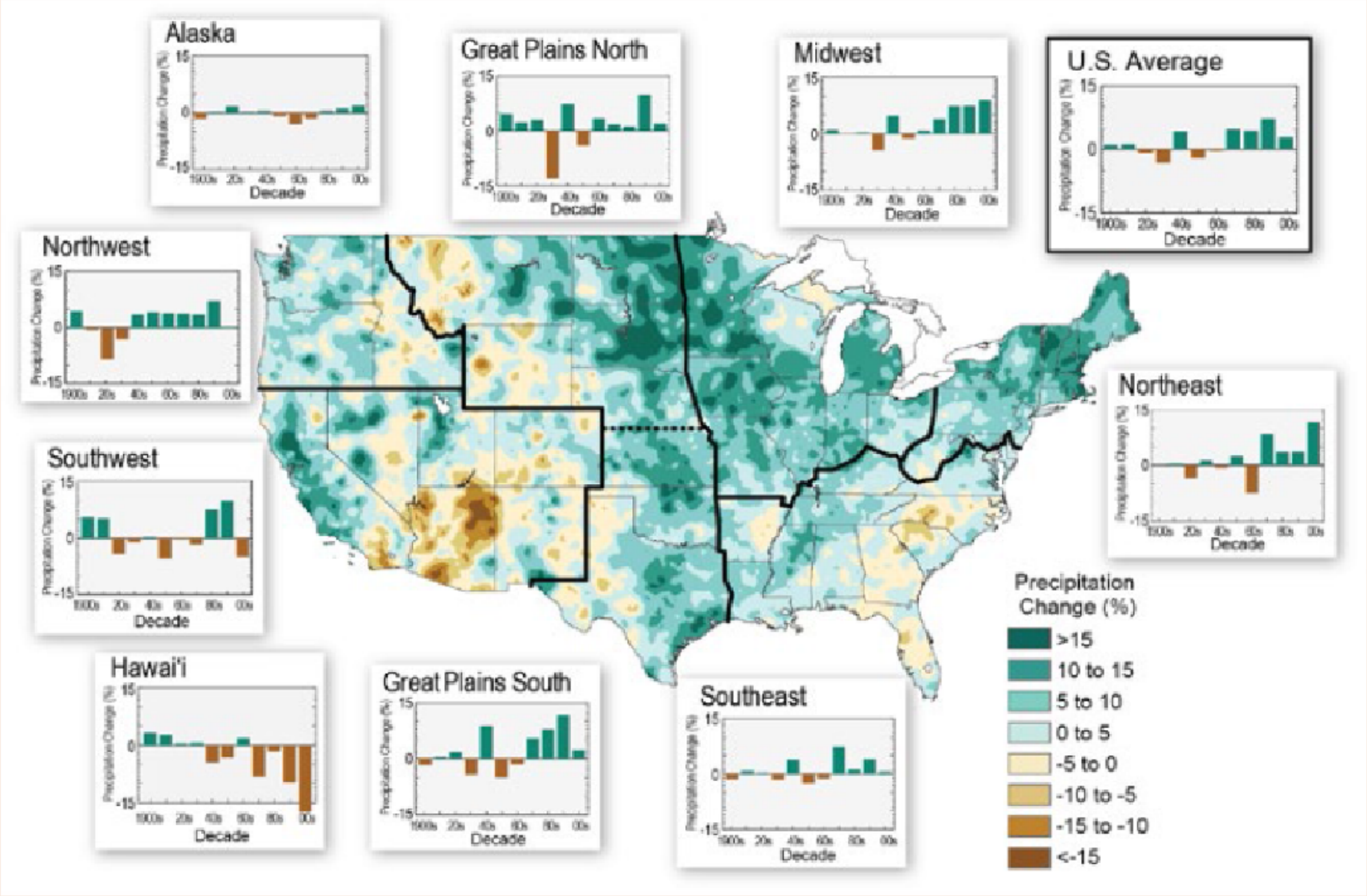


Figure 2.12. The colors on the map show annual total precipitation changes for 1991-2012 compared to the 1901-1960 average, and show wetter conditions in most areas. The bars on the graphs show average precipitation differences by decade for 1901-2012 (relative to the 1901-1960 average) for each region. The far right bar in each graph is for 2001-2012. (Figure source: adapted from Peterson et al. 2013[48]).

Observed Change in Very Heavy Precipitation

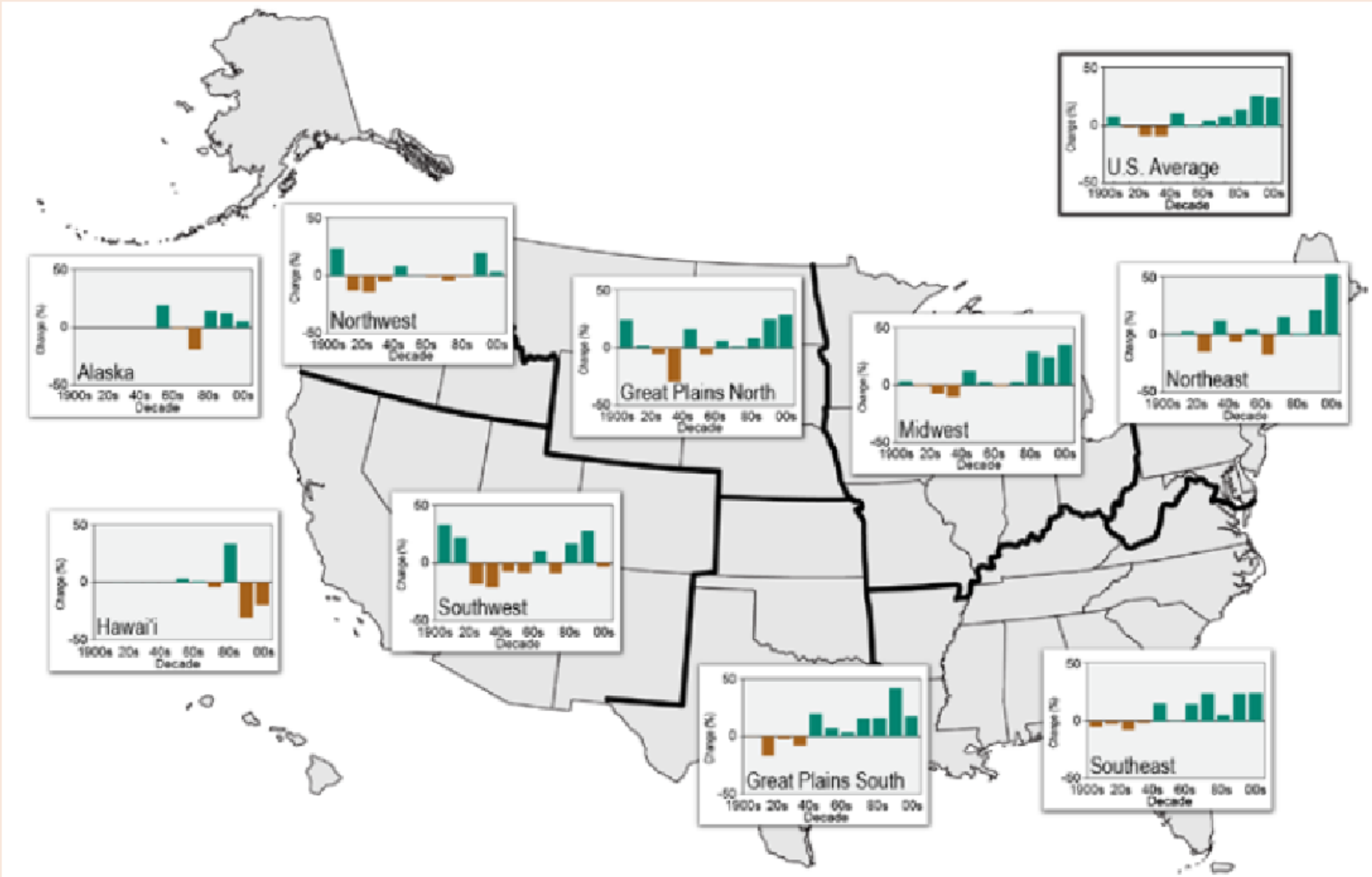


Figure 2.17. Percent changes in the annual amount of precipitation falling in very heavy events, defined as the heaviest 1% of all daily events from 1901 to 2012 for each region. The far right bar is for 2001-2012. In recent decades there have been increases nationally, with the largest increases in the Northeast, Great Plains, Midwest, and Southeast. Changes are compared to the 1901-1960 average for all regions except Alaska and Hawai'i, which are relative to the 1951-1980 average. (Figure source: NOAA NCDC / CICS-NC).

Observed Change in Very Heavy Precipitation

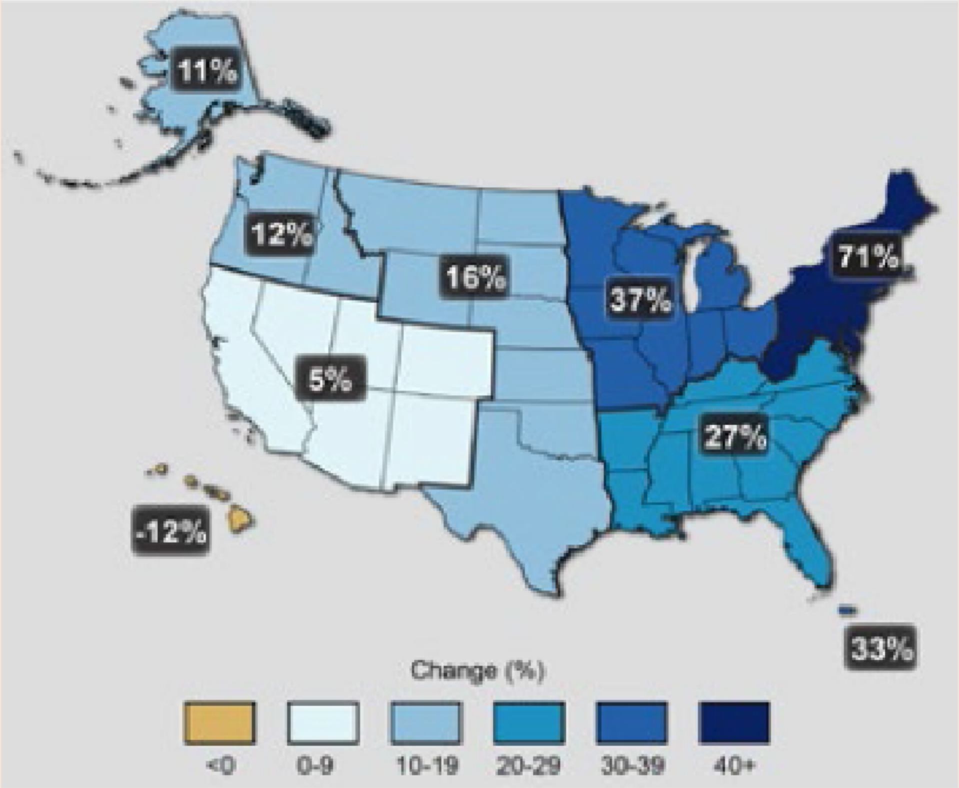


Figure 2.18. The map shows percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States. These trends are larger than natural variations for the Northeast, Midwest, Puerto Rico, Southeast, Great Plains, and Alaska. The trends are not larger than natural variations for the Southwest, Hawai'i, and the Northwest. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012. (Figure source: updated from Karl et al. 2009[1]).

Trends in Flood Magnitude

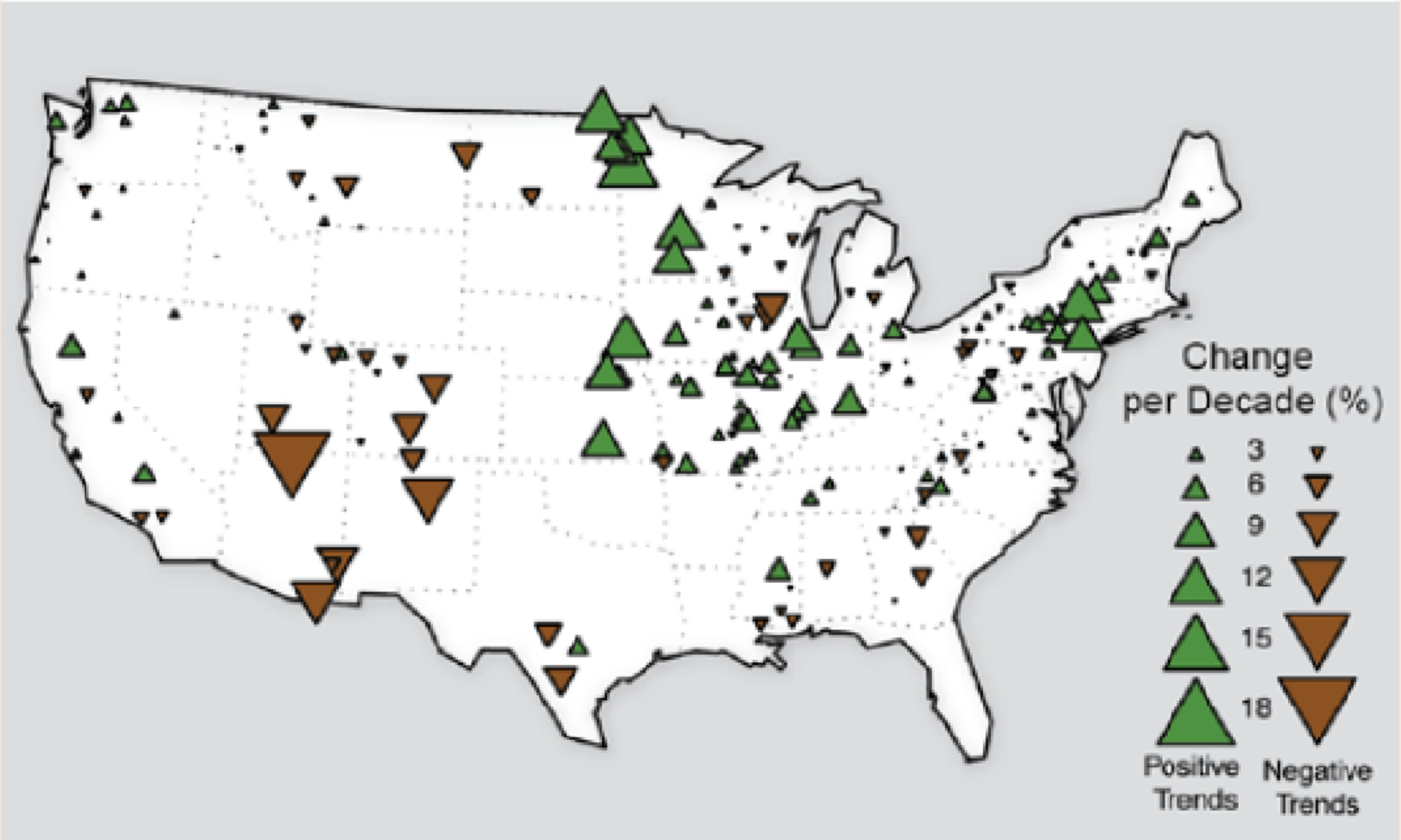


Figure 2.21. Trend magnitude (triangle size) and direction (green = increasing trend, brown = decreasing trend) of annual flood magnitude from the 1920s through 2008. Local areas can be affected by land-use change (such as dams). Most significant are the increasing trend for floods in the Midwest and Northeast and the decreasing trend in the Southwest. (Figure source: Peterson et al. 2013[48]).

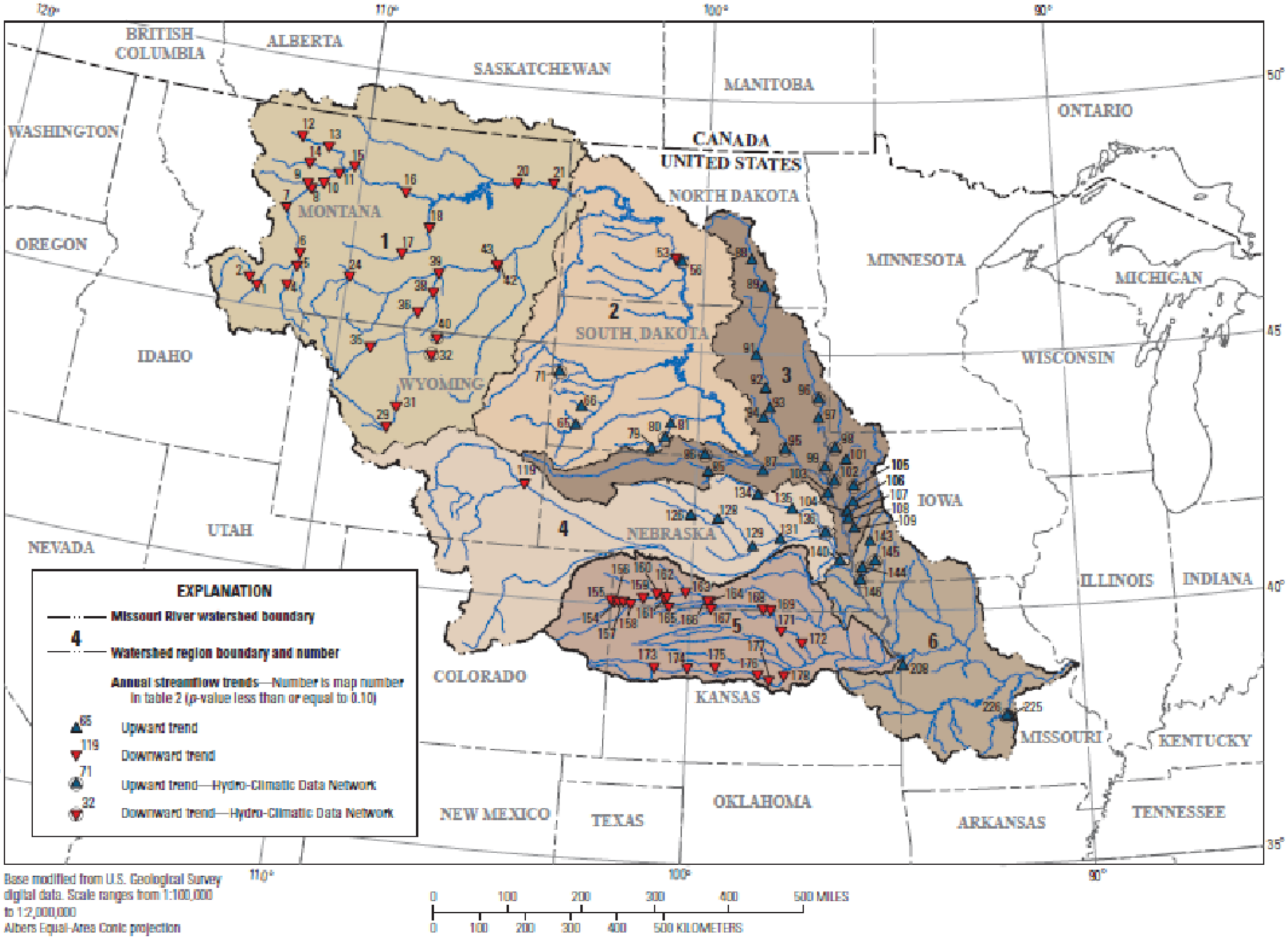


Figure 11. Streamgages in the Missouri River watershed with statistically significant trends in annual streamflow for water years 1960–2011.

Annual Surface Soil Moisture Trends

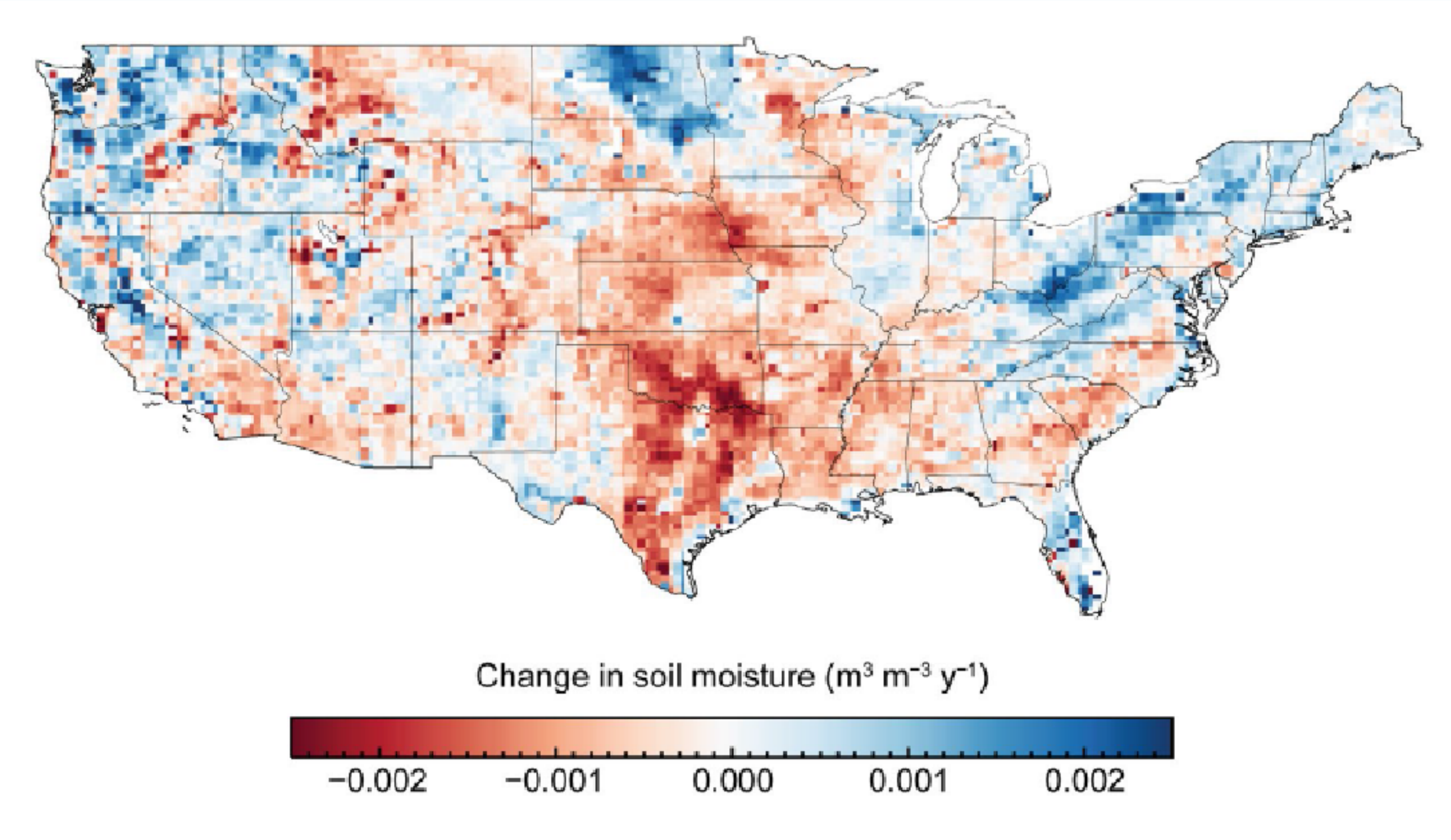


Figure 3.2. Changes in annual surface soil moisture per year over the period 1988 to 2010 based on multi-satellite datasets. Surface soil moisture exhibits wetting trends in the Northeast, Florida, upper Midwest, and Northwest, and drying trends almost everywhere else. (Images provided by W. Dorigo[35]).

Seasonal Surface Soil Moisture Trends

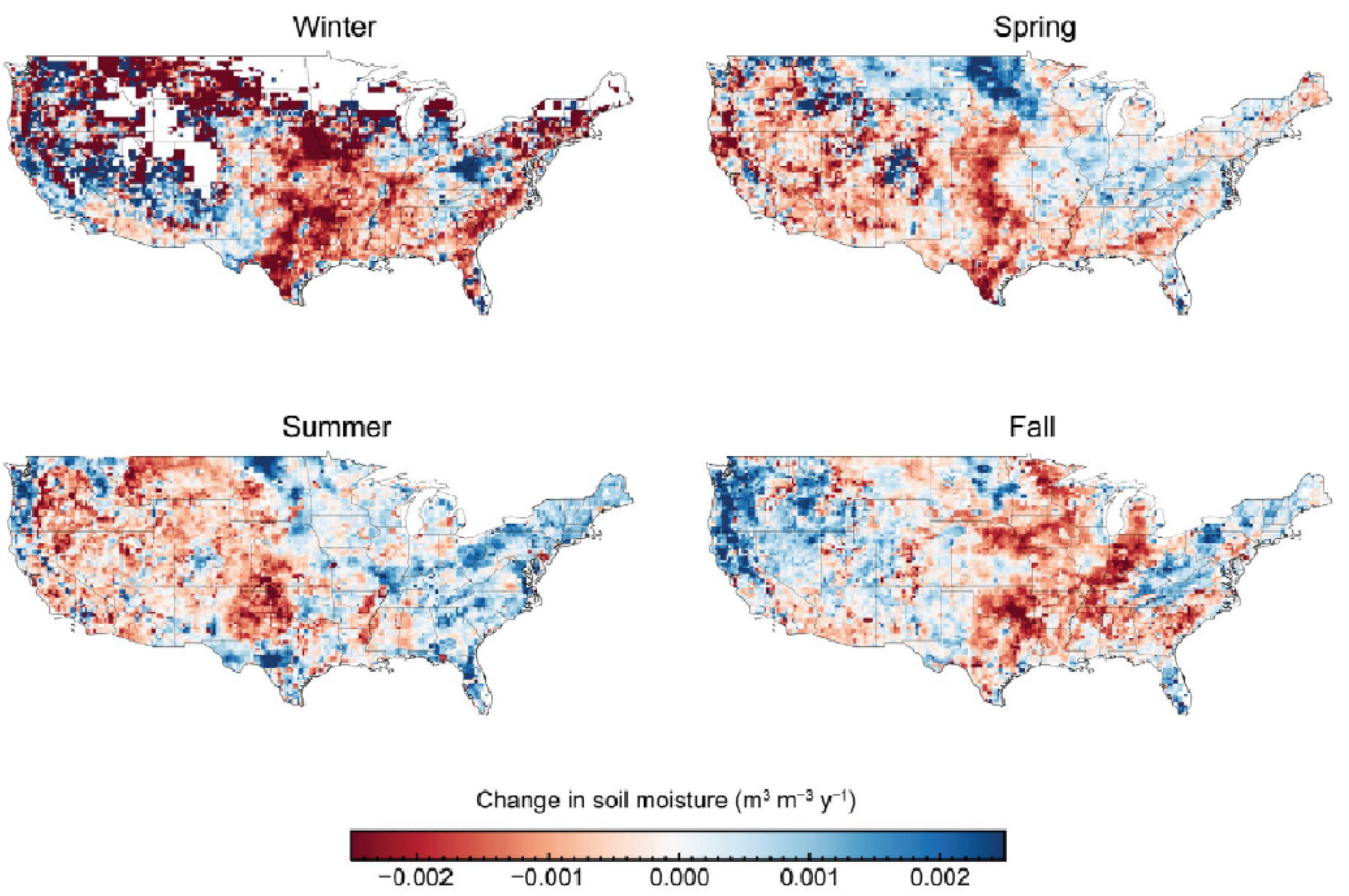
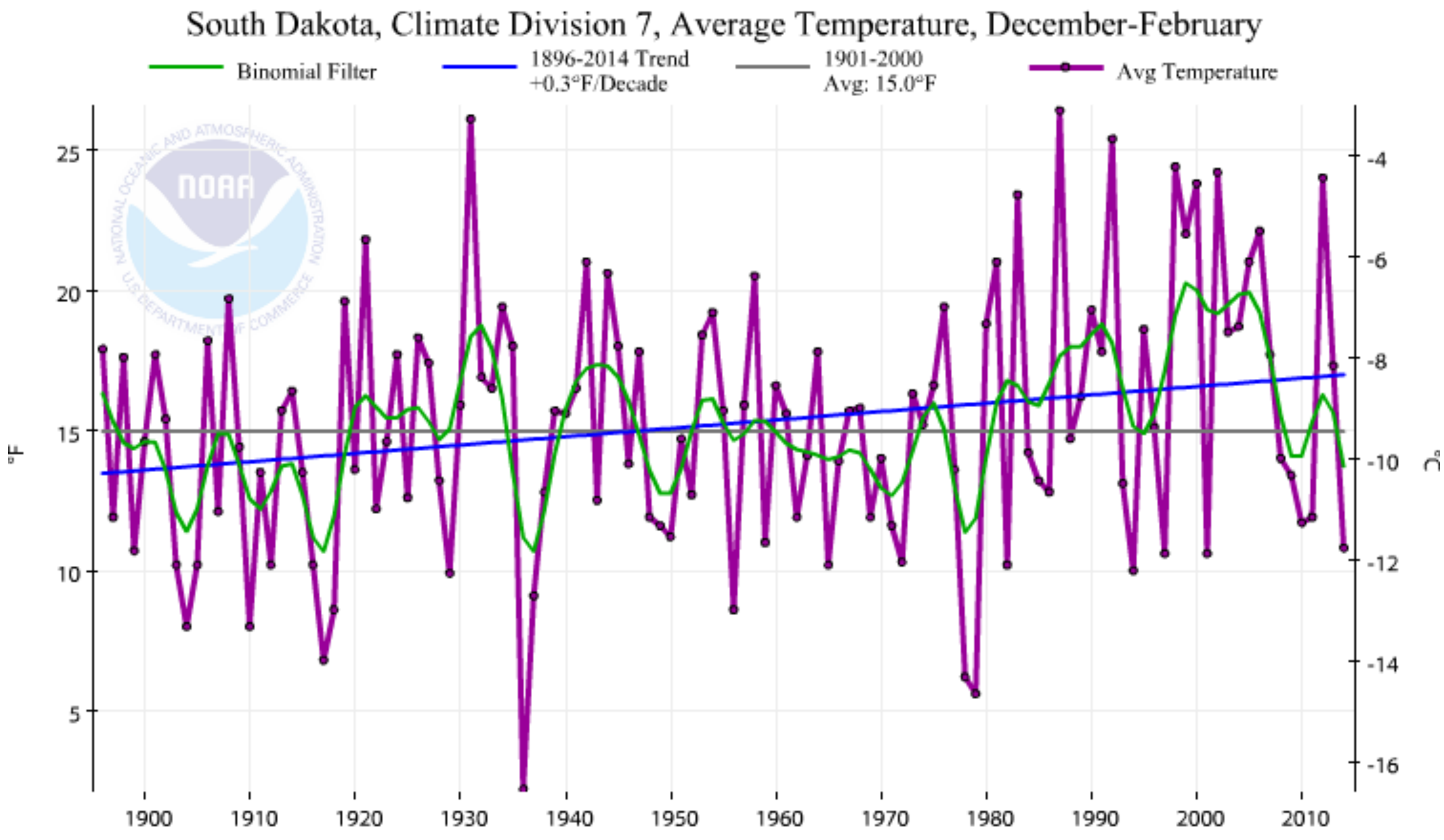


Figure 3.3. Changes in seasonal surface soil moisture per year over the period 1988 to 2010 based on multi-satellite datasets.[35] Seasonal drying is observed in central and lower Midwest and Southeast for most seasons (with the exception of the Southeast summer), and in most of the Southwest and West (with the exception of the Northwest) for spring and summer. Soil moisture in the upper Midwest, Northwest, and most of the Northeast is increasing in most seasons. (Images provided by W. Dorigo).

ADDITIONAL LOCAL CHANGES

- http://www.ncdc.noaa.gov/cag/time-series/us

Summer Temperature Trends (June – August) SD



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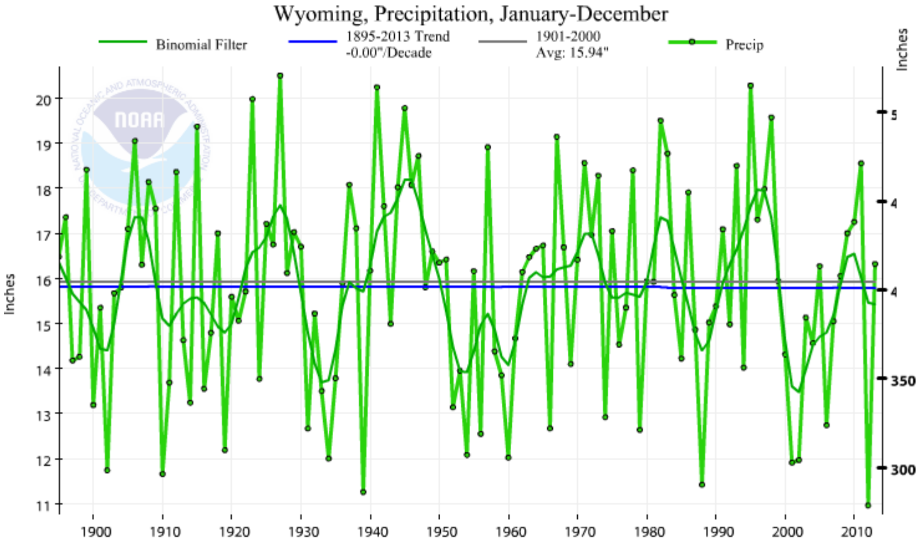
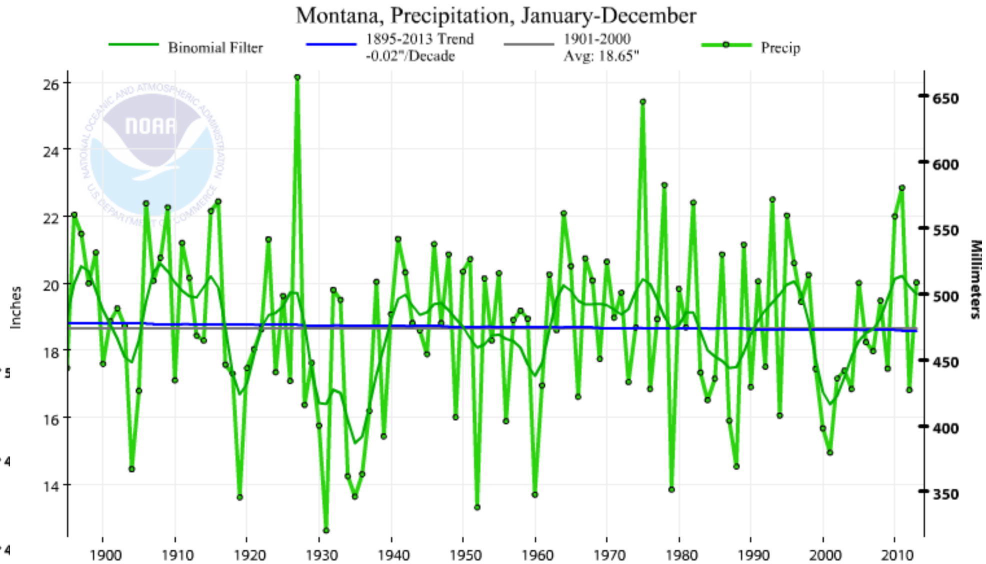
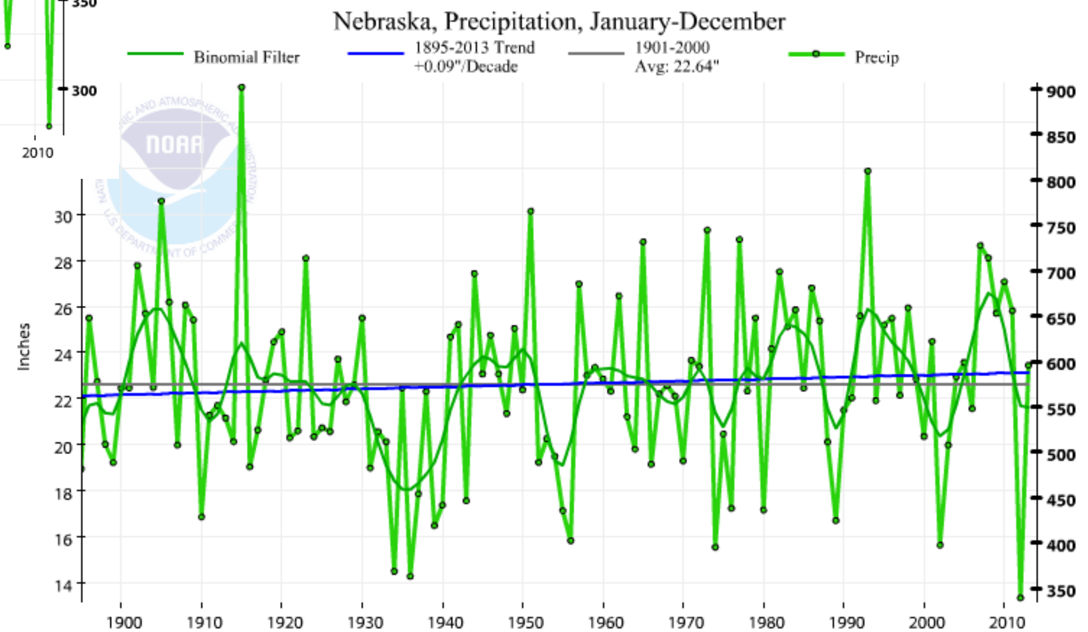
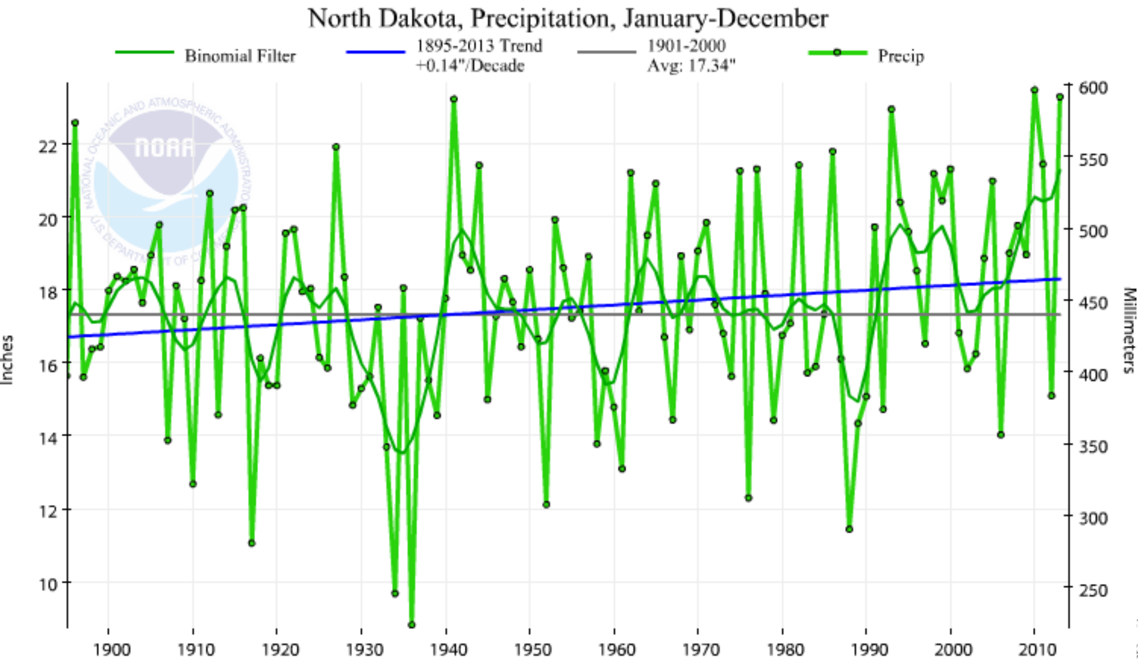
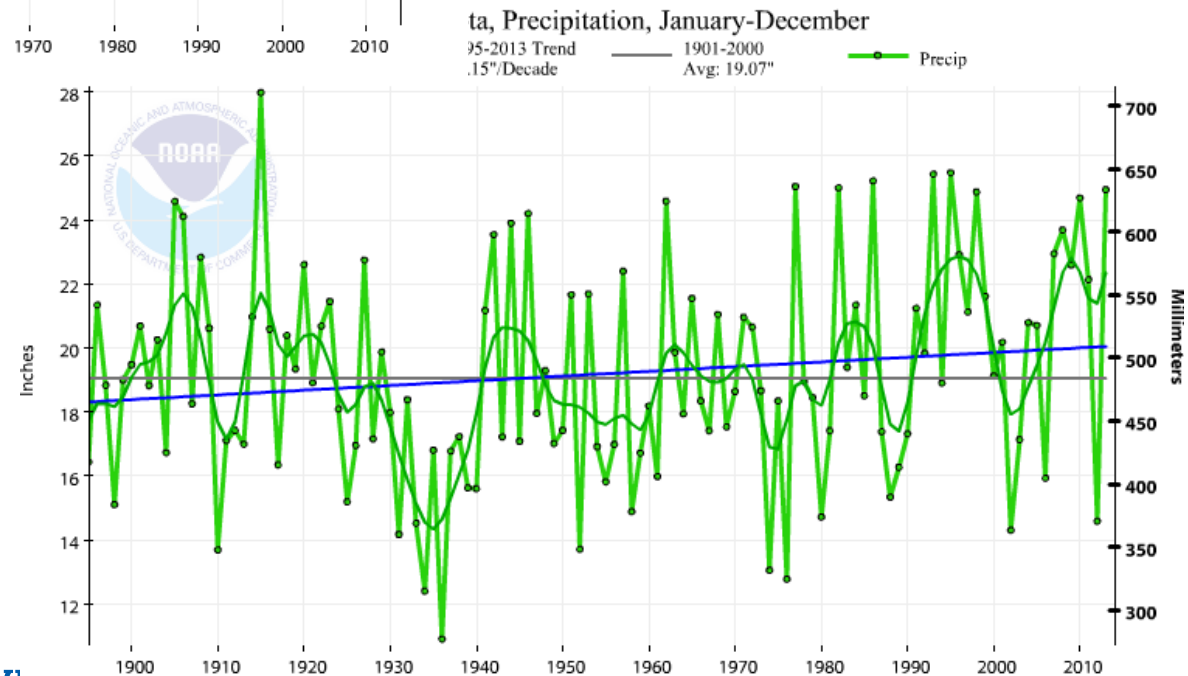

Wyoming, Precipitation, January-December
Binomial Filter
1895-2013 Trend
-0.00"/Decade
1901-2000
Avg: 15.94"
Precip
Inches

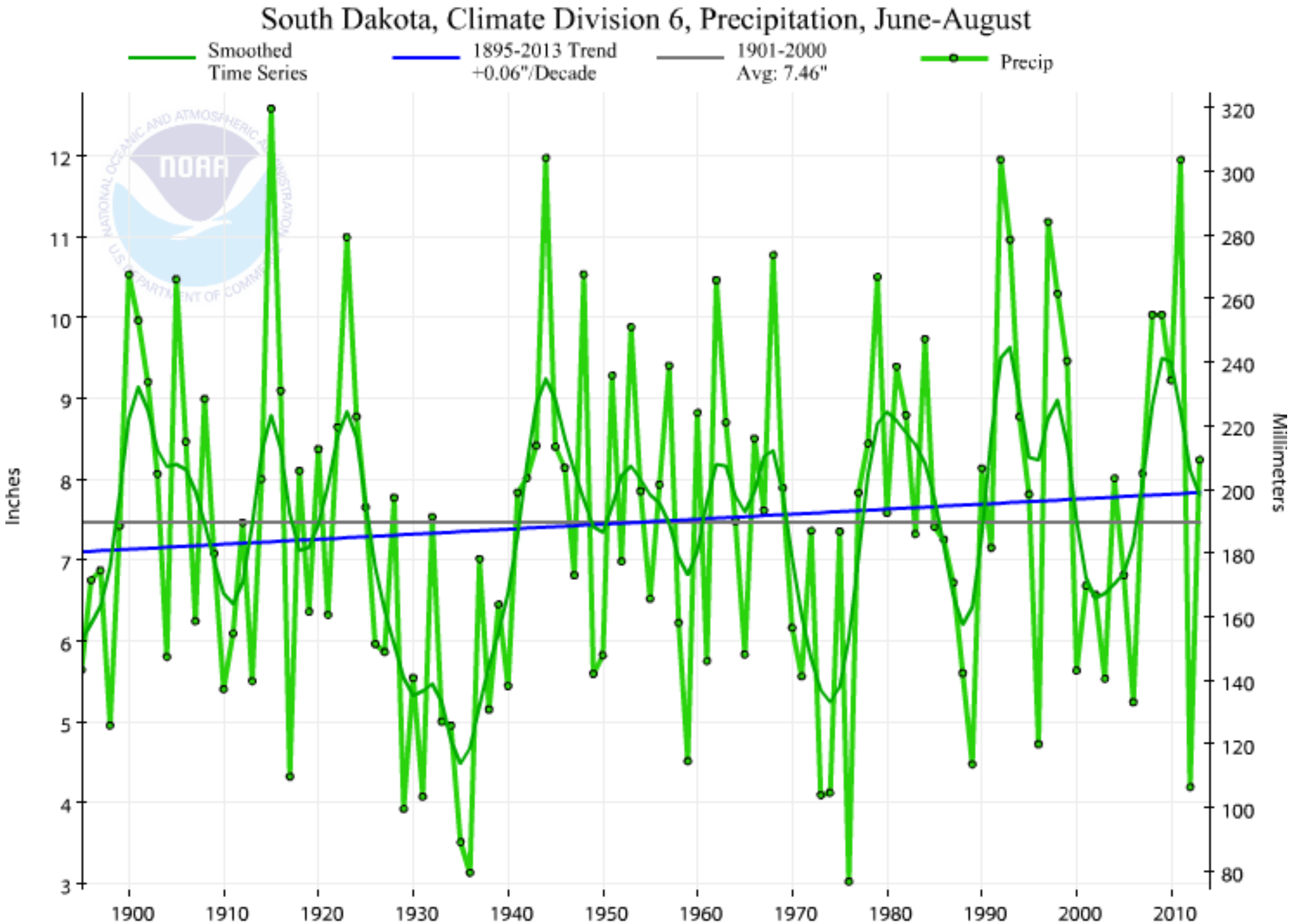

Montana, Precipitation, January-December
Binomial Filter
1895-2013 Trend
-0.02"/Decade
1901-2000
Avg: 18.65"
Precip
Inches
Millimeters

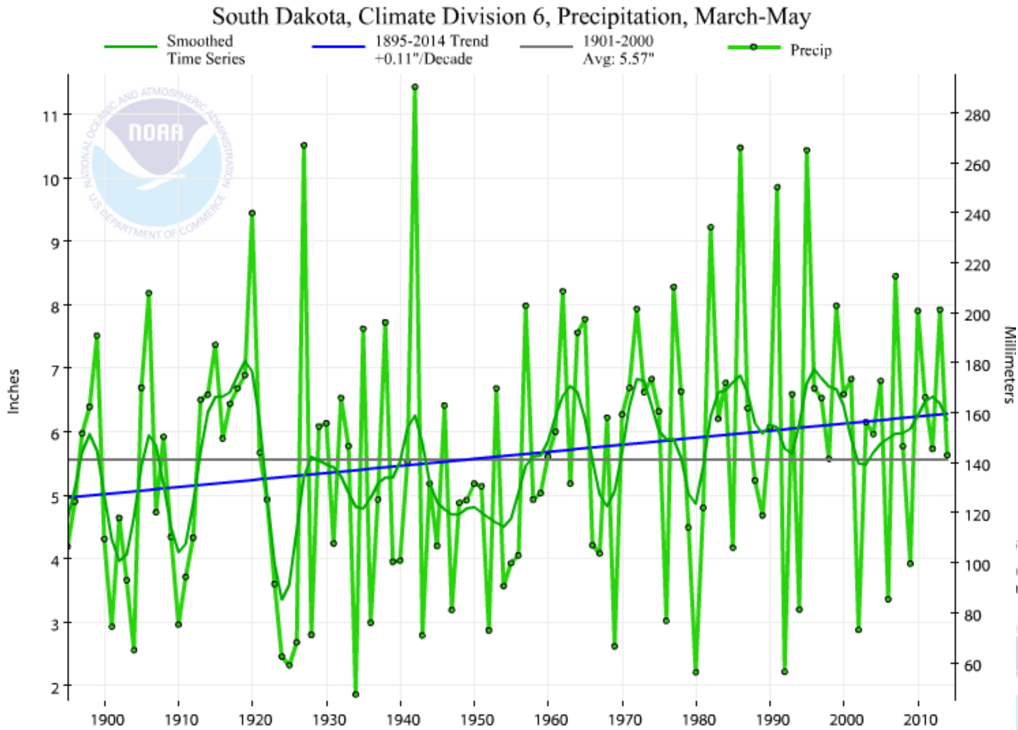

Nebraska, Precipitation, January-December
Binomial Filter
1895-2013 Trend
+0.09"/Decade
1901-2000
Avg: 22.64"
Precip
Inches
Millimeters


North Dakota, Precipitation, January-December
Binomial Filter
1895-2013 Trend
+0.14"/Decade
1901-2000
Avg: 17.34"
Precip
Inches
Millimeters

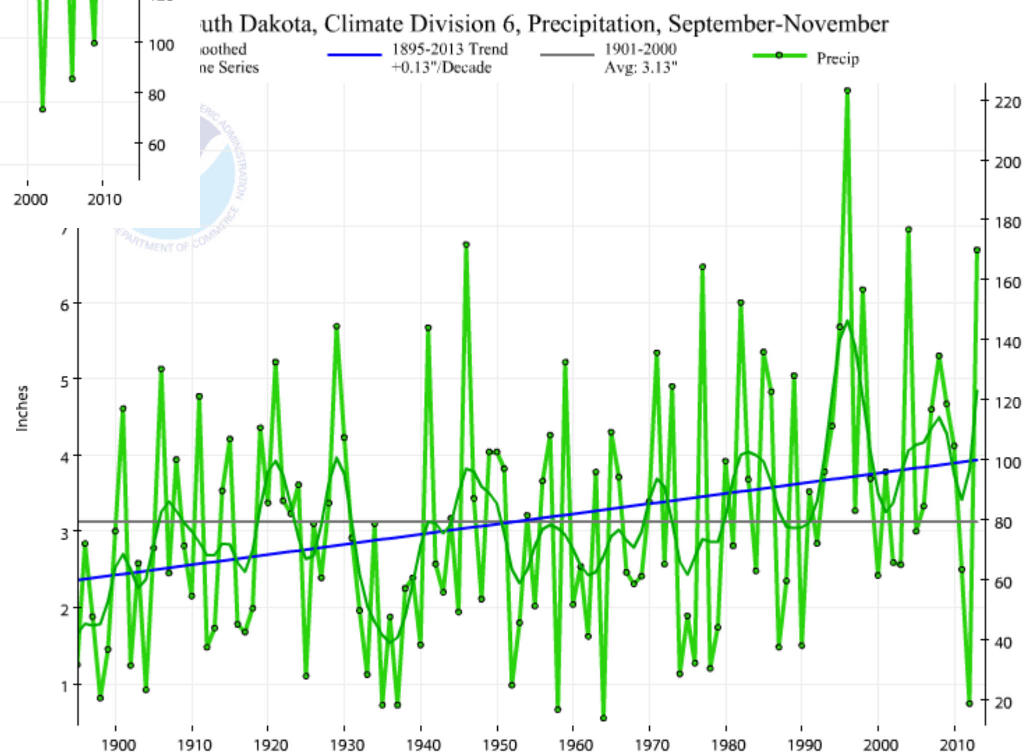

ta, Precipitation, January-December
95-2013 Trend
.15"/Decade
1901-2000
Avg: 19.07"
Precip
Inches
Millimeters

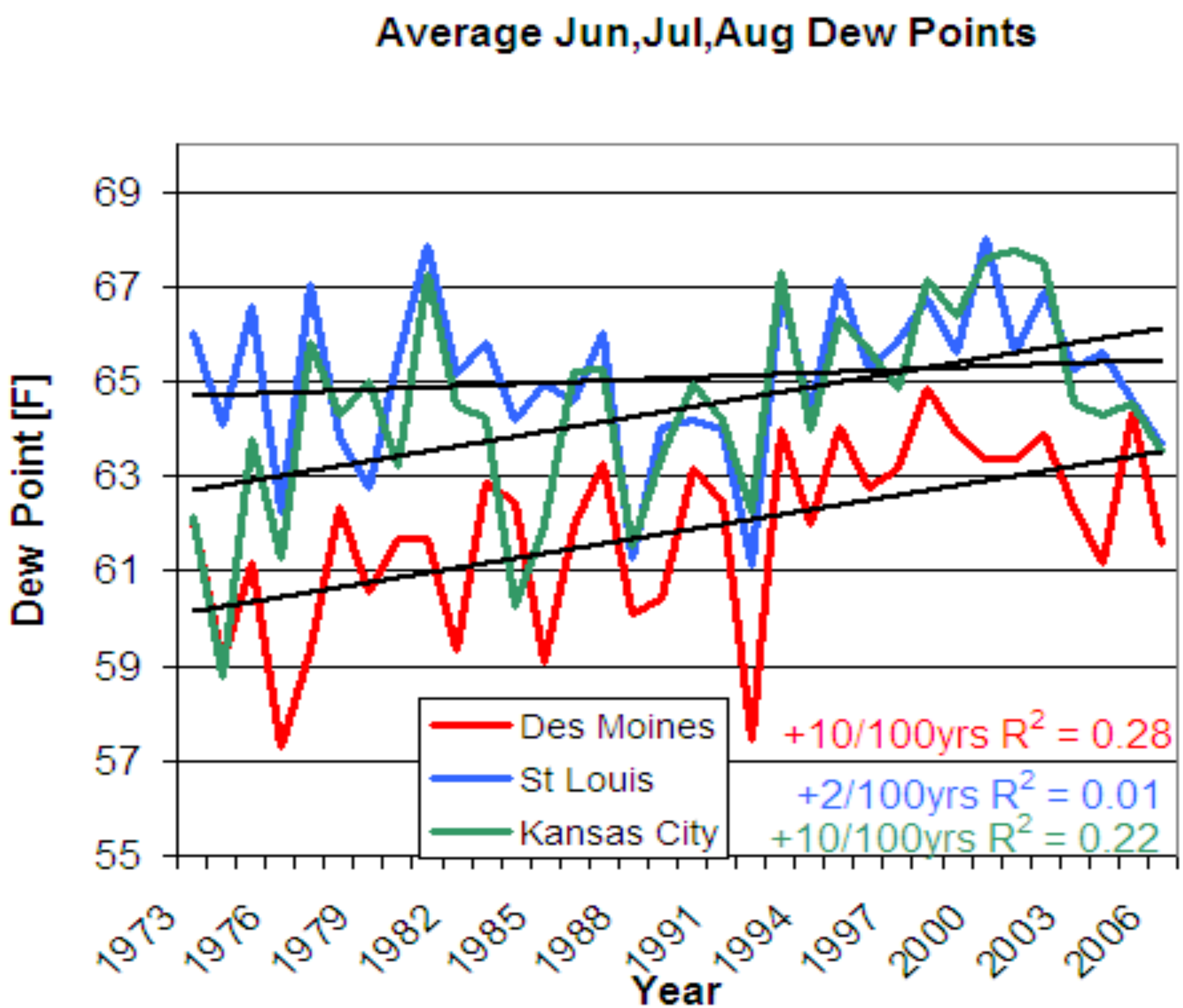
Summer Precipitation Trends (June – August) SD

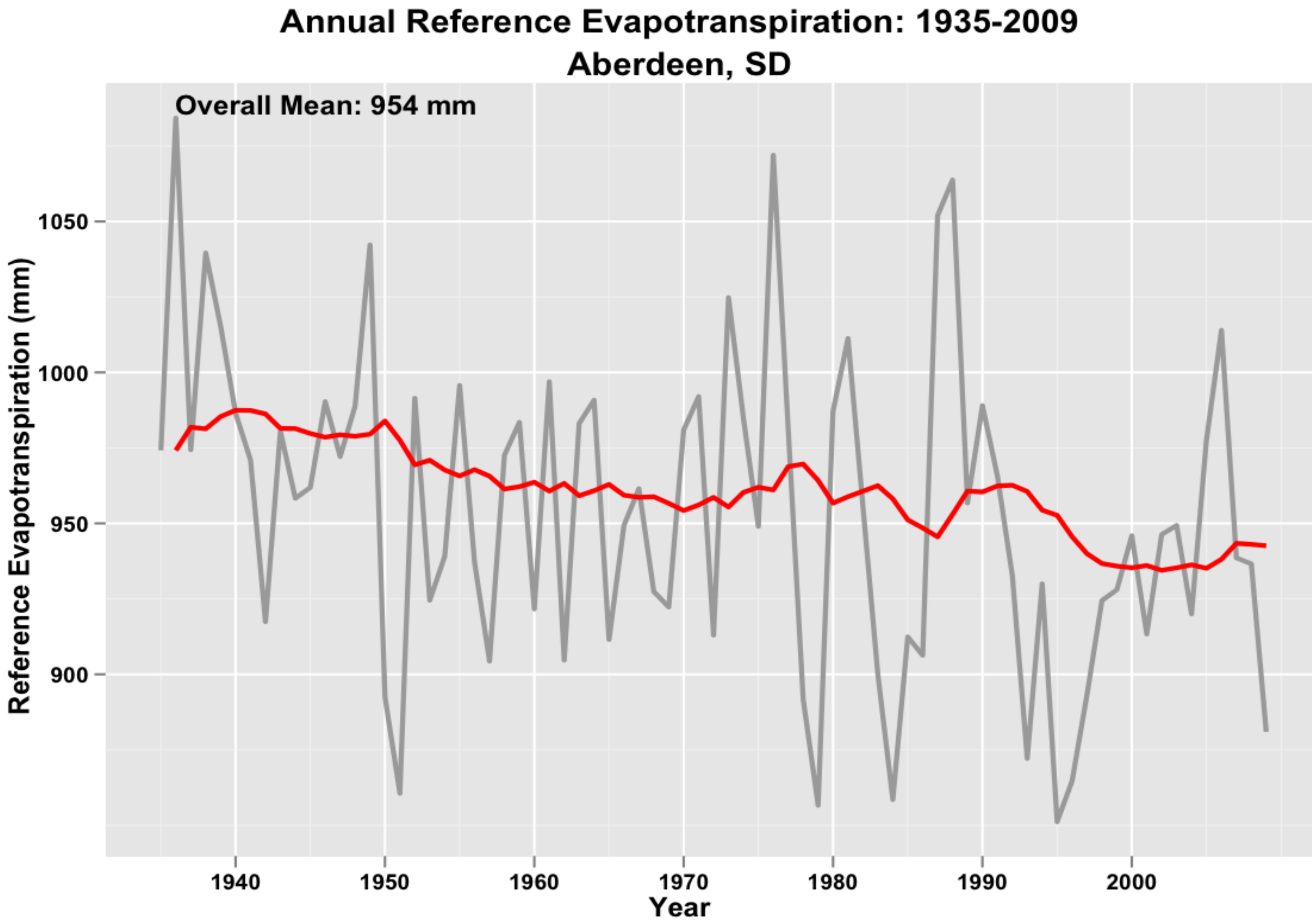




Spring and Fall Precipitation Trends SD




Average Jun,Jul,Aug Dew Points
Dew Point [F]
69
67
65
63
61
59
57
55
Des Moines
St Louis
Kansas City
+10/100yrs R2 = 0.28
+2/100yrs R2 = 0.01
+10/100yrs R2 = 0.22
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
Year



ET – Evapotranspiration, a combination of surface evaporation and transpiration from a crop

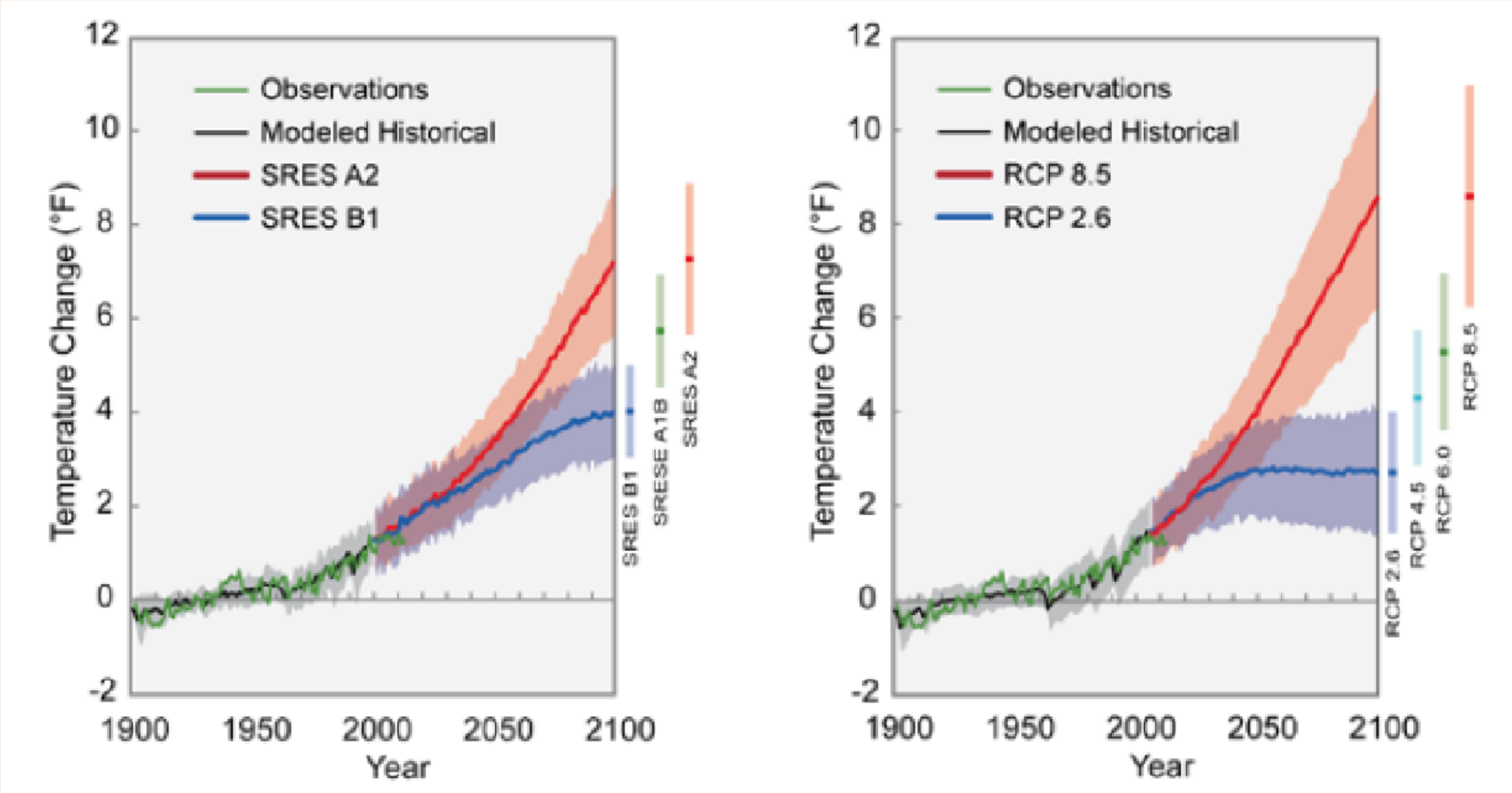
Calculated based on temperature index

Other changes

- Winter warming
- Higher dew points/humidity
- Lower summer highs – reduced ET

PROJECTED CLIMATE CHANGES

Emissions Levels Determine Temperature Rises



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Changes

- Complex – not just overall warming
- Precipitation changes
- Changes during year
- Max/min
- Locational

Projected Temperature Change

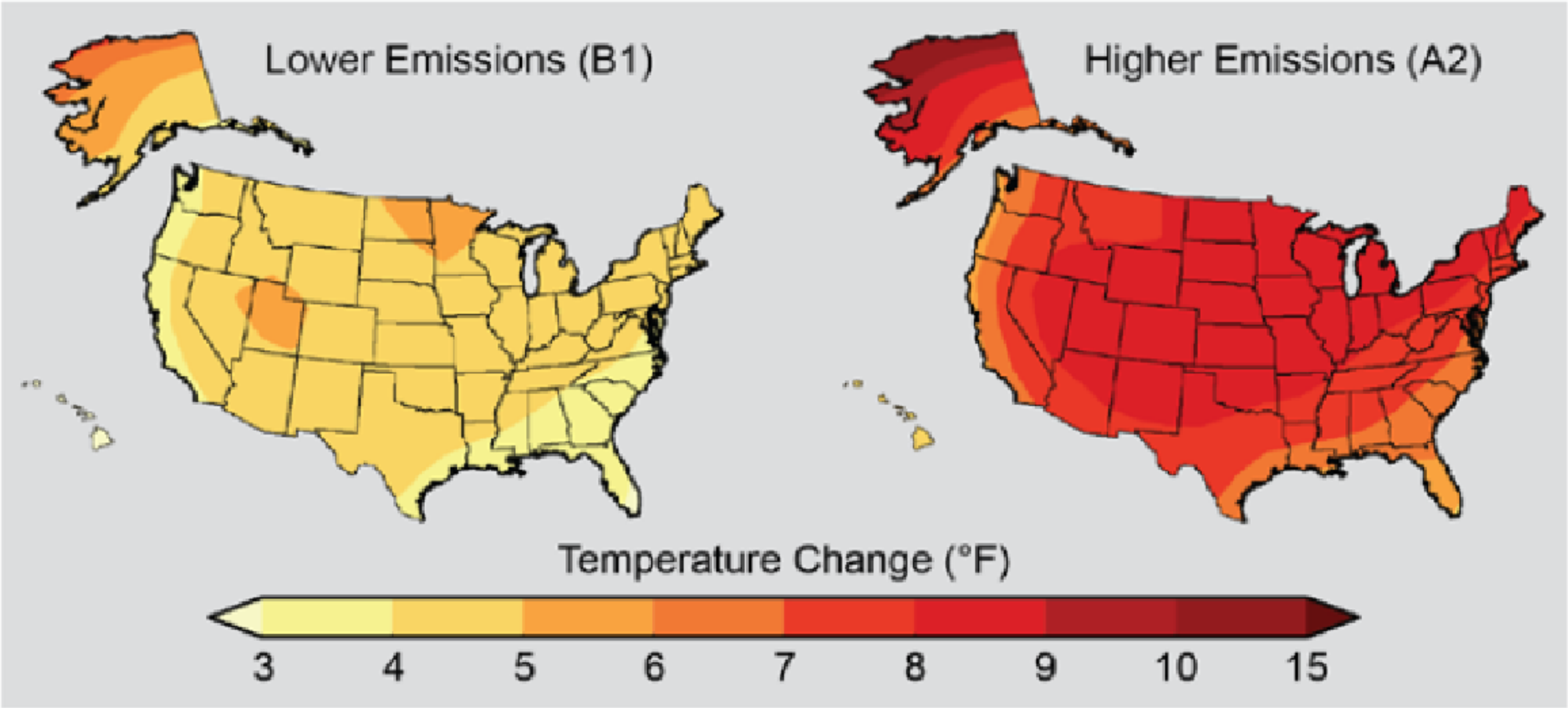

Figure 2.8. Maps show projected change in average surface air temperature in the later part of this century (2071-2099) relative to the later part of the last century (1970-1999) under a scenario that assumes substantial reductions in heat trapping gases (B1, left) and a higher emissions scenario that assumes continued increases in global emissions (A2, right). (See Appendix 3: Climate Science, Supplemental Message 5 for a discussion of temperature changes under a wider range of future scenarios for various periods of this century). (Figure source: NOAA NCDC / CICS-NC).

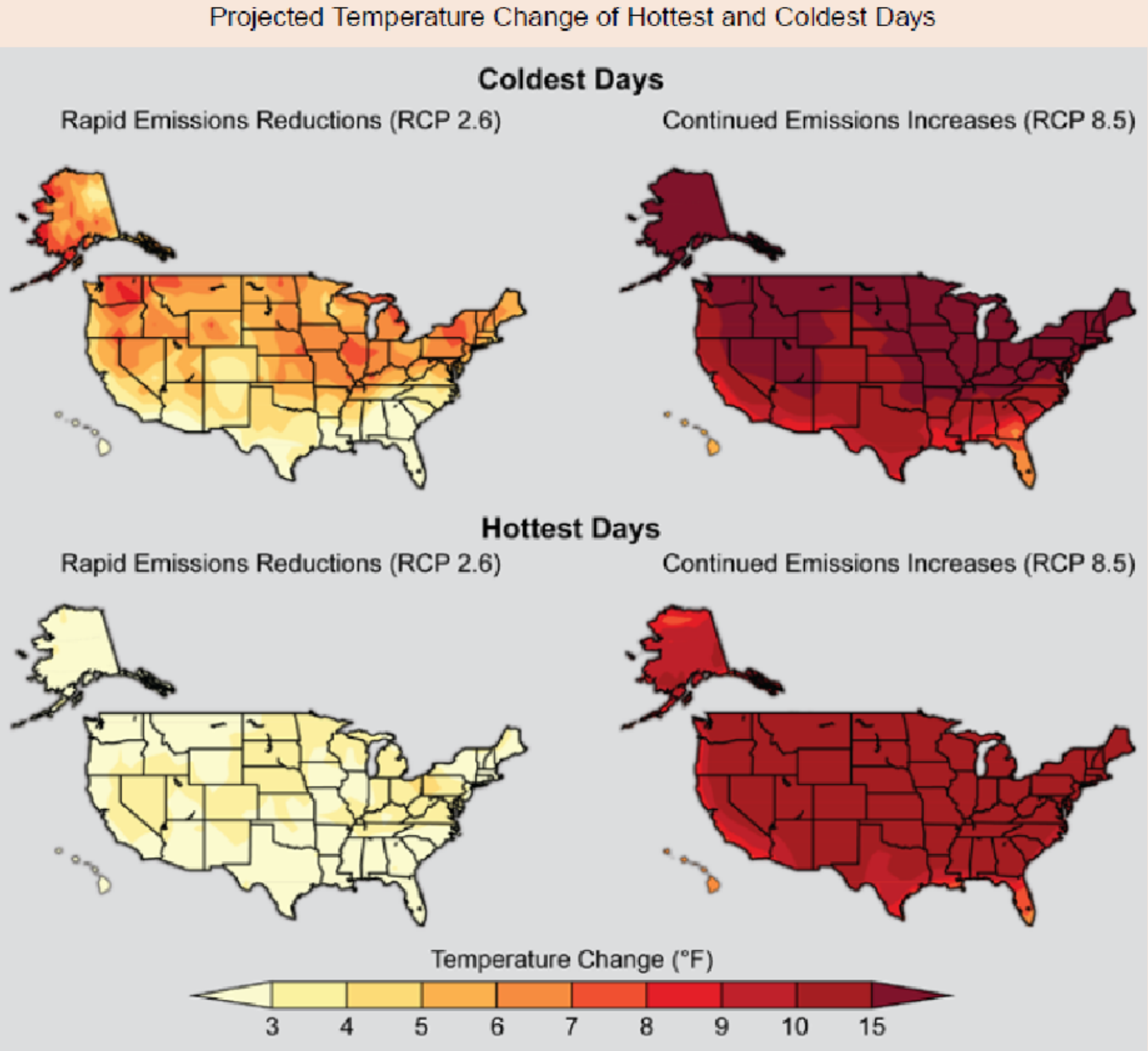

Figure 2.20. Change in surface air temperature at the end of this century (2081-2100) relative to the turn of the last century (1986-2005) on the coldest and hottest days under a scenario that assumes a rapid reduction in heat trapping gases (RCP 2.6) and a scenario that assumes continued increases in these gases (RCP 8.5). This figure shows estimated changes in the average temperature of the hottest and coldest days in each 20-year period. In other words, the hottest days will get even hotter, and the coldest days will be less cold. (Figure source: NOAA NCDC / CICS-NC).

Newer simulations for projected precipitation change (CMIP5 models)

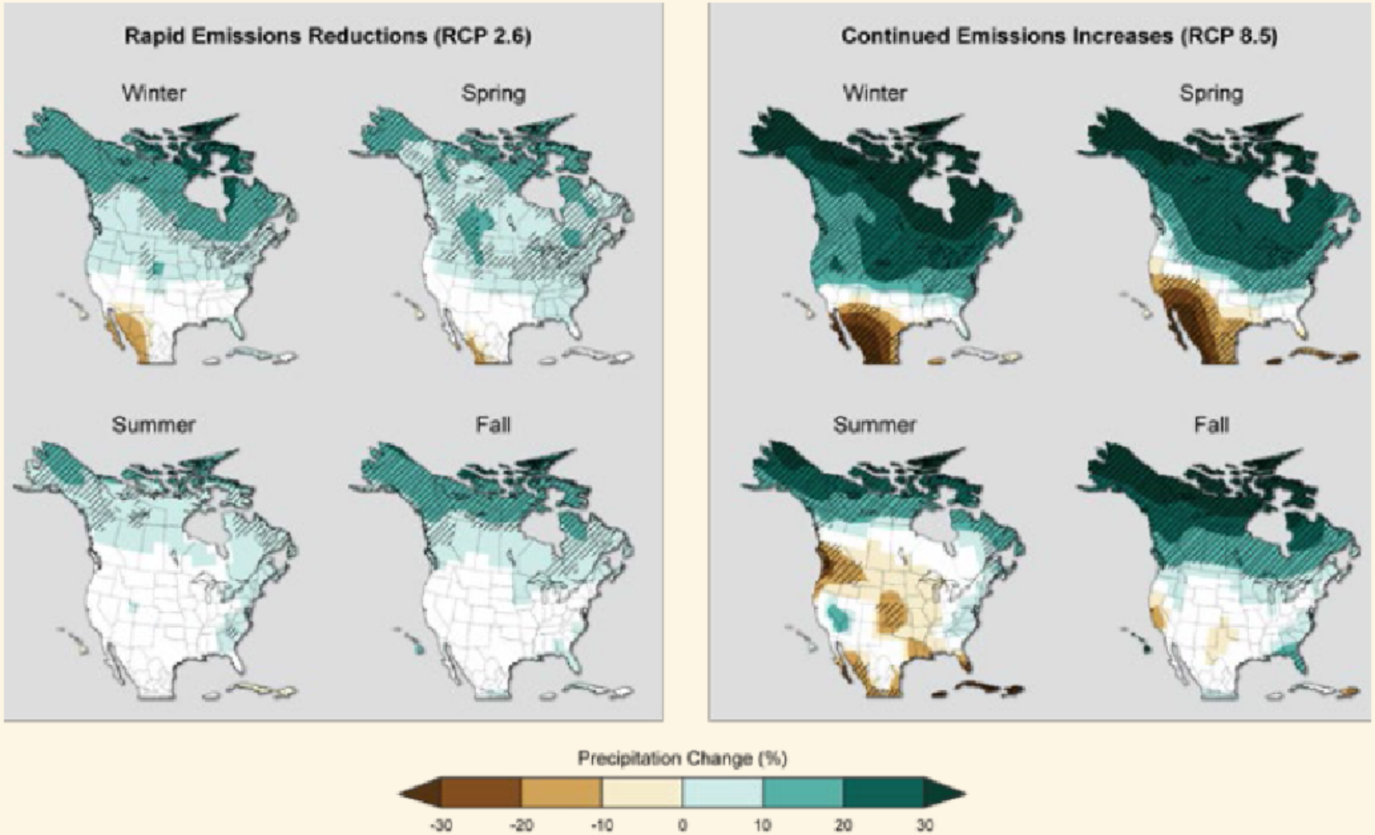

Figure 2.15. Seasonal precipitation change for 2071-2099 (compared to 1970-1999) as projected by recent simulations that include a wider range of scenarios. The maps on the left (RCP 2.6) assume rapid reductions in emissions – more than 70% cuts from current levels by 2050 – and a corresponding much smaller amount of warming and far less precipitation change. On the right, RCP 8.5 assumes continued increases in emissions, with associated large increases in warming and major precipitation changes. These would include, for example, large reductions in spring precipitation in the Southwest and large increases in the Northeast and Midwest. Rapid emissions reductions would be required for the more modest changes in the maps on the left. Hatched areas indicate that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. (Figure source: NOAA NCDC / CICS-NC).

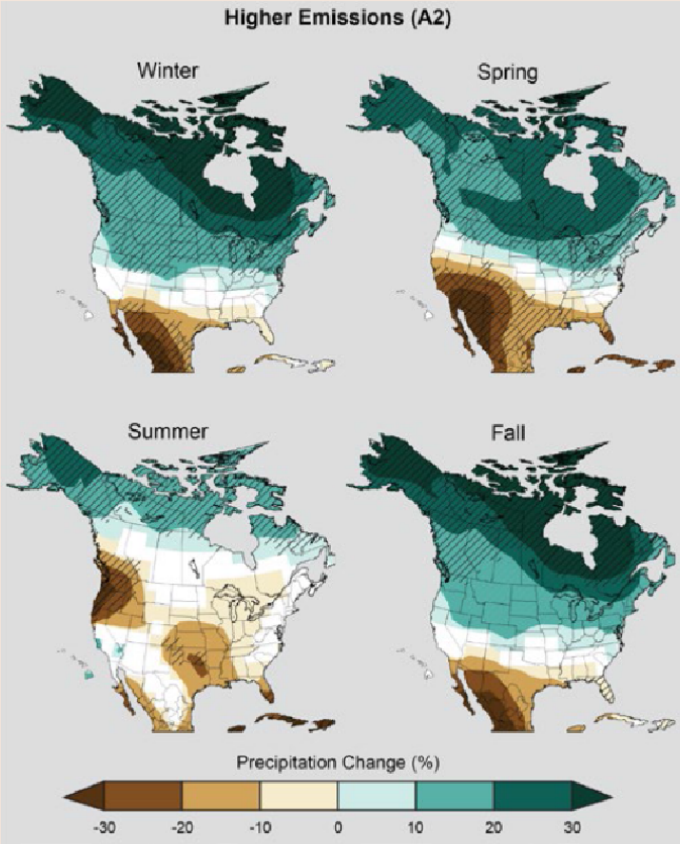

Figure 2.14. Projected change in seasonal precipitation for 2071-2099 (compared to 1970-1999) under an emissions scenario that assumes continued increases in emissions (A2). Hatched areas indicate that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. In general, the northern part of the U.S. is projected to see more winter and spring precipitation, while the southwestern U.S. is projected to experience less precipitation in the spring. (Figure source: NOAA NCDC / CICS-NC).

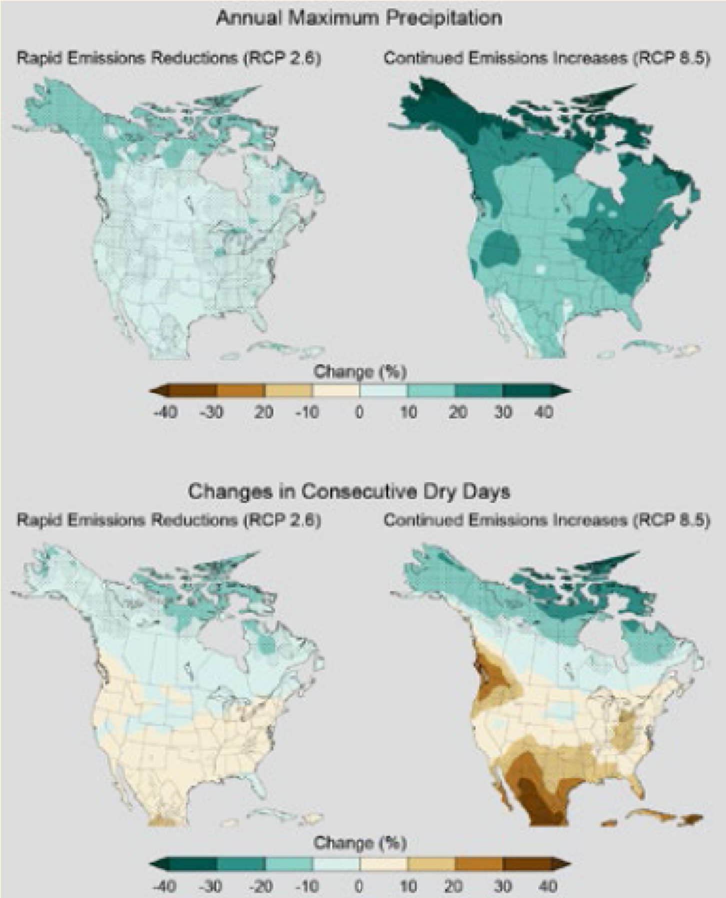

Figure 2.13. Top panels show simulated changes in the average amount of precipitation falling on the wettest day of the year for the period 2070-2099 as compared to 1971-2000 under a scenario that assumes rapid reductions in emissions (RCP 2.6) and one that assumes continued emissions increases (RCP 8.5). Bottom panels show simulated changes in the annual maximum number of consecutive dry days (days receiving less than 0.04 inches (1 mm) of precipitation) under the same two scenarios. Simulations are from CMIP5 models. Stippling indicates areas where changes are consistent among at least 80% of the models used in this analysis. (Figure source: NOAA NCDC / CICS-NC).

Projected Change in Heavy Precipitation Events

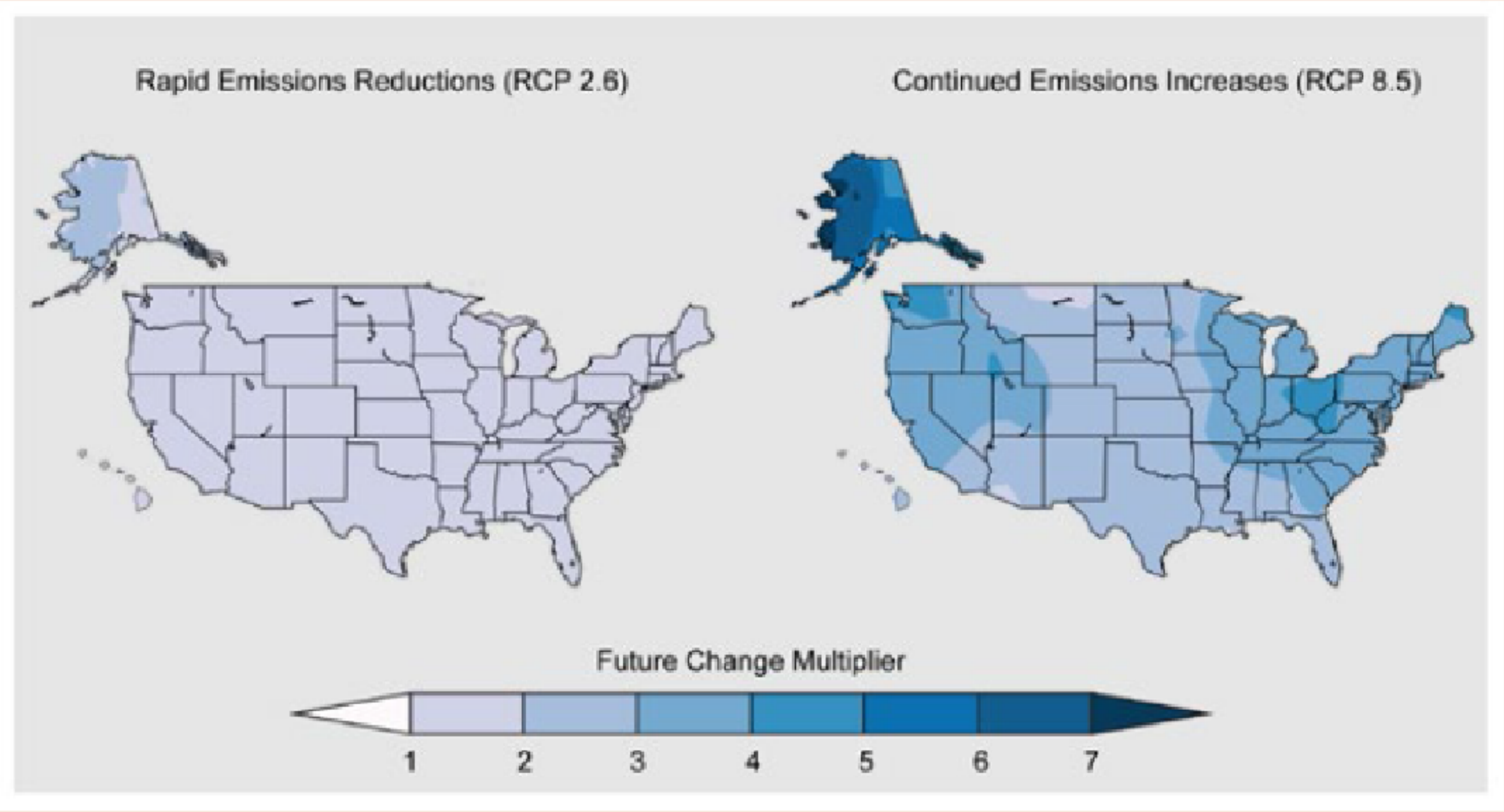

Figure 2.19. Maps show the increase in frequency of extreme daily precipitation events (a daily amount that now occurs once in 20 years) by the later part of this century (2081-2100) compared to the later part of last century (1981-2000). Such extreme events are projected to occur more frequently everywhere in the United States. Under the rapid emissions reduction scenario (RCP 2.6), these events would occur nearly twice as often. For the scenario assuming continued increases in emissions (RCP 8.5), these events would occur up to five times as often. (Figure source: NOAA NCDC / CICS-NC).

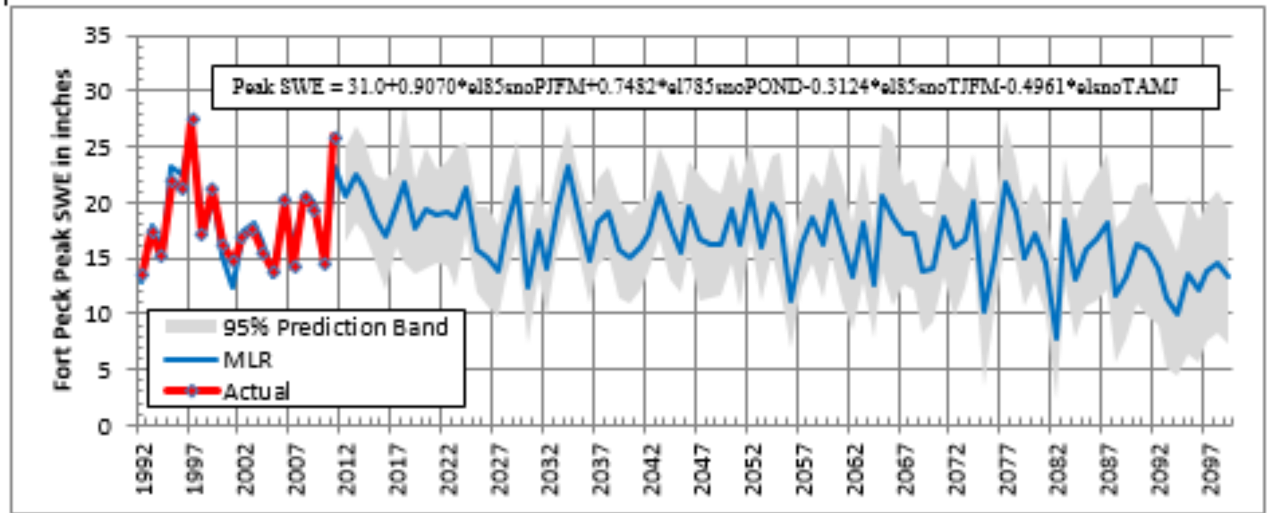

Figure 10. Projected Fort Peck Peak SWE.

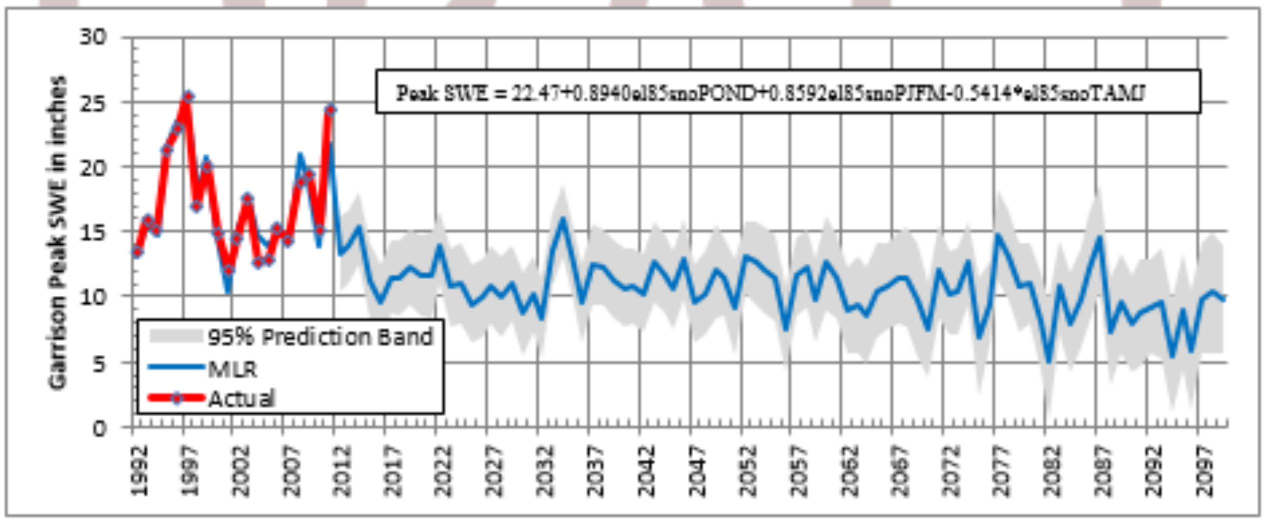

Figure 11. Projected Garrison Peak SWE.

4. Projected MJJ Runoff

Figures 12 and 13, as well as Table 13, show the projected MJJ runoff for Fort Peck and Garrison, respectively. Also refer to Table 15 for further discussion.

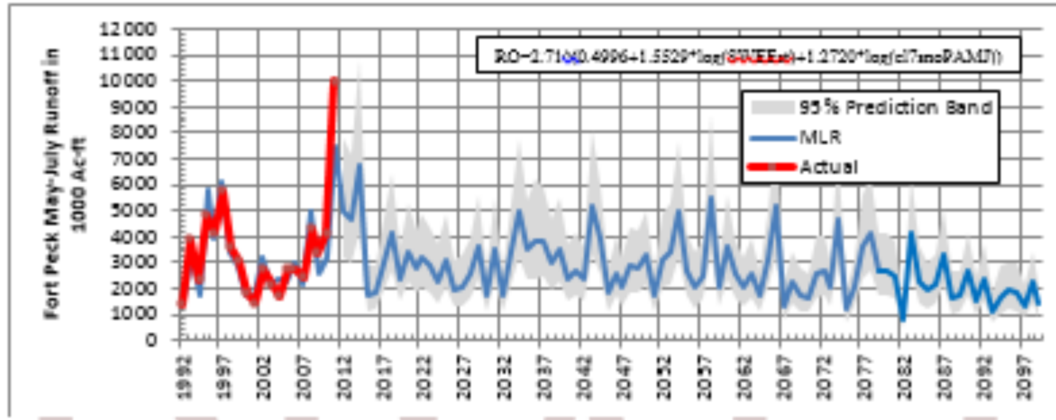

Figure 12. Fort Peck projected MJJ runoff.

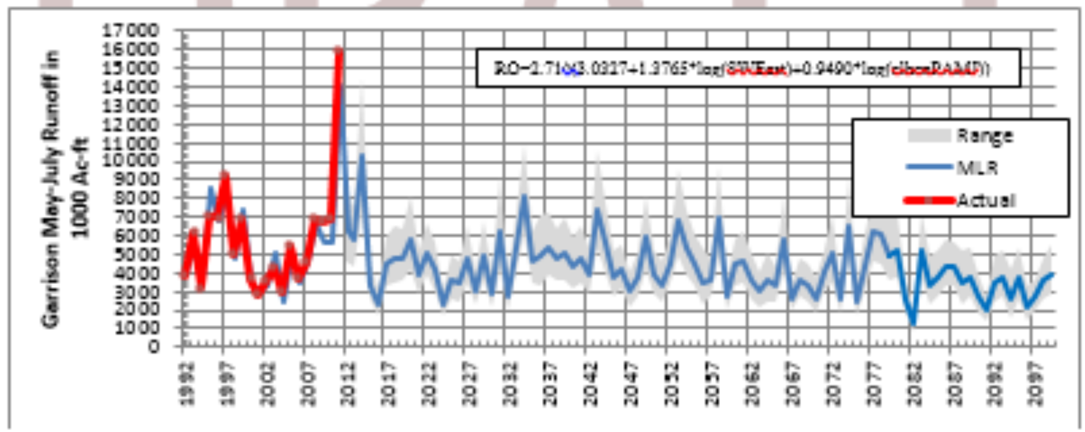

Figure 13. Garrison projected MJJ runoff.

Projected Changes in Soil Moisture for the Western U.S.

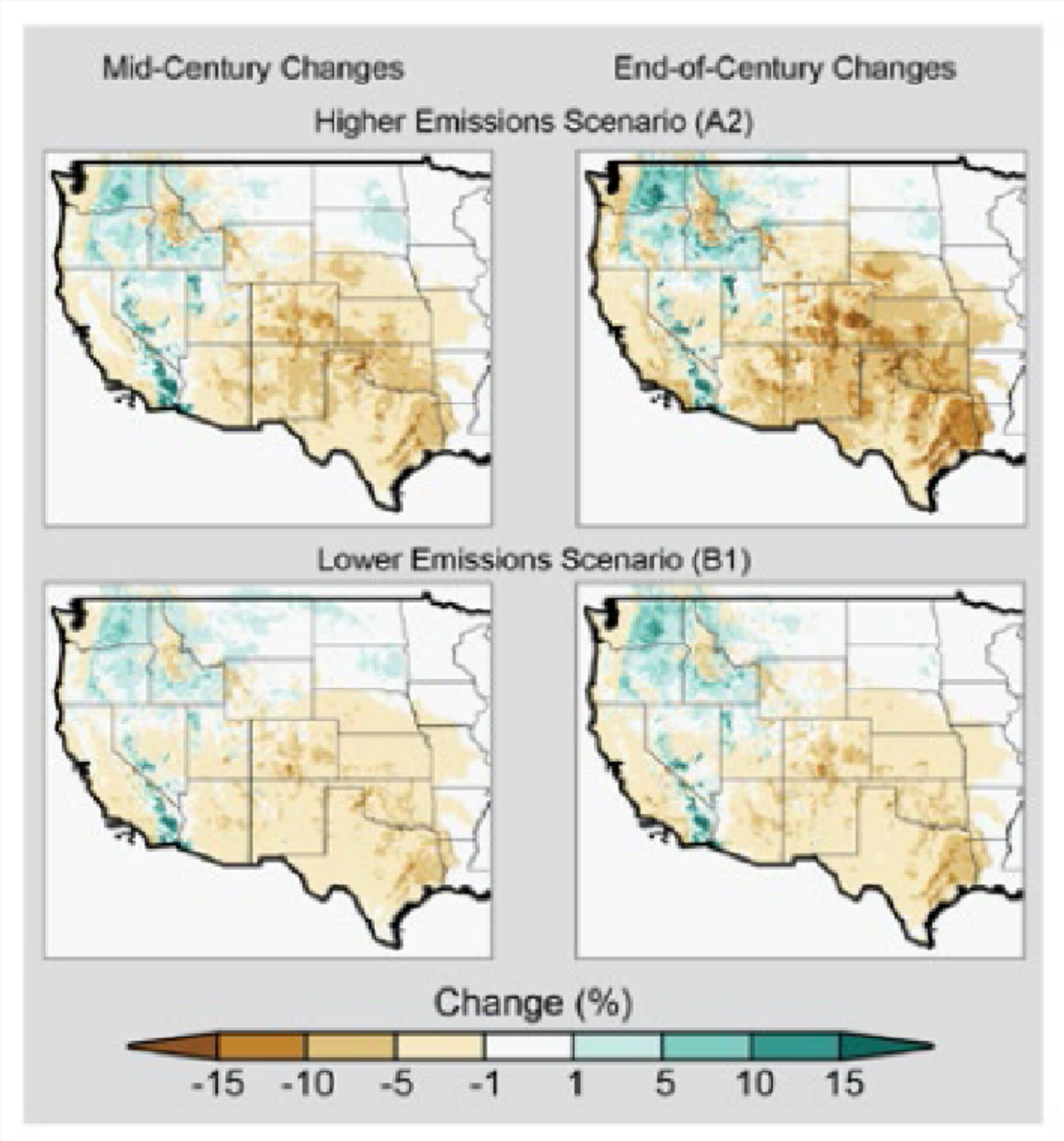

Figure 2.22. Average change in soil moisture compared to 1971-2000, as projected for the middle of this century (2041-2070) and late this century (2071-2100) under two emissions scenarios, a lower scenario (B1) and a higher scenario (A2).[75,77] The future drying of soils in most areas simulated by this sophisticated hydrologic model (Variable Infiltration Capacity or VIC model) is consistent with the future drought increases using the simpler Palmer Drought Severity Index (PDSI) metric. Only the western U.S. is displayed because model simulations were only run for this area. (Figure source: NOAA NCDC / CICS-NC).

Water Supplies Projected to Decline

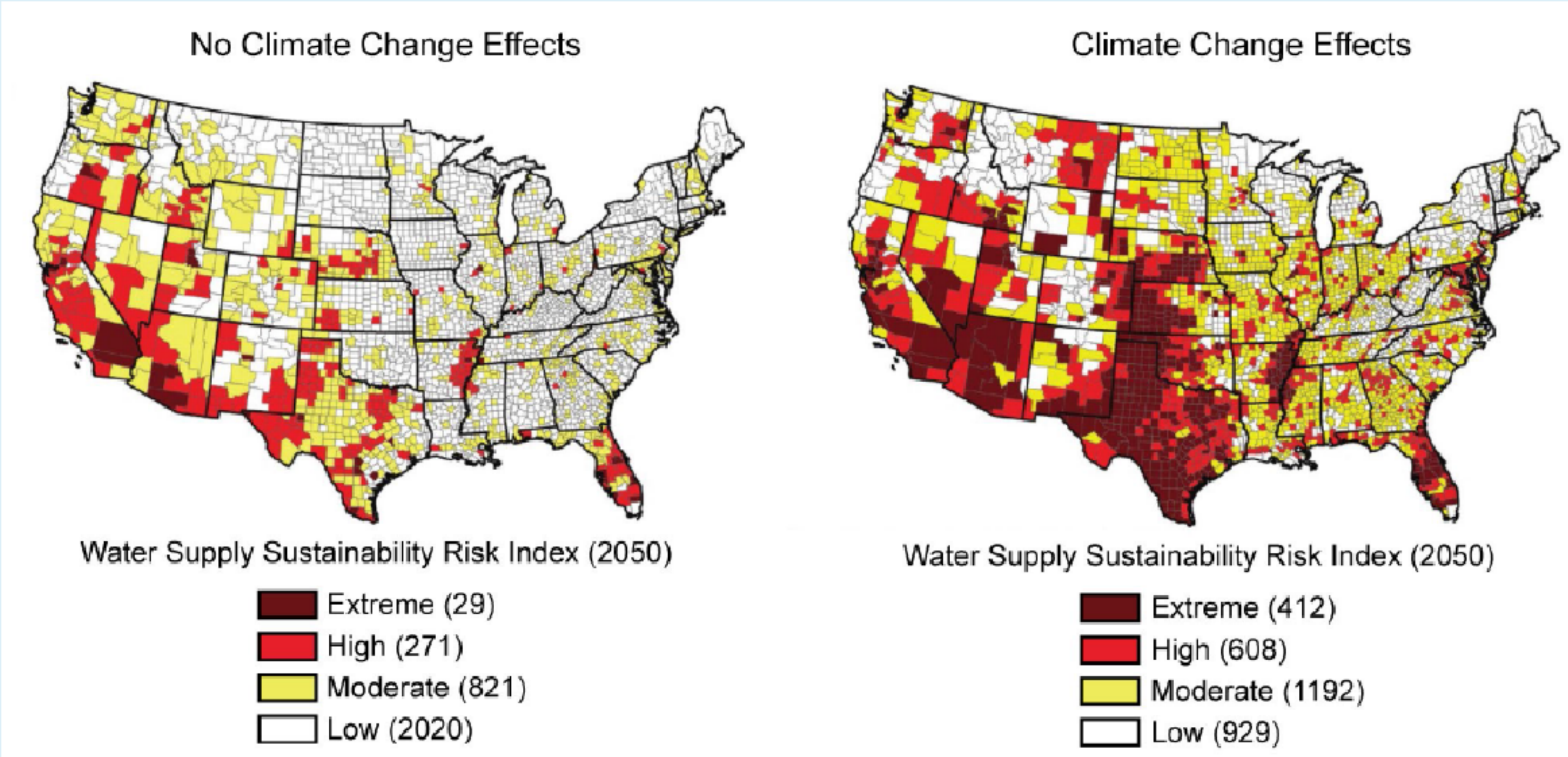

Figure 8.1. Climate change is projected to reduce the ability of ecosystems to supply water in some parts of the country. This is true in areas where precipitation is projected to decline, and even in some areas where precipitation is expected to increase. Compared to 10% of counties today, by 2050, 32% of counties will be at high or extreme risk of water shortages. Projections assume continued increases in greenhouse gas emissions through 2050 and a slow decline thereafter (A1B scenario). Numbers in parentheses indicate number of counties in each category. (Reprinted with permission from Roy et al., 2012.[27] Copyright 2012 American Chemical Society).

Streamflow Projections for River Basins in the Western U.S.

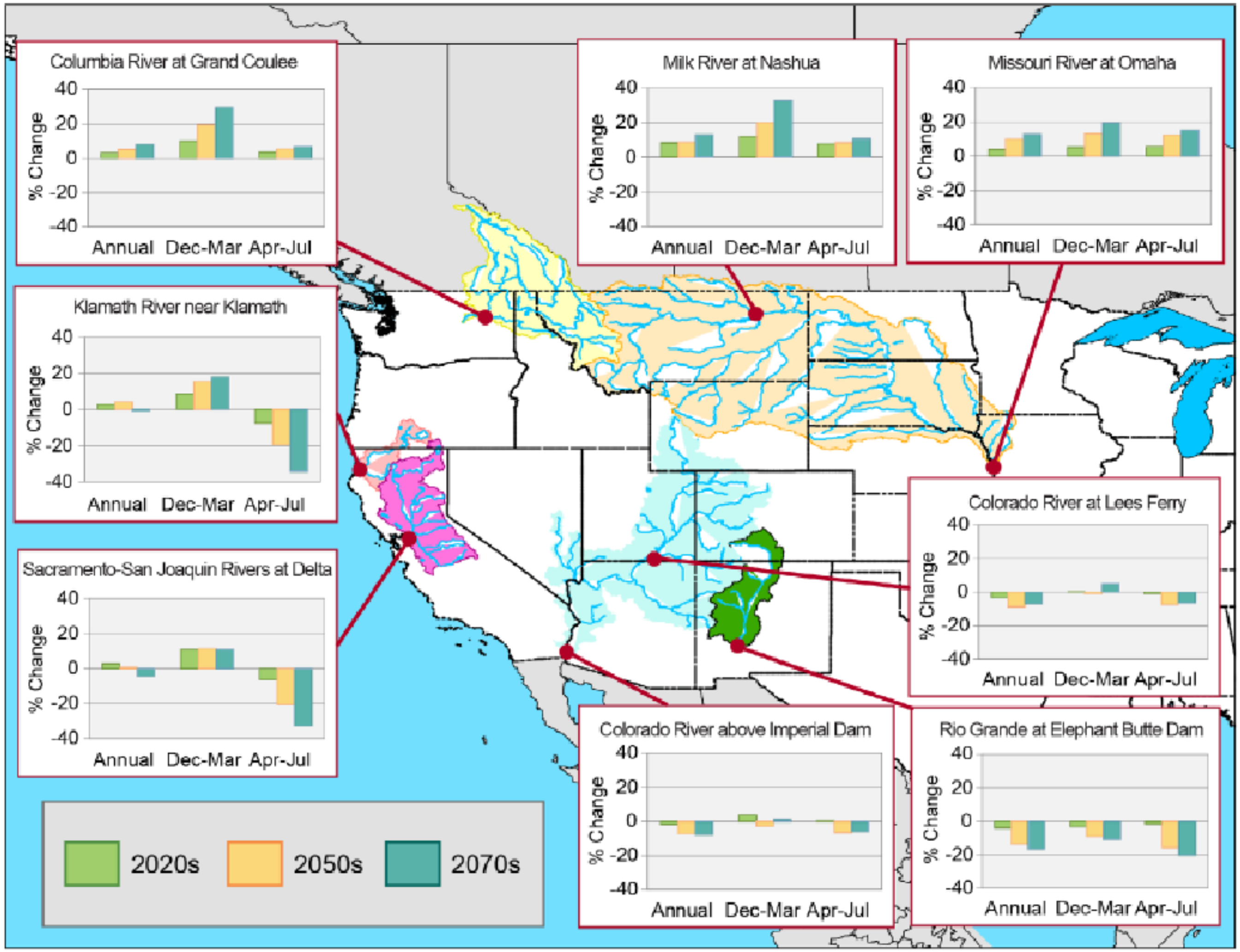

Figure 3.4. Annual and seasonal streamflow projections based on the B1 (with substantial emissions reductions), A1B (with gradual reductions from current emission trends beginning around mid-century), and A2 (with continuation of current rising emissions trends) CMIP3 scenarios for eight river basins in the western United States. The panels show percentage changes in average runoff, with projected increases above the zero line and decreases below. Projections are for annual, cool, and warm seasons, for three future decades (2020s, 2050s, and 2070s) relative to the 1990s. (Source: U.S. Department of the Interior – Bureau of Reclamation 2011;[41] Data provided by L. Brekke, S. Gangopadhyay, and T. Pruitt)

CHANGING EXTREMES

Missouri River Run-off

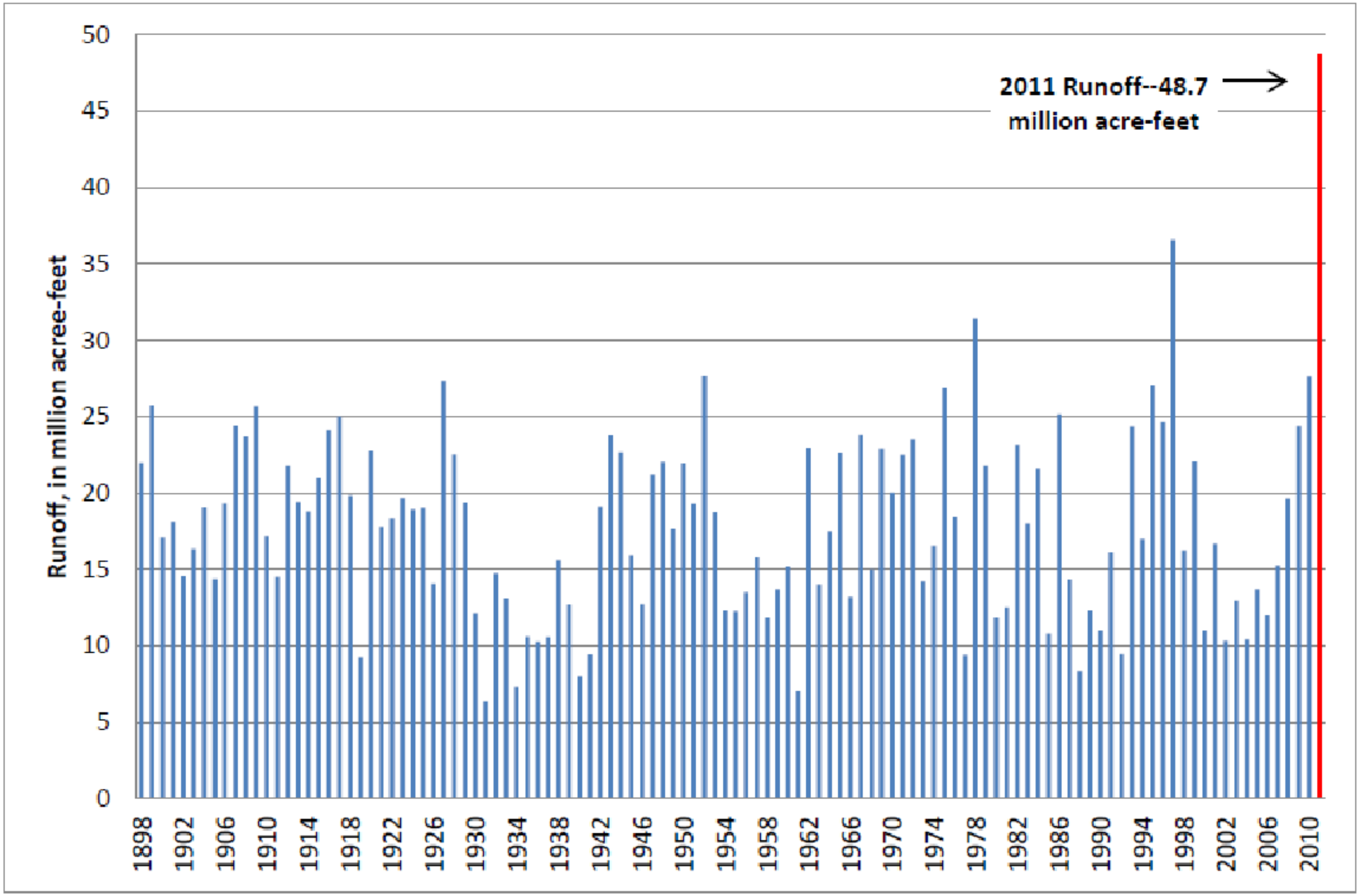

Figure 1. Annual March–July runoff, Missouri River basin, upstream of Sioux City, Iowa, 1898-2011

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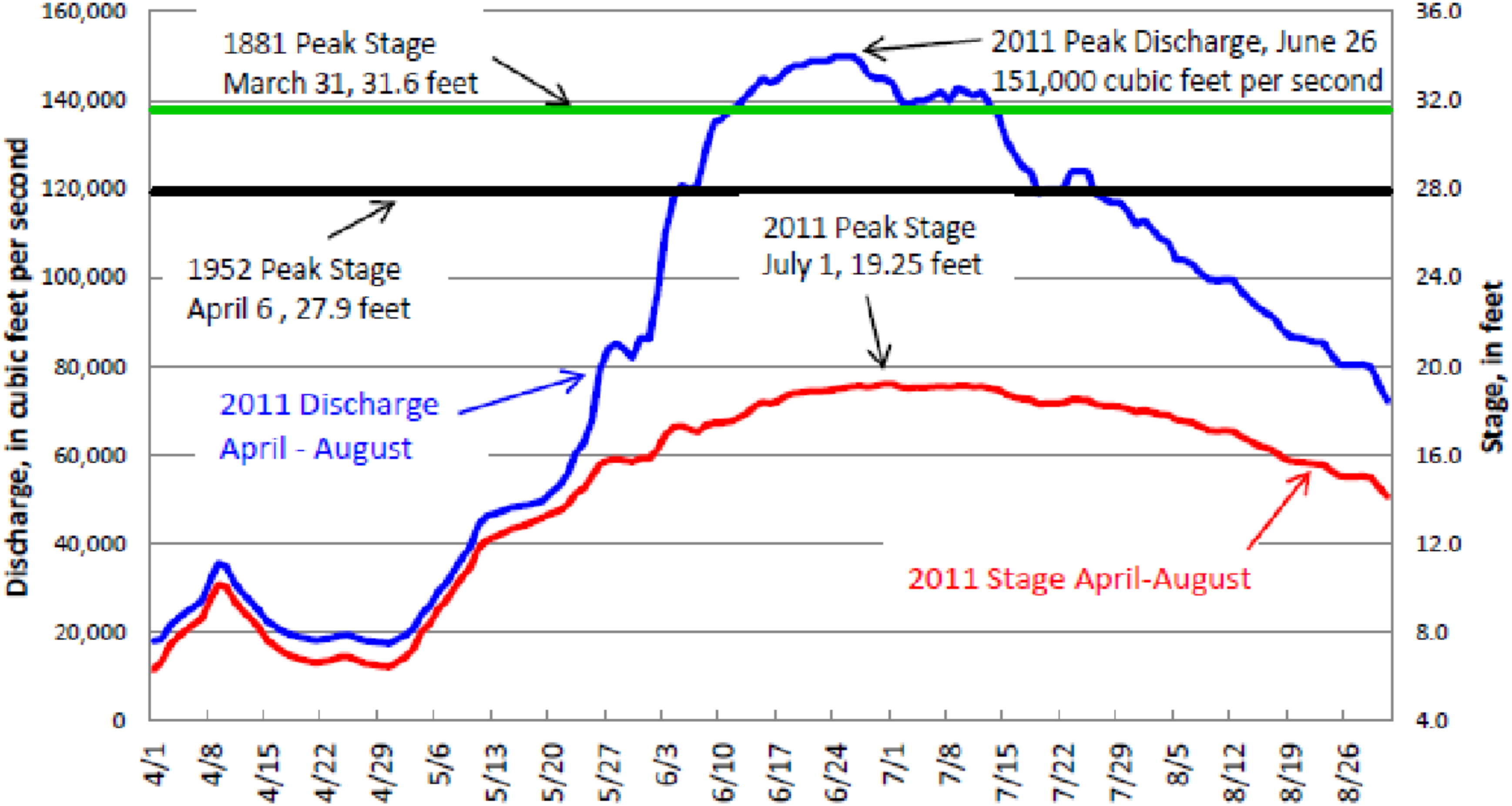


Figure 4. Discharge and stage at Missouri River at Bismarck, North Dakota, April–August, 2011, compared with previous historic stages

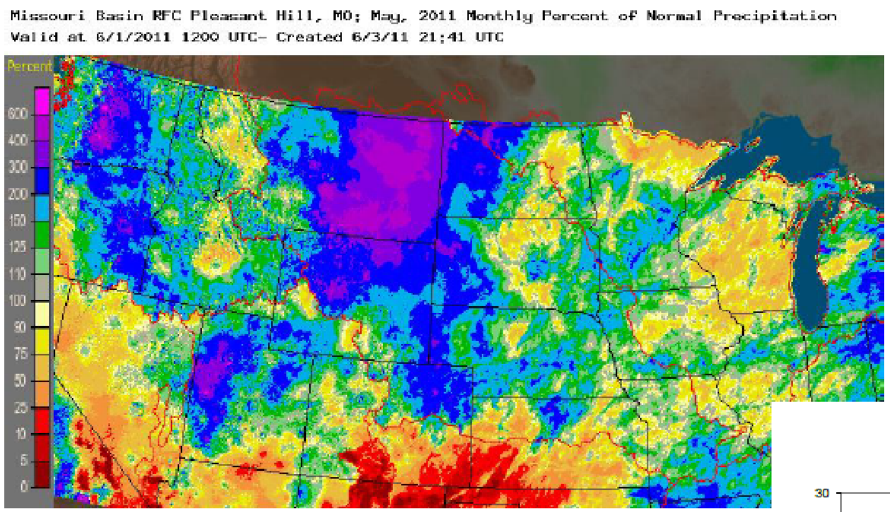


Figure 17. May 2011 percent of normal precipitation

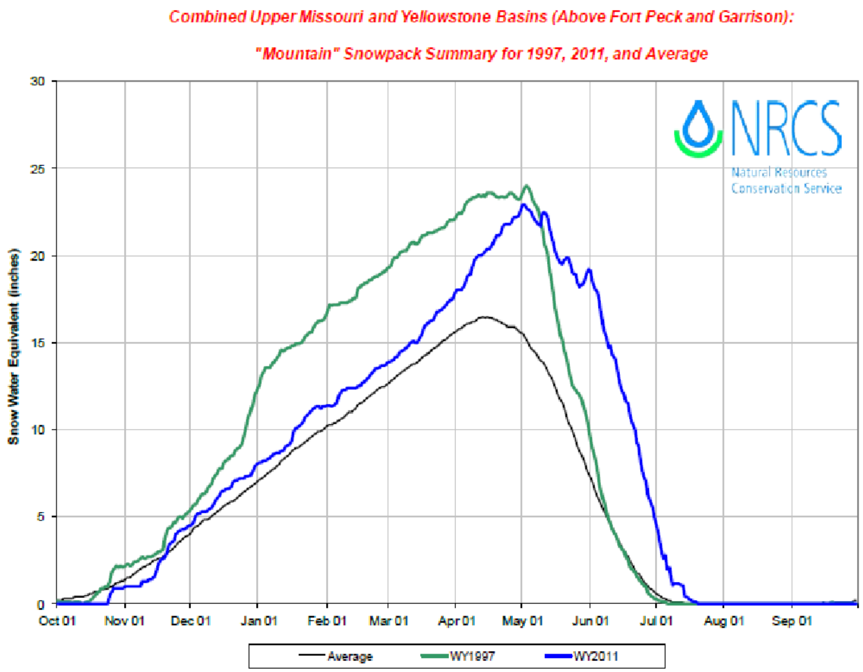
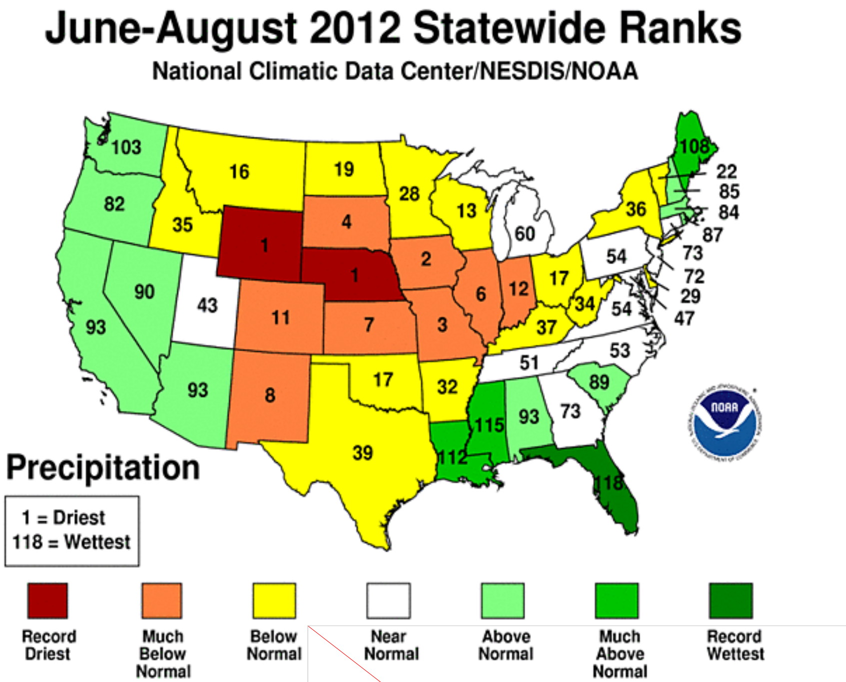
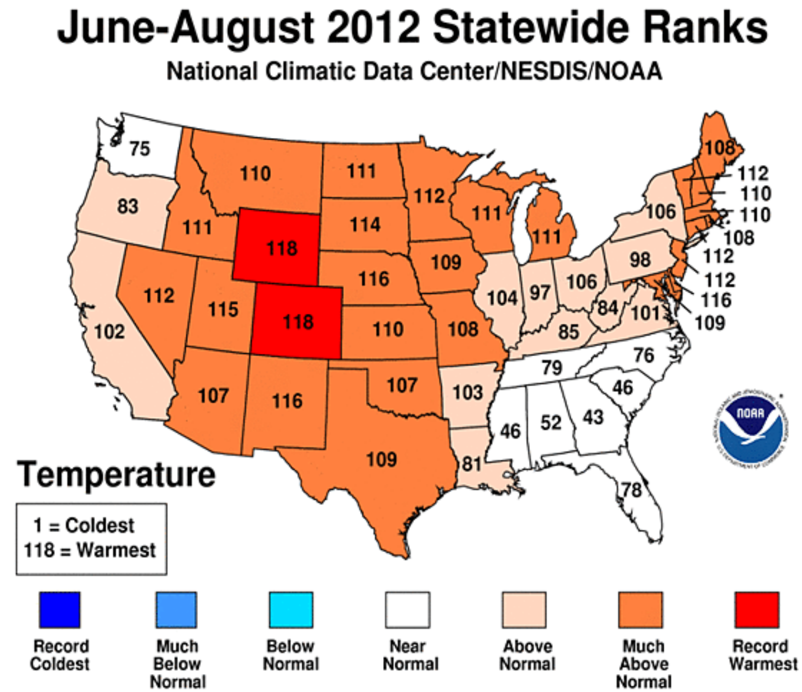


Figure 24. Mountain Snowpack Summary for Upper Missouri River and Yellowstone River Basins, 1997, 2011, and Average Year.

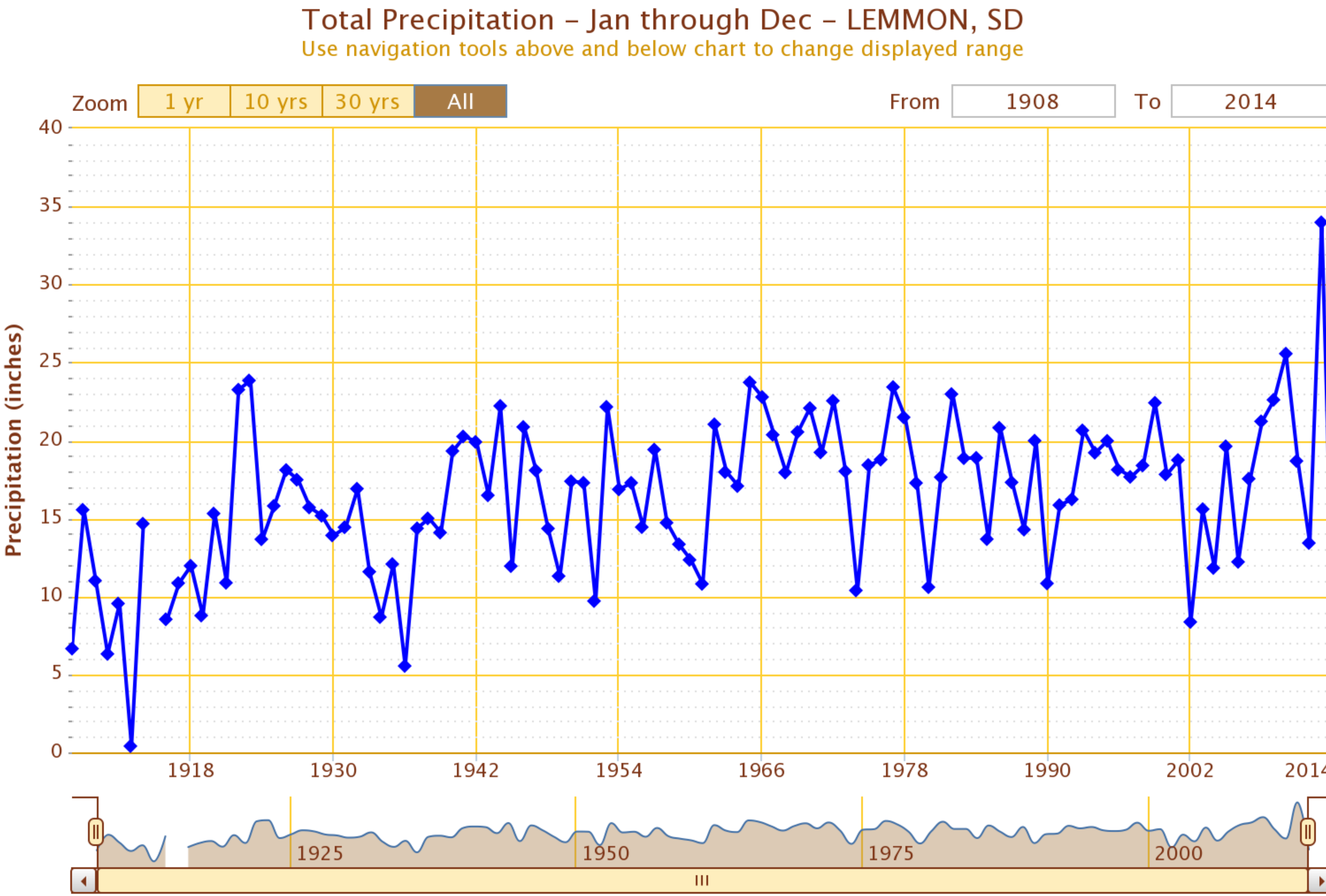

June-August 2012 Statewide Ranks
National Climatic Data Center/NESDIS/NOAA
Precipitation
1 = Driest
118 = Wettest
Record Driest
Much Below Normal
Below Normal
Near Normal
Above Normal
Much Above Normal
Record Wettest


June-August 2012 Statewide Ranks
National Climatic Data Center/NESDIS/NOAA
Temperature
1 = Coldest
118 = Warmest
Record Coldest
Much Below Normal
Below Normal
Near Normal
Above Normal
Much Above Normal
Record Warmest

Bigger extremes

- Lemmon/Lead 2013 (near 50”)
- Canton/Sioux Falls 2014 (June 19.75”)
- Brookings 2010

- Breaking records by large amounts



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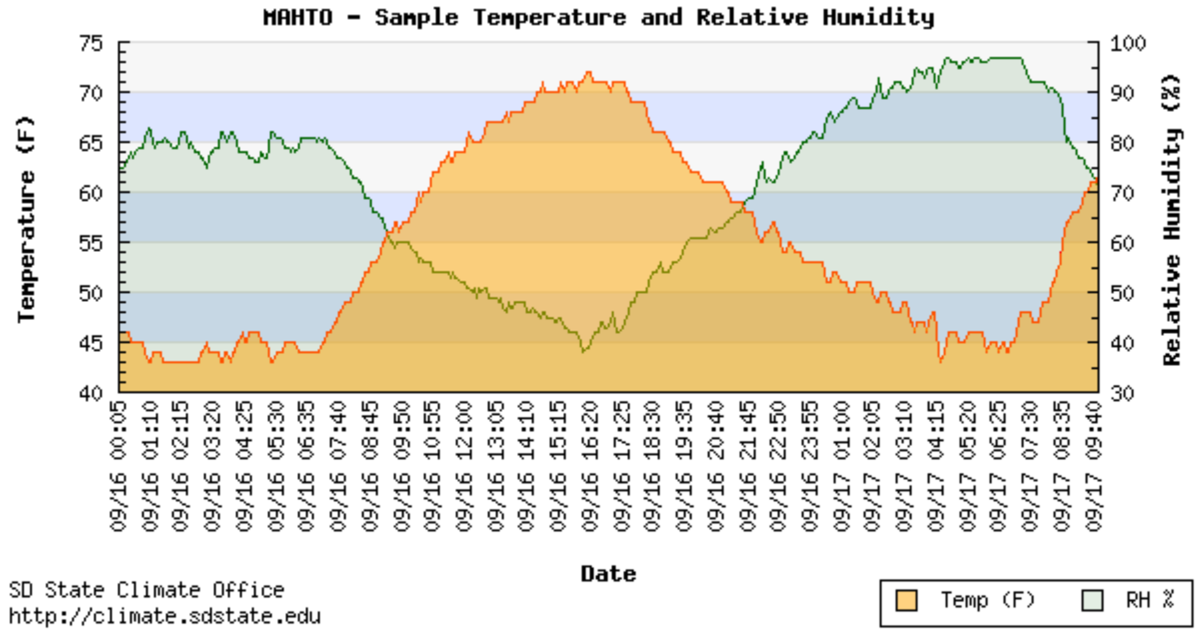
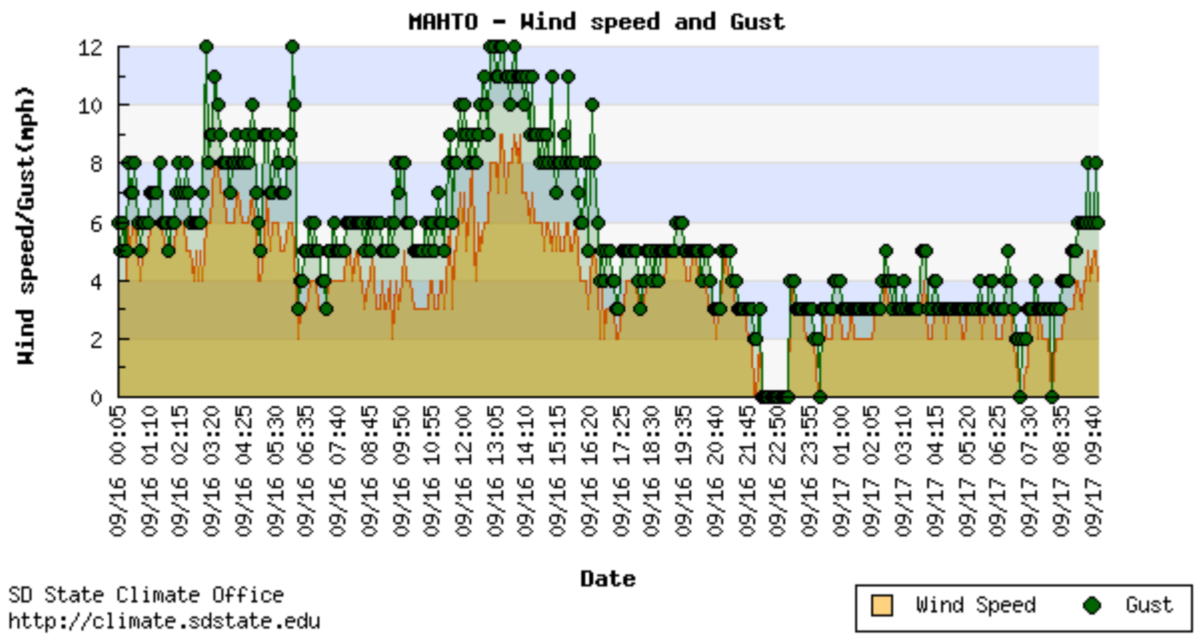
Summary

- Large number of variables in the climate of the plains
- Variability issues – continue/worsen
- Overall warming should continue (trend)
- Precipitation increasing – w/large variabilities
- Shifting seasons

Summary - 2

- SD-specific
  - Reworking state drought plan – opportunity for interaction – drought planning
  - Monitoring in the state http://climate.sdstate.edu
  - Climate education opportunities
  - SDSU Extension connections





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Questions?

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– South Dakota State Climatologist
– dennis.todey@sdstate.edu
– 605-688-5678
– http://climate.sdstate.edu
– Facebook: SDSUclimate
– Blog: http://www.sustainablecorn.org/blog/

Temperatures are Rising in the Midwest

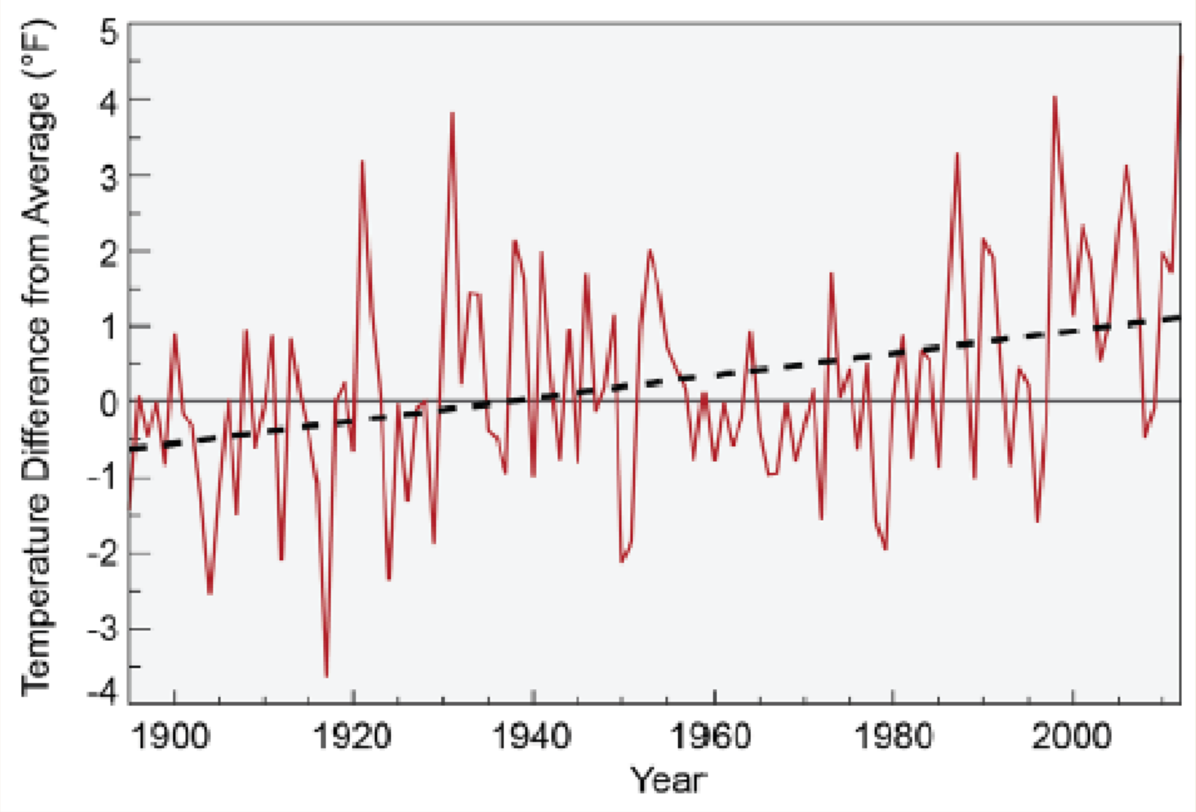


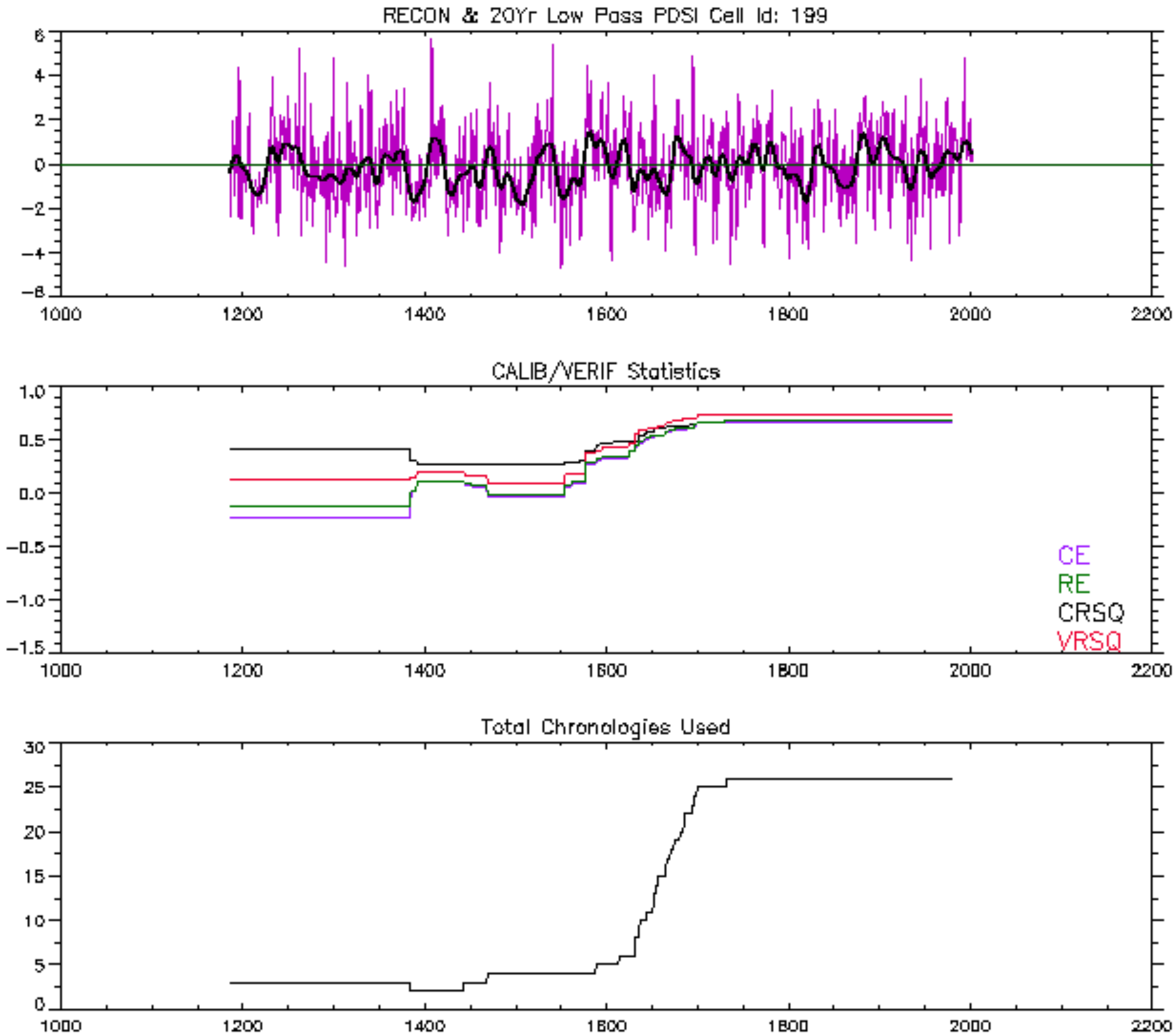
Figure 18.1. Annual average temperatures (red line) across the Midwest show a trend towards increasing temperature. The trend (dashed line) calculated over the period 1895-2012 is equal to an increase of 1.5°F. (Figure source: updated from Kunkel et al. 2013[4]).

Records of wetness

- Instrumented – best
- Proxies – longer, but not as accurate
  - Tree rings
  - Lake cores (salinity)

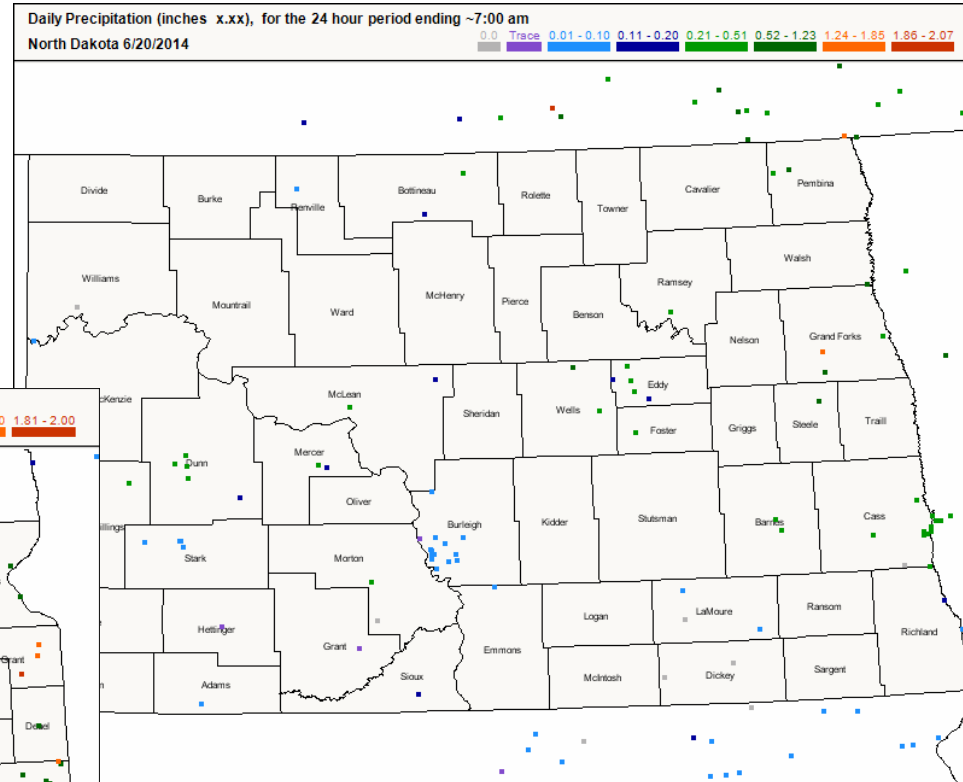
Tree ring reconstructions

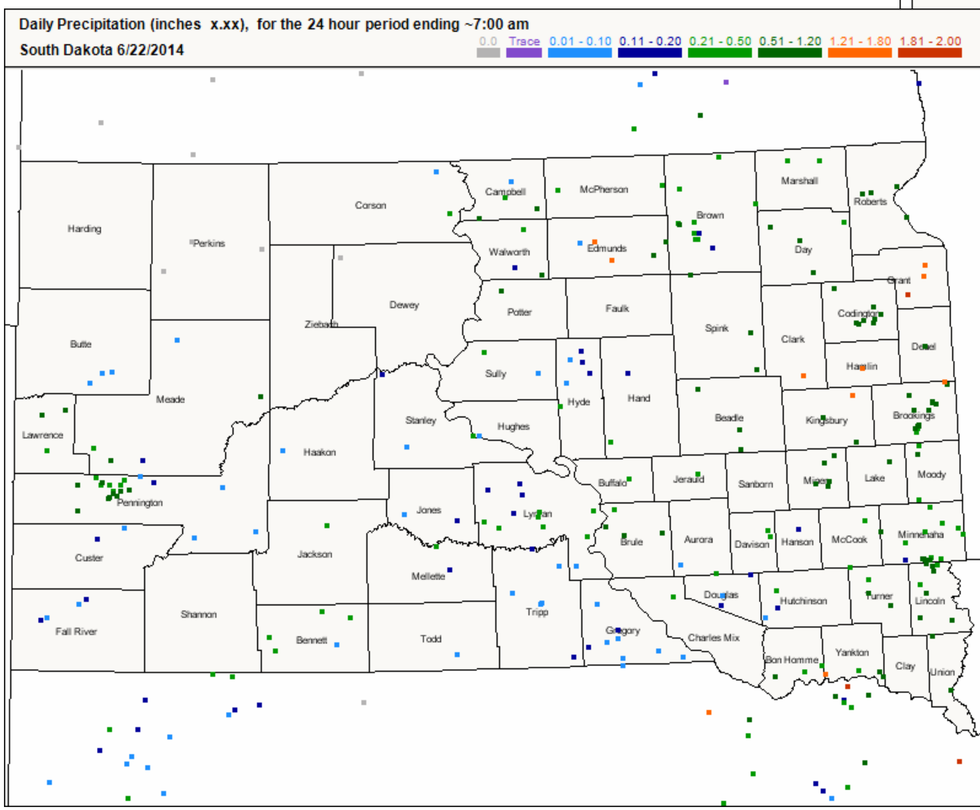
Northeast Iowa



http://www.ncdc.noaa.gov/paleo/newpdsi.html

Cocorahs





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http://www.cocorahs.org

CoCoRaHS

- Volunteer precipitation monitoring
- Local information
- Plotted immediately
- Validation of local conditions

- Used by, state climatologists, NWS, various other….

CoCoRaHS

- 4 inch diameter rain gauge
- Sign up on-line

- Always looking for people
- http://www.cocorahs.org

- Help yourselves and us…..