Regional Climate Change Projections - Potential Impacts to Nuclear Facilities

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The Midwest region

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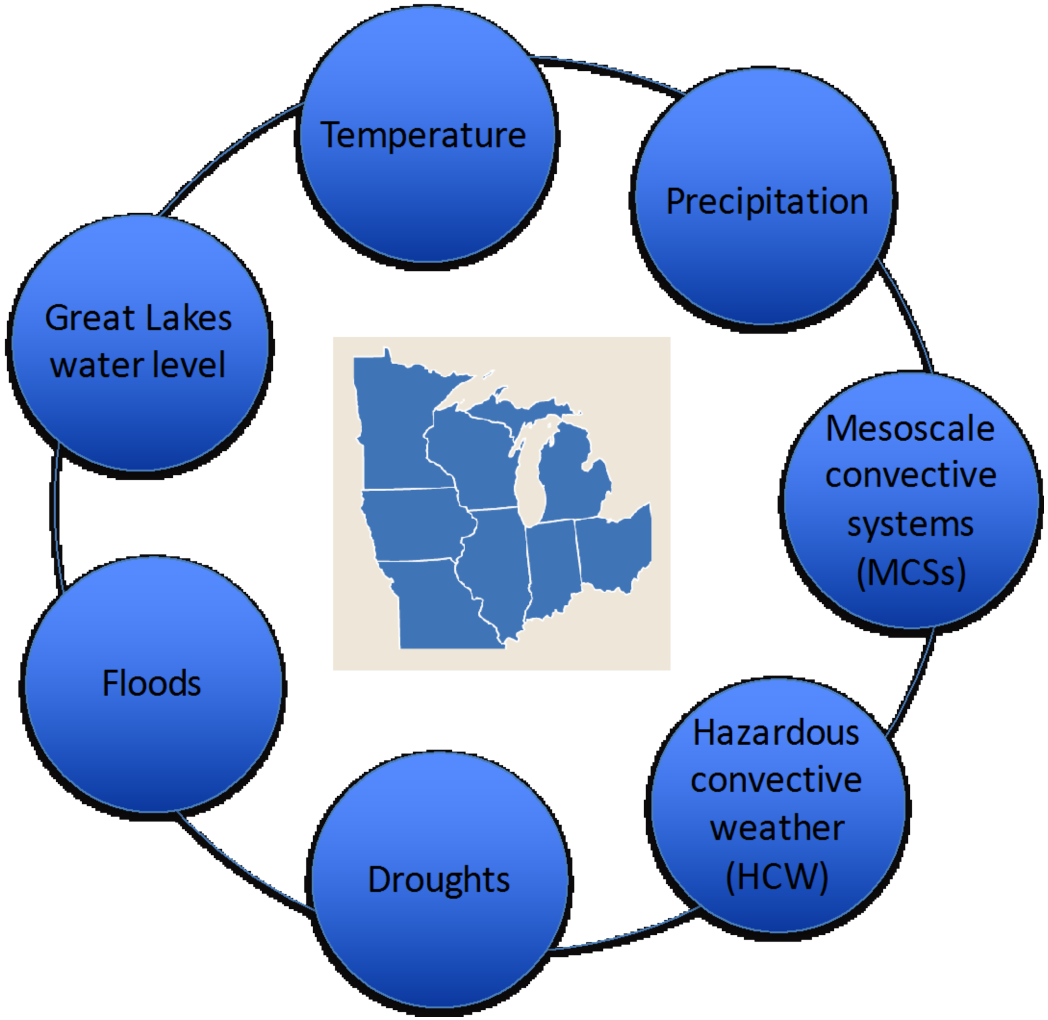
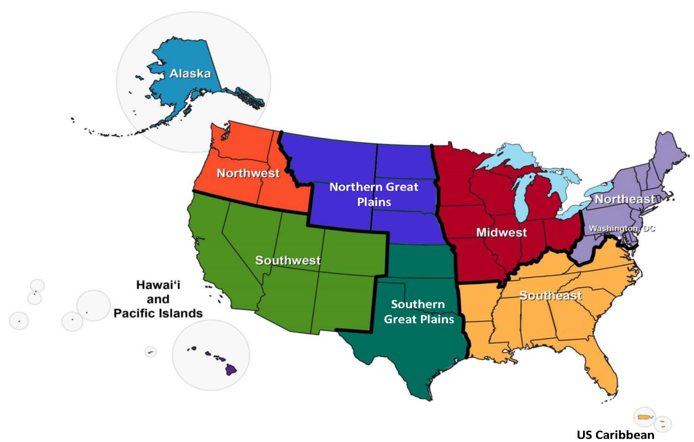
- **Midwest Region in NCA3 and NCA4**: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin
- All states in the Midwest Region except for Indiana, have operating nuclear power plants

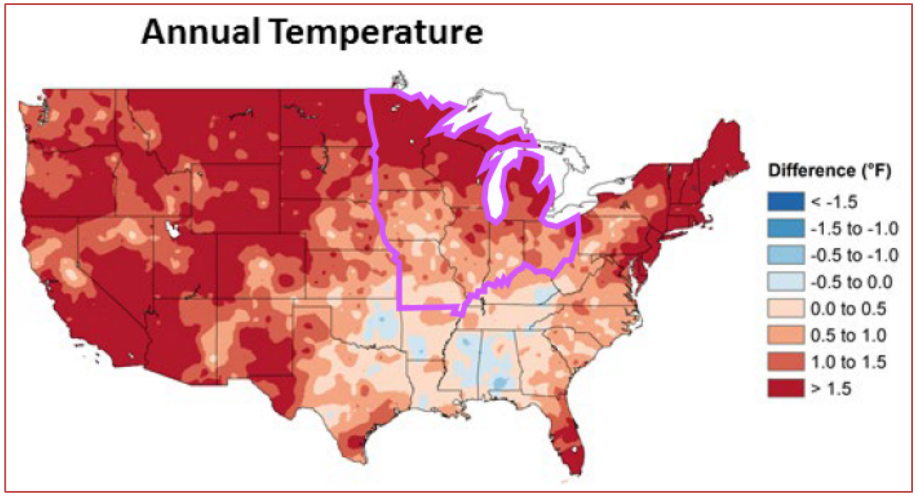




NCA4 regions

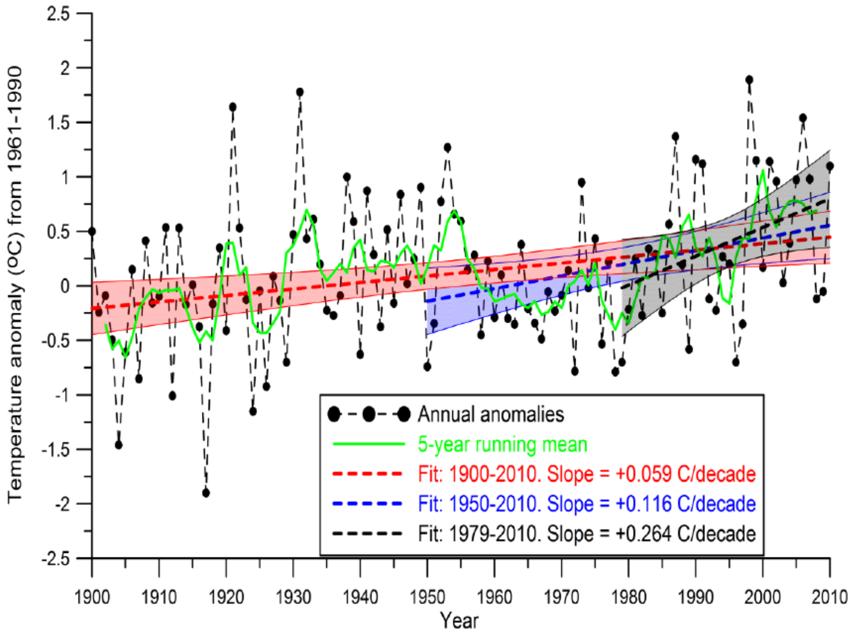
Observed temperature trends in the Midwest

Observed changes between (1986 to 2015) and (1901 to 1960)



(Voss et al. 2017)

Larger rates of warming in more recent decades



(Kunkel et al. 2013)

Future changes in heat waves

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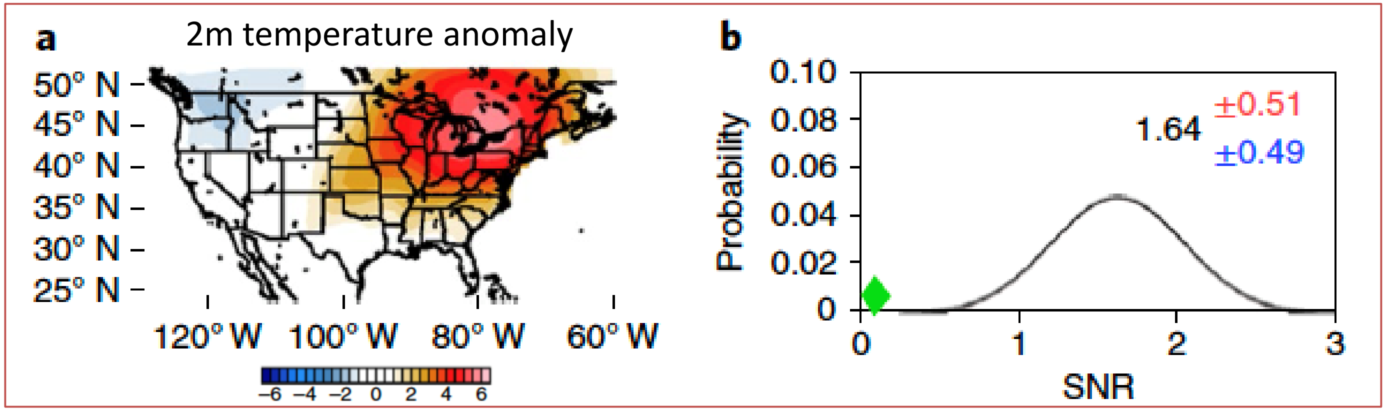
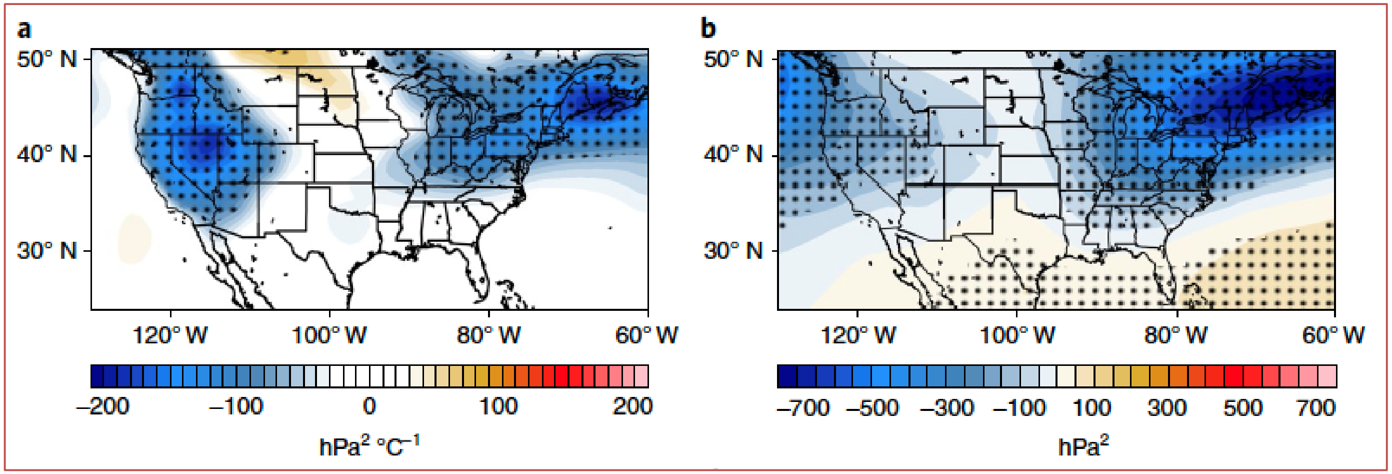
Historically the Great Lakes region is a heat wave cluster, which is projected to strengthen in the future (Lopez et al. 2018)



Projected weakening of storm tracks contribute to increase in heat waves in the Great Lakes region

Relationship between storm activities and 2m T

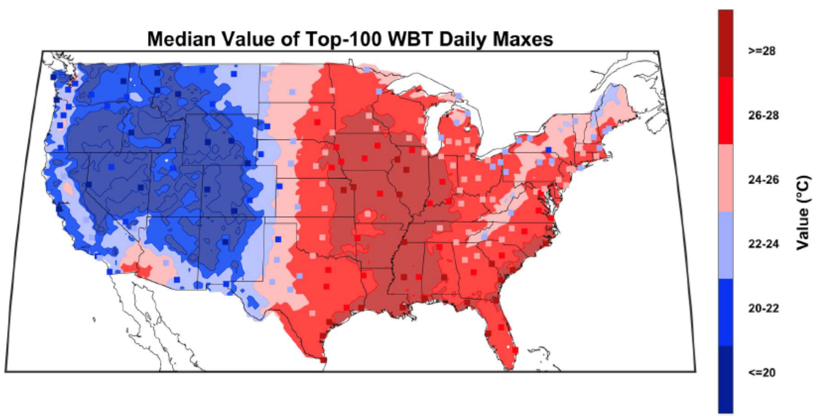
Projected changes in storm activities

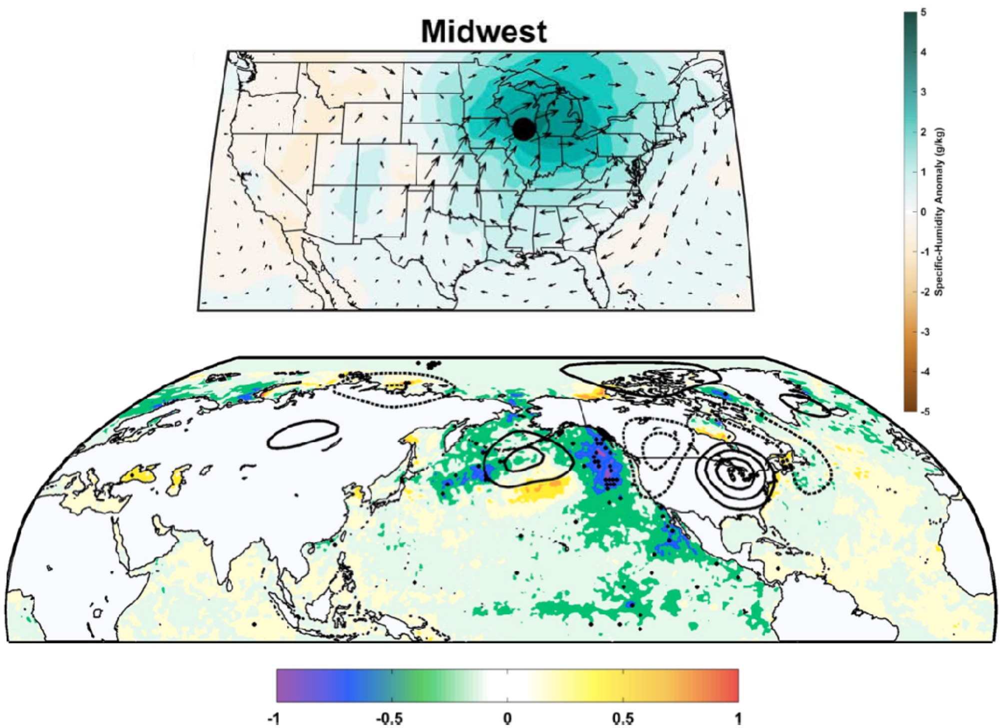


Wet bulb temperature

- Humidity anomalies have larger influence on extreme WBT than temperature anomalies
- For the Midwest, extreme WBT is associated with westward expansion of Bermuda high and enhanced southerly moisture transport at the low level and wave train with an upper level ridge

Top-100 WBT daily maximums in the Midwest are between 26°C and 30°C

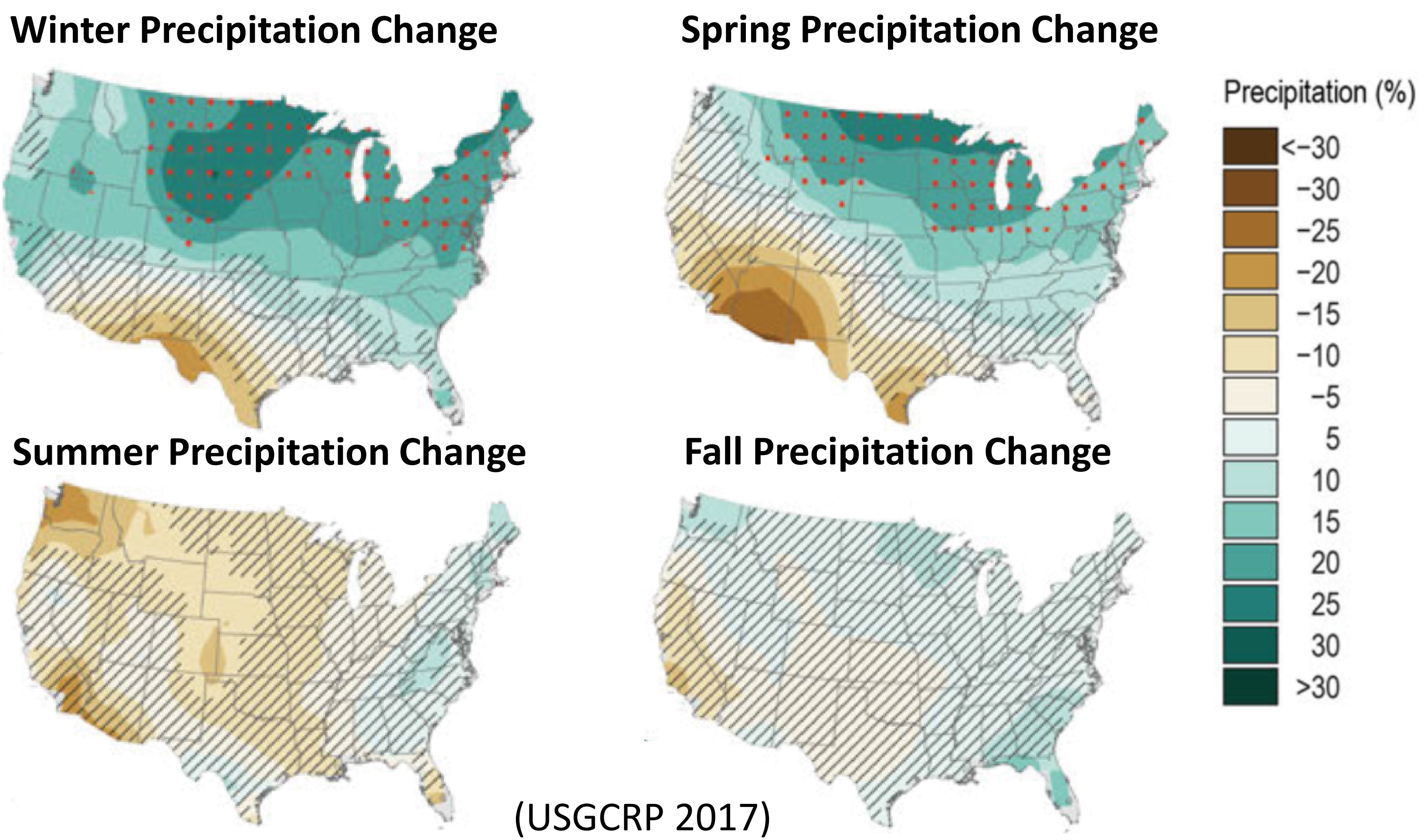




(Raymond et al. 2017)

Seasonal precipitation changes

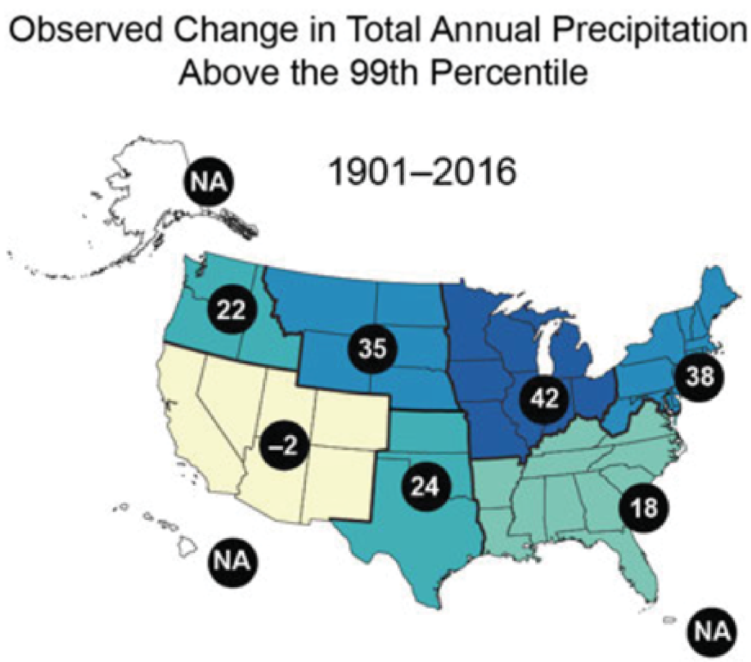
- Annual precipitation in the Midwest has increased by 5% to 15%from 1901–1960 compared to 1986–2015
- Increase in cold season precipitation due to poleward shift of storm tracks

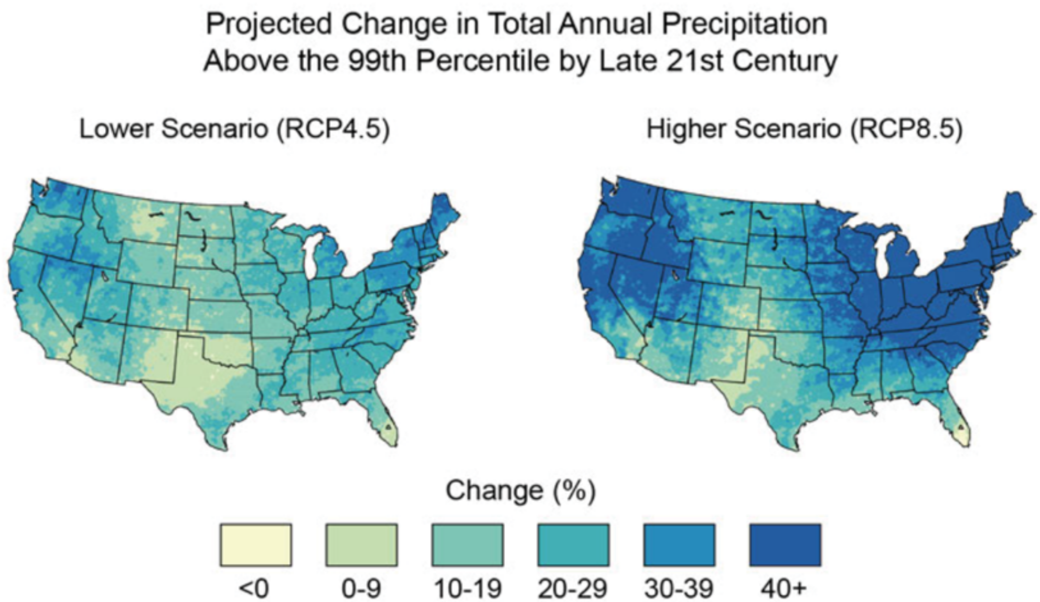


(USGCRP 2017)

Changes in extreme precipitation

- Observed changes are largest over the Midwest
- Projected changes are largest over the Midwest and western U.S.





(USGCRP 2017)

Projected changes in precipitation

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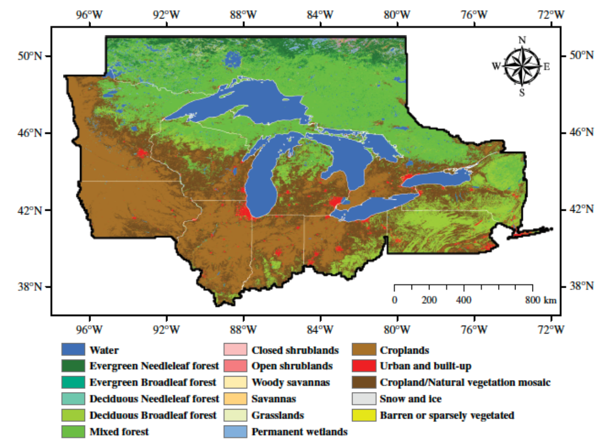
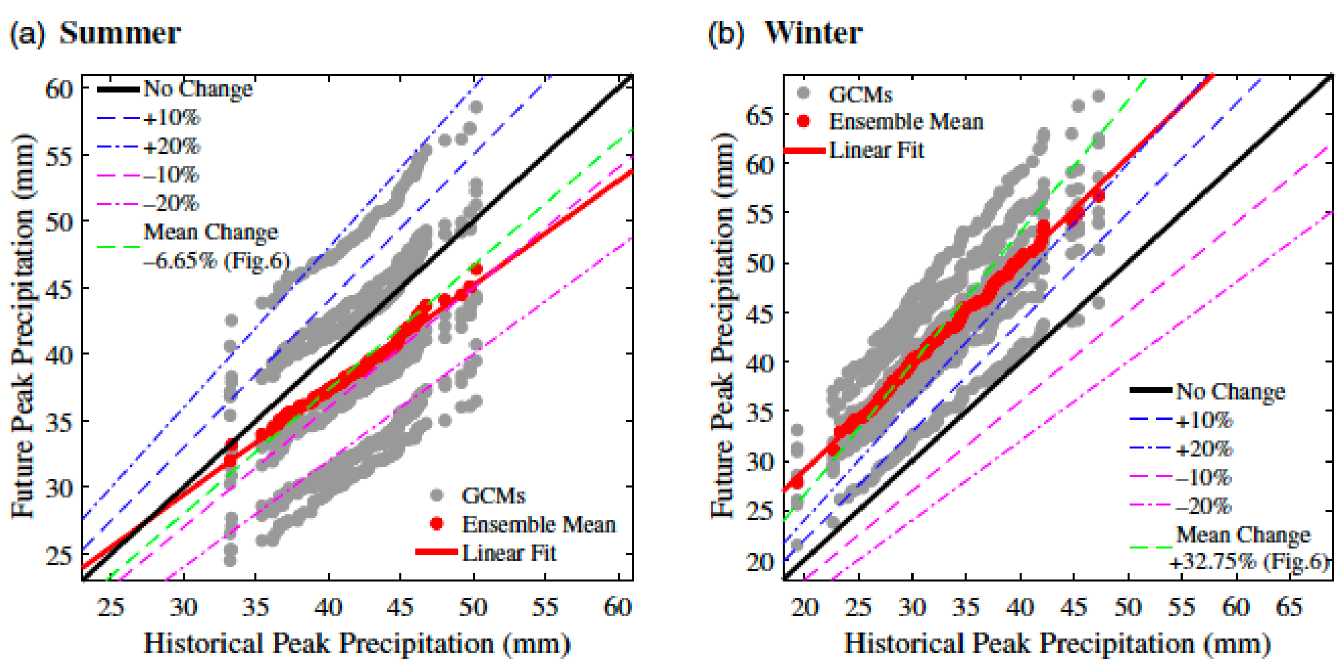
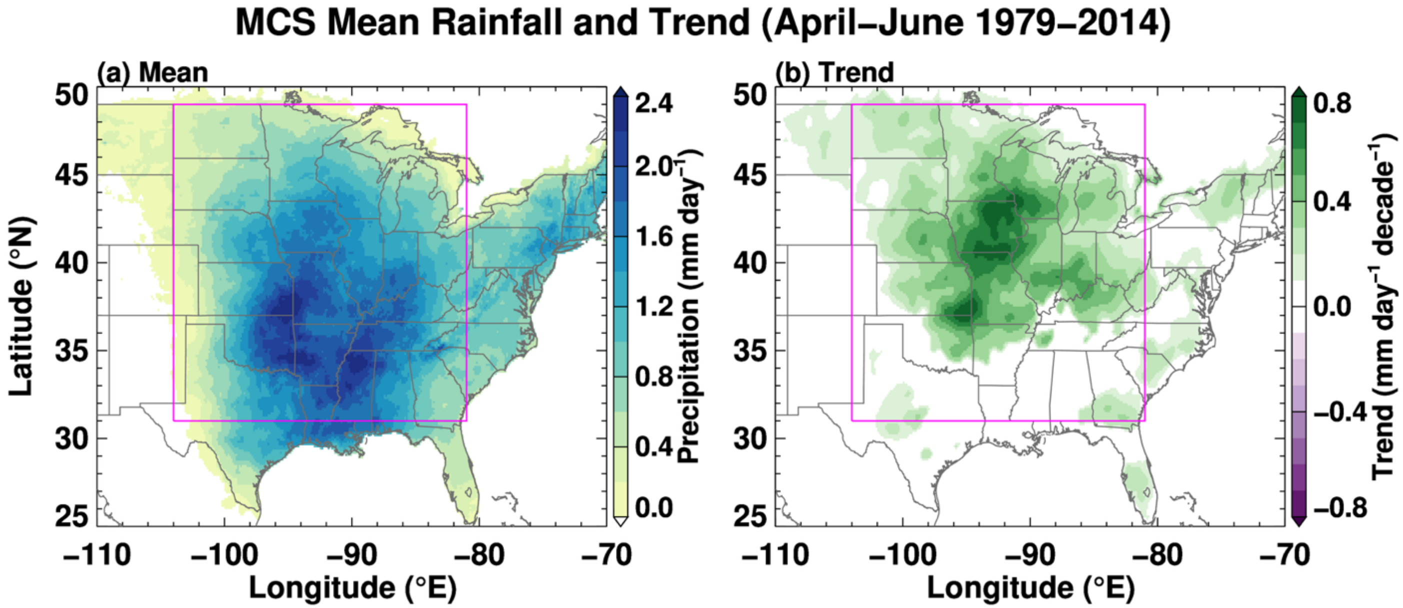
- Select 10 best performing GCMs from 31 CMIP5 models capturing the range of projections
- Use the hybrid delta method to statistically downscaled the 10 GCMs
- Fit GEV and analyze daily peak values



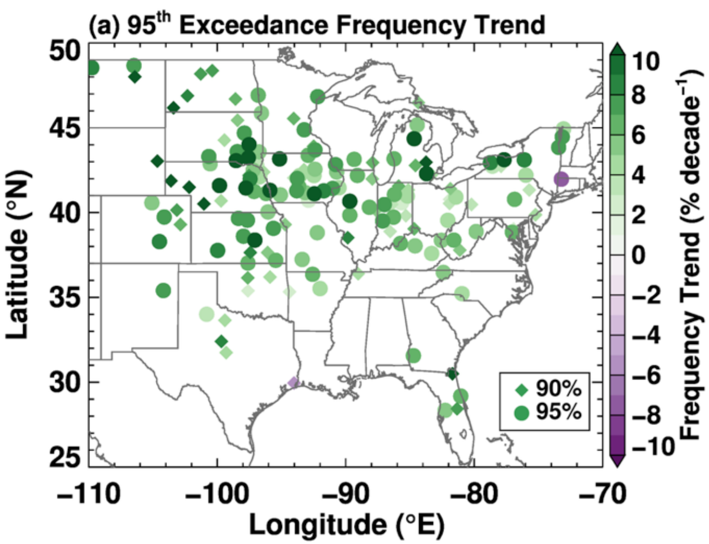


(Byun and Hamlet 2018)

MCS rainfall increased in the past



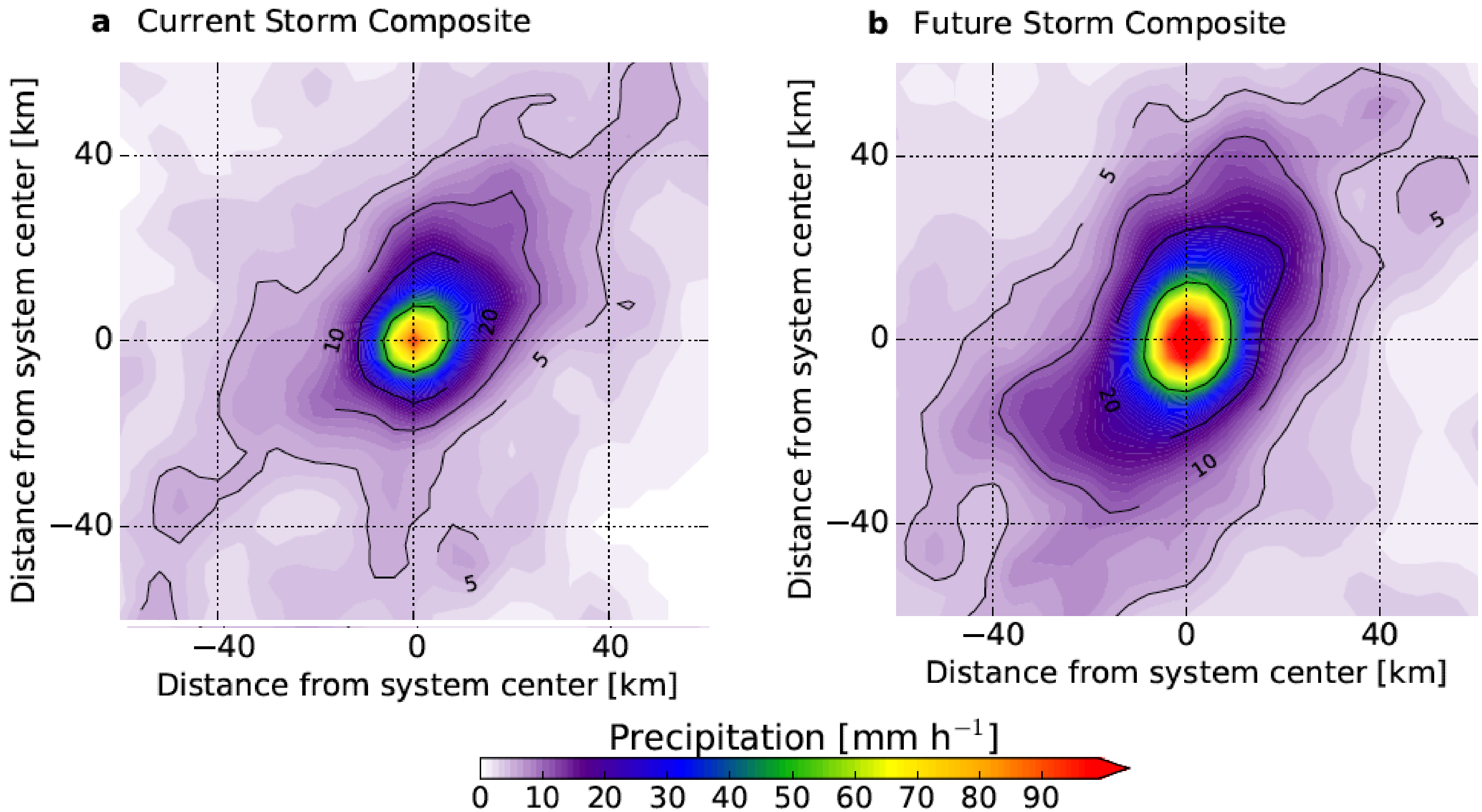
- Some regions in Midwest experienced 0.4-0.8 mm day^{-1} (20-40%) increase in MCS precipitation
- 95th percentile MCS hourly rain-rate increase Moderate to heavy rain-rate (5-30 mm h^{-1}) become more frequent



(Feng et al. 2016 Nature Commun.)

Future changes in MCS precipitation

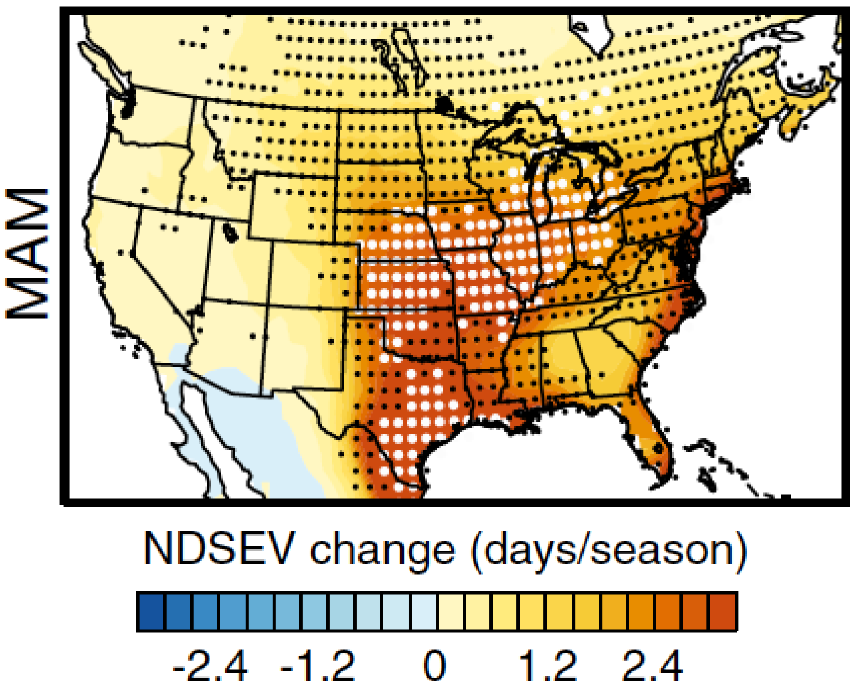
- Intense summertime MCS frequency will more than triple in North America
- MCSs that move slower than 20 kmh^{-1} reduce their speed by up to 20% in the Midwest, Mid-Atlantic, and Canada

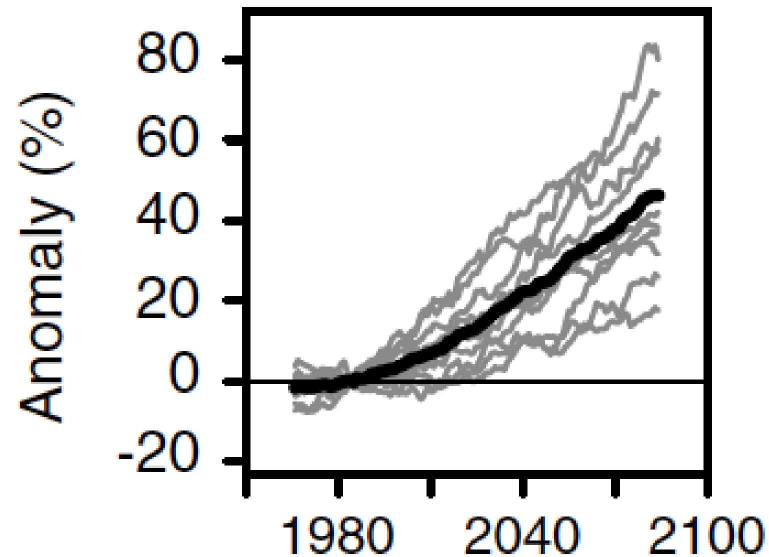


(Prein et al. 2017 Nature Climate Change)

Changes in severe storm environment

Changes in number of days with spring (March-April-May) severe thunderstorm environment (NDSEV) comparing 2070 to 2099 with 1970 to 1999 from CMIP5 models in the RCP8.5 scenario

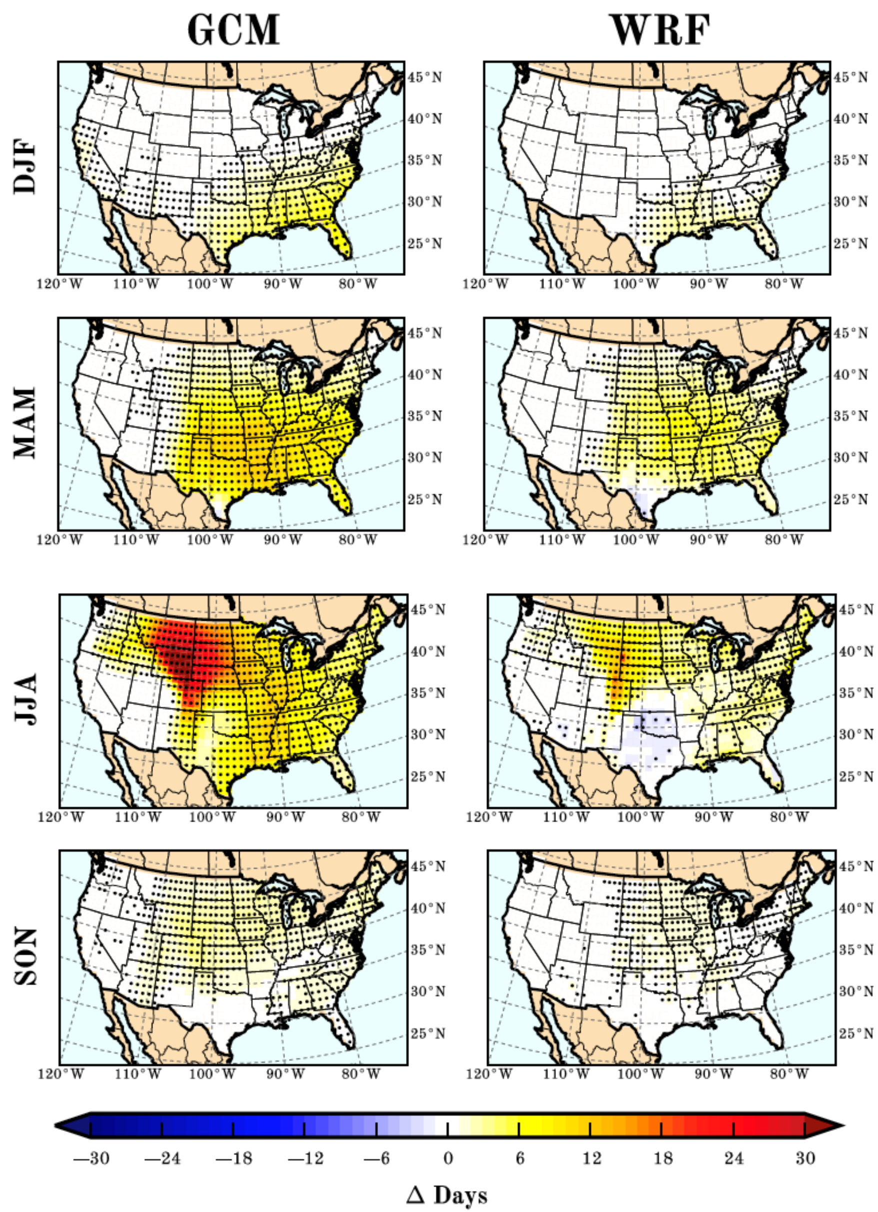




(Diffenbaugh et al. 2013)

Severe weather environment vs. downscaled HCW

- Larger increase in NDSEV than HCW, particularly in spring and summer
- A ~25% reduction in extratropical cyclone frequency in JJA reduces forced ascent and may be responsible for the smaller change in HCW, despite large change in NDSEV

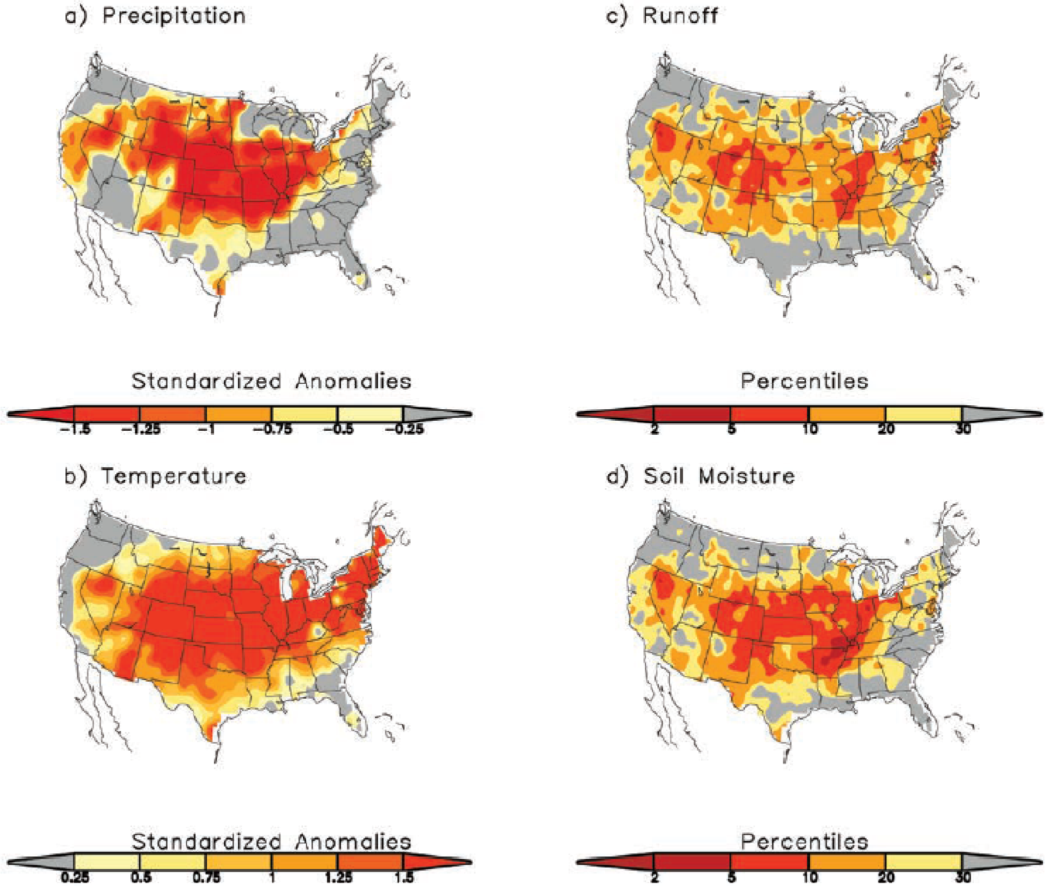


(Hoogewind et al. 2017)

Midwest droughts - historical

- Meteorological (precipitation deficit), Agricultural (soil moisture deficit), and Hydrological (runoff/streamflow deficit)
- 2012 Great Plains/Midwest drought, most severe observed meteorological drought- caused by large-scale meteorology reducing rain during summer (May-August, 2012)

Standardized anomalies over May – Aug 2012 relative to 1979-2011



(Hoerling et al., 2014 BAMS)

Midwest droughts - projected

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- Increases in temperatures in the future are expected to result in increases in evapotranspiration exceeding increases in precipitation, leading to increased soil moisture deficits and agricultural droughts

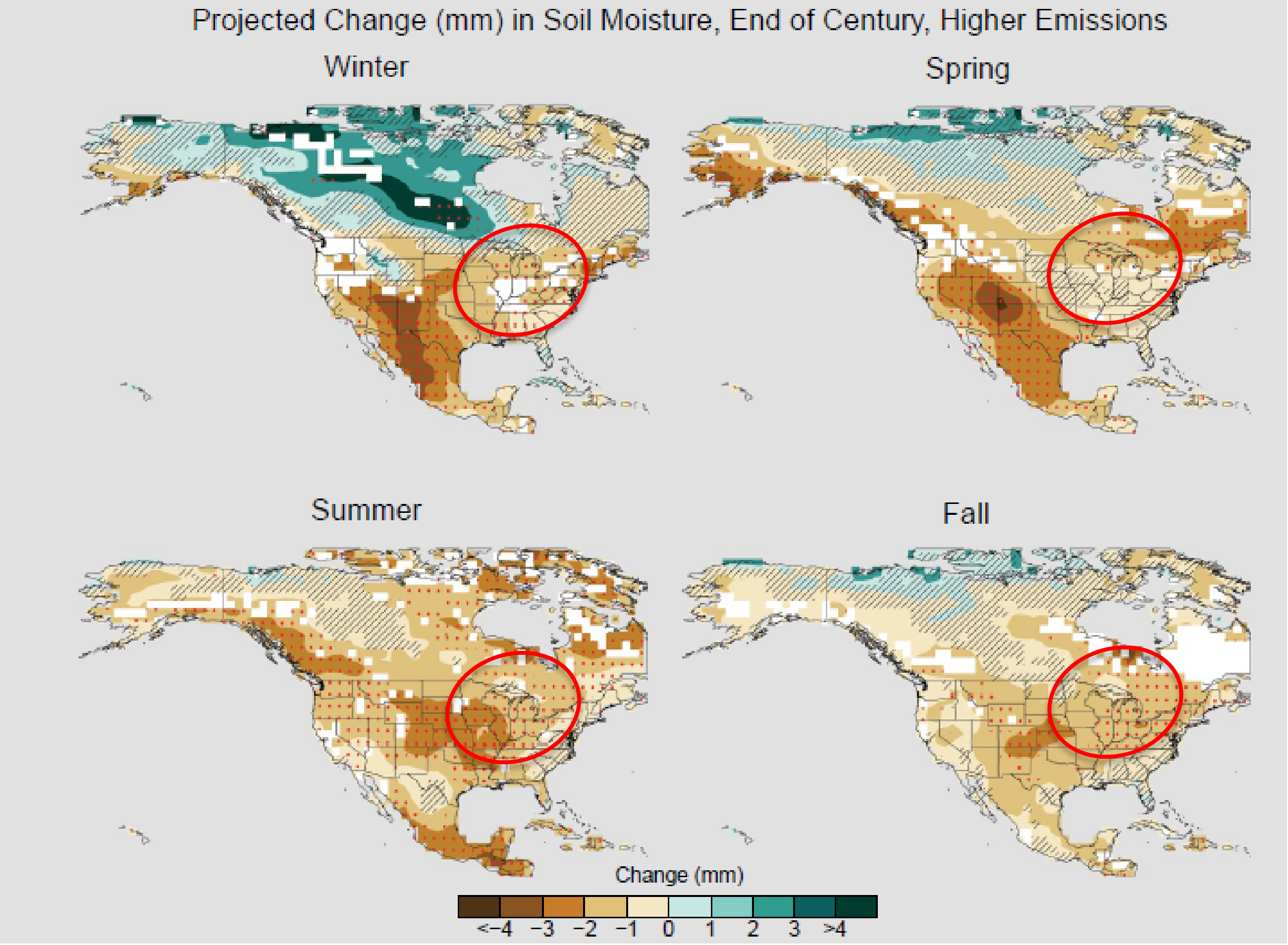

Figure 8.1: Projected end of the 21st century weighted CMIP5 multimodel average percent changes in near surface seasonal soil moisture (mrsos) under the higher scenario (RCP8.5). Stippling indicates that changes are assessed to be large compared to natural variations. Hashing indicates that changes are assessed to be small compared to natural variations. Blank regions (if any) are where projections are assessed to be inconclusive (Appendix B). (Figure source: NOAA NCEI and CICS-NC).

(USGCRP 2017)

Midwest floods - historical

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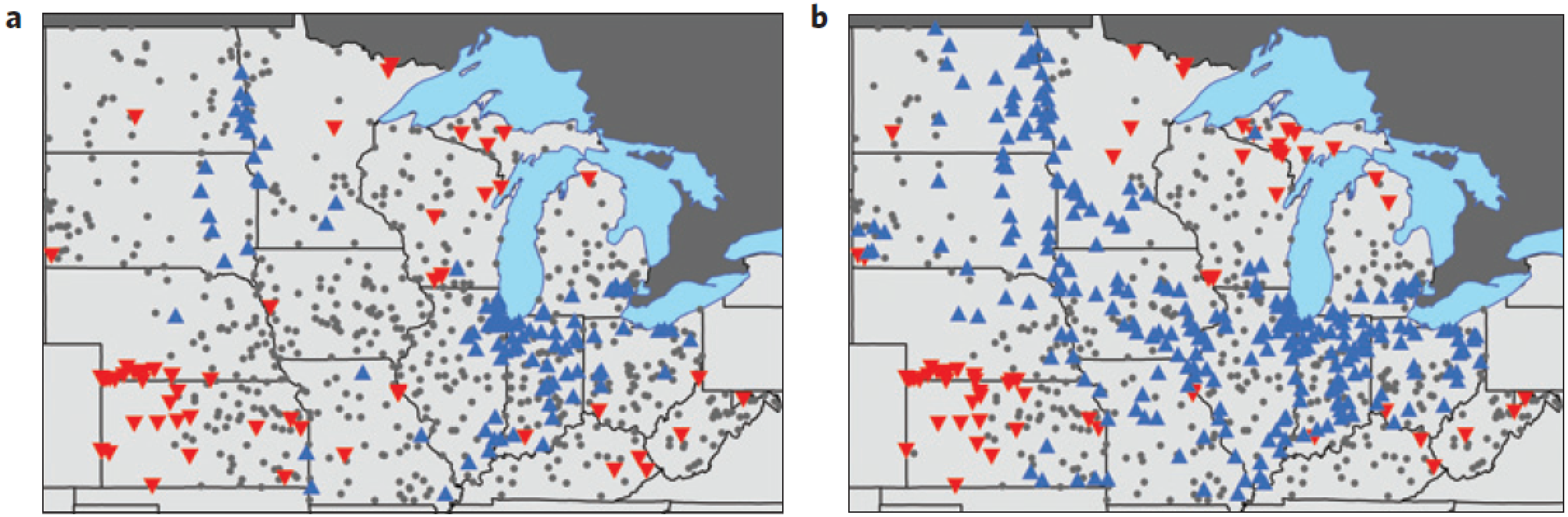
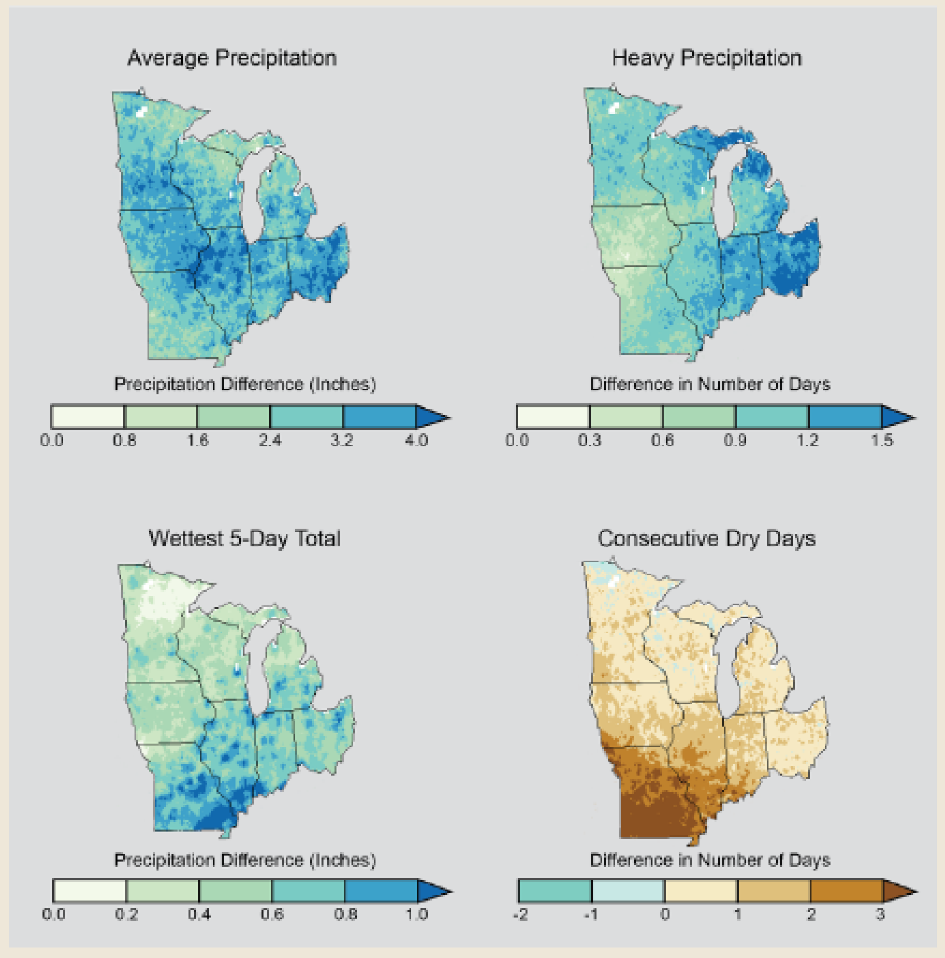
- 2008 floods (USGS Professional Paper 1775)
  - Above-average snowpack, record precipitation, saturated soils, remnants of two hurricanes
- 2011 floods (USGS Professional Paper 1798-B)
  - Large snowpack, near-record spring rainfall, large releases from dams
- Peterson et al. 2013
  - Long-term data from catchments with minimal land-use/water management changes showed peak discharge trend from -10 to +15 percent per decade
- Mallakpour and Villarini, 2015, 2016



Magnitude ▲ Positive trend ▼ Negative trend Frequency

Midwest floods - projected

- Projected future floods
  - NCA3: Increases in rainfall and flooding are expected to continue in the future
    - Total amount of precipitation to increase
    - Number of days with top 2% of rainfalls to increase
    - Wettest 5 -day total precipitation to increase
    - Consecutive dry days to increase (related to droughts)
    - Warm-season precipitation to increase
  - NCA4:
    - Frequency and intensity of heavy precipitation events to increase (high confidence); based on physical reasoning local flooding in some catchments or regions would increase (medium confidence)



Midwest floods - projected

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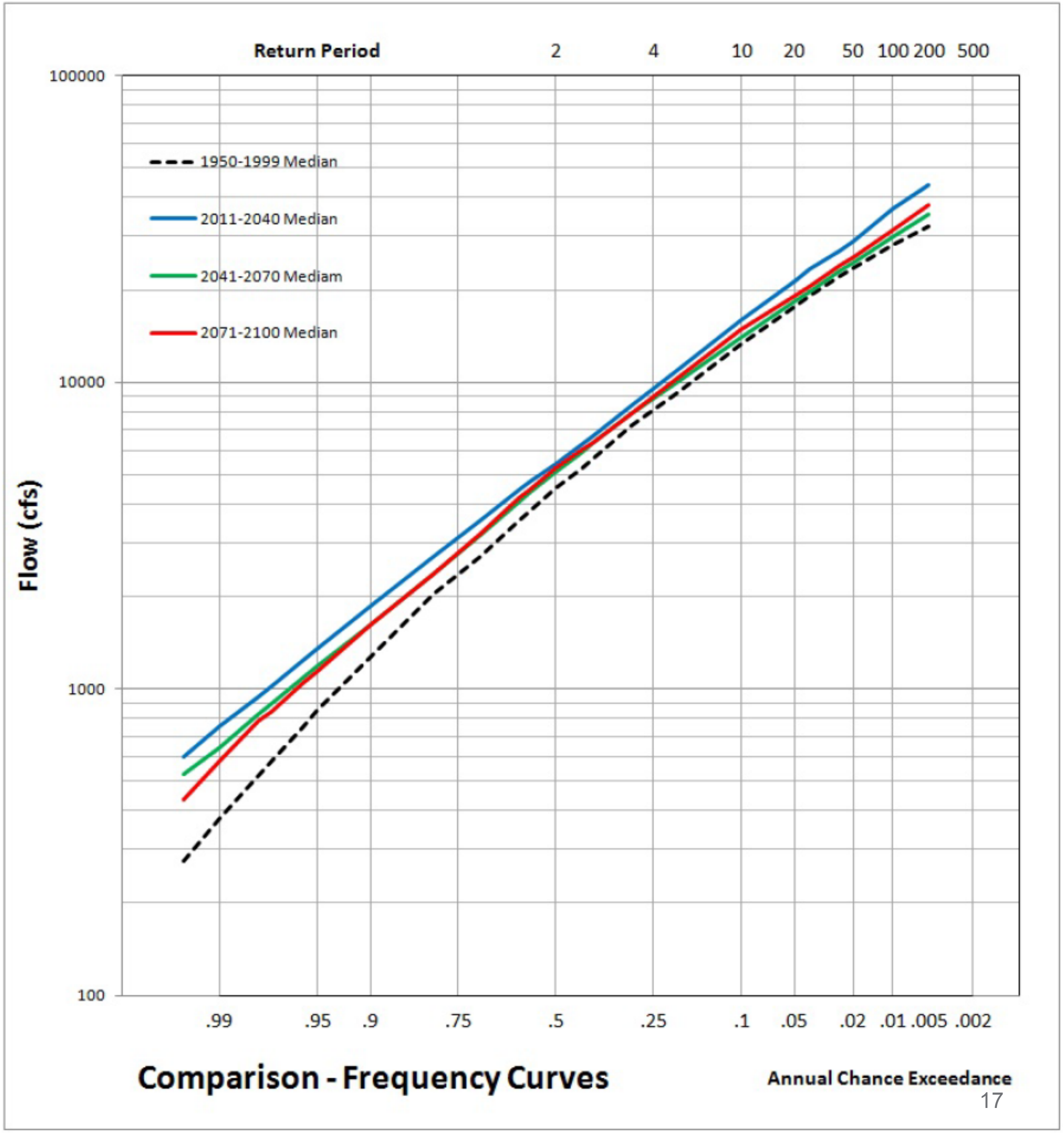
- Projected future floods
  - USACE 2015 – Pilot Study, Impacts of Climate Change on Flood Frequency Curve
    - Red River of the North at Fargo, North Dakota



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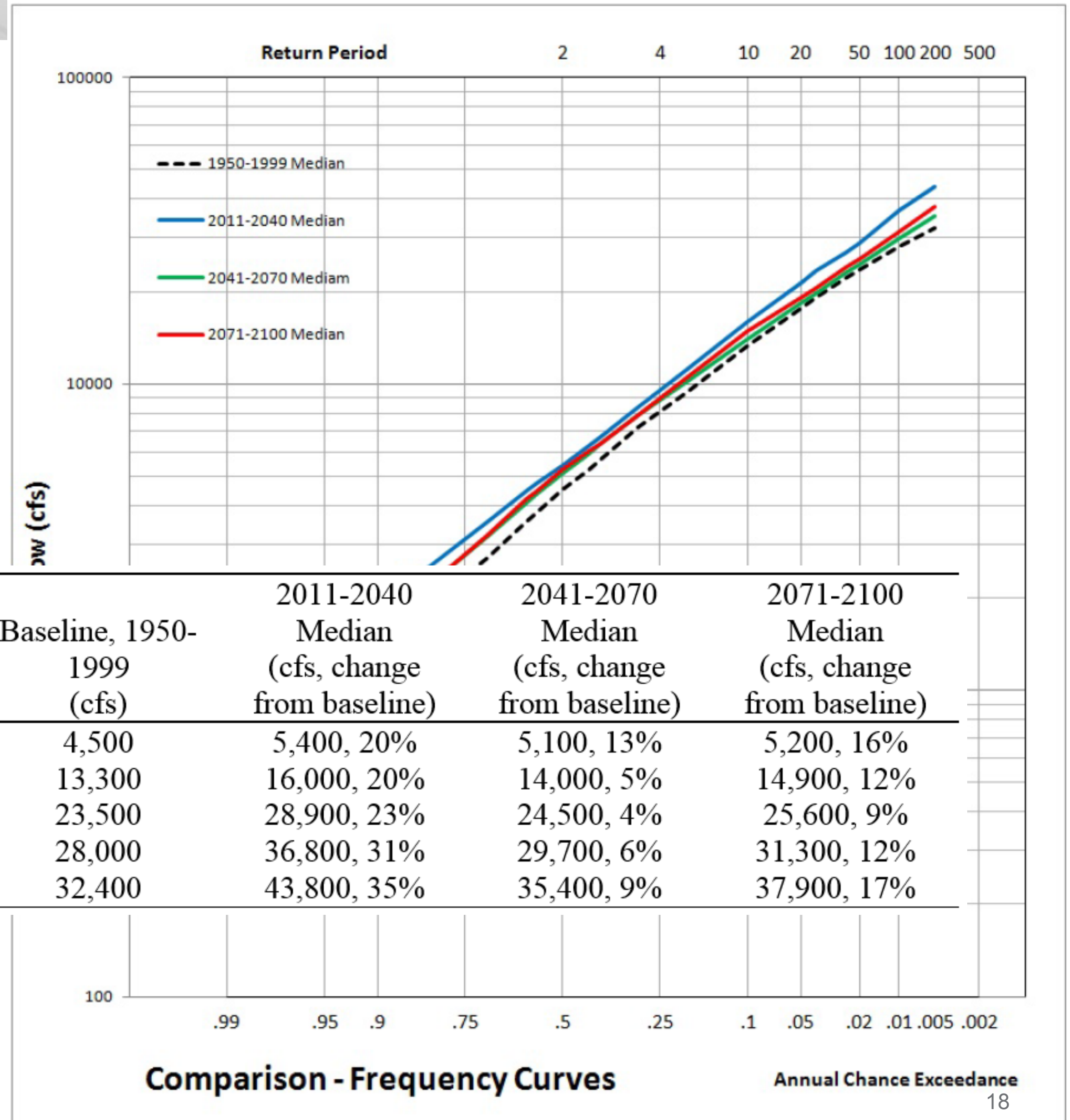

Annual Exceedance Probability	Return Period (yr)	Baseline, 1950-1999 (cfs)	2011-2040 Median (cfs, change from baseline)	2041-2070 Median (cfs, change from baseline)	2071-2100 Median (cfs, change from baseline)
0.5	2	4,500	5,400, 20%	5,100, 13%	5,200, 16%
0.1	10	13,300	16,000, 20%	14,000, 5%	14,900, 12%
0.02	50	23,500	28,900, 23%	24,500, 4%	25,600, 9%
0.01	100	28,000	36,800, 31%	29,700, 6%	31,300, 12%
0.005	200	32,400	43,800, 35%	35,400, 9%	37,900, 17%

Great Lakes water levels - historical

- Historical water levels
  - GLERL's Seasonal and Inter-Annual Water Supply Forecasting Project
    - Uses a suite of hydrologic and hydraulic models
  - Large Lake Statistical Water Balance Model
    - Treats water balance components as random variables; estimates prior probability distributions using historical data; estimates posterior probability distributions using Bayesian approach
    - Was used to explain the record rate of rise in Lakes Superior and Michigan-Huron between January 2013 and December 2014

Great Lakes water levels - historical

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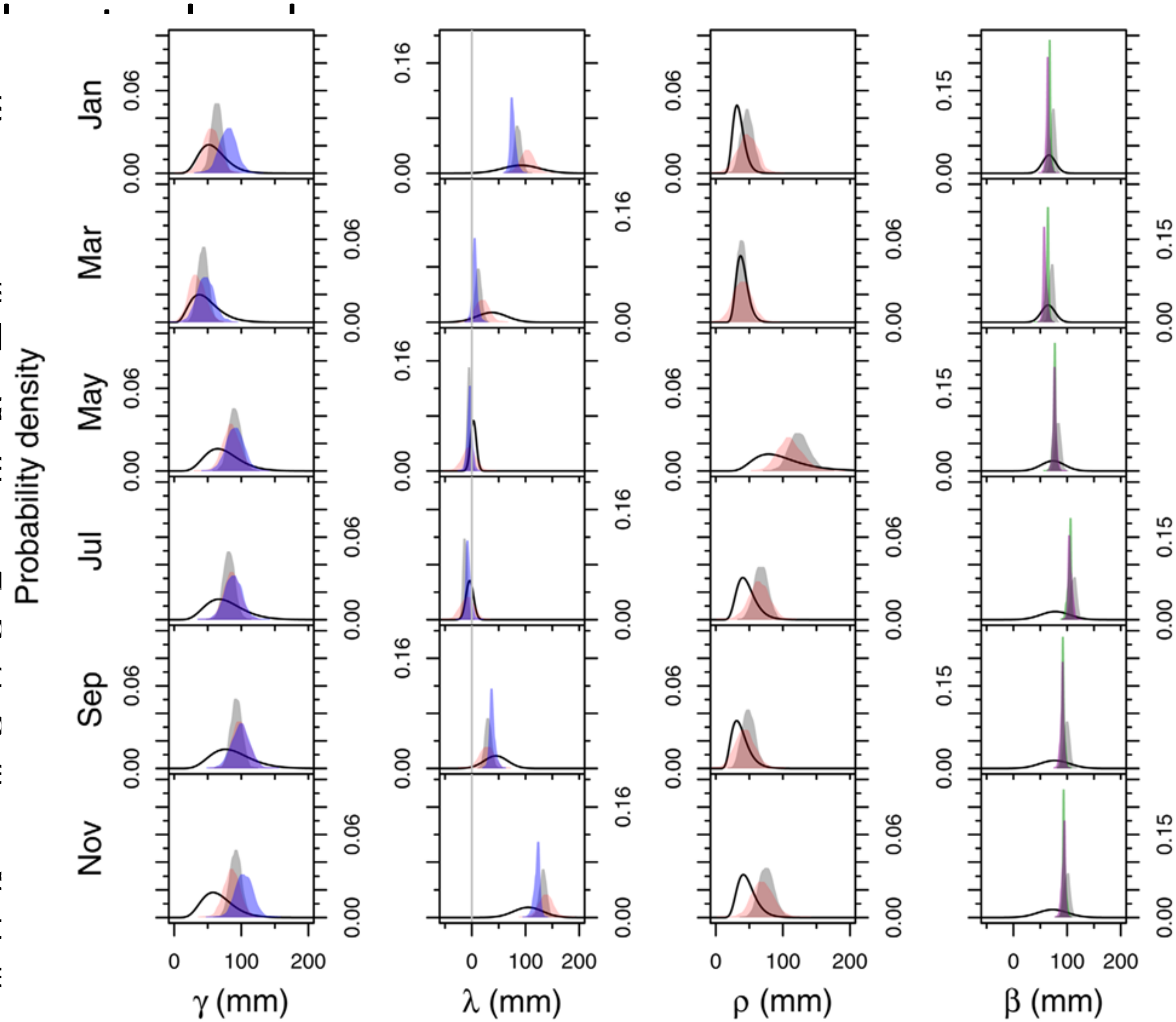

Great Lakes water levels - historical

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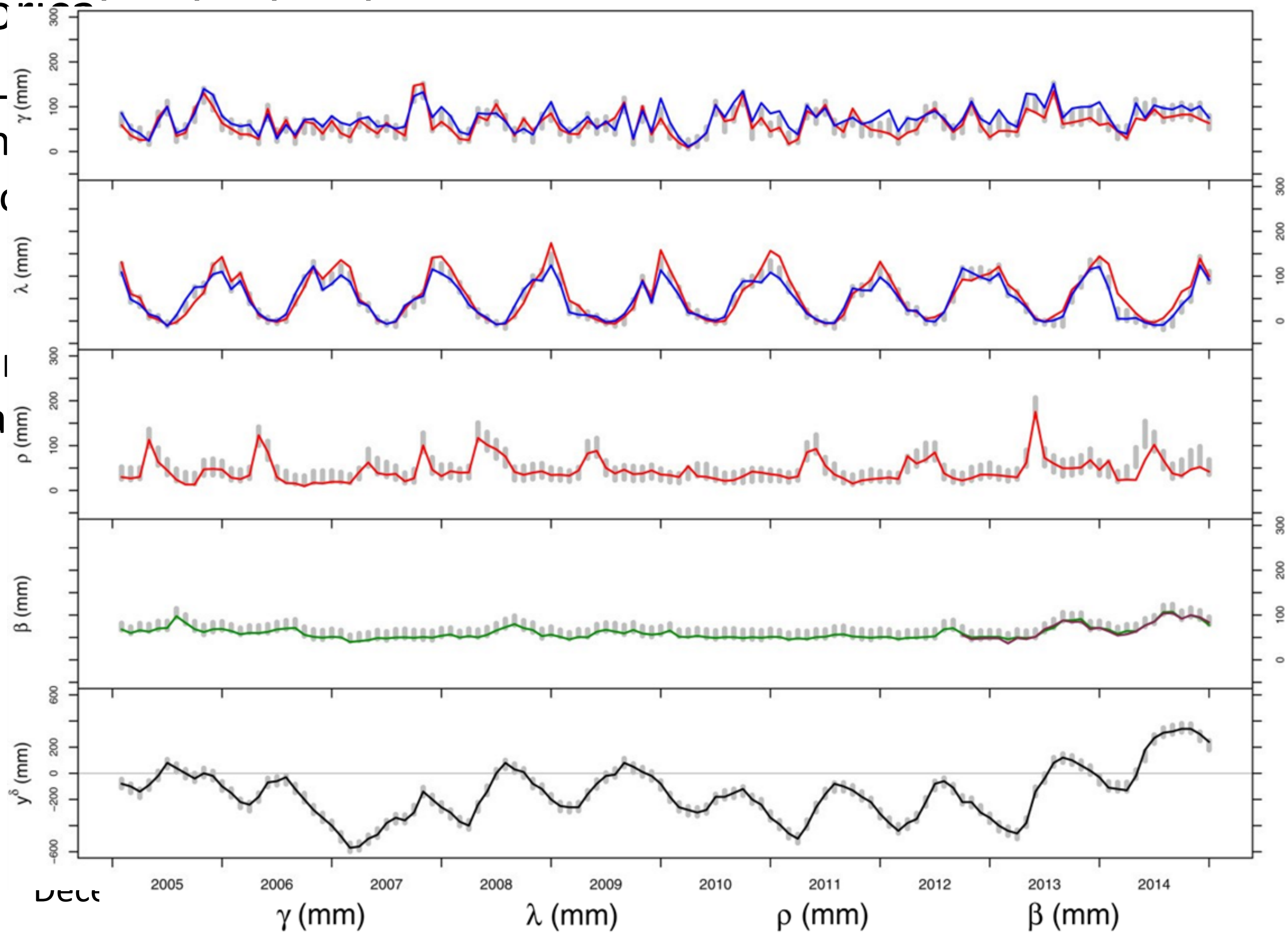

Great Lakes water levels - projected

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- Projected future water levels
  - International Upper Great Lakes Study, 2012
  - NCA3: Angel and Kunkel, 2010; MacKay and Seglenieks, 2012
  - Notaro et al. 2015
  - Lofgren et al. 2011; Lofgren and Rouhana 2016

Table 4-3: Estimated Lake Level Changes for Lake Michigan-Huron at the 5th, 50th and 95th percentiles

Year	5th	50th	95th
B1 Emission Scenario			
2020	-0.60	-0.18	0.28
2050	-0.79	-0.23	0.15
2080	-0.87	-0.25	0.31
A1B Emission Scenario			
2020	-0.55	-0.07	0.46
2050	-0.91	-0.24	0.40
2080	-1.43	-0.28	0.83
A2 Emission Scenario			
2020	-0.63	-0.18	0.20
2050	-0.94	-0.23	0.42
2080	-1.81	-0.41	0.88

Source: Angel and Kunkel (2010)

Great Lakes water levels - projected

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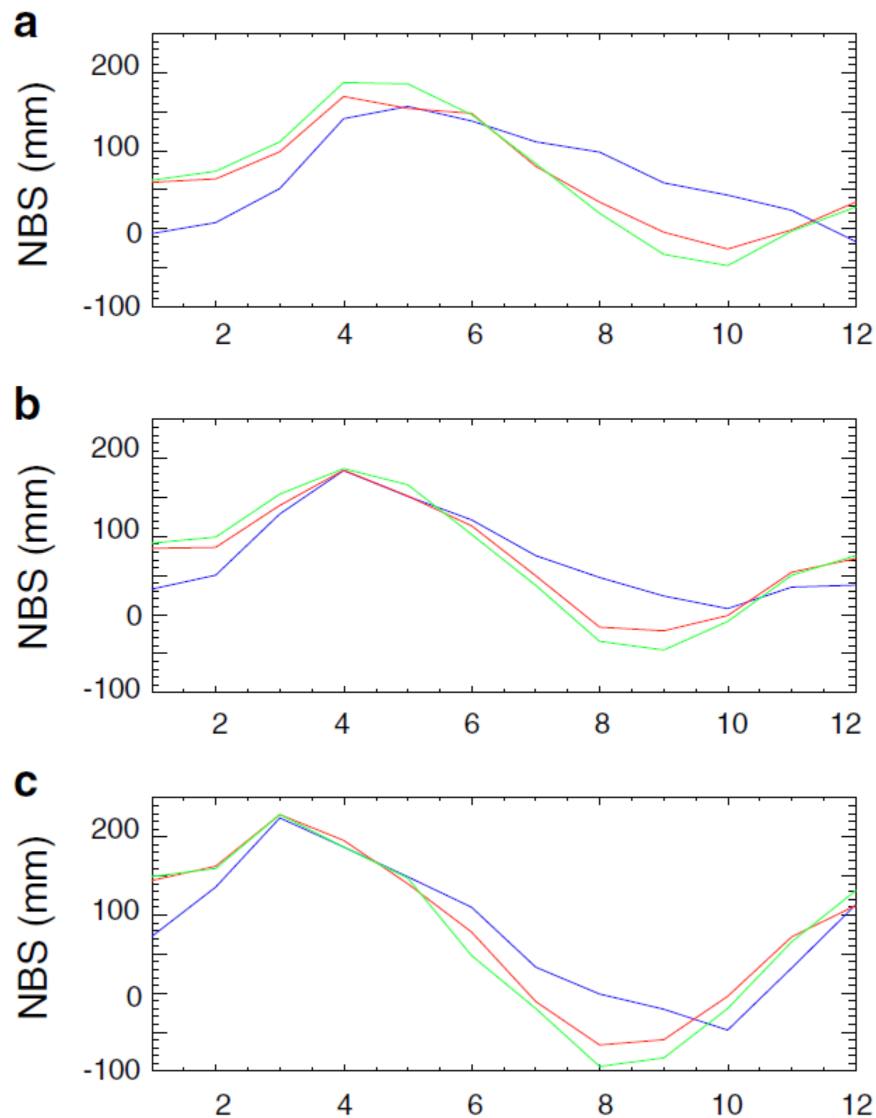

Fig. 3 NBS mean seasonal cycle for: **a** Lake Superior; **b** Lake Michigan – Huron; **c** Lake Erie. blue-observed (EC residual method); red-GLRCM 1962–1990; green-GLRCM 2021–2050. Units are mm over lake surface area

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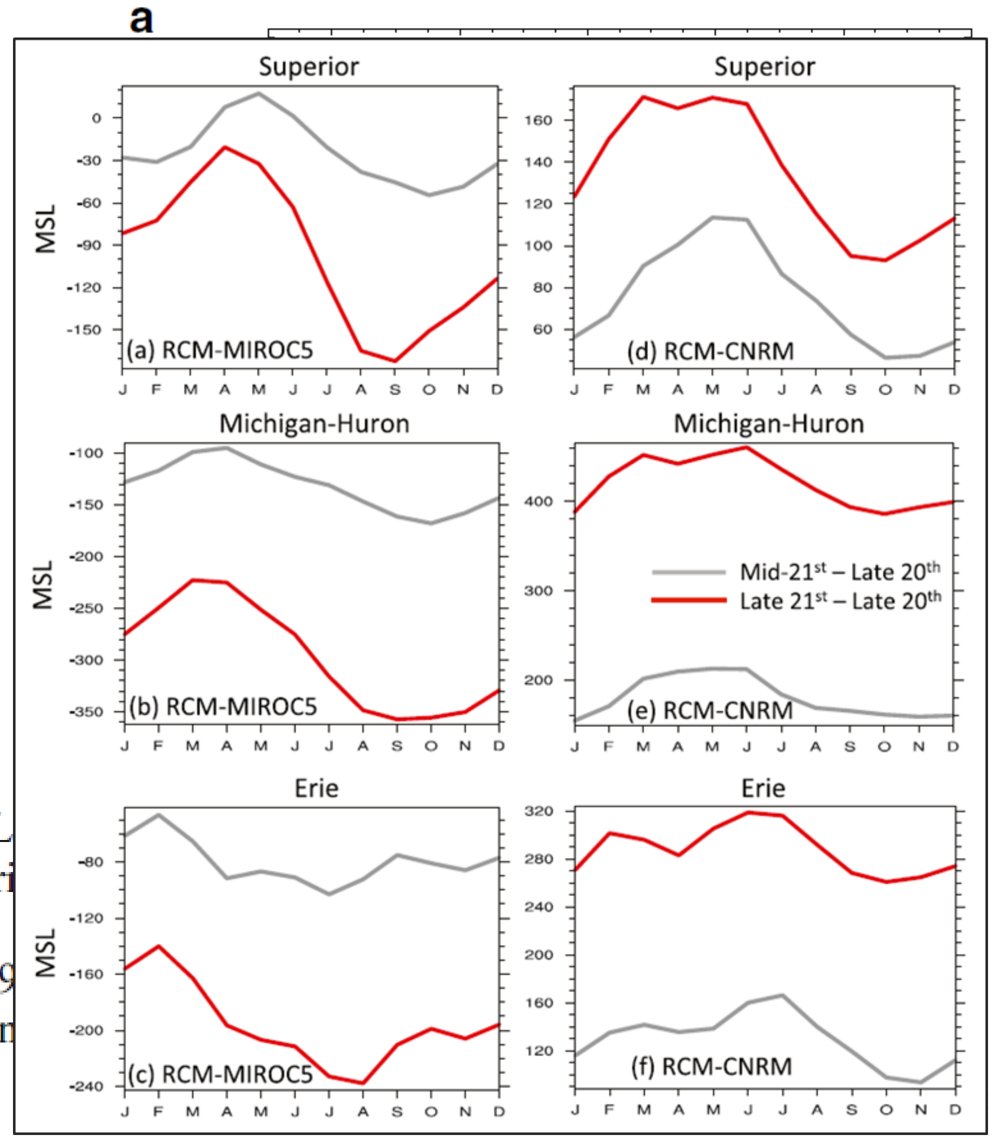

Summary

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- The Midwest has seen warming and larger increase in precipitation in the past compared to other US states
- Hot days and extreme precipitation are projected to increase in the future
- Convection permitting modeling is becoming viable for projecting changes in MCSs and HCW
  - MCS precipitation has increased in the past and is projected to increase in the future
  - HCW and its large-scale environment are projected to be more frequent in the future
- Droughts are projected to be more intense and last longer due to earlier snowmelt and increase in summer ET
- Floods may increase as extreme precipitation increases
- Great Lakes water level may become lower in the future