

# **Climate Extremes Research: Recent Findings and New Directions**

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<http://assessment.globalchange.gov>

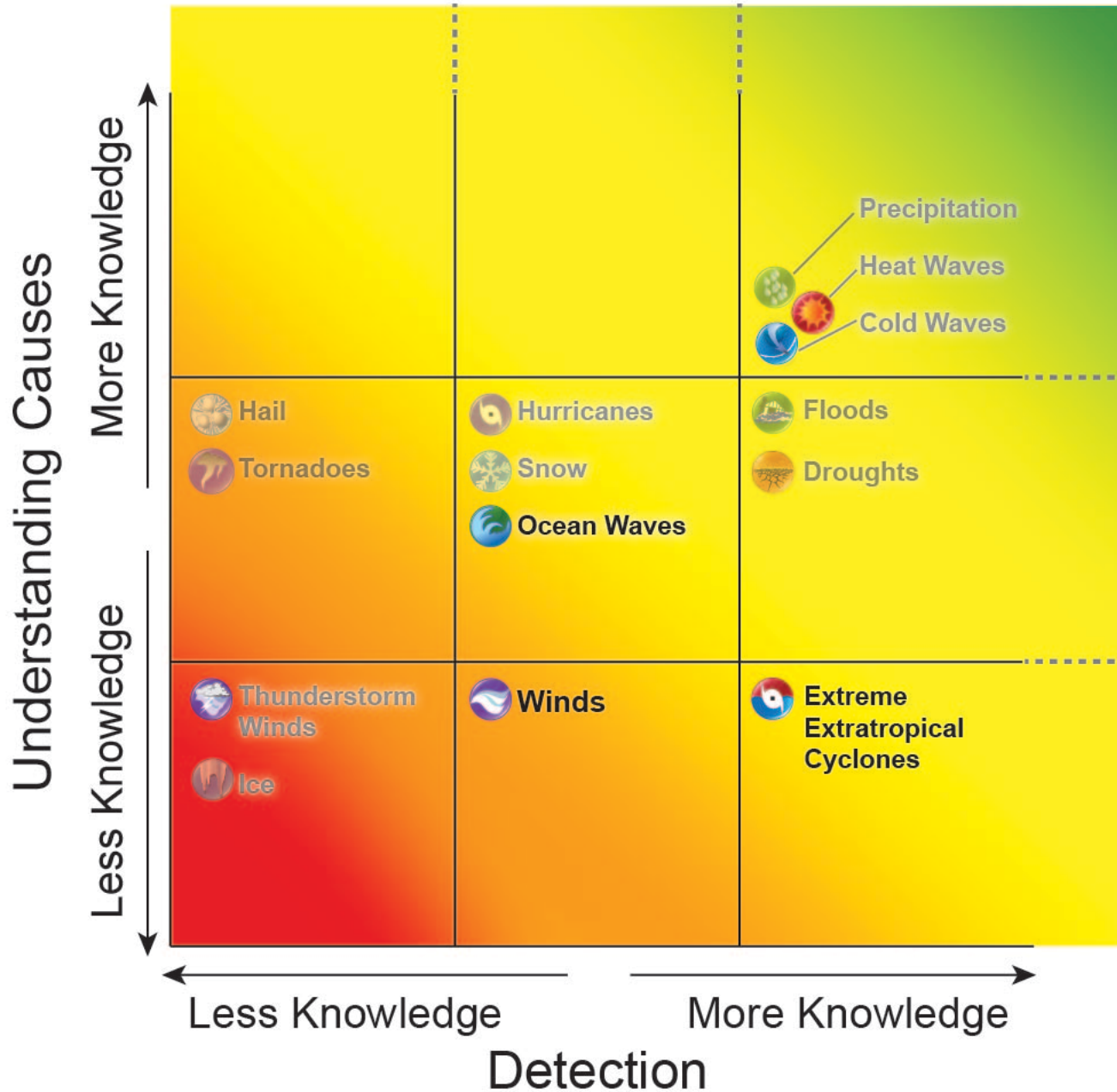
# Content

- Focus on U.S. extremes
- Extreme types
  - Heavy precipitation
  - Severe thunderstorms
  - Winter storms
  - Heat and cold waves
  - Drought

# Adequacy of Data To Detect Historical Trends

- The following assessment based on a series of three workshops that brought together about 70 experts to evaluate the quality of historical data and the understanding of causes of trends
- Three workshop report papers published or accepted for publication in the Bulletin of the American Meteorological Society
  - Monitoring and Understanding Changes in **Extreme Storm** Statistics: State of Knowledge. Kunkel, K.E. et al., 2013, BAMS.
  - Monitoring and Understanding Changes in **Heat Waves, Cold Waves, Floods and Droughts** in the United States: State of Knowledge. Peterson, T.C. et al., 2013, BAMS.
  - Monitoring and Understanding Changes in **Extreme Winds, Waves, and Extratropical Storms** along the Coasts: State of Knowledge. Vose, R.S. et al., in press BAMS.

# Adequacy for Detection and Understanding Causes of Changes for Classes of Extremes



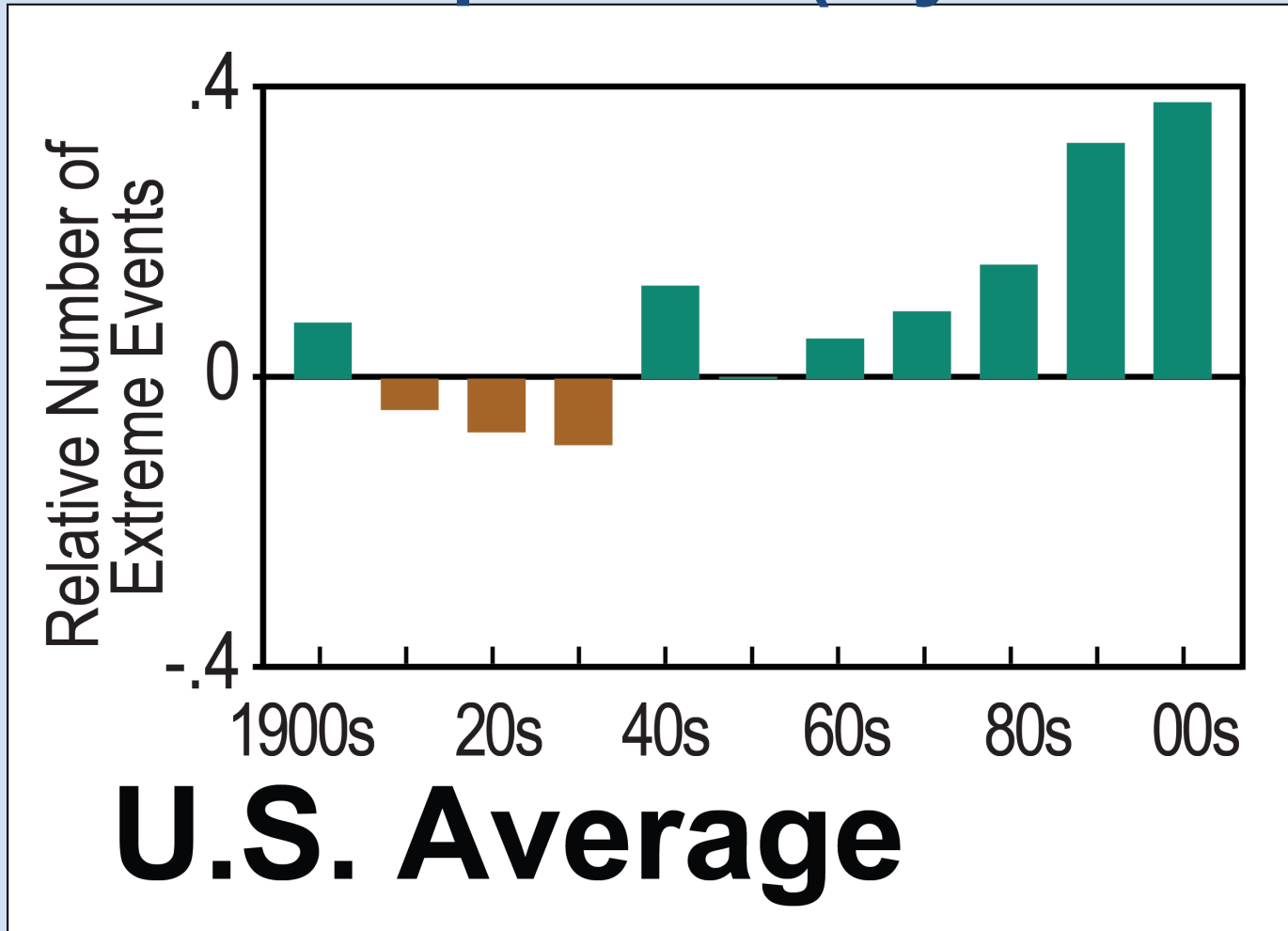
# Extreme Precipitation



# Extreme Precipitation Episodes

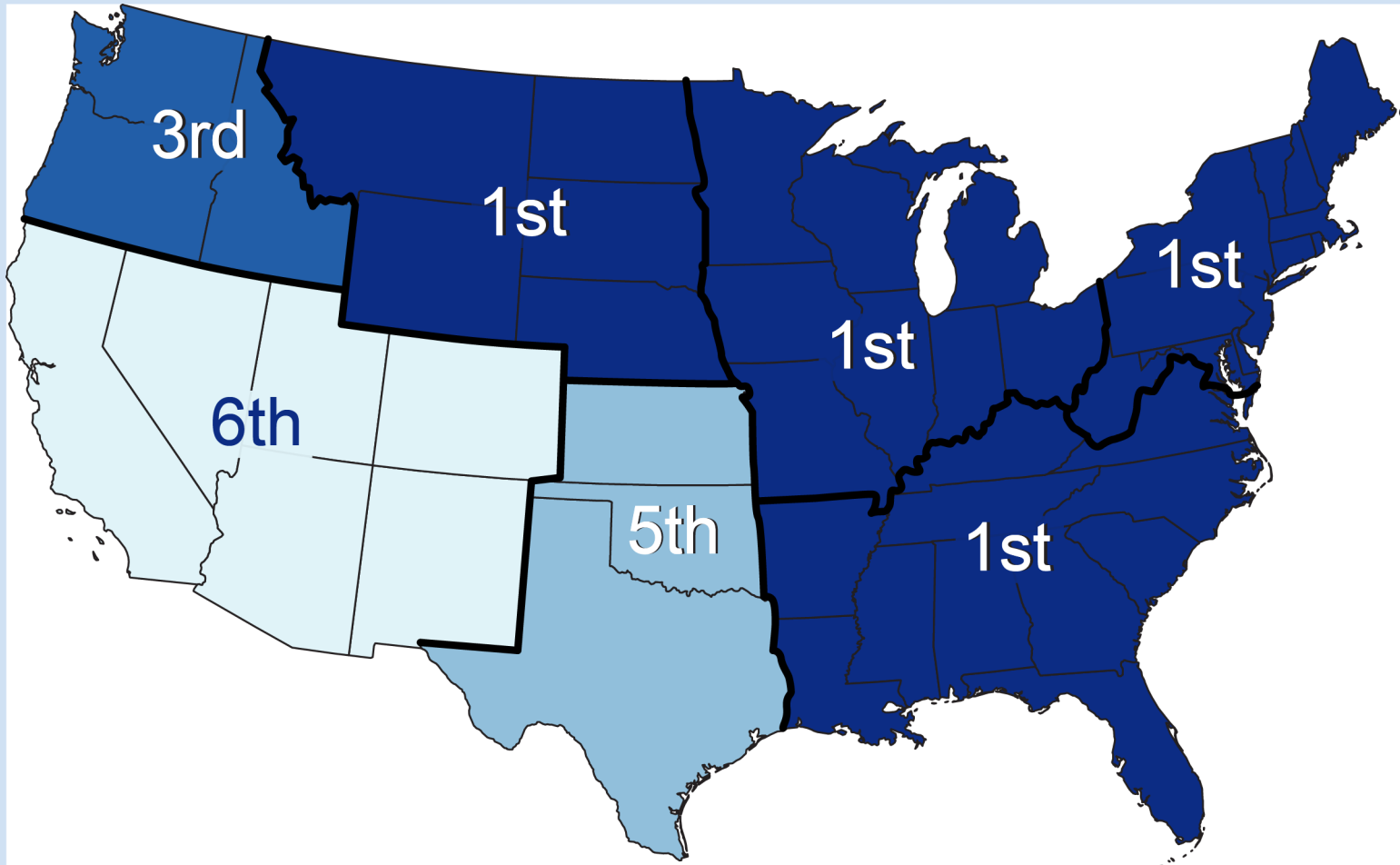
- Number of events exceeding a threshold precipitation amount for a specified average recurrence interval and duration
  - Daily, 1 in 5-year events
- Strong upward trend in number of events
  - Regional variations

# Extreme Precipitation (5-yr Storms)



We have seen a very large increase in the number of extreme precipitation events

# Rank of 2001-2011 “Decade”



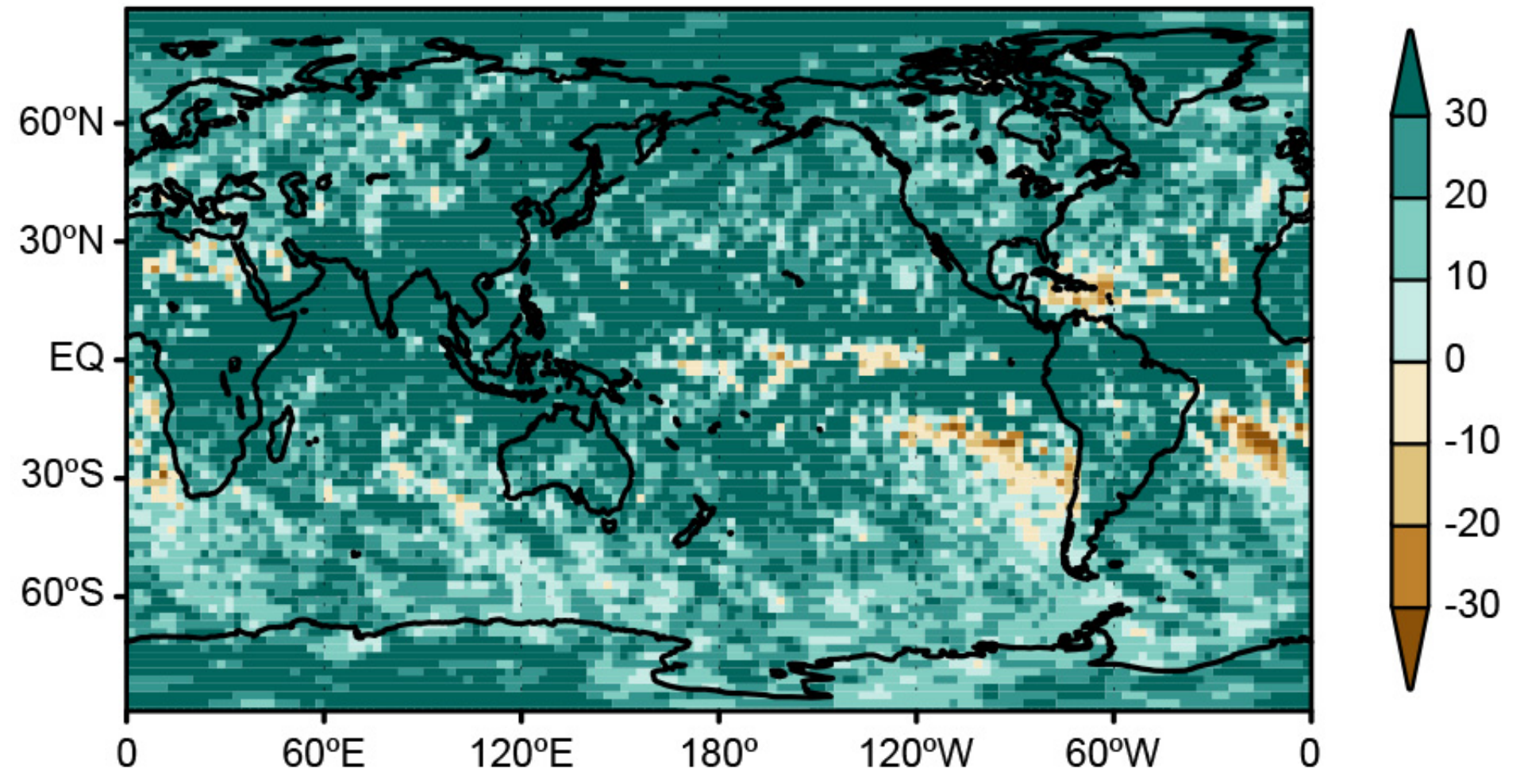
The most recent decade has seen the highest number of extreme precipitation events in northern and eastern parts of U.S.



# Projected Extreme Precipitation Episodes

- Maximum daily precipitation for 2071-2100 compared to 1971-2000 under a high emissions scenario
  - Kunkel, K.E., T.R. Karl, D.R. Easterling, K. Redmond, J. Young, X. Yin, and P. Hennon, 2013: Probable maximum precipitation (PMP) and climate change. *Geophys. Res. Lett.*, 40, doi:10.1002/grl.50334.

# Maximum Daily Precipitation Difference (%): (2071-2100) - (1971-2000), RCP8.5



The most extreme precipitation amounts are projected to increase by a lot over all of U.S. and almost everywhere globally under a high emissions scenario

# Confidence in Projected Extreme Precipitation

- High
- Why? Because there is a direct link between air temperature and the amount of water vapor in the atmosphere over the oceans. As **temperature increases**, the capacity of the atmosphere to hold **water vapor increases**.
- Climate model simulations show increases in the most extreme precipitation amounts as a direct consequence of increased water vapor

# New Directions

- High confidence in projections warrants their inclusion in **design and planning of runoff control structures** (long lifetimes ensure that climate change will become a factor and under-design is a risk)
- Barriers:
  - Extreme rainfall design values (e.g. the 100-yr storm) have been based solely on historical observations, essentially **a stationary climate assumption**
  - Incorporation of climate change would **increase** the values and associated **costs of construction**.
  - No accepted methodology for incorporation.

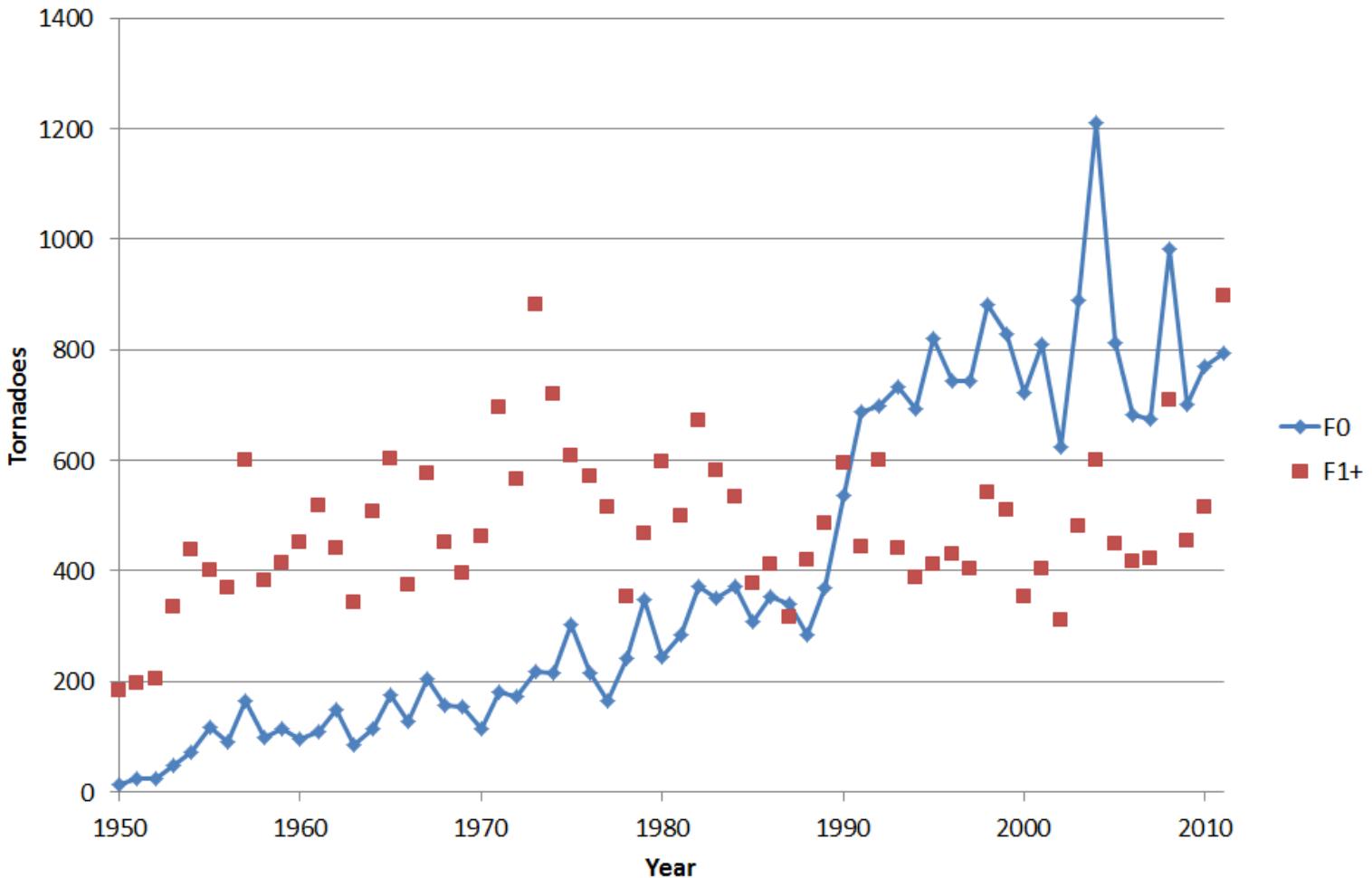
# New Directions (cont'd)

- Connections to flooding
  - Relatively **direct link** between short-duration extreme precipitation and **flash and urban flooding**
  - For **river flooding**, additional variables are important because the **temporal scales, spatial scales, and the runoff capacity** are larger. Also, **antecedent soil moisture** is important and this is likely to decrease in many areas because of increases in temperature-cause evaporation rate increases. This could negate the increase in flood risks posed by increases in extreme rainfall
  - Hydrologic modeling

# Severe Thunderstorms

- Data generally lacking in quality to assess trends
- Small spatial scale environment critical to these phenomena, particularly tornadoes

## US Annual Tornadoes



Large increase in small (F0) tornadoes is almost certainly due to better detection because there is no increase in stronger tornadoes. Probably no overall trend.

# Projections of Severe Thunderstorms

- Small spatial scale of important processes is a challenge for climate models
- Competing effects:
  - thermodynamic instability, which promotes thunderstorm development; likely to **increase** due to warmer surface temperatures and higher water vapor content
  - vertical wind shear, which is necessary for thunderstorm rotation; likely to **decrease**



# Confidence in Projected Severe Thunderstorms

- Low
- Why? Because the two key atmospheric conditions necessary for severe thunderstorms appear likely to change in **opposite directions** in response to global warming

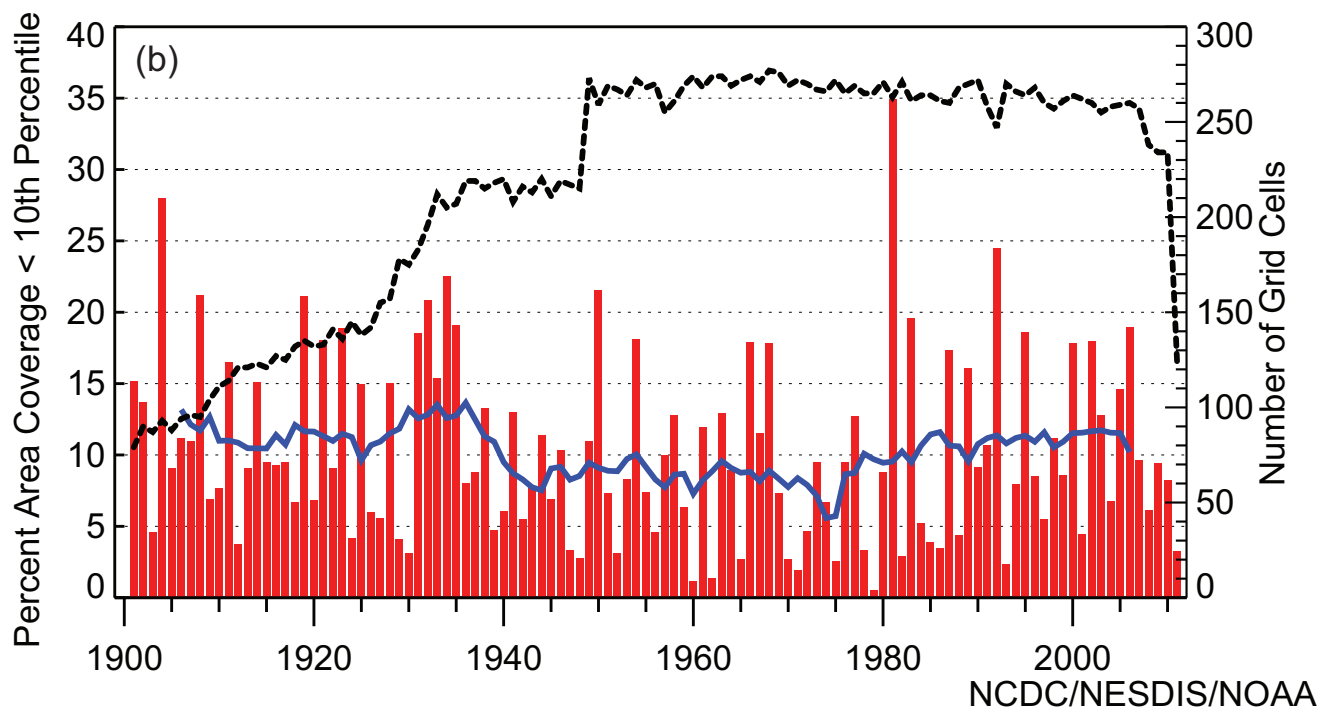
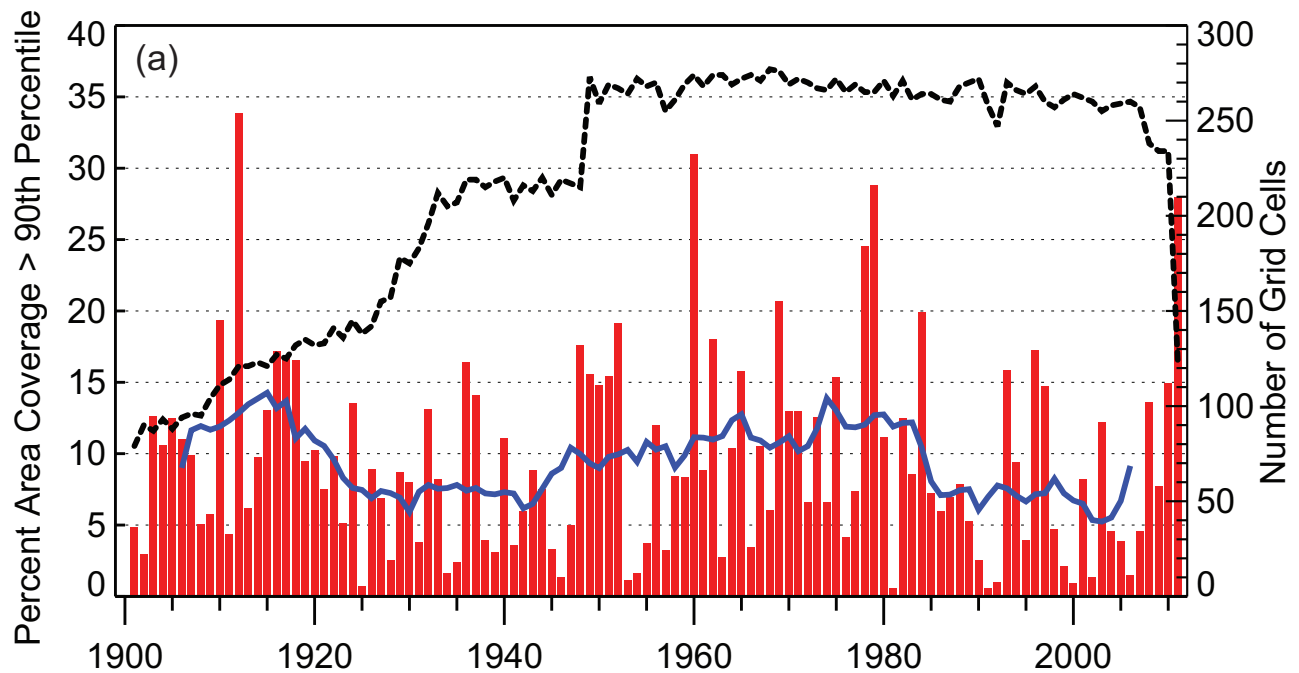
# New Directions

- More detailed examination of atmospheric environmental conditions in climate model simulations may provide more confidence in how the balance of factors may turn out
- No prospects in the 5-yr time frame that GCMs will generally be run at a resolution to produce the parent thunderstorms of these phenomena. Need to get to at least **4 km resolution, ideally 2 km.**

# Winter Storms

- Percent area with seasonal snowfall above 90<sup>th</sup> percentile and below 10<sup>th</sup> percentile

From  
Kunkel, K.E., M. Palecki, L. Ensor,  
D. Easterling, K. G. Hubbard, D.  
Robinson, K. Redmond, 2009:  
Trends in 20<sup>th</sup> Century U.S.  
extreme snowfall seasons.  
*Journal of Climate*, **22**,  
6204-6216.



# Projections of Winter Storms

- Regionally variable
  - **Higher moisture content** would favor larger snowstorms in areas where it is cold enough to snow
  - Decreases on southern margins of climatologically snowy areas
    - becomes **too warm to snow**

# Confidence in Projected Winter Storm Frequency and Intensity

- Medium
- Why? Because there is high confidence about **increases in temperature** and associated changes in where it can snow and in the amount of water vapor in the atmosphere but lower confidence in whether the **number and intensity of low pressure storms will change** over the U.S.

# New Directions

- Further understanding could be achieved by an **event-based analysis** of climate model simulations
- Considerable ongoing work on extratropical cyclones (low pressure winter storms) in model simulations
- East coast storms in particular very sensitive to spatial resolution of simulations; **rain-snow line** critical to impacts

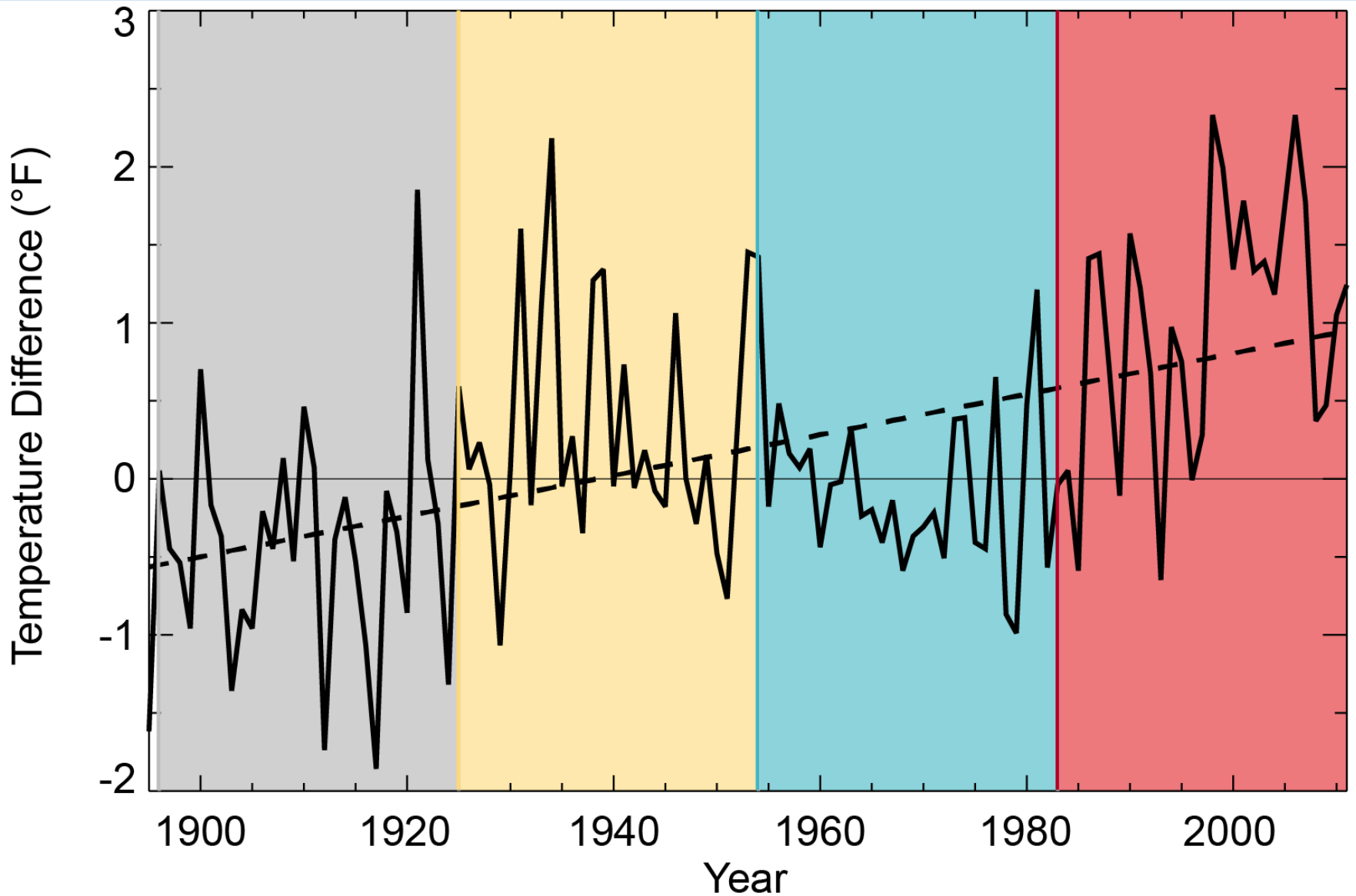
# Observed Extreme Temperature Episodes

- Record hot and cold temperatures
  - Daily records
  - Monthly temperature records



# U.S. Temperature

2012 off the charts  
charts ✖

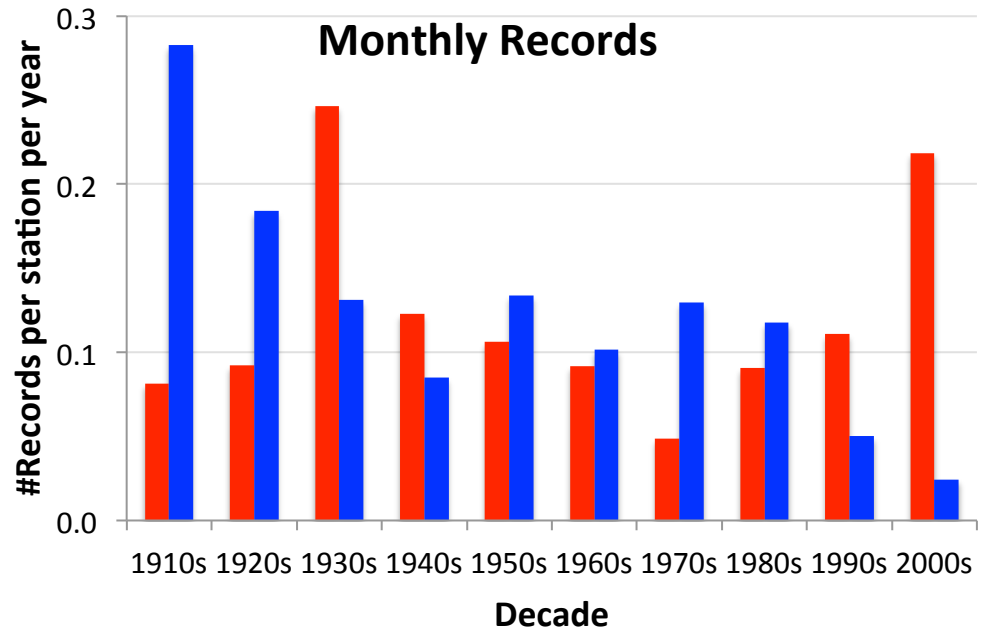
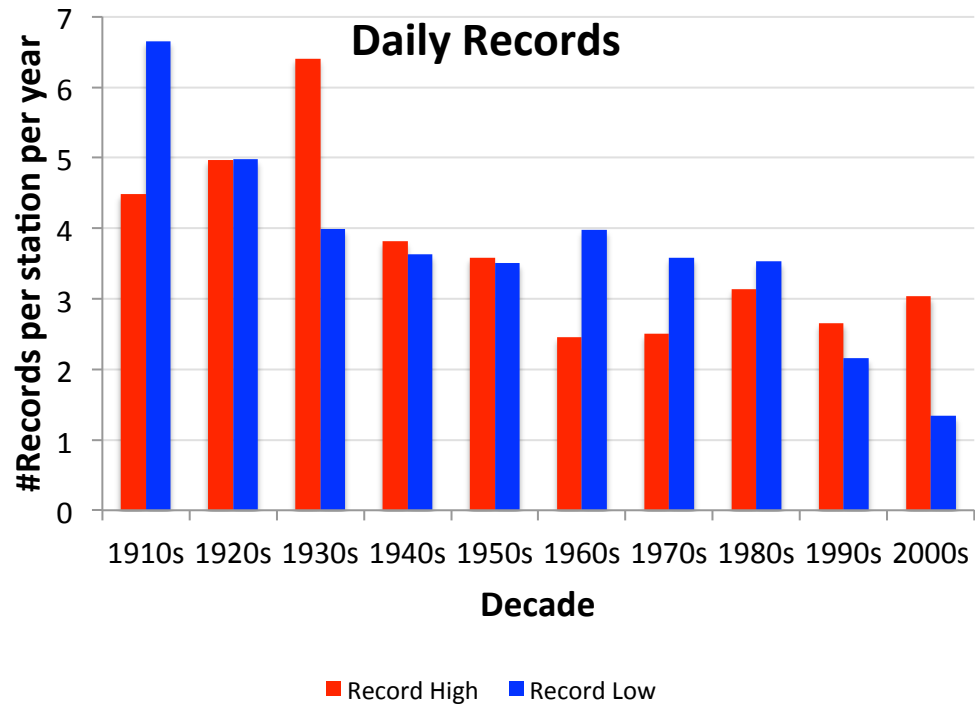


# Recent Events

- July 2012 was hottest month on record in contiguous U.S., breaking old (venerable) record set in July 1936
- Summer 2012 hottest summer on record in CO and WY
- Summer 2011 hottest summer on record in NM, TX, OK, and LA

# All-time Temperature Records

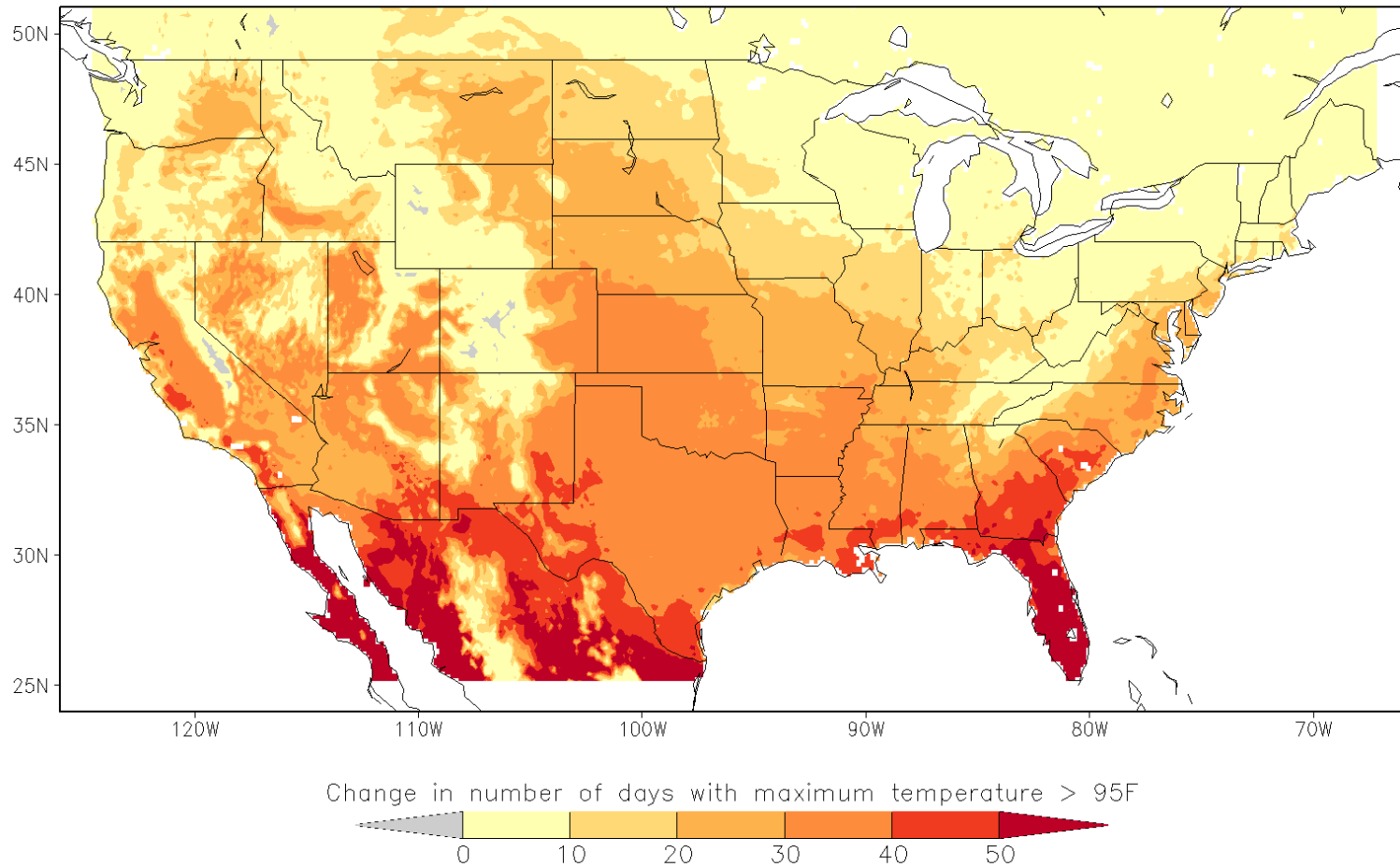
- The number of record lows has reached the lowest levels since 1900
- The number of daily record highs has been about normal but the number of monthly record highs is near the Dust Bowl years



# Projected Extreme Temperature Episodes

- Number of days above 95 deg F

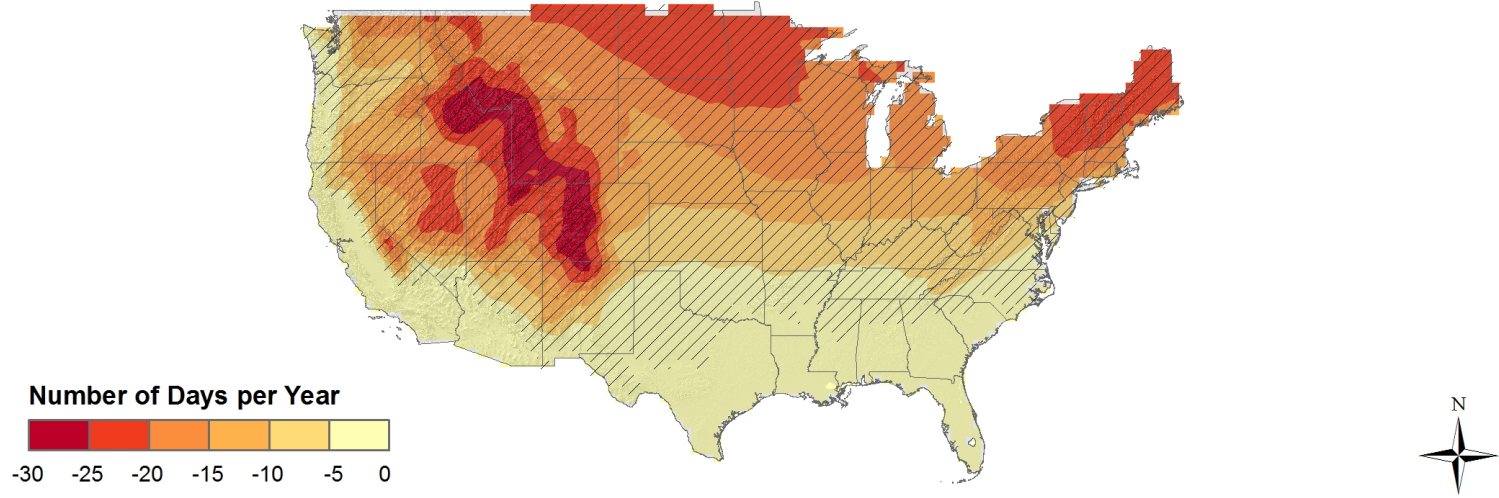
DIFFERENCE IN ANNUAL NUMBER OF DAYS WITH MAXIMUM TEMPERATURE > 95F  
Daily\_CMIP3 multi-model mean (2041–2070 minus 1971–2000), SRES A2



**Large increases in the number of 95F days in much of U.S. by mid-century under a high emissions scenario**

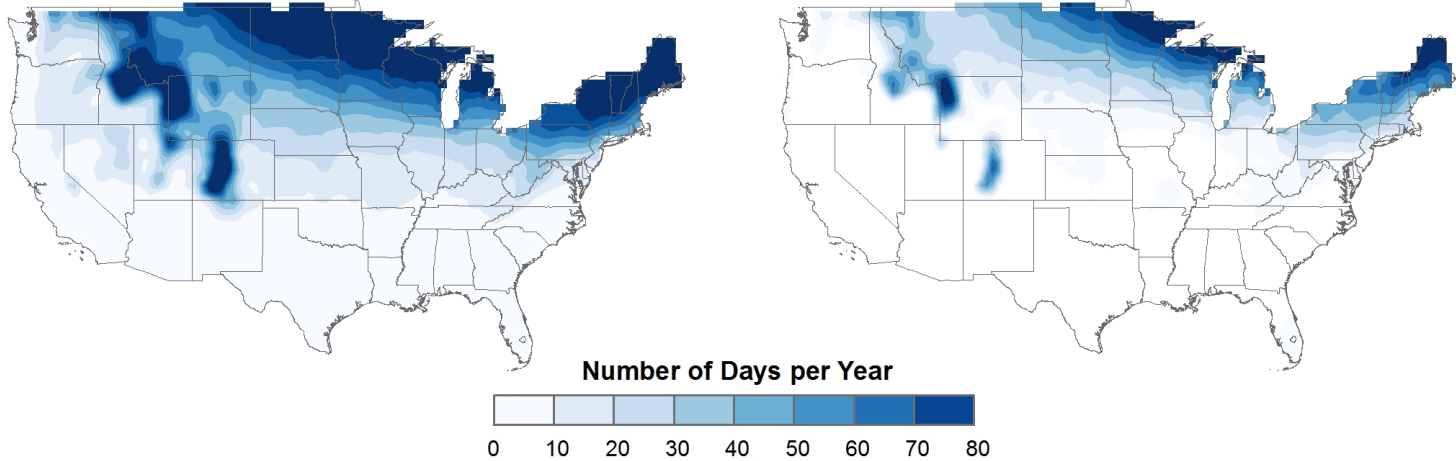
# NARCCAP, SRES A2, ANNUAL NUMBER OF DAYS TMIN < 10F

Multi-Model Mean Simulated Difference (2041-2070 minus 1980-2000)



Climatology (1980-2000)

Multi-Model Mean Simulation (2041-2070)



Large decrease in the number of cold days (<10F) by mid-century under a high emissions scenario

# Confidence in Projected Extreme Temperatures

- High
- Why? Because there is high confidence about **increases in mean temperature** and to a first approximation climate models simulate similar changes in extreme temperatures

# New Directions

- More insights:
  - shift in mean vs mean shifts plus changes in width of distribution
- Blocking
  - Will there be changes in frequency and duration of blocking episodes?
- Acclimatization and adaptation



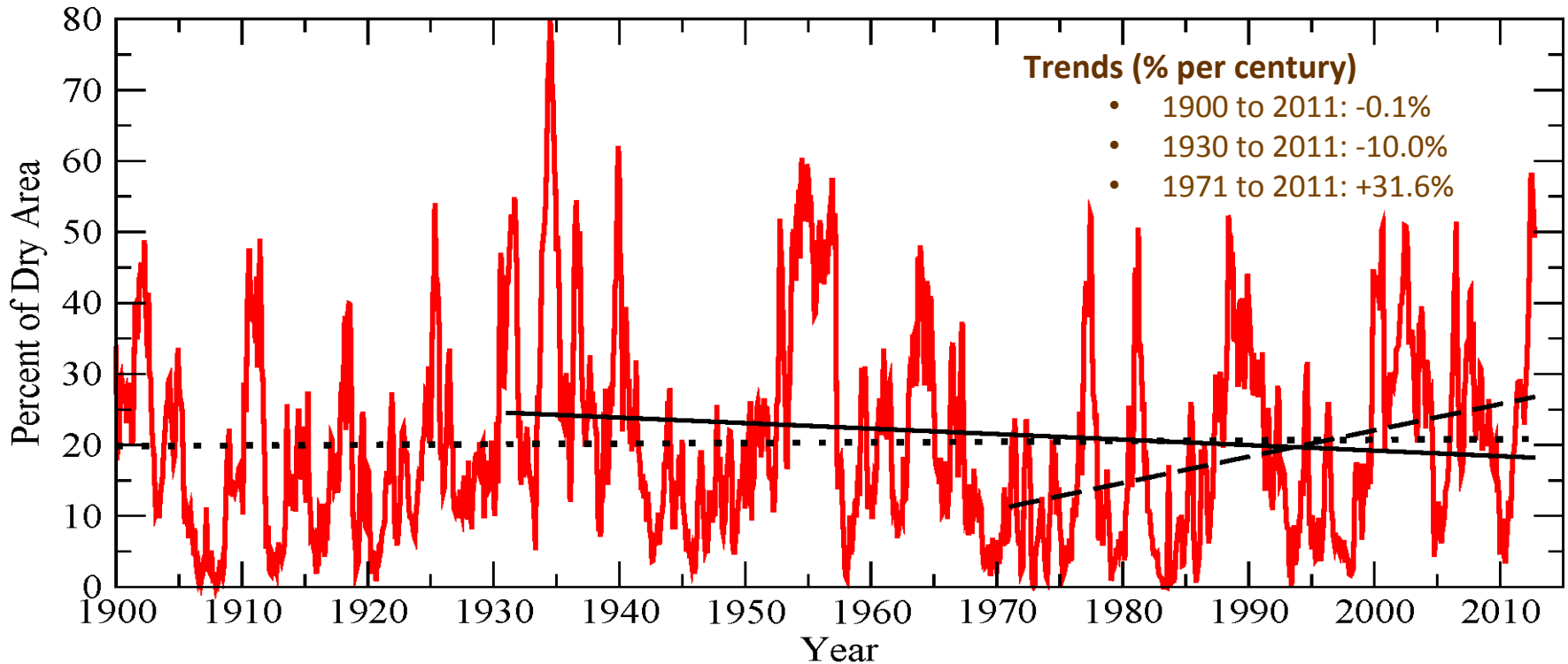
# Drought

- No national average trend in areal coverage of severe to extreme drought
- Upward trend in western U.S.

# Drought

## Percent of U.S. Area in Moderate to Extreme Drought

January 1900 to October 2012

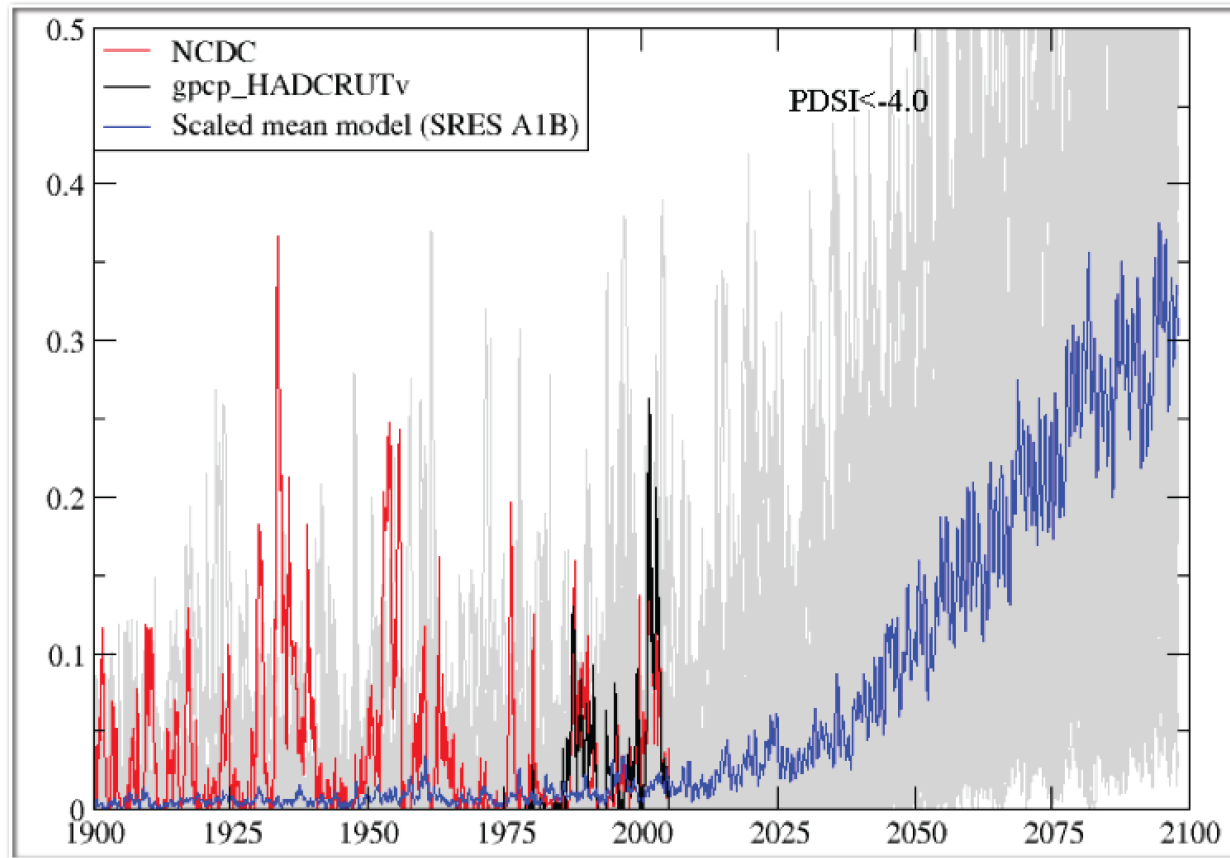


- Widespread persistent drought
  - 1930s (Central and Northern Great Plains, Northwest, Great Lakes)
  - 1950s (Southern Plains, Southwest), 1980s (West, Southeast)
  - First decade of the 21st century (West, Southeast)

# Drought

- Increased temperature leads to increased evaporation rates and tendency toward decreased soil moisture

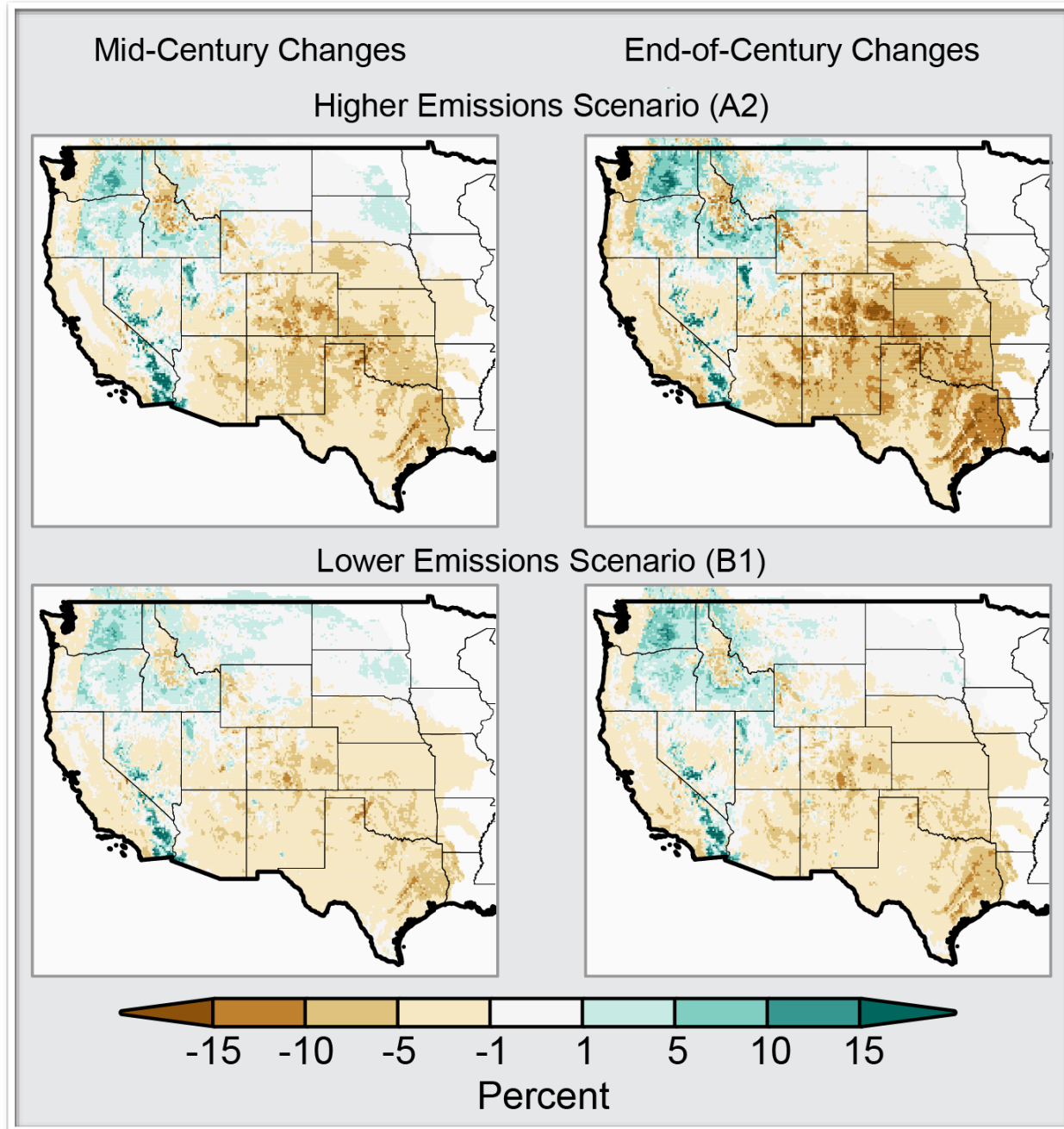
## Extreme Drought in the U.S. and Mexico, Past and Future



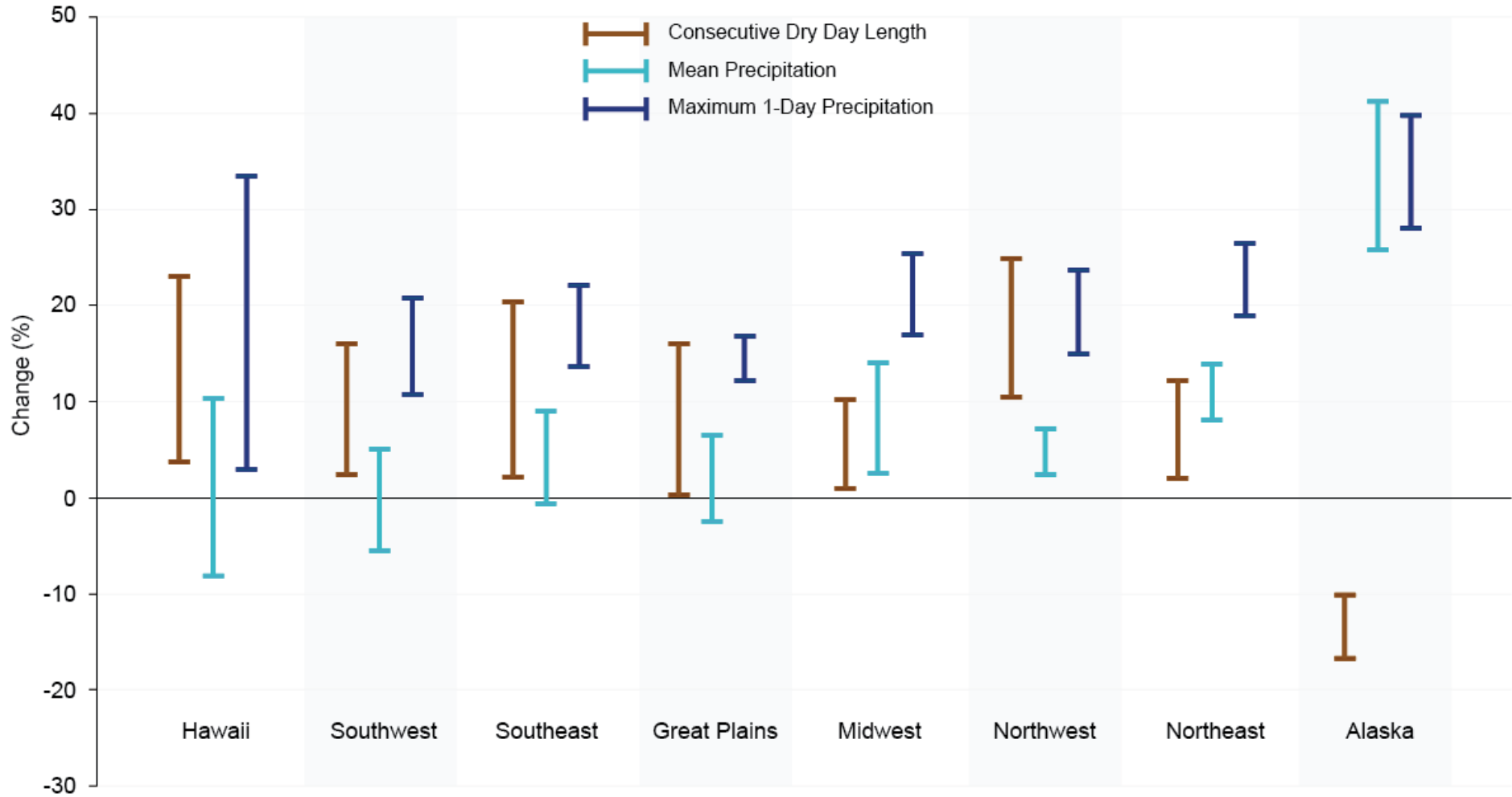
From Wehner, M., D.R. Easterling, J.H. Lawrimore, R.R. Heim Jr, R.S. Vose, and B.D. Santer, 2011: Projections of Future Drought in the Continental United States and Mexico. *Journal of Hydrometeorology*, **12**, 1359-1377 doi: 10.1175/2011JHM1351.1 [Available online at <http://journals.ametsoc.org/doi/abs/10.1175/2011JHM1351.1>]

# Pattern of Projected Changes in Soil Moisture

Average soil moisture is projected to decline almost everywhere in the western U.S., even in some places where mean annual precipitation increase. This is due to increased evaporation from warmer temperatures



Change in Simulated CMIP5 Precipitation (Middle 50% of Models)  
RCP 8.5, 2070-2099 minus 1971-1999



Mean annual precipitation changes are small in many regions. However, both extreme precipitation and dryness increase in all regions.

# Confidence in Projected Extreme Drought

- Medium
- Why? Because there is high confidence about **increases in mean temperature** and this will lead to increases in evaporation and **decreases in soil moisture**. But there is low confidence in changes in precipitation over much of U.S.

# New Directions

- Traditional drought indices not ideal for use in characterizing future drought
  - Overly **sensitive to temperature** changes
  - They are designed under a **stationary climate** assumption
  - Use of current climate as a baseline may paint a distorted view of future
- New methods of characterizing future drought would support better assessment of impacts



# Key Messages

- Incorporation of highly confident projections into decisions and designs
- More useful assessments of flood and drought projections
- Progress on severe thunderstorm phenomena likely to be slow