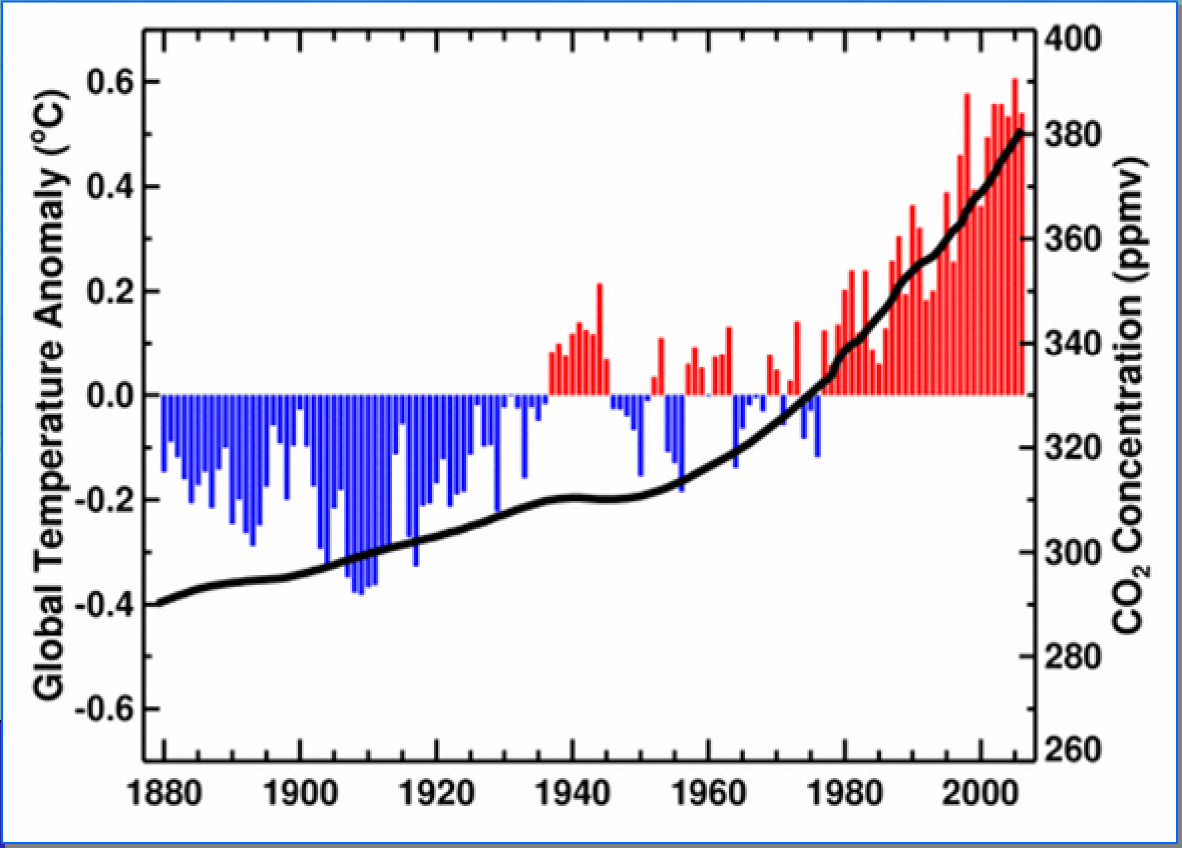
Weather & Climate Extremes in a Changing Climate

Great Lakes Environmental Research Lab
Ann Arbor, Michigan

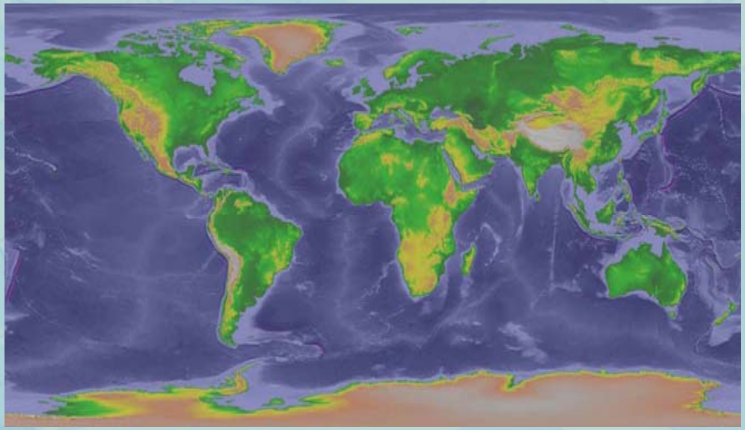


Tom Karl, L.H.D

Director, NOAA's National Climatic Data Center
Asheville, North Carolina

Weather and Climate Extremes in a Changing Climate

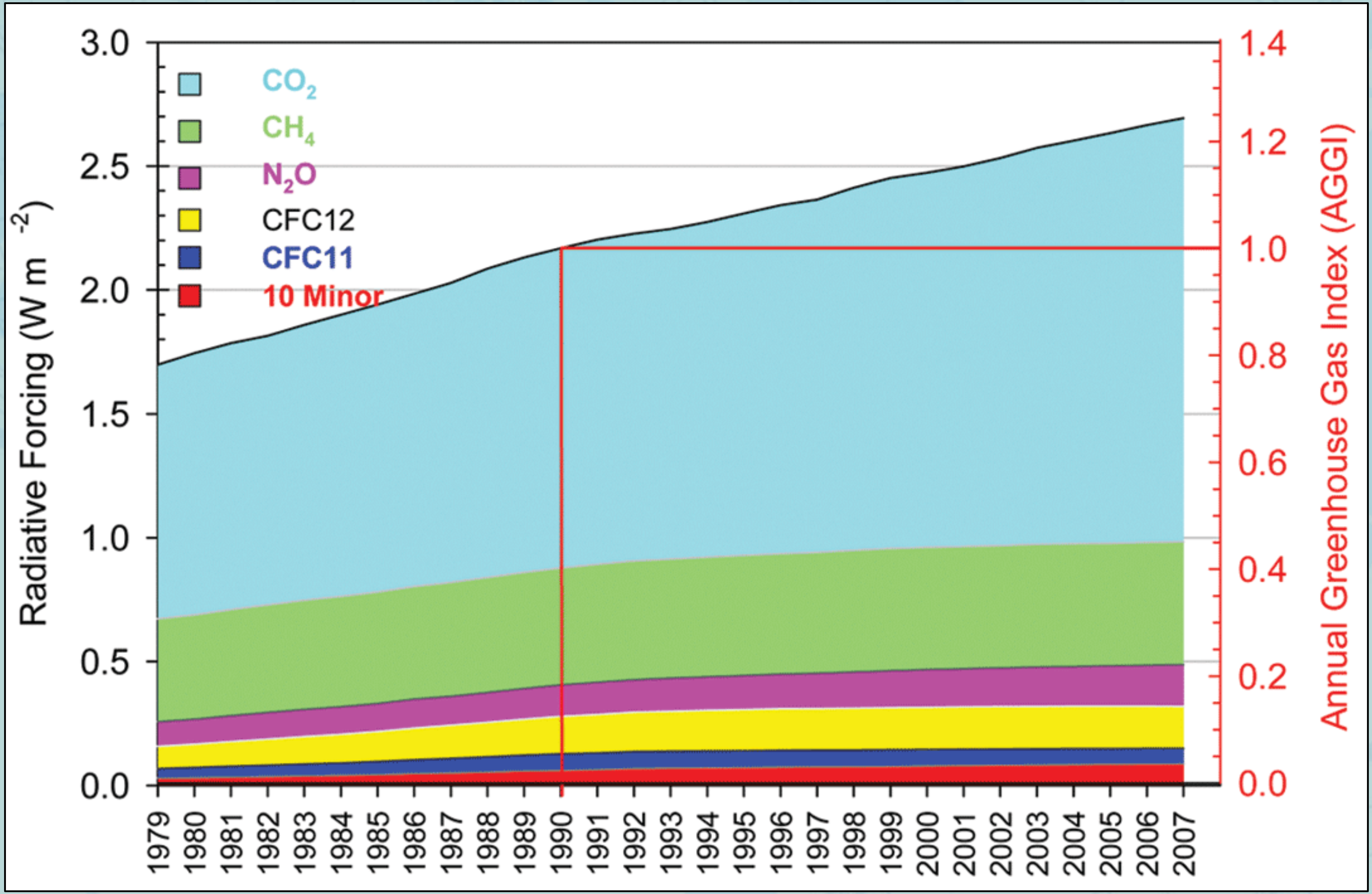
1) Background
   A) Forcings
   B) Temperature
   C) Precipitation
   D) Sea level rise
   E) Sea Ice
   F) Greenland
   G) Snow cover Extent



2) North America Extremes (CCSP 3.3)
   A) Temperature
   B) Precipitation
   C) Drought
   D) Hurricanes
   E) Other Storms

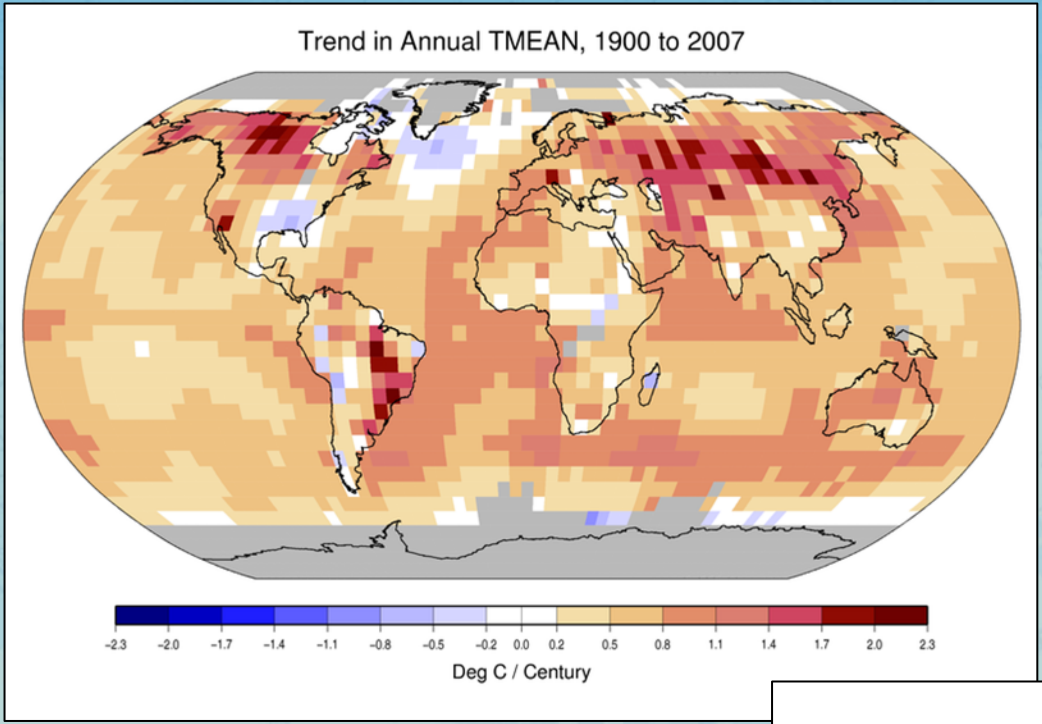
3) Reducing Uncertainty

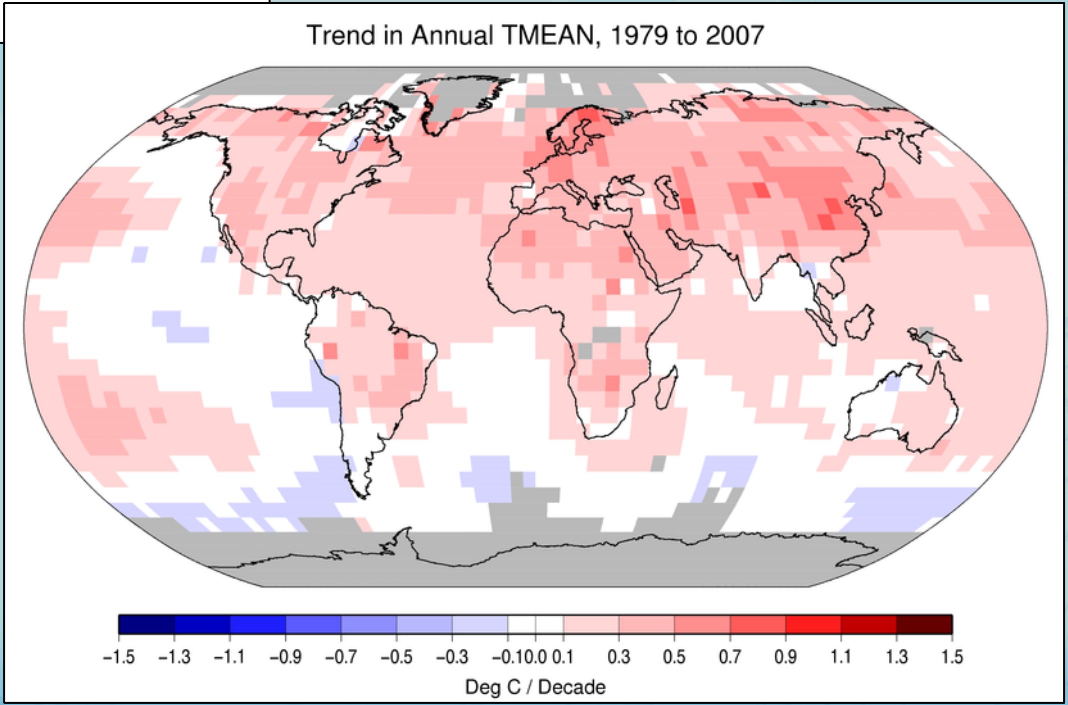
The NOAA Annual Greenhouse Gas Index (AGGI)



Calculated from the total direct radiative forcing normalized to 1990, the baseline year of the Kyoto Protocol (*Source: D. Hoffman, NOAA/ESRL*)

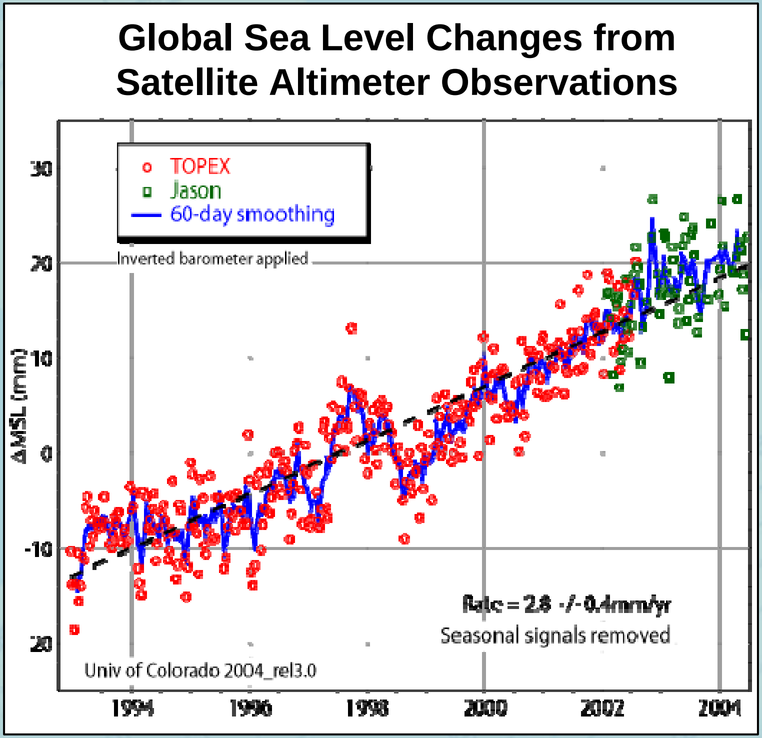
Spatially Varying Trends





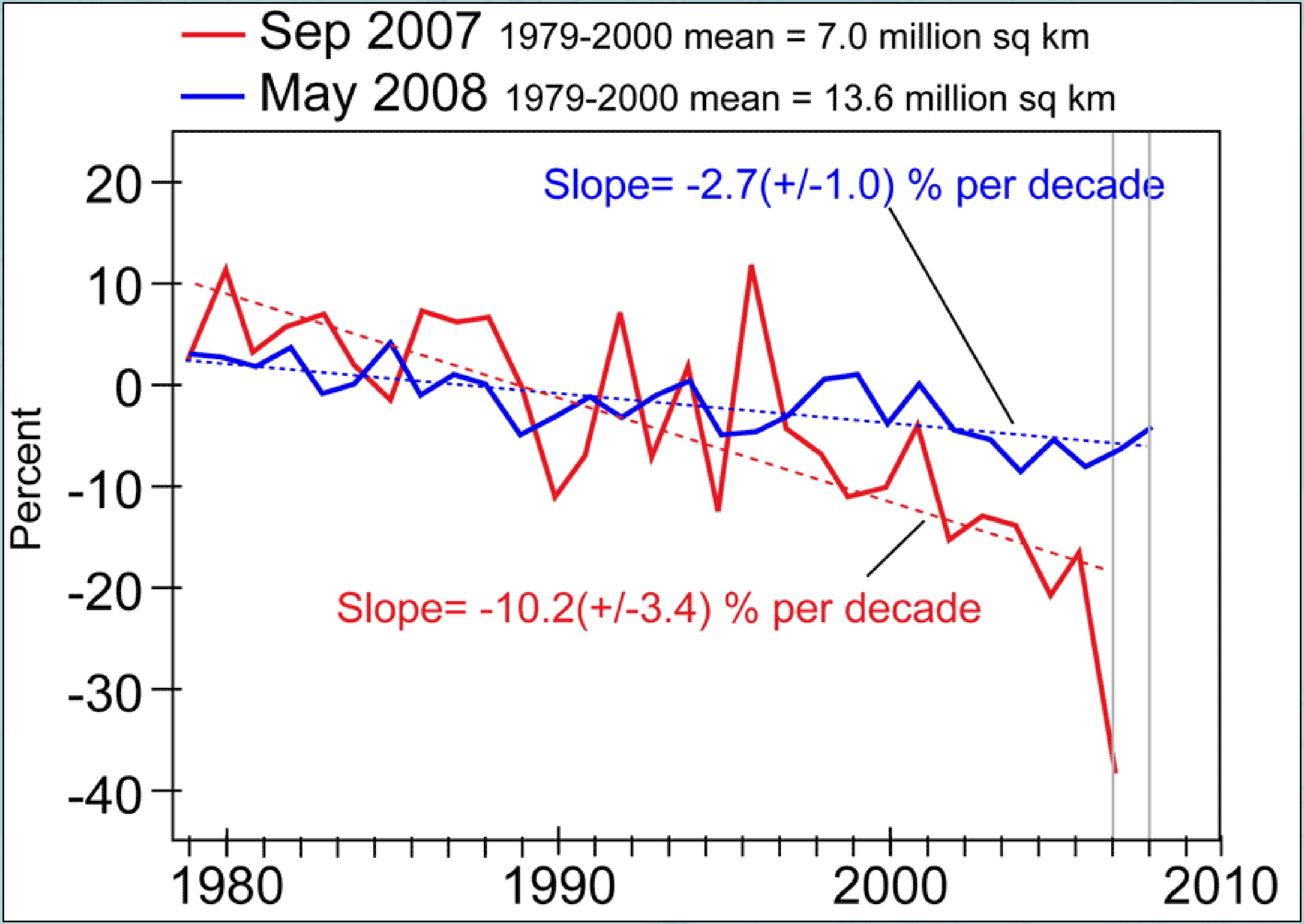
Sea-Level Rise

- **Geographical patterns similar to upper ocean heat content change**
  - Suggests that regional sea level changes are largely controlled by thermal processes
  - Additional trend is likely due to melting of grounded ice on Greenland and/or Antarctica

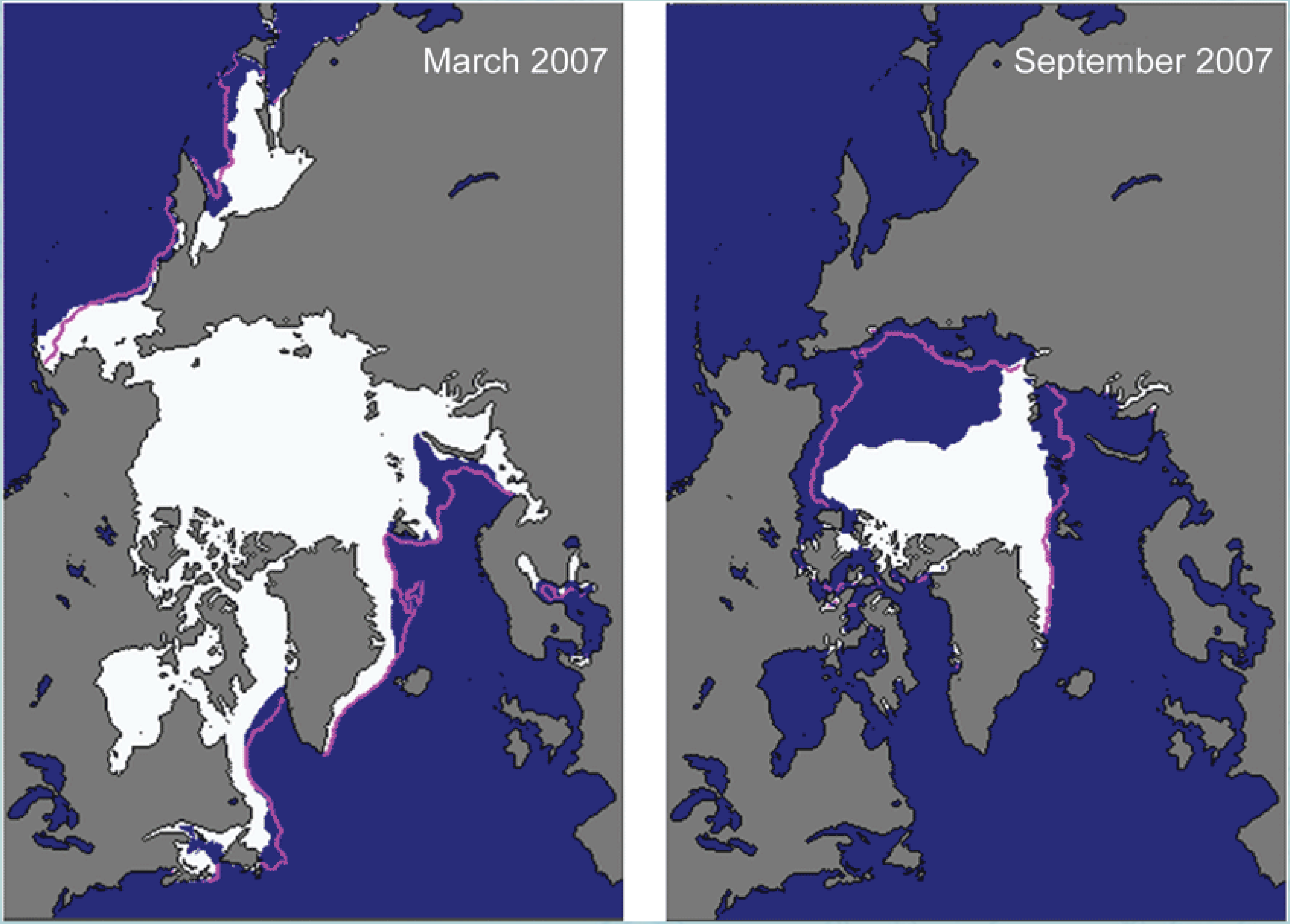


- **Trend is significantly higher than 20th century rate of 1.8 ±0.3 mm from tide gauge measurements over the past 50-100 years**
  - Is this part of a longer-term trend or just decadal variability?

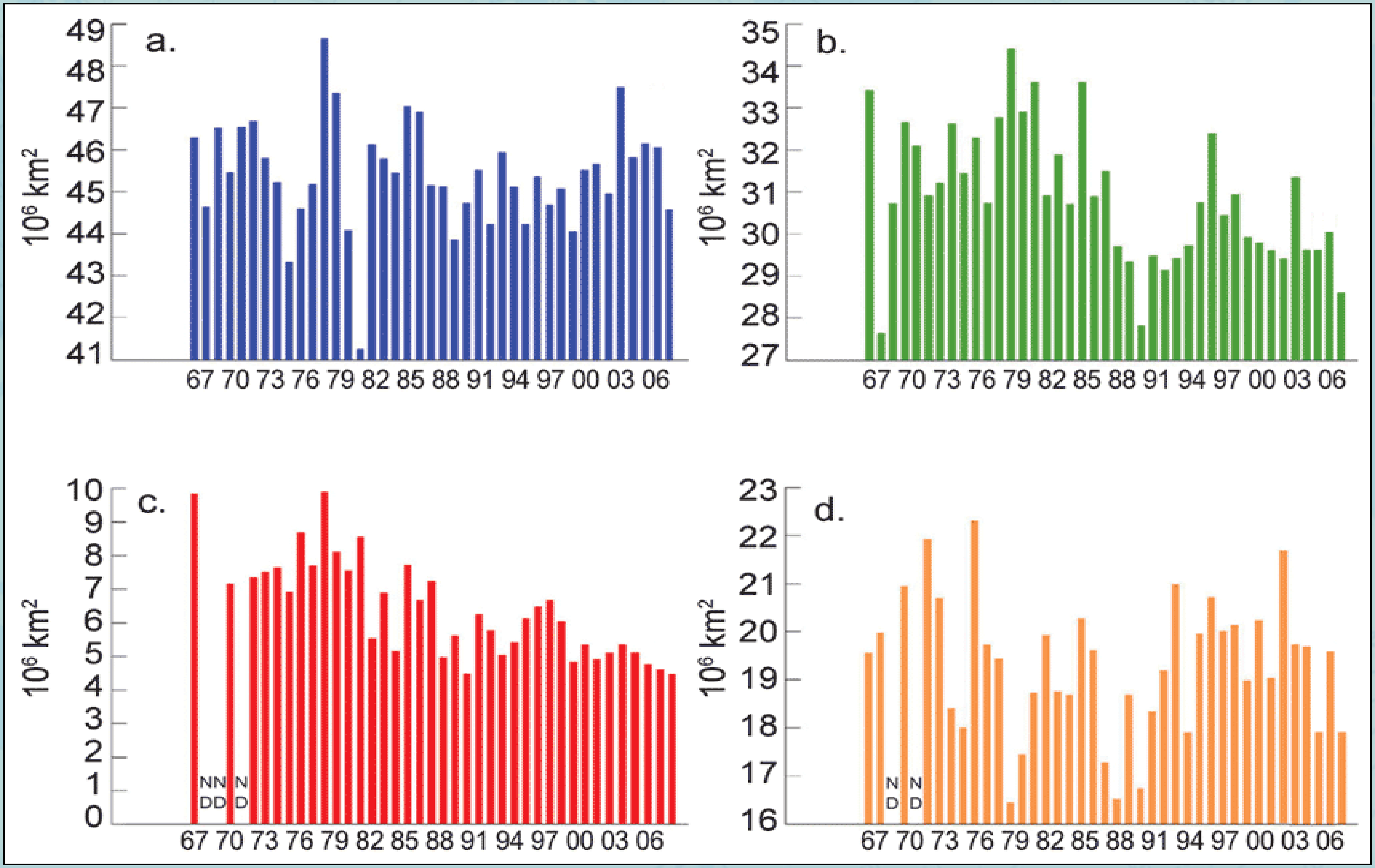
Arctic Sea Ice Extent



Sea ice extent in March 2007 and September 2007

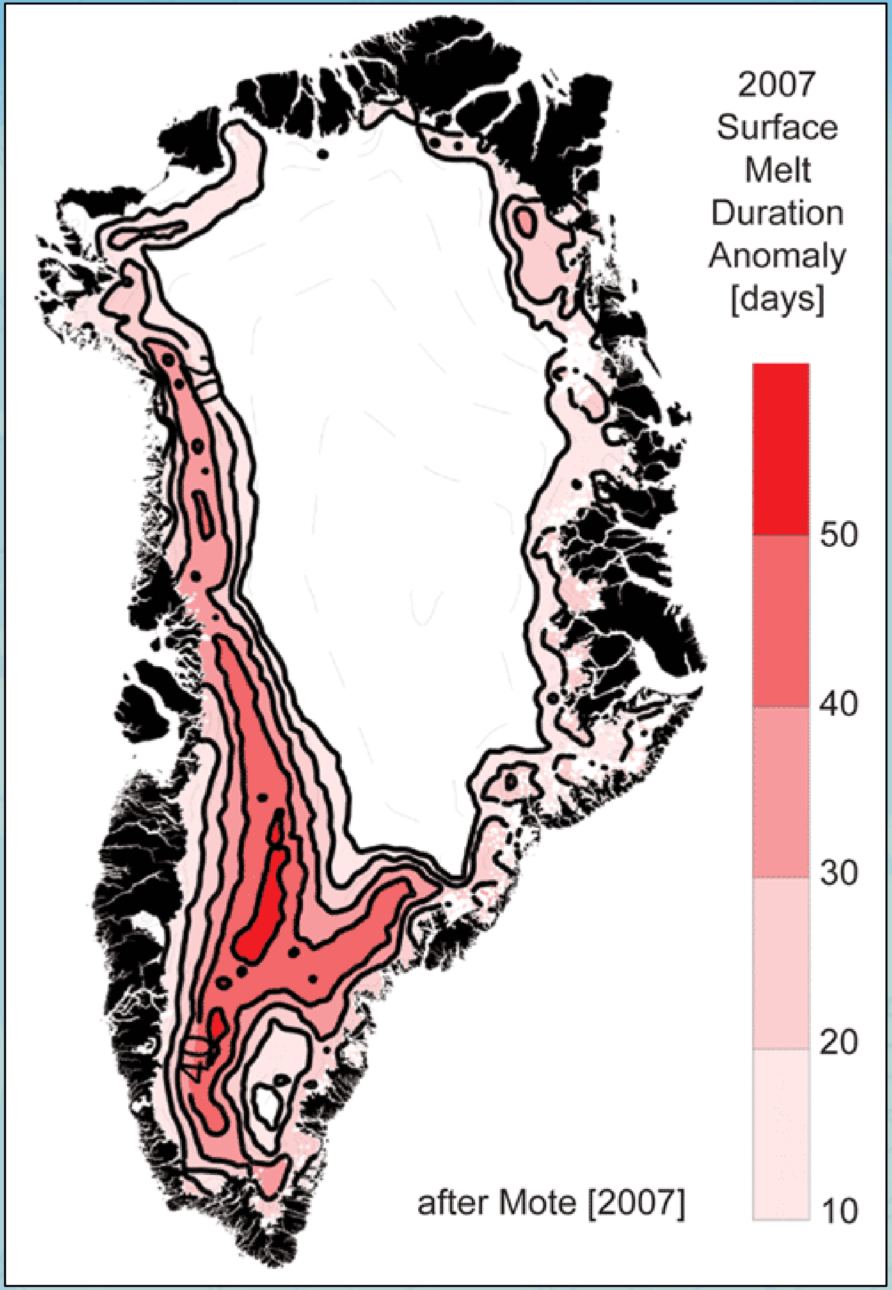


Extent of (a) winter (DJF), (b) spring (MAM), (c) summer (JJA), and (d) autumn (SON) seasonal snow cover over Northern Hemisphere lands (including Greenland).



Surface melt duration departure from average for summer (Jun-Aug) 2007 from SSM/I; units are days.

The average is based on the summers from 1973-2000 (excluding 1975, 1977 and 1978).



North America

Observed changes in North American extreme events, assessment of human influence for the observed changes, and likelihood that the changes will continue through the 21st century[1].

Phenomenon and direction of change	Where and when these changes occurred in past 50 years	Linkage of human activity to observed changes	Likelihood of continued future changes in this century
Warmer and fewer cold days and nights	Over most land areas, the last 10 years had lower numbers of severe cold snaps than any other 10-year period	Likely warmer extreme cold days and nights, and fewer frosts[2]	Very likely[4]
Hotter and more frequent hot days and nights	Over most of North America	Likely for warmer nights[2]	Very likely[4]
More frequent heat waves and warm spells	Over most land areas, most pronounced over northwestern two thirds of North America	Likely for certain aspects, e.g., night-time temperatures; & linkage to record high annual temperature[2]	Very likely[4]
More frequent and intense heavy downpours and higher proportion of total rainfall in heavy precipitation events	Over many areas	Linked indirectly through increased water vapor, a critical factor for heavy precipitation events[3]	Very likely[4]
Increases in area affected by drought	No overall average change for North America, but regional changes are evident	Likely, Southwest USA.[3] Evidence that 1930's & 1950's droughts were linked to natural patterns of sea surface temperature variability	Likely in Southwest U.S.A., parts of Mexico and Carribean[4]
More intense hurricanes	Substantial increase in Atlantic since 1970; Likely increase in Atlantic since 1950s; increasing tendency in W. Pacific and decreasing tendency in E. Pacific (Mexico West Coast) since 1980[5]	Linked indirectly through increasing sea surface temperature, a critical factor for intense hurricanes[5]; a confident assessment requires further study[3]	Likely[4]

[1]Based on frequently used family of IPCC emission scenarios
[2]Based on formal attribution studies and expert judgment
[3]Based on expert judgment
[4]Based on model projections and expert judgment
[5]As measured by the Power Dissipation Index (which combines storm intensity, duration and frequency)

TEMPERATURE EXTREMES

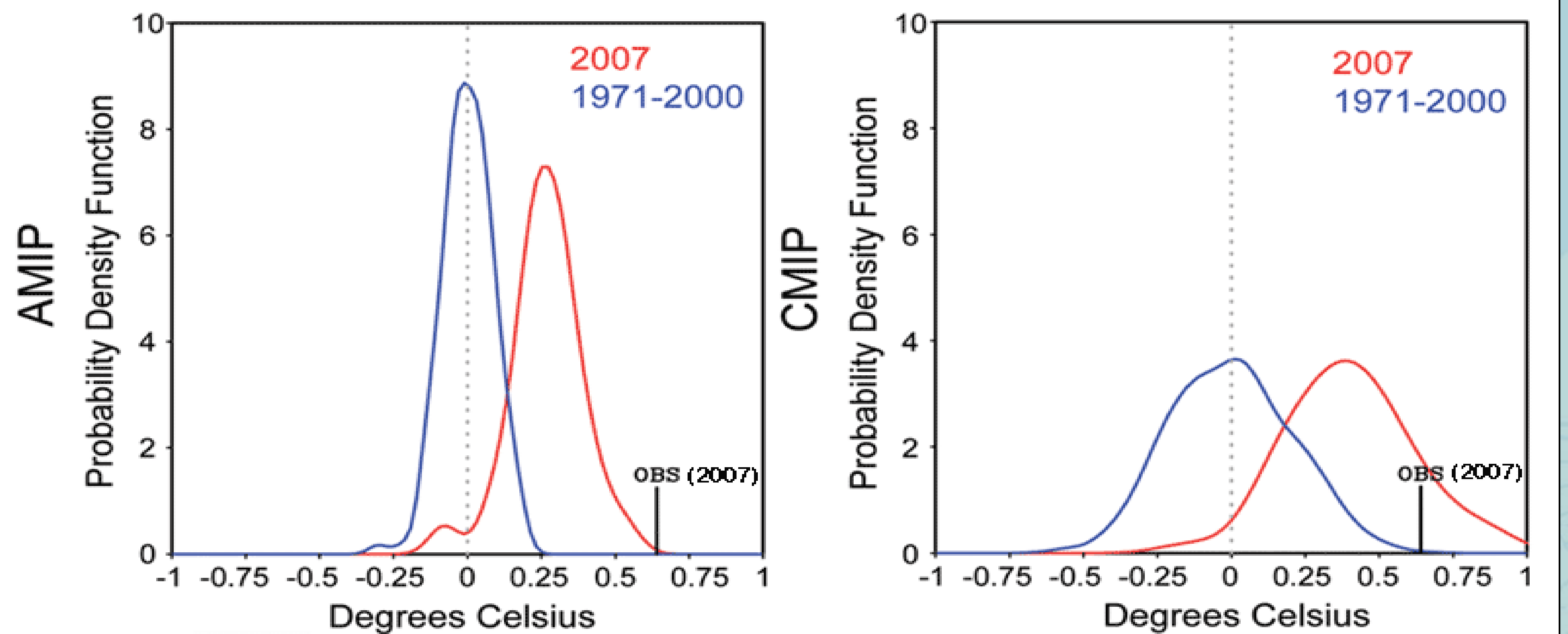
Observed Changes

- Since the record hot year of 1998, six of the last ten years (1998-2007) have had annual average temperatures that fall in the hottest 10% of all years on record for the U.S.
- Over recent decades:
  - Most of North America is experiencing more unusually hot days and nights. (since 1950 – best coverage)
- The number of heat waves (extended periods of extremely hot weather) has been increasing…but,
  - Heat waves of the 1930s (*e.g.*, daytime temperatures) remain the most severe in the U.S. historical record.
- There have been fewer unusually cold days during the last few decades.
  - The last 10 years have seen fewer severe cold waves than for any other 10-year period in the historical record, which dates back to 1895.
  - There has been a decrease in frost days and a lengthening of the frost-free season.

TEMPERATURE EXTREMES

Attribution of Changes

Probability distribution functions (PDFs) of the globally averaged 2007 annual land surface temperature

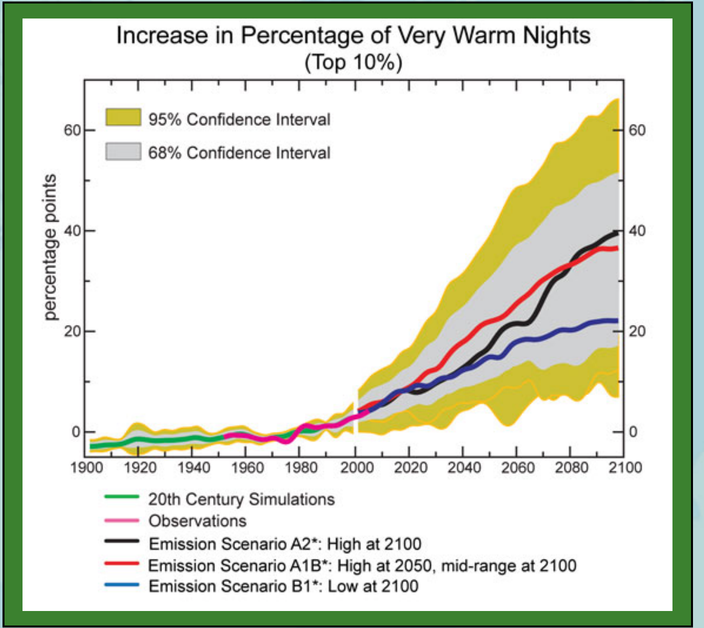


(Source: NOAA CSI Team)

TEMPERATURE EXTREMES

Projected Changes

- Abnormally hot days and nights, and heat waves are very likely to become more frequent.
- Cold days and cold nights are very likely to become much less frequent.
- The number of days with frost is very likely to decrease.
- Increase in the % of days in a year over North America in which the daily low temperature is unusually warm (falling in the top 10% of annual daily lows).
- Sea ice extent is expected to continue to decrease increasing extreme episodes of coastal erosion in Arctic Alaska and Canada.



PRECIPITATION EXTREMES
Observed Changes

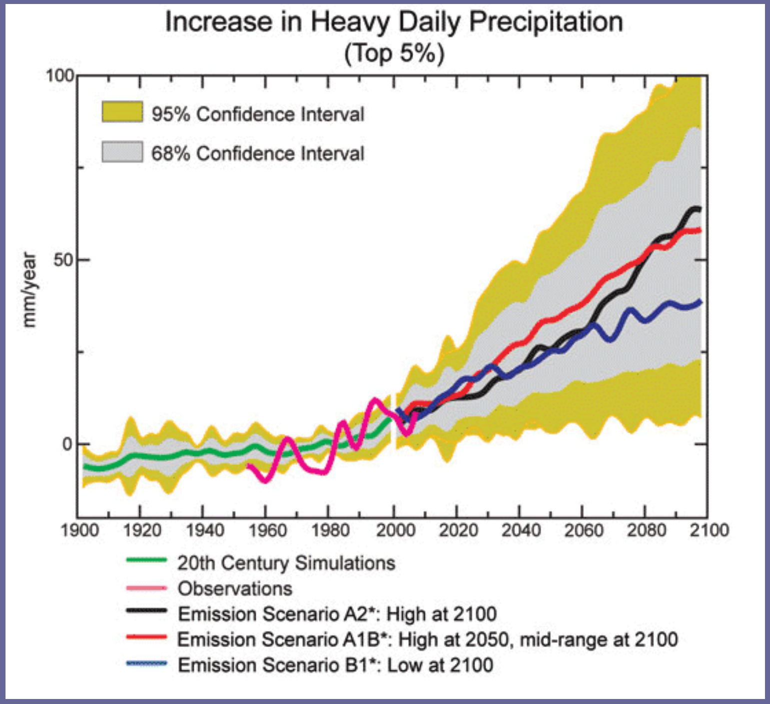
- Heavy downpours have become more frequent and more intense in recent decades over most of North America and now account for a larger percentage of total precipitation.
  - Intense precipitation events (the heaviest 1%) in the continental U.S. increased by 20% over the past century while total precipitation increased by 7%.

- North American Monsoon
  - The season is beginning about 10 days later than usual in Mexico.
  - In the SW, there are fewer rain events, but the events are more intense.

PRECIPITATION EXTREMES

Attribution of Changes

The increase in precipitation intensity is consistent with the observed increases in atmospheric water vapor (linked to human-induced increases in greenhouse gases).

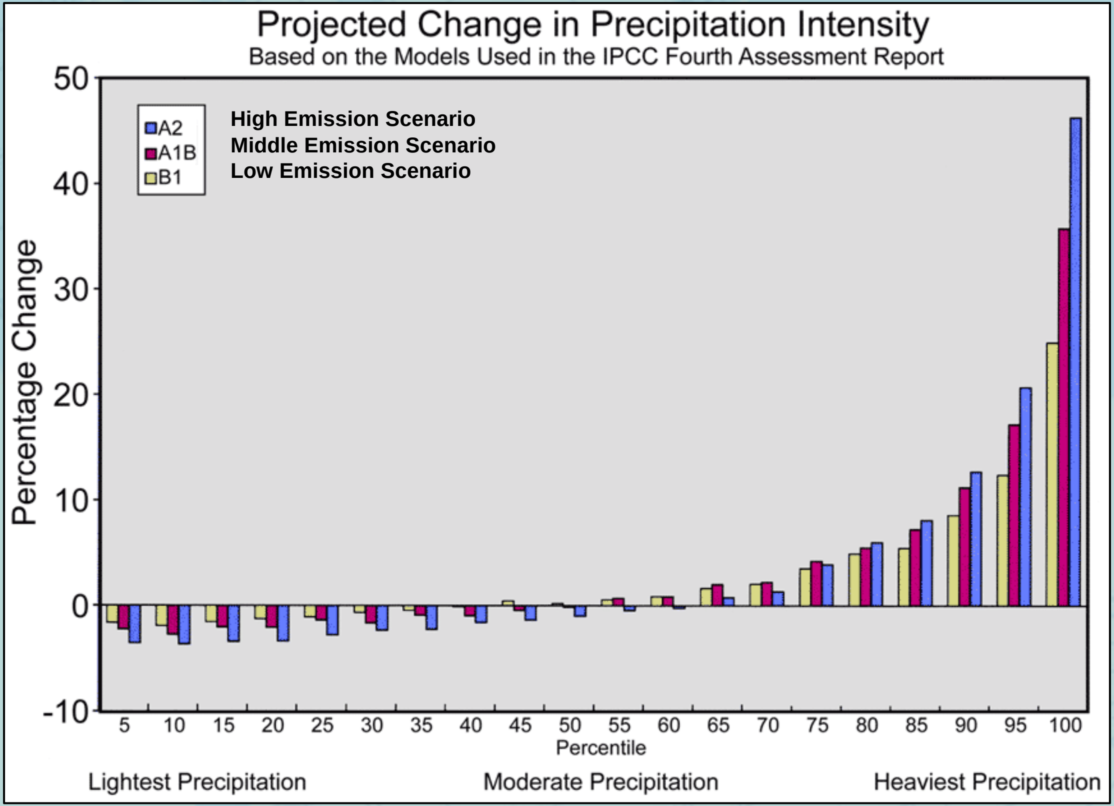


Increase in the amount of daily precipitation over North America that falls in heavy events

PRECIPITATION EXTREMES

Projected Changes

- The lightest precipitation is projected to decrease.
- The heaviest precipitation is projected to increase strongly.
- Higher greenhouse gas emission scenarios produce larger changes in extreme precipitation.

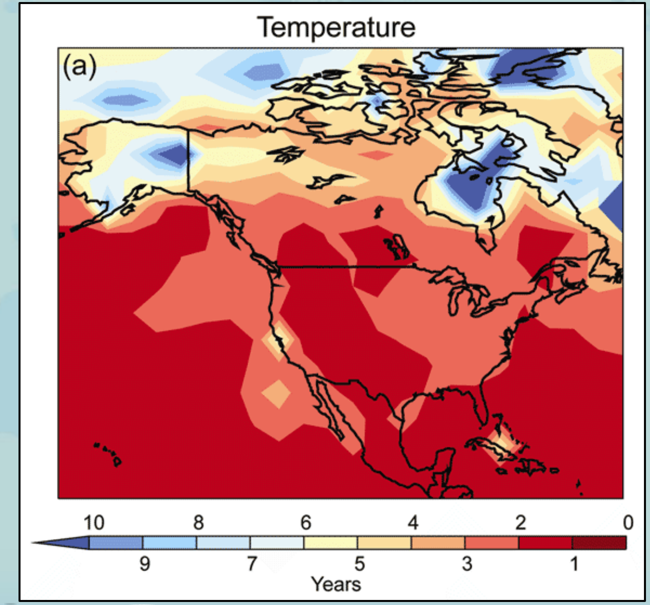


TEMPERATURE & PRECIPITATION

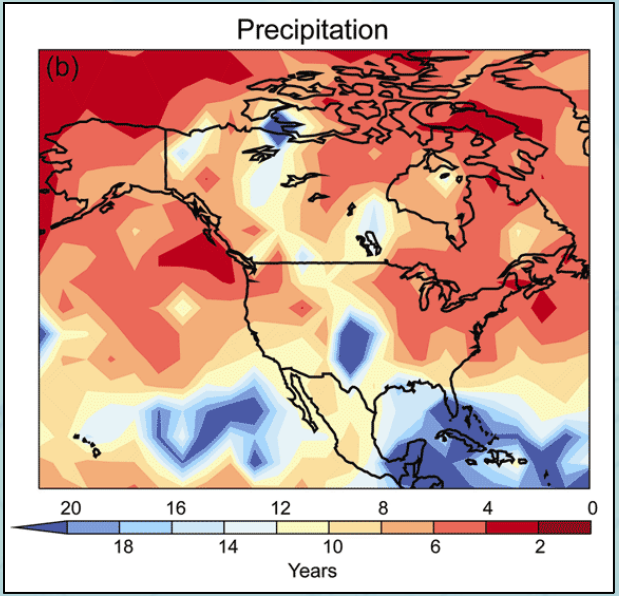
Projected Changes

Hot days currently experienced once every 20 years would occur every other year or more by the end of the century

Daily total precipitation events that occur on average every 20 years would occur once every 4-6 years for NE North America

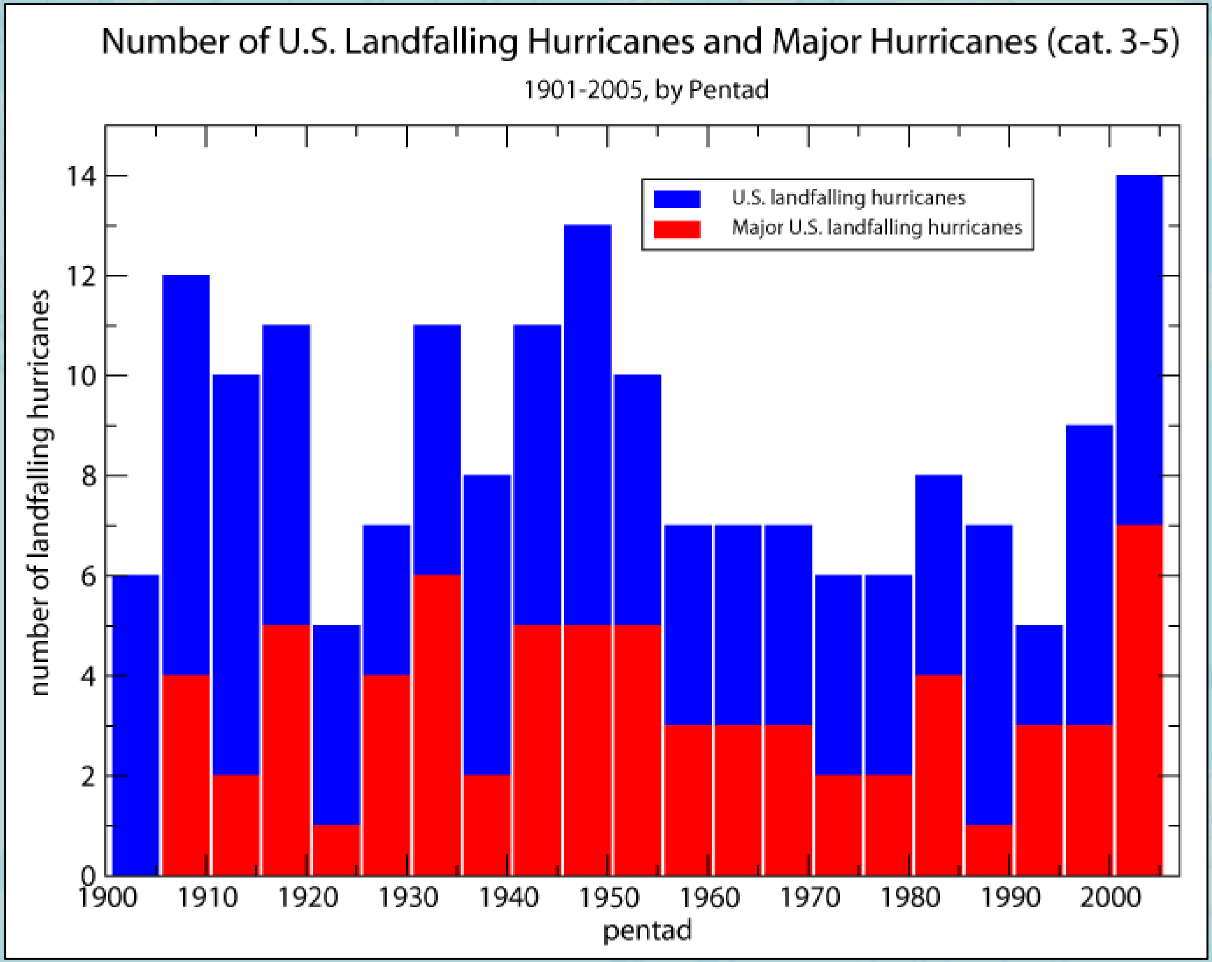


Simulations for 2090-2099 indicating how currently rare extremes (1 in 20 year event) are projected to become more commonplace



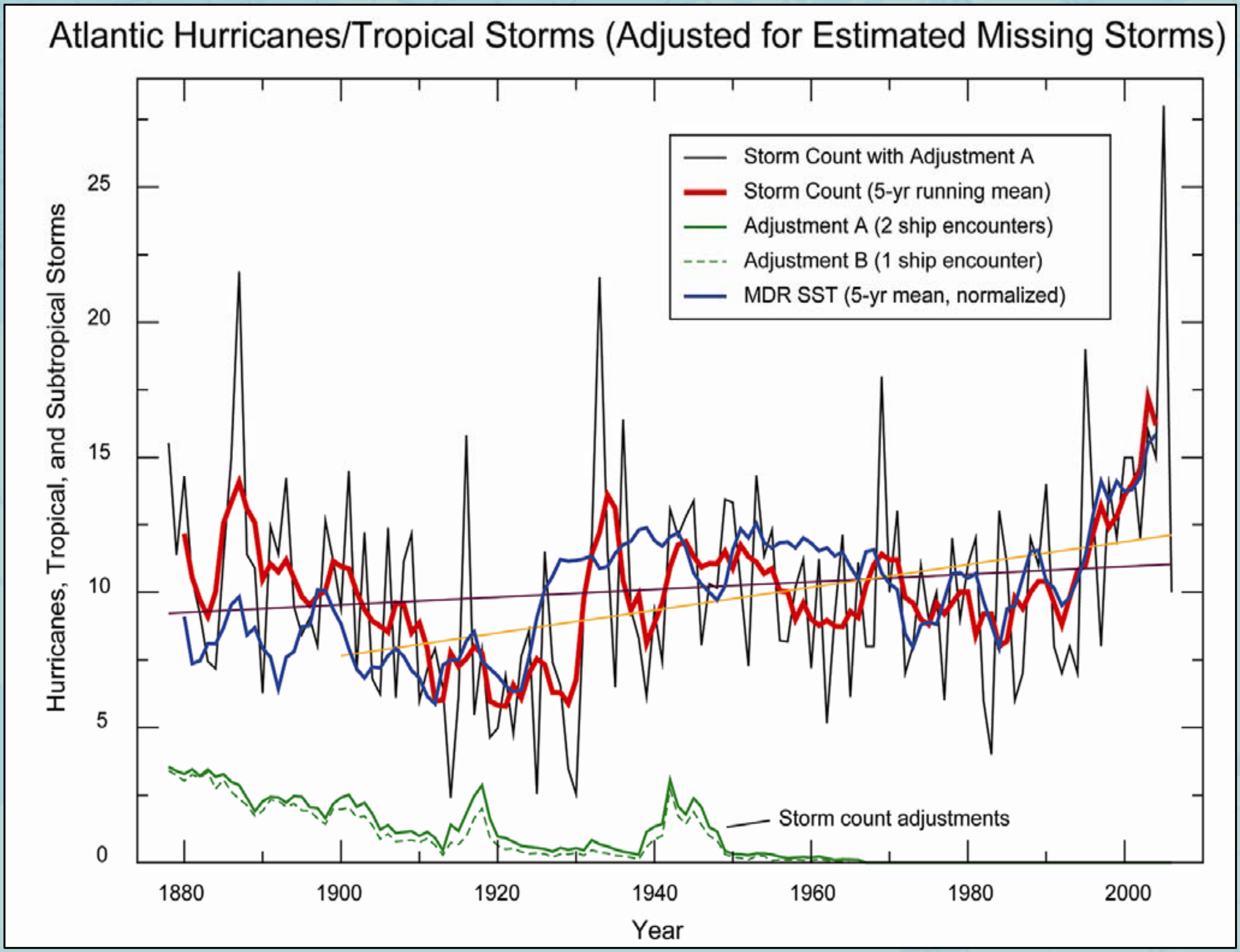
STORMS & HURRICANES

Observed Changes



STORMS & HURRICANES

Observed Changes



Atlantic hurricanes and tropical storms for 1878-2006, adjusted for missing storms.

Black curve is adjusted annual storm count,

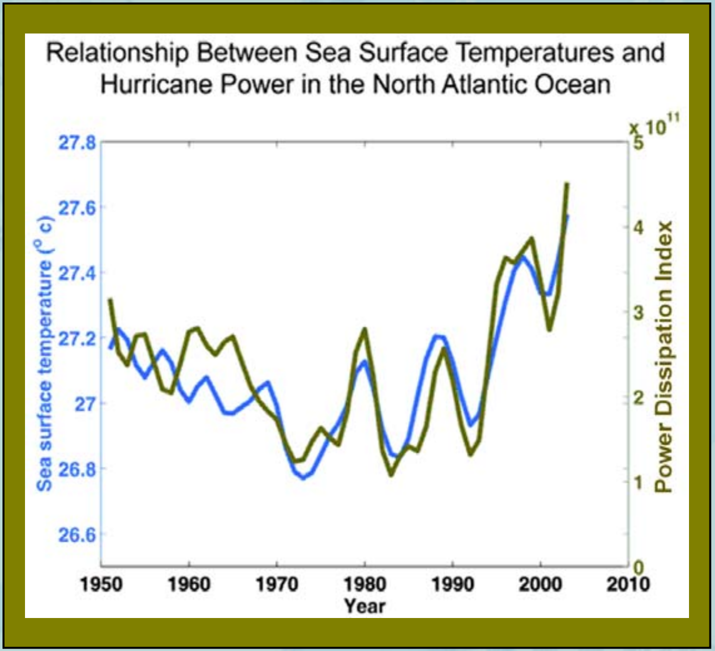
Red curve is 5-year running mean, and

Blue curve is a normalized 5-year running mean SST index for Main Development Region

STORMS & HURRICANES

Attribution of Changes

- It is very likely that the human induced increase in greenhouse gases has contributed to the increase in SSTs in the hurricane formation regions.
- There is a strong statistical connection between tropical Atlantic SSTs and Atlantic hurricane activity.
- This evidence suggests a substantial human contribution to recent hurricane activity.
- However, a confident assessment of human influence on hurricanes will require further studies with models and observations.



Sea surface temperatures (blue) and the Power Dissipation Index (green) for North Atlantic hurricanes

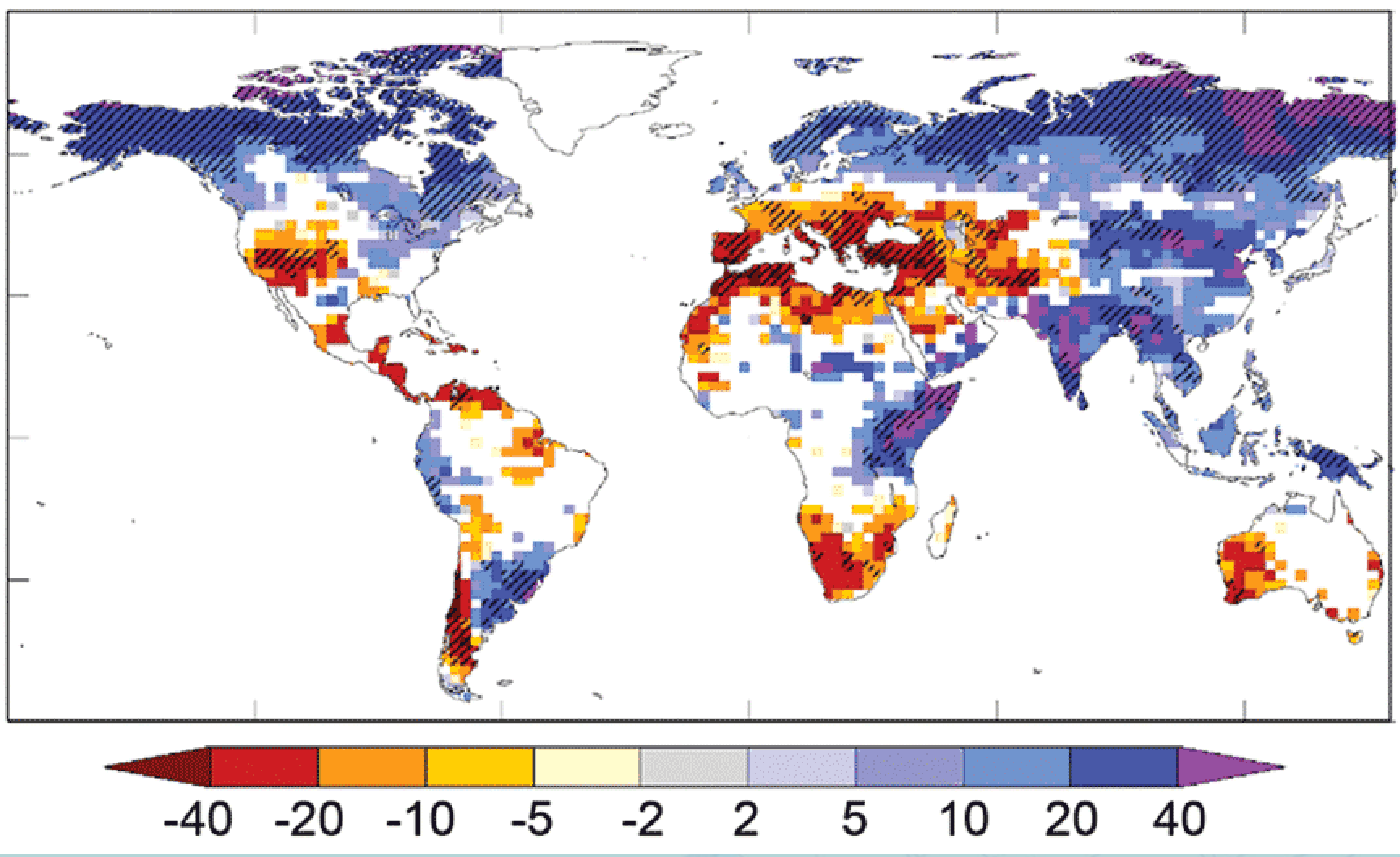
STORMS & HURRICANES

Projected Changes

- It is likely that hurricane rainfall and wind speeds will increase in response to human-caused warming.
- For each 1°C increase in tropical sea surface temperatures, core rainfall rates will increase by 6-18%.
- Surface wind speeds of the strongest hurricanes will increase by about 1-8%.

DROUGHT

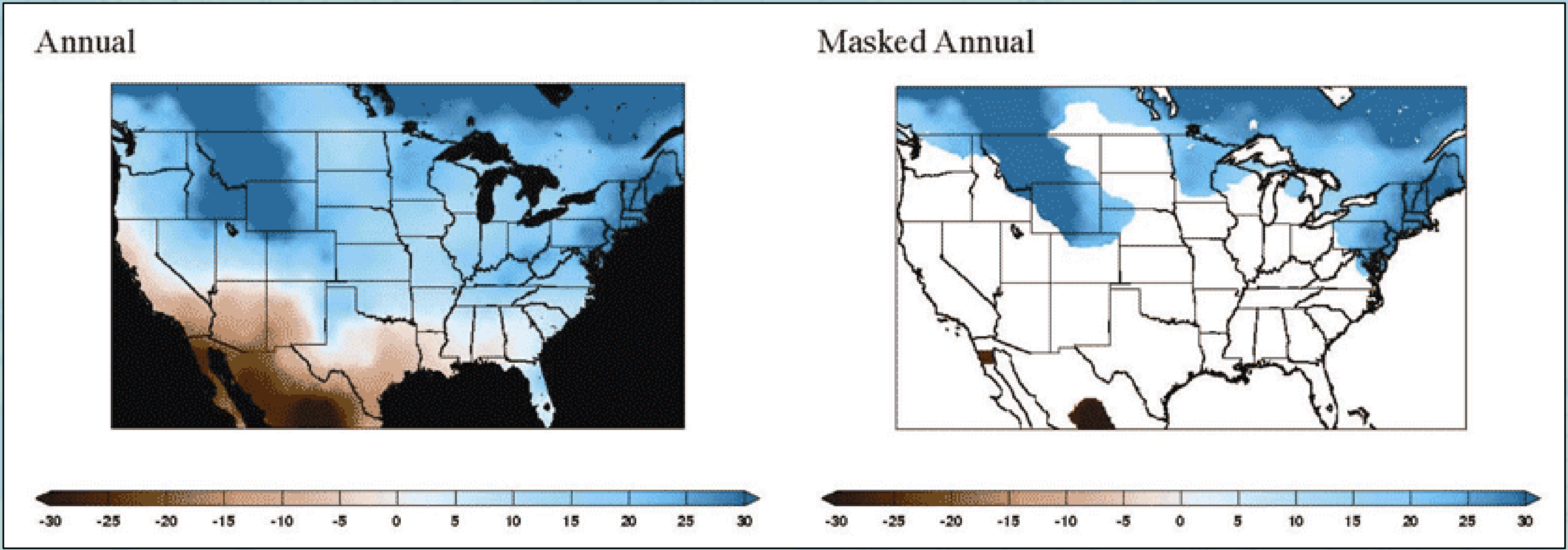
Projected Changes



DROUGHT

Projected Changes

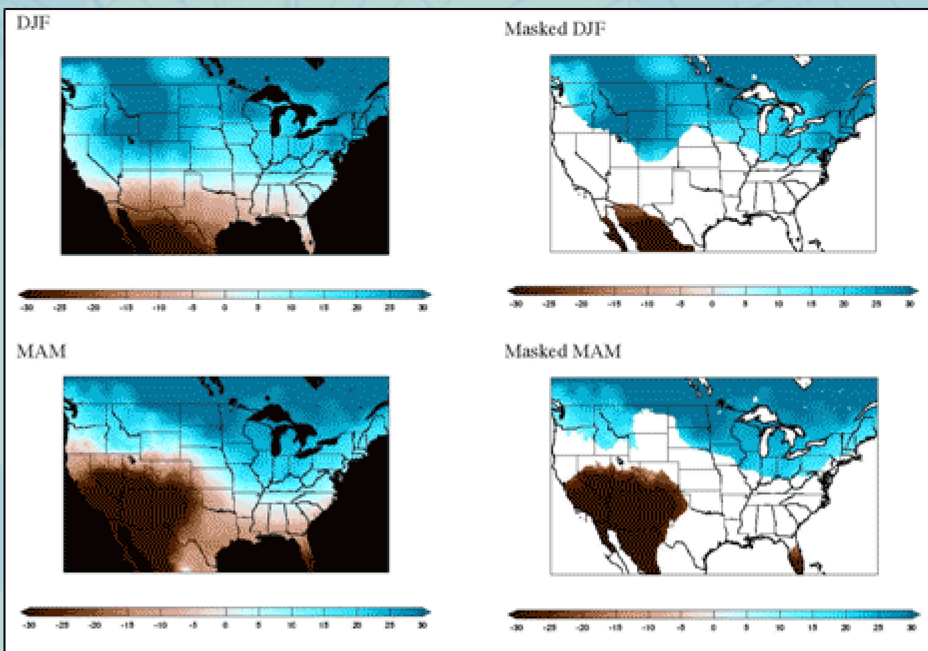
Model Projected Changes (2080-2099) in Precipitation
(Average and regions of model agreement A2 scenario)

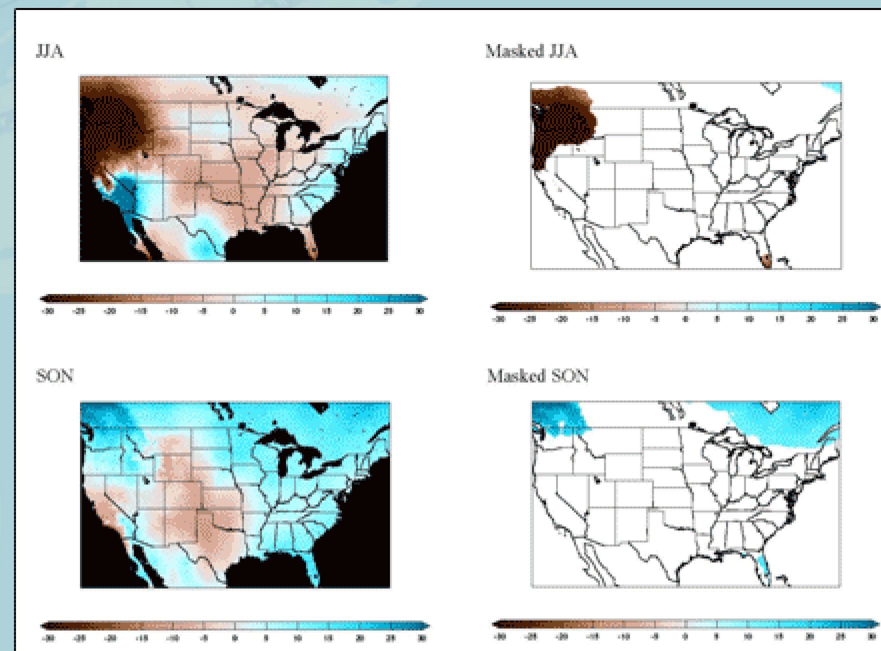


DROUGHT

Projected Changes

Model Projected Changes (2080-2099) in Precipitation
(Average and regions of model agreement A2 scenario)





OTHER STORMS

Observed Changes

Snowstorms

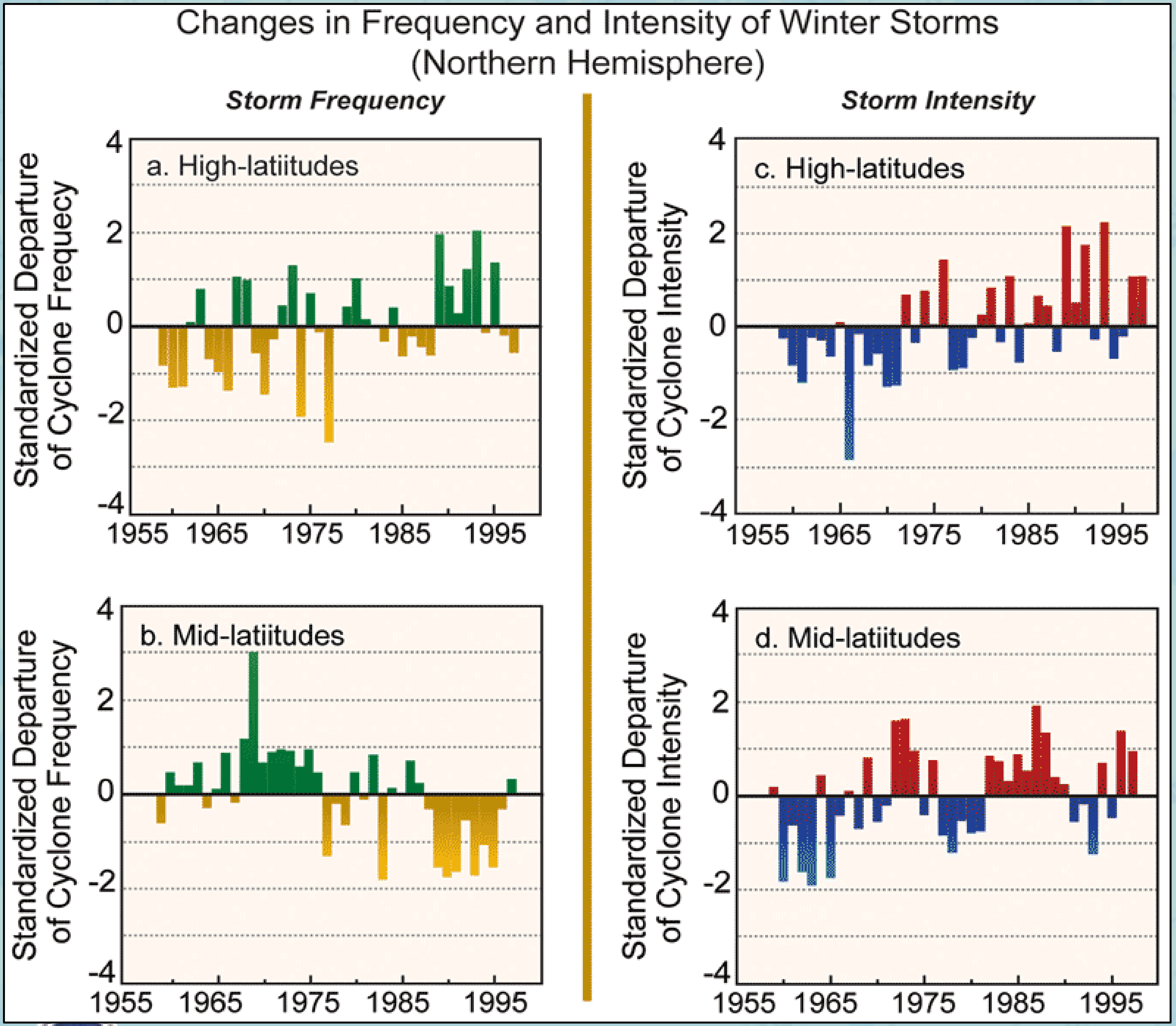
- Over the 20th century, there has been considerable decade-to-decade variability in the frequency of snow storms (6 inches or more) and ice storms.
- There has been a northward shift in snow storm occurrence, and this shift, combined with higher temperature, is consistent with a decrease in snow cover extent over North America.
- In northern Canada, there has also been an observed increase in heavy snow over the same time period.
- Changes in heavy snow events in southern Canada are dominated by decade to decade variability.

Local Severe Weather

- The data used to examine changes in the frequency and severity of tornadoes and severe thunderstorms are inadequate to make definitive statements about actual changes.

OTHER STORMS

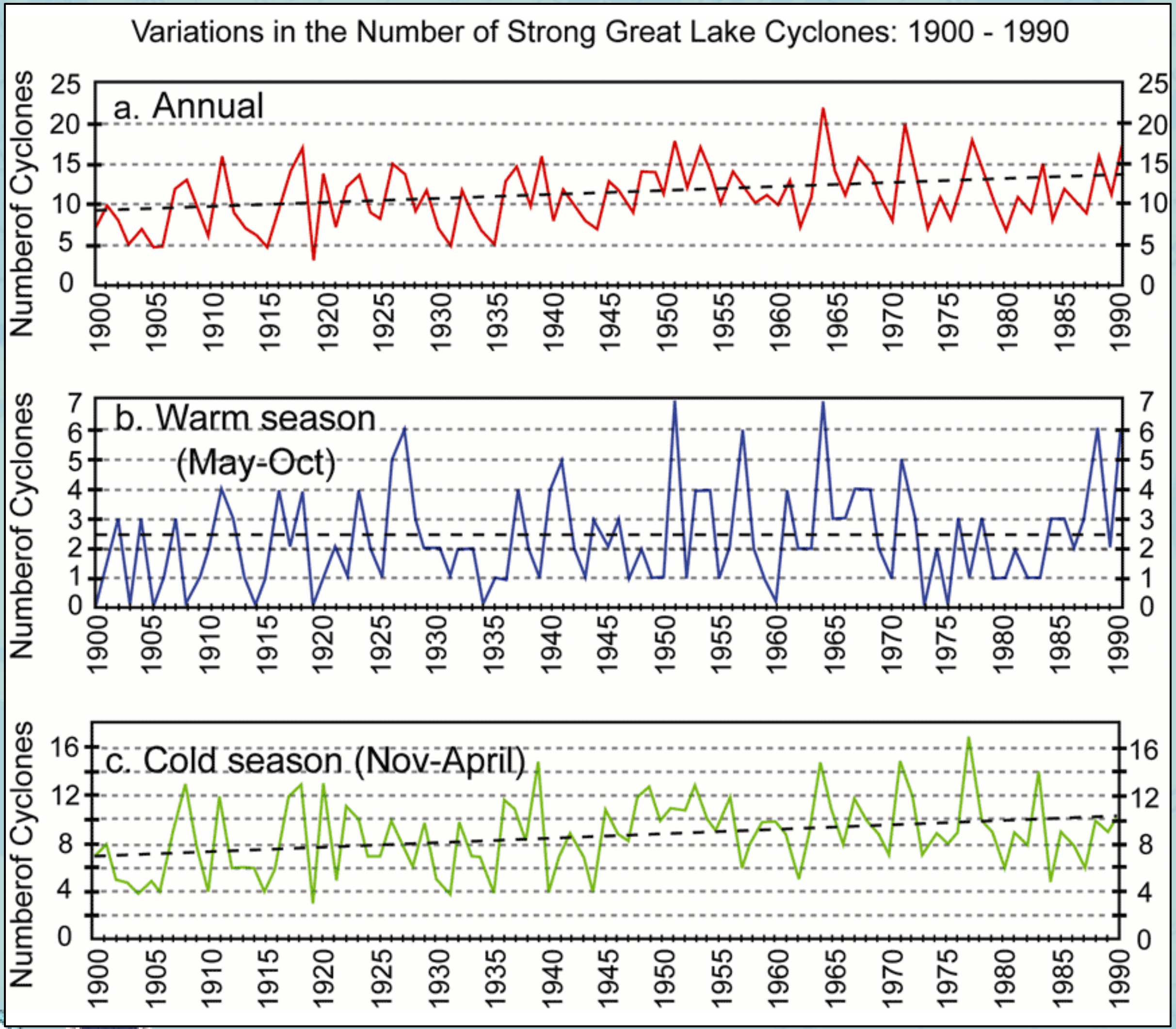
Observed Changes



Changes from average (1959-1997) in the number of winter storms each year in the Northern Hemisphere for high and mid-latitudes, and the change from average of winter storm intensity in the Northern Hemisphere each year for high and mid-latitudes.

OTHER STORMS

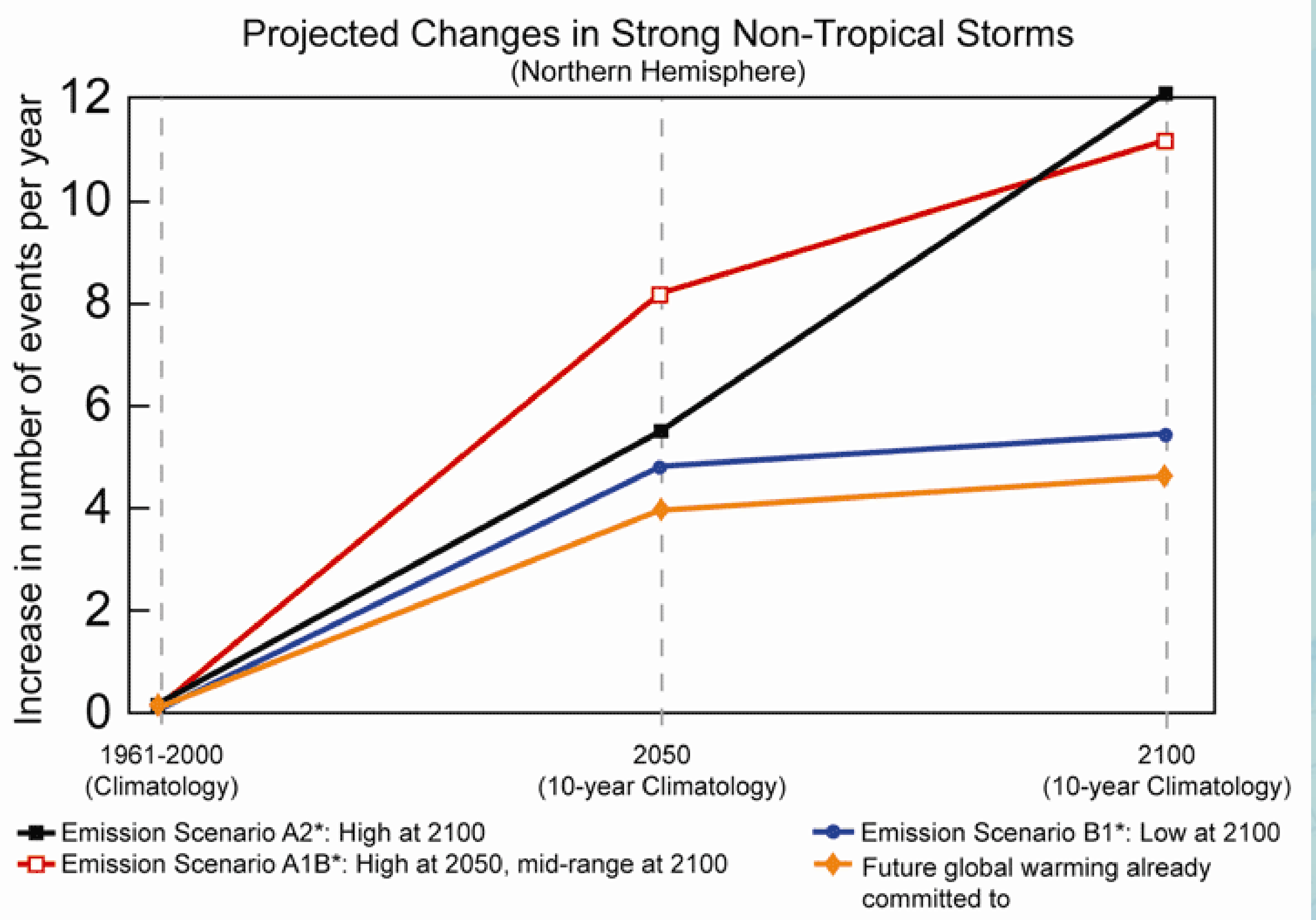
Observed Changes



Time series of the number of strong cyclones (< 992mb) across the Great Lakes region over the period 1900-1990.

OTHER STORMS

Projected Changes



Key priorities for improving our understanding of climate and weather extremes in a changing climate:

1. The continued development and maintenance of high quality climate observing systems will improve our ability to monitor and detect future changes in climate extremes.

2. Efforts to digitize, homogenize, and analyze long-term observations in the instrumental record with multiple independent experts and analyses improve our confidence in detecting past changes in climate extremes.

3. Weather observing systems adhering to standards of observation consistent with the needs of both the climate and the weather research communities improve our ability to detect observed changes in climate extremes.

4. Extended reconstructions of past climate using weather models initialized with homogenous surface observations would help improve our understanding of strong extra-tropical cyclones and other aspects of climate variability.

Key priorities for improving our understanding of climate and weather extremes in a changing climate:

5. The creation of annually-resolved, regional-scale reconstructions of the climate for the past 2,000 years would help improve our understanding of very long-term regional climate variability.

6. Improvements in our understanding of the mechanisms that govern hurricane intensity would lead to better short- and long-term predictive capabilities.

7. Establishing a globally-consistent wind definition for determining hurricane intensity would allow for more consistent comparisons across the globe.

8. Improvements in the ability of climate models to recreate the recent past as well as make projections under a variety of forcing scenarios are dependent on access to both computational and human resources.

Key priorities for improving our understanding of climate and weather extremes in a changing climate:

9. More extensive access to high temporal resolution data (daily, hourly) from climate model simulations both of the past and for the future would allow for improved understanding of potential changes in weather and climate extremes.

10. Research should focus on the development of a better understanding of the physical processes that produce extremes and how these processes change with climate.

11. Enhanced communication between the climate science community and those who make climate-sensitive decisions would strengthen our understanding of climate extremes and their impacts.

12. A reliable database on damage costs, associated with extreme weather and climate events, and how best to account for changing socioeconomic conditions, including adaptation over time, would improve our understanding of losses associated with climate extremes.

Questions?