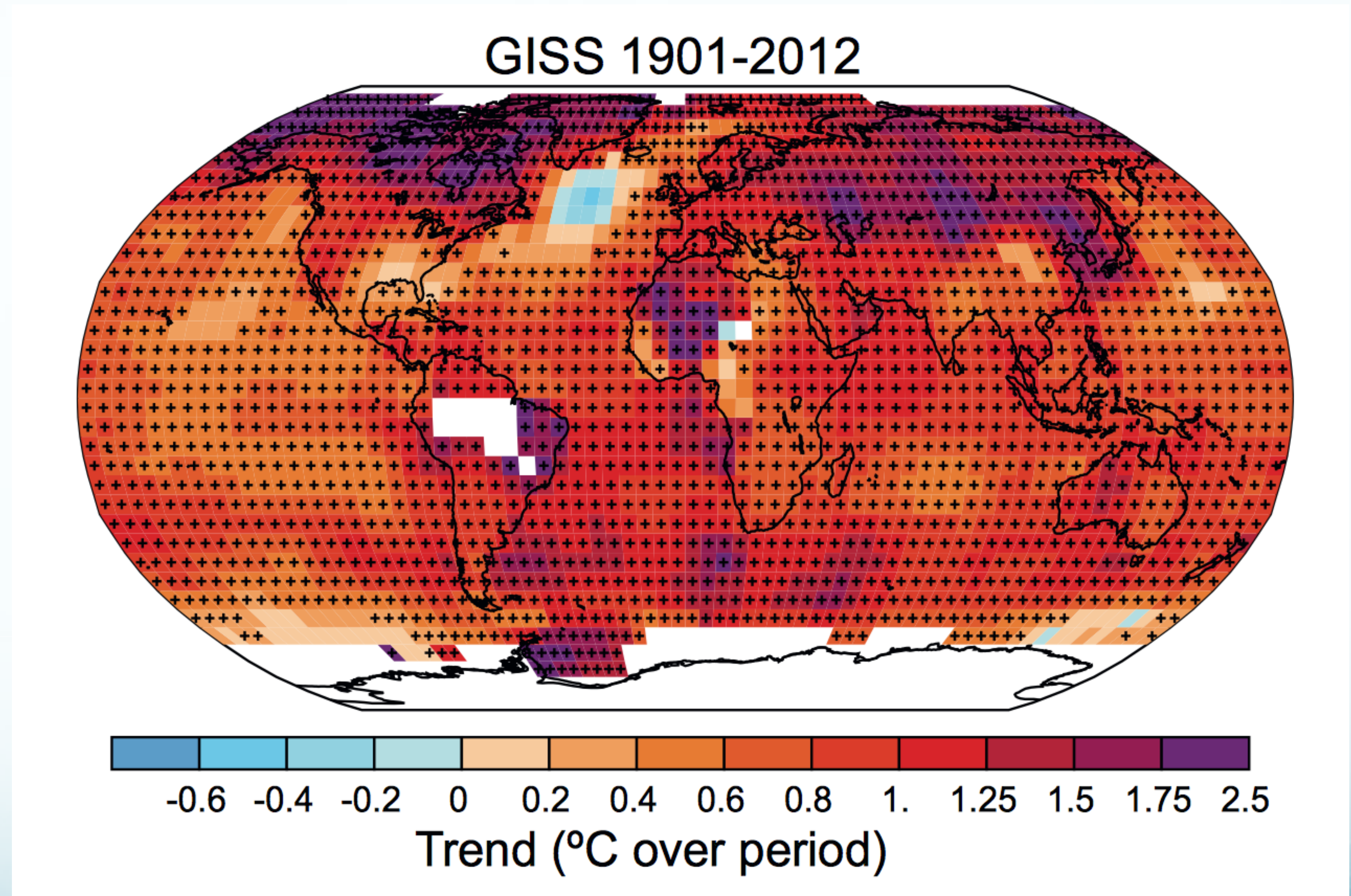


ATM S 103

# Hurricanes and Thunderstorms

Their Science and Impacts



# The Final

- 8:30-10:20 AM Thursday June 13th
- **Bring a scantron form**
- Material covered:
  - 50% Homework 7-9; Readings weeks 7-10; associated lecture slides (May 17 to end of class).
  - 50% earlier material
- 45 questions
- Closed book, notes, electronics.



# Course evaluations

- <https://uw.iasystem.org/survey/209385>
- Open through 11:59 PM June 11<sup>th</sup>
- Suggestions for improving the course are particularly encouraged



# Finally, our own one!



## Thunderstorms Possible Friday

**When:** Afternoon &  
Evening Hours

**Where:** Around & East of  
Puget Sound

**May Contain:**

- Brief Heavy Downpours
- Small Hail
- Dangerous Lightning



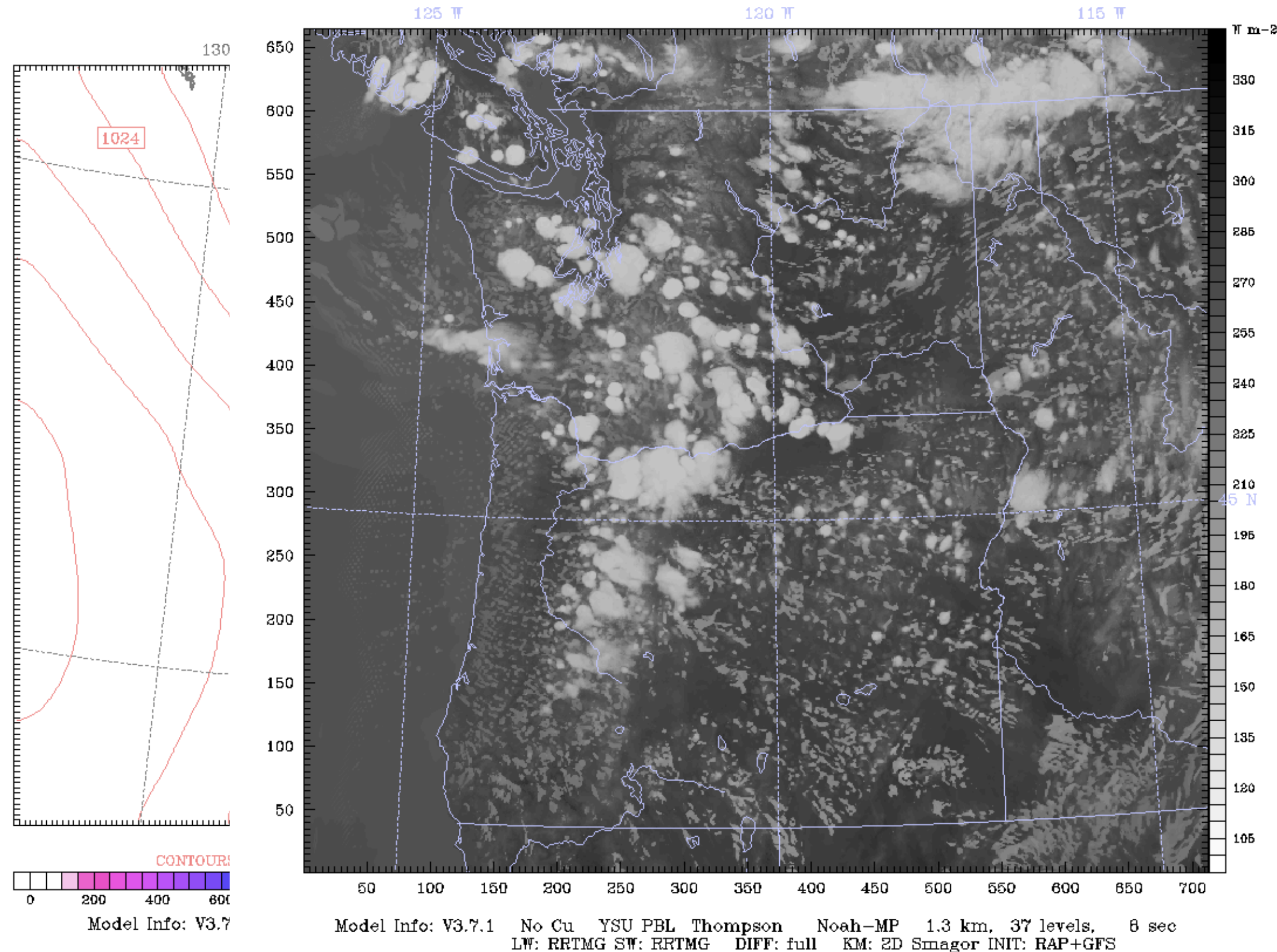
NATIONAL WEATHER SERVICE  
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

*Seattle*

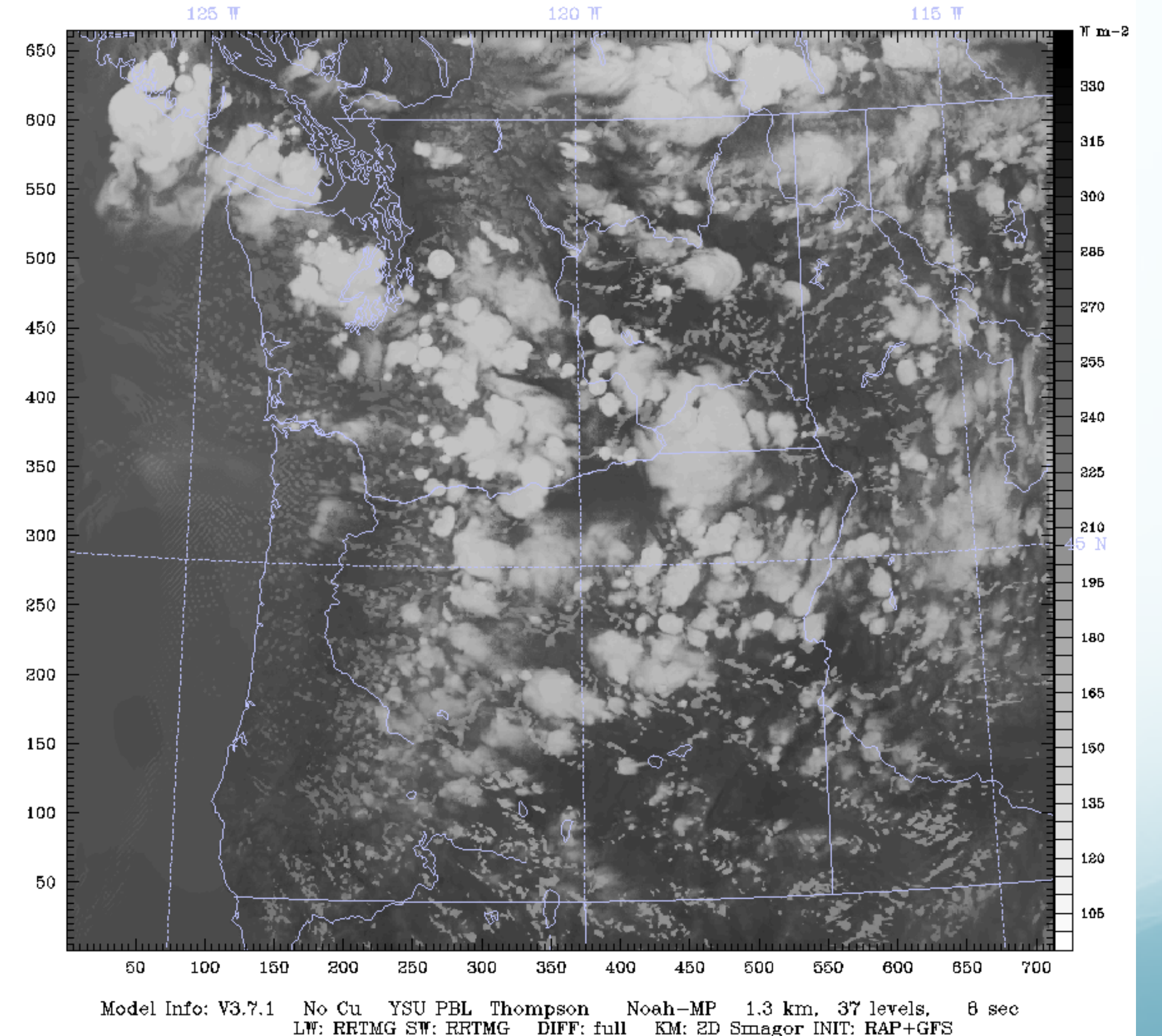


# Forecast

UW WRF-GFS 12km UW WRF-GFS 1.33km Domain Init: 12 UTC Thu 06 Jun 19  
Fest: 33 h Fest: 33.00 h Valid: 21 UTC Fri 07 Jun 19 (14 PDT Fri 07 Jun 19 )  
Maximum CAPE (J/Kg) Outgoing Longwave Radiation ( $\text{W m}^{-2}$ )  
Sea Level Pressure



UW WRF-GFS 1.33km Domain Init: 12 UTC Thu 06 Jun 19  
Fest: 36.00 h Valid: 00 UTC Sat 08 Jun 19 (17 PDT Fri 07 Jun 19 )  
Outgoing Longwave Radiation ( $\text{W m}^{-2}$ )





W

# Hurricane Harvey (2017) was one of the costliest hurricanes ever because of

The extreme high rainfall totals

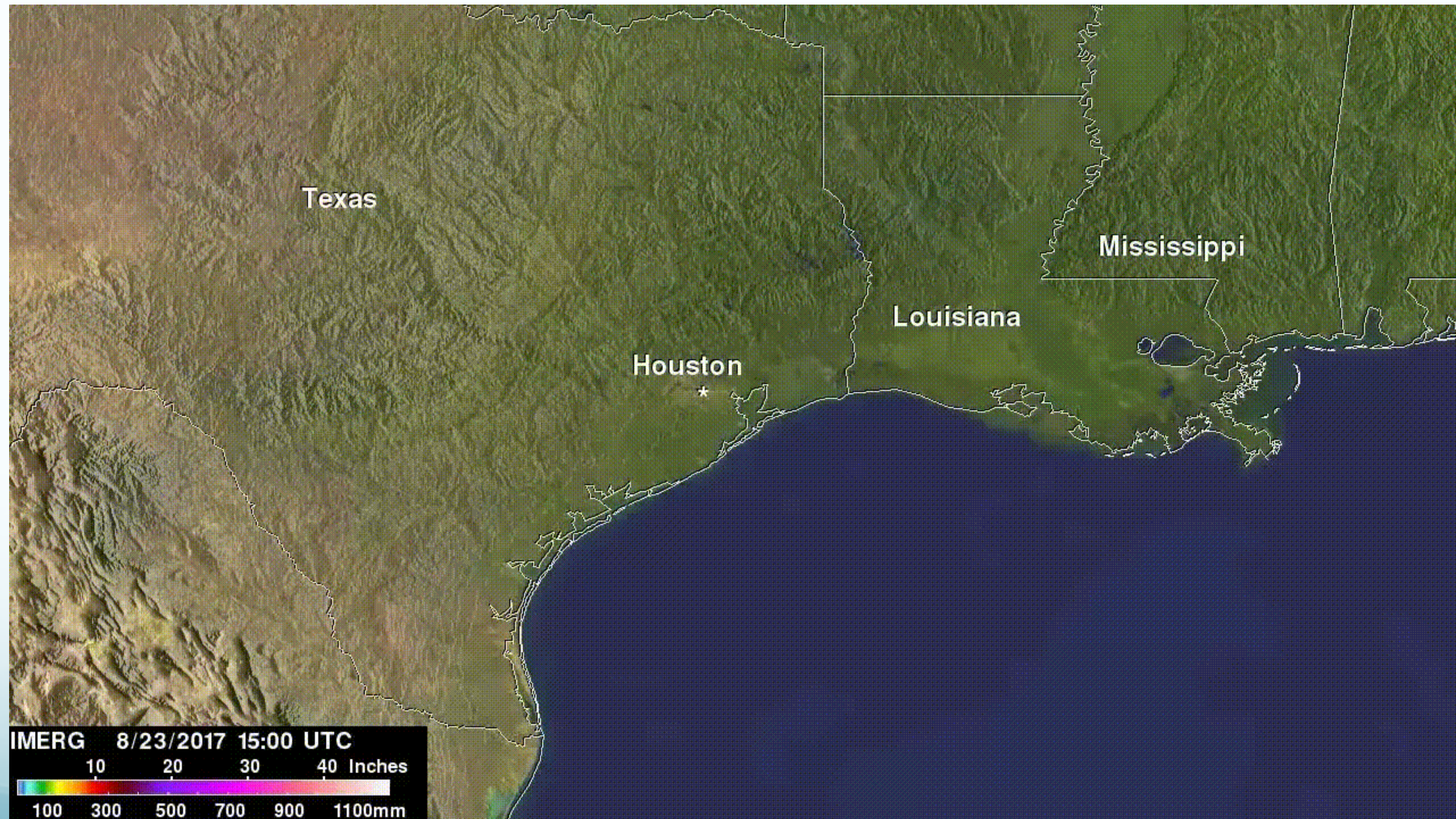
The storm surge

The strong winds (category 5)

The hail damage to crops



# Answer: Extreme high rainfall





# W Which of the following is associated with Hurricane Maria (2017)?

The longest blackout in the  
United States history

Slow deliveries/installations  
of blue roofs

Tens of thousands of people  
leaving Puerto Rico

All of the above



Answer: all of the above

# Topics for Today

- Hurricanes in a warmer climate



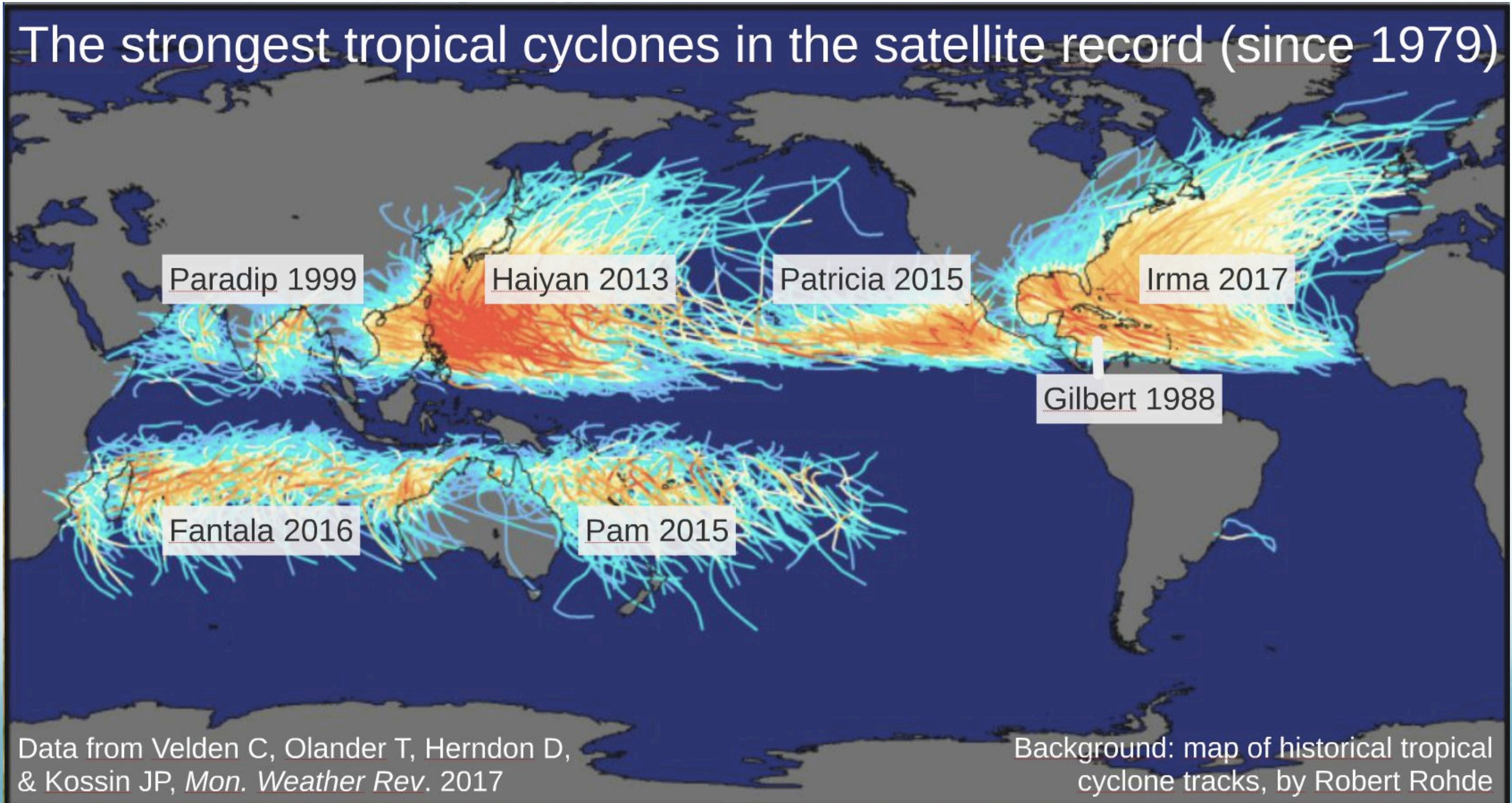
# Tropical Cyclones and Climate Change

- What can we expect as future changes linked to global warming?



# Strongest Ones

The strongest tropical cyclones in the satellite record (since 1979)



Data from Velden C, Olander T, Herndon D, & Kossin JP, *Mon. Weather Rev.* 2017

Background: map of historical tropical cyclone tracks, by Robert Rohde



# Hurricane Patricia

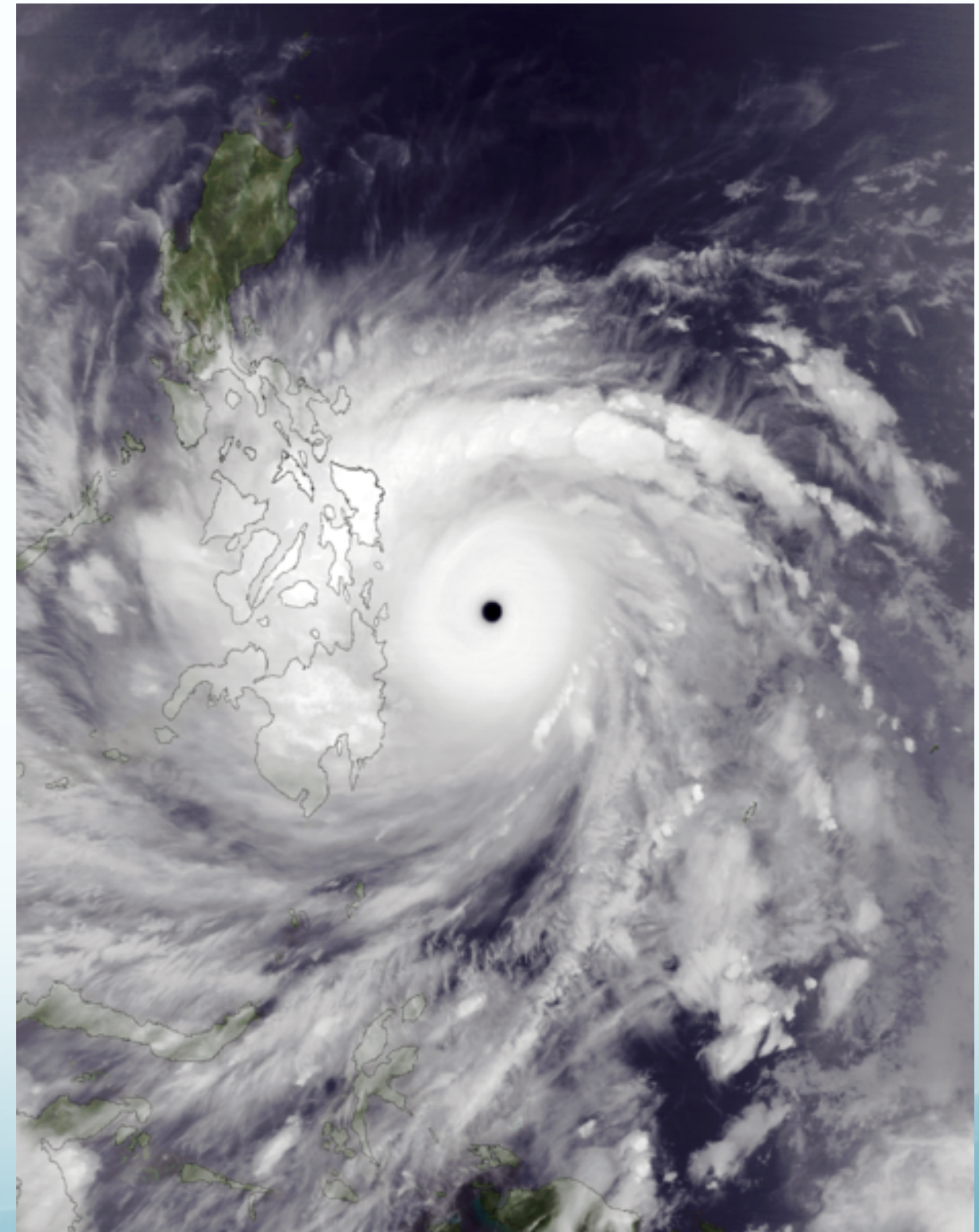
- 10 PM eastern time, Wed. 10/21: Patricia was a 65 mph tropical storm
  - But rapid intensification was predicted
  - Because of warm ocean temperatures and weak shear
- 4 AM eastern time, Fri. 10/23: 200 mph winds!
  - The strongest hurricane ever observed in the Western Hemisphere
- Caused flooding & mudslides
  - Although major cities were spared from the biggest damage





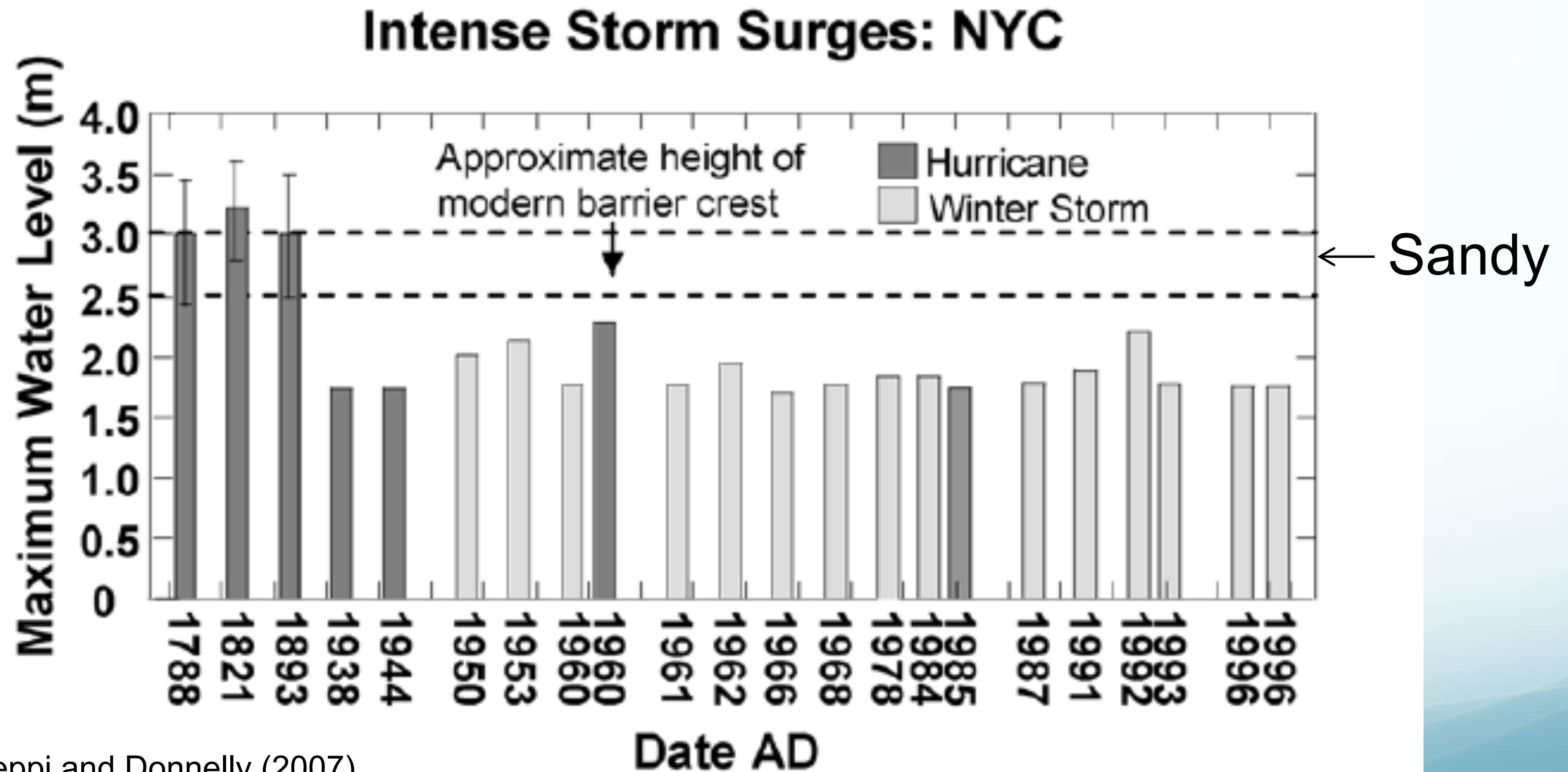
# Typhoon Haiyan

- Haiyan struck the Philippines on Nov 8, 2013
- Most powerful storm ever at landfall (195 mph winds)
  - 6340 fatalities, 11 million affected
- Preceded by Typhoon Bopha in Dec 2012 (175 mph winds)
- These storms & Patricia would be category 6 or 7 if it existed!





# Storm surge at Battery highest ever recorded by tide gauge (since 1920)

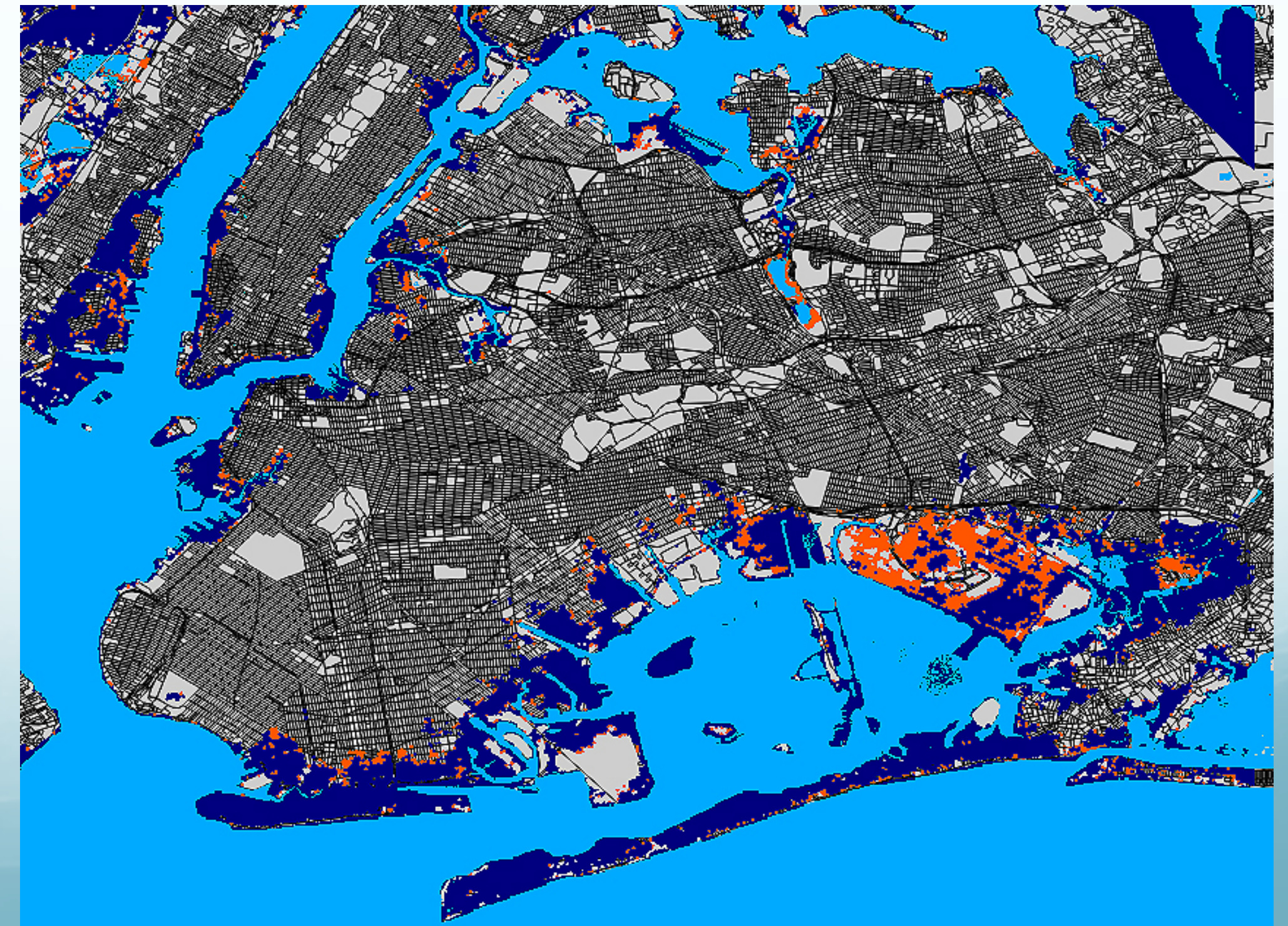
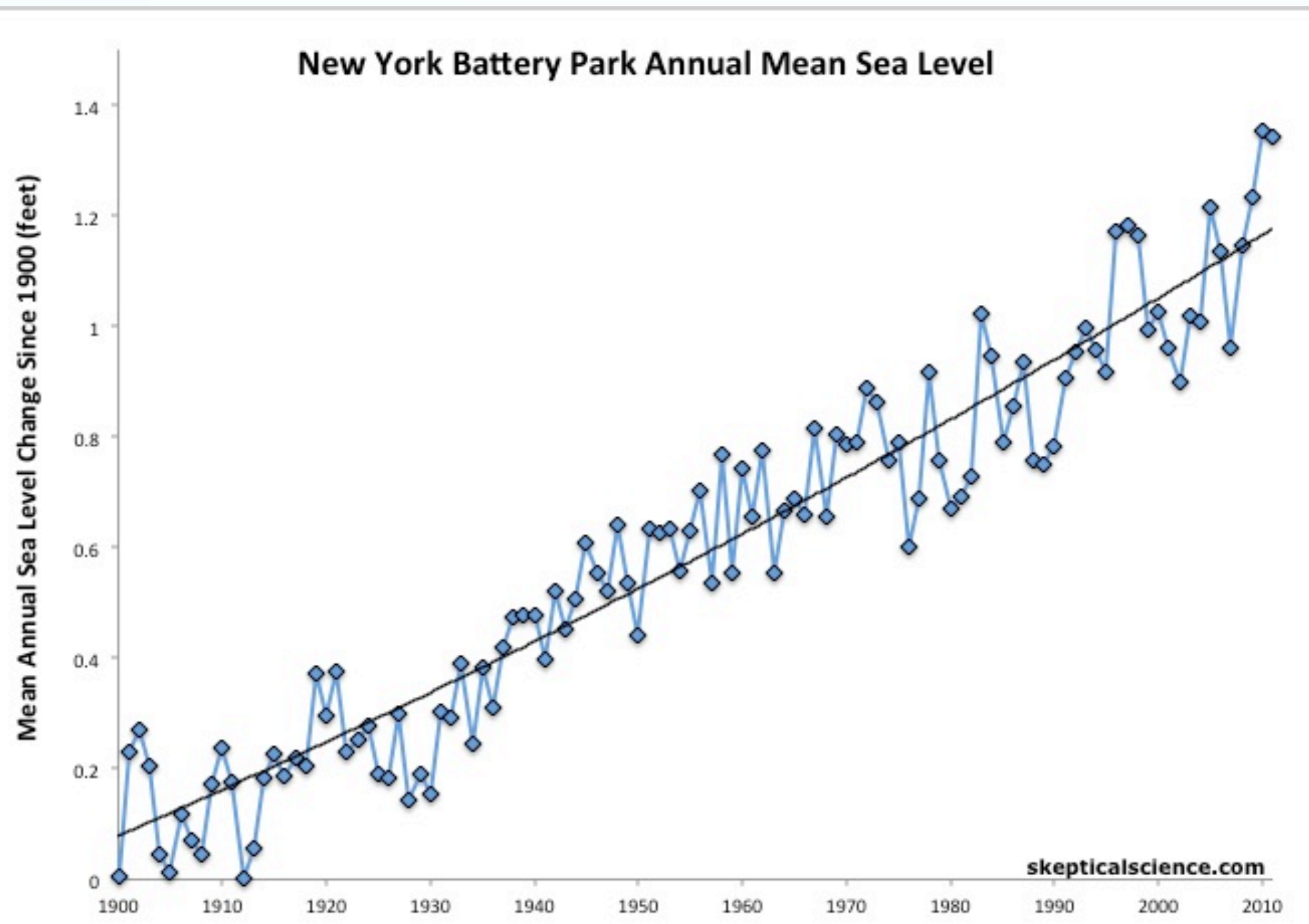


Scilleppi and Donnelly (2007)



# Relation to sea level rise

- Sea level rise led to 27 square miles more flooding
- Affected 83,000 more people
- \$2 billion more in damages





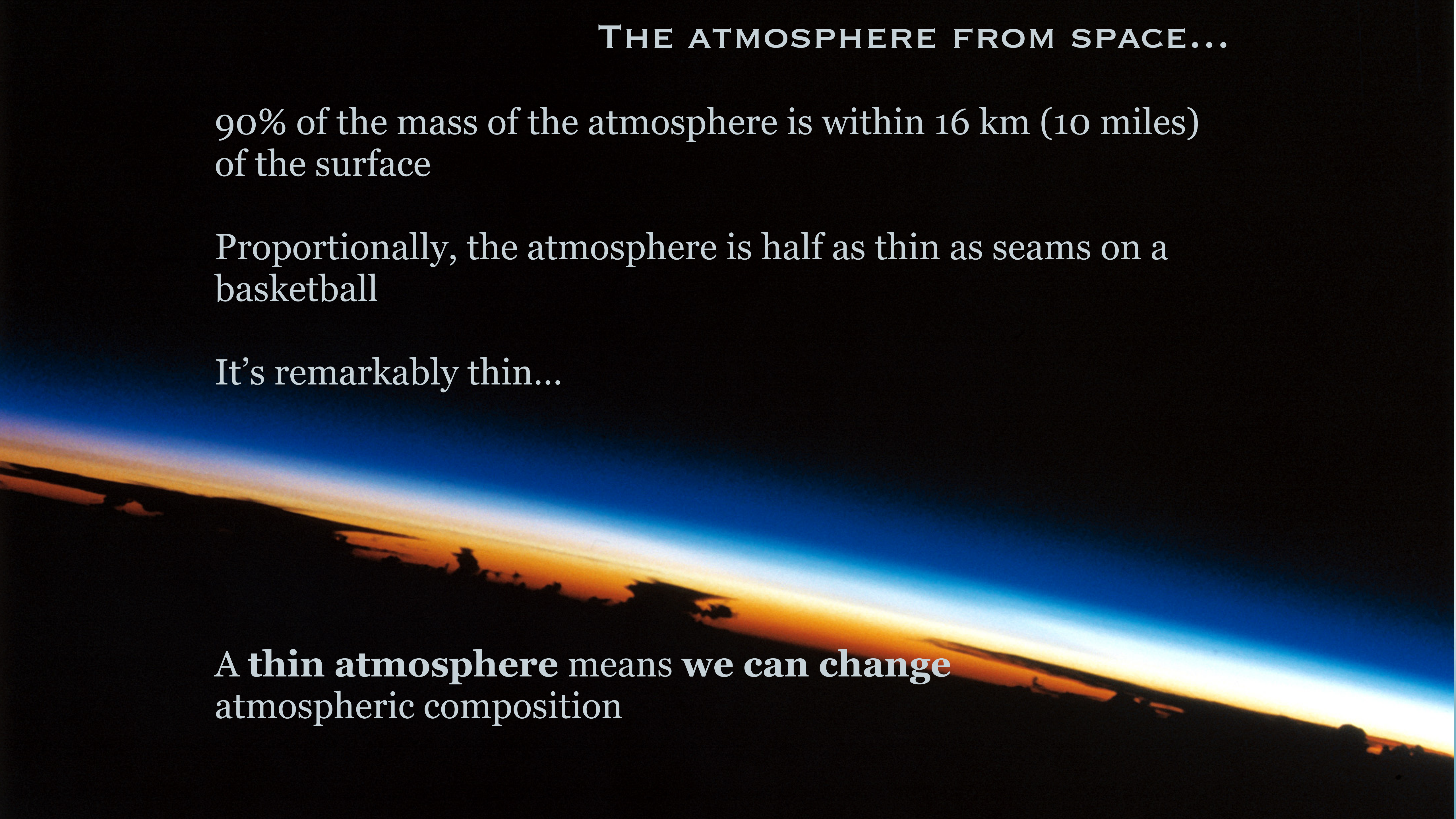
# THE ATMOSPHERE FROM SPACE...

90% of the mass of the atmosphere is within 16 km (10 miles) of the surface

Proportionally, the atmosphere is half as thin as seams on a basketball

It's remarkably thin...

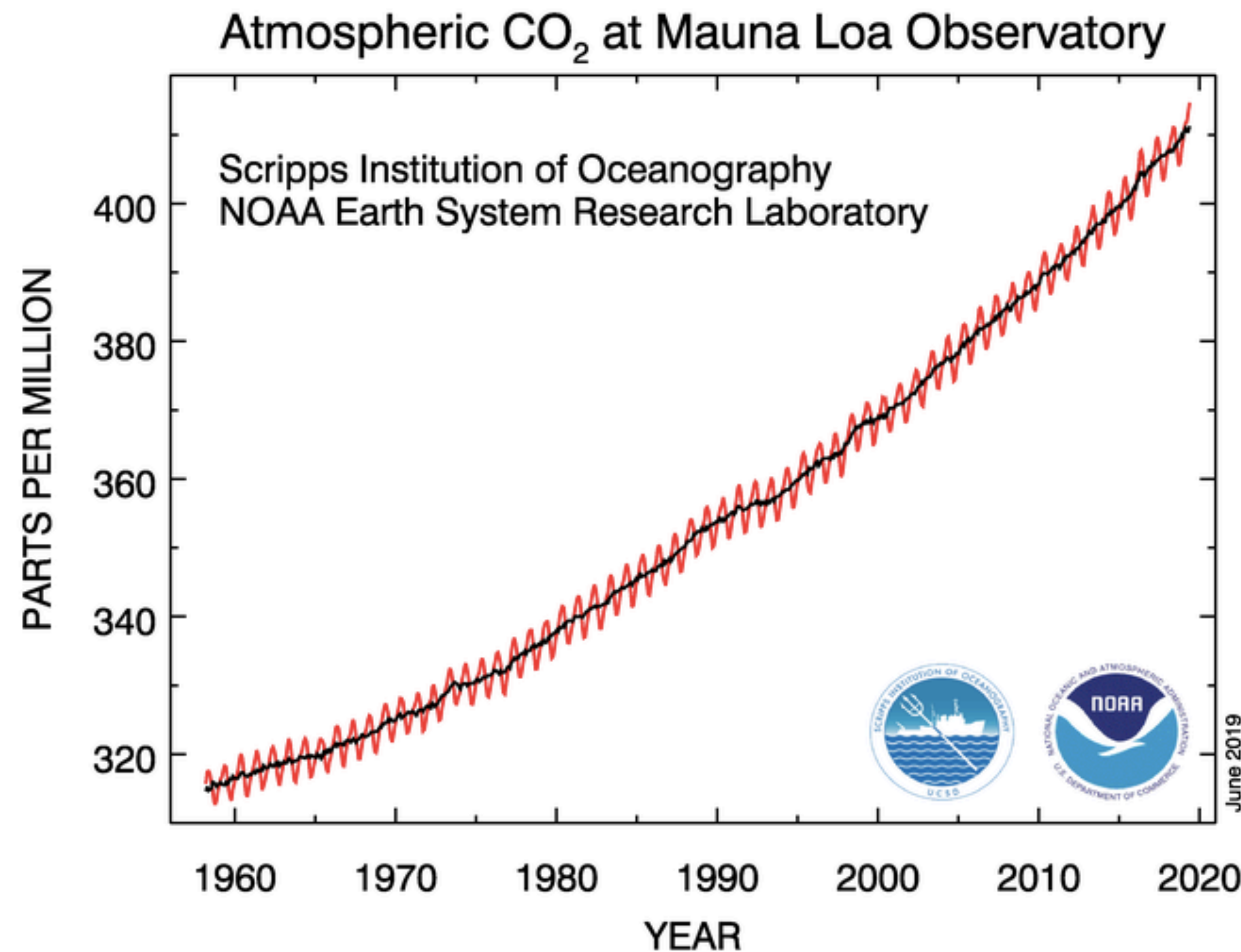
**A thin atmosphere means we can change atmospheric composition**





# We Modify the Composition of the Atmosphere

- Carbon dioxide (CO<sub>2</sub>) has been measured at Mauna Loa, Hawaii since 1958



“Keeling curve”: first measured by David Keeling in March ’58

Over **25% increase** since the first measurement

Human induced:  
Due to **fossil fuel burning** (90%) and deforestation (10%)



# CO<sub>2</sub> is a Greenhouse Gas

- Greenhouse gases **slow heat loss to space**
  - Has been known for a long time (J. Fourier in 1824)



This is why it's  
hot

The Sun heats the Earth.

Greenhouse gases cause the Earth to be a lot warmer than if there was no atmosphere:

**58° F (32° C) warmer**

↗ The natural greenhouse effect

Joseph Fourier



“There is general scientific agreement that the most likely manner in which mankind is influencing the global climate is through carbon dioxide release from the burning of fossil fuels”

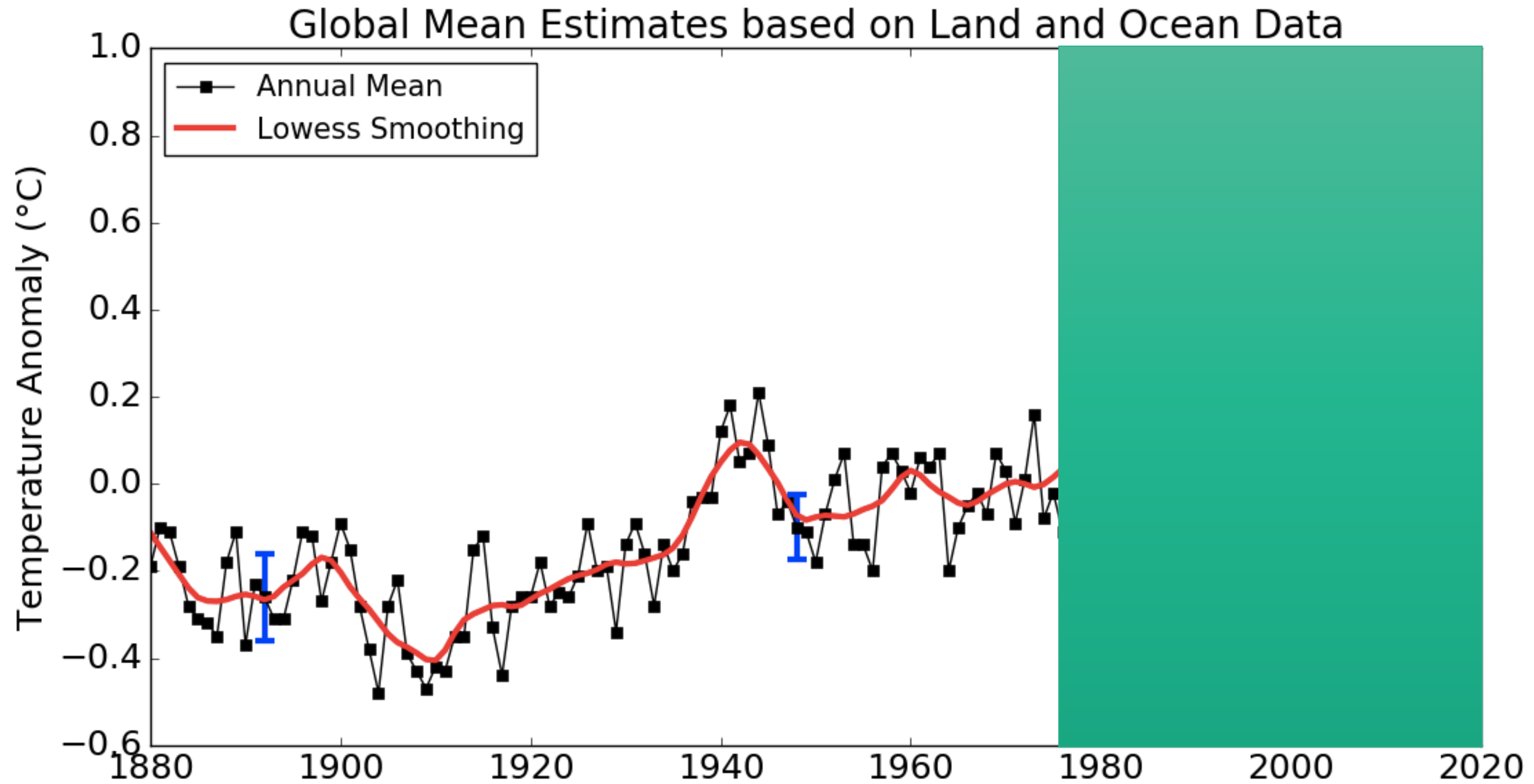
- Exxon scientist James Black to top management of Exxon

**What year?**





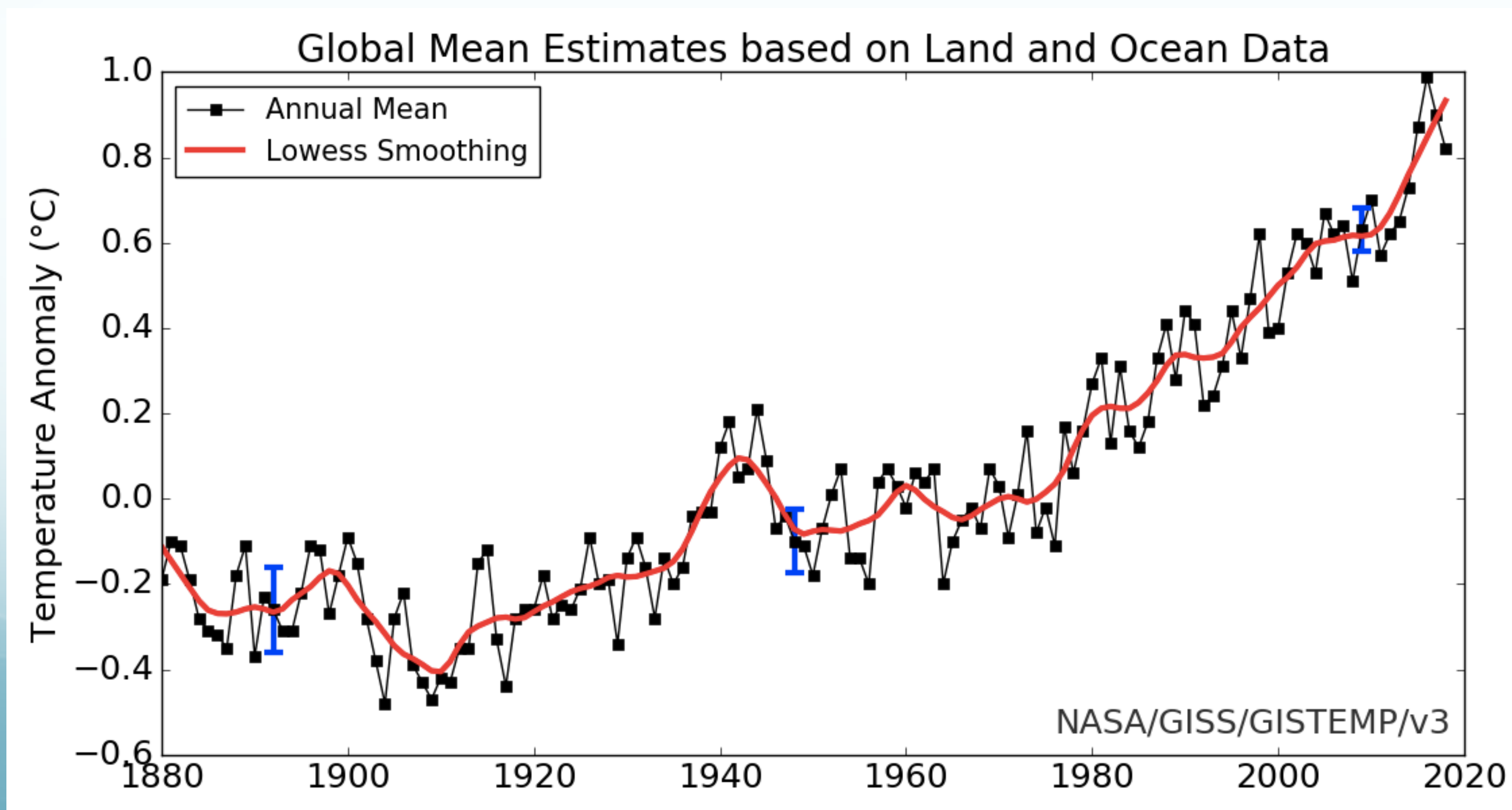
# What's happened to the climate since 1977?





# The Earth is Warming

- More CO<sub>2</sub> → warmer atmosphere (eventually)
- And the Earth has definitely been warming



2° F

1° F

0° F

It's warmed about  
**1° C (1.8° F)** in  
the last 130 years

Especially rapid  
warming since the  
mid-'70s

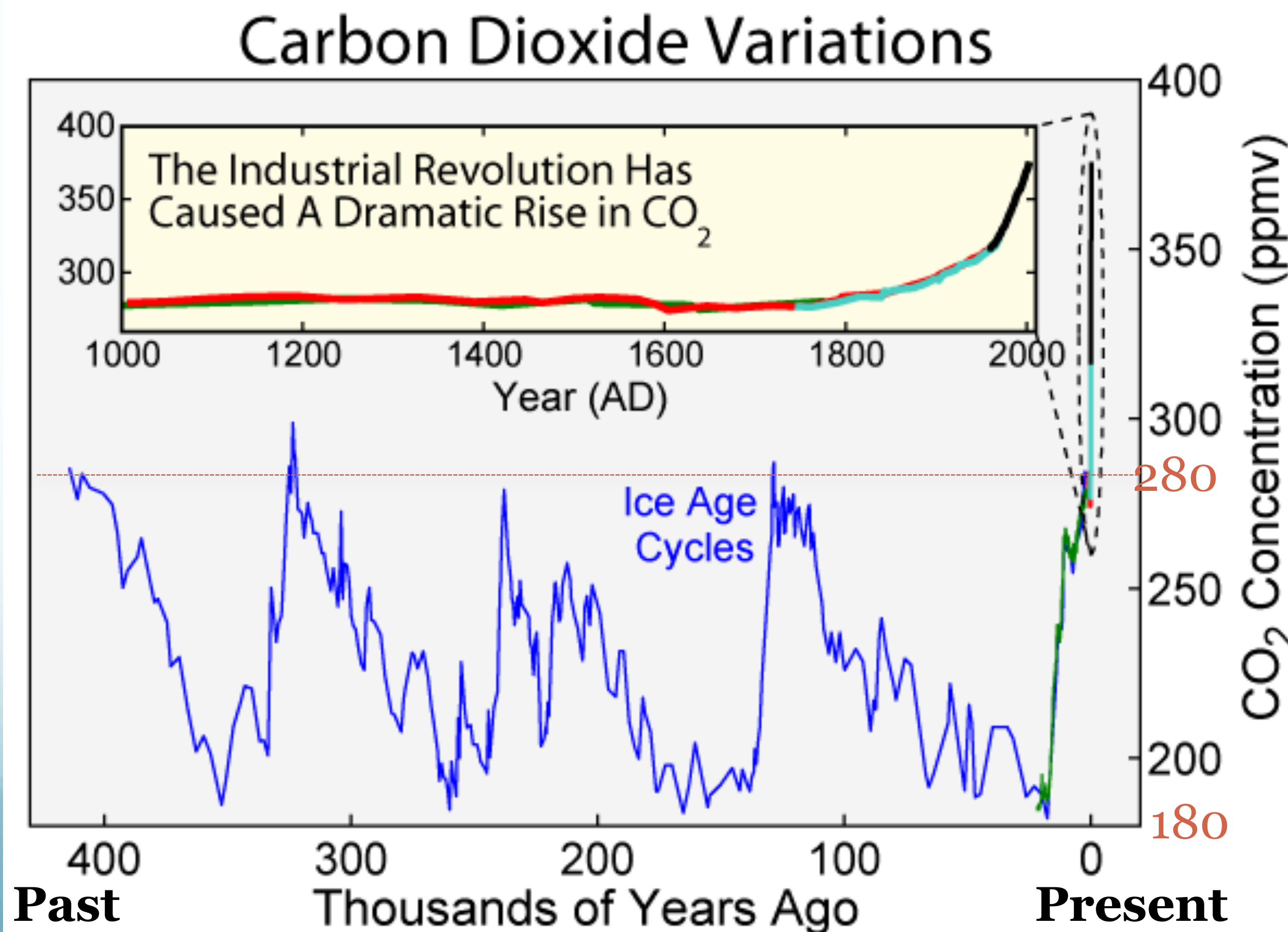
**16 out of the top  
17 hottest years  
on record were the  
last 16 years**

Src: NASA GISS



# Let's Look Way Back to 450,000 Years

- We're over 410 ppm now

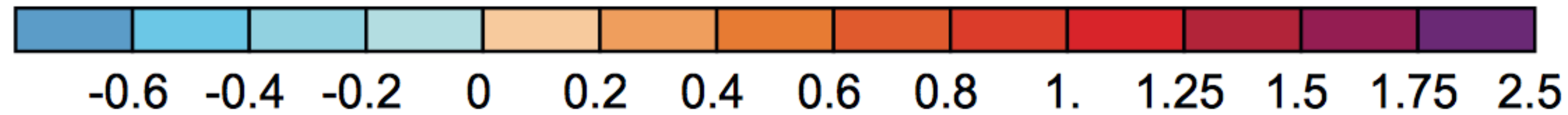
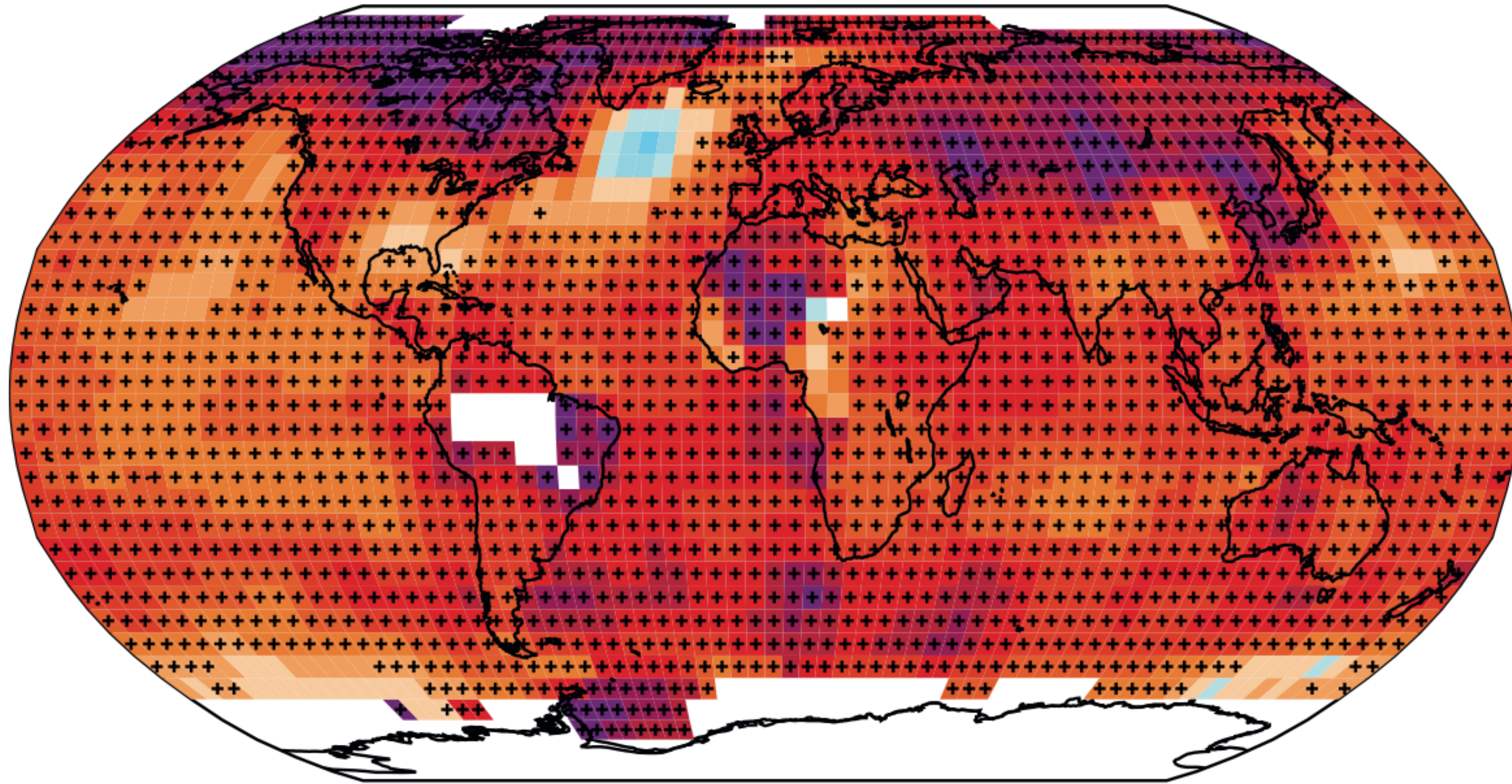


Natural variation over  
Ice Age Cycles:  
**180-280 ppm**

Current rate of increase  
is **100-1000 times**  
**faster** than nature can  
change CO<sub>2</sub>



# GISS 1901-2012



Source: IPCC AR5

Trend ( $^{\circ}\text{C}$  over period)

Warming has happened **almost everywhere**.  
**Northern high latitudes** have warmed the most.  
**Land** has warmed more than **ocean**.



# All Calculations Predict

- Adding **CO<sub>2</sub>, methane, ...** increases the average equilibrium surface temperature of the Earth.
- **Water vapor** concentrations are determined as part of the atmospheric/oceanic response.
- The ocean heats up, too (and becomes more acidic).



# What's Certain?

- No doubt about the sign and qualitative values of **global** temperature changes at **equilibrium** in response to added greenhouse gases.
- No doubt that sea levels will be rising due to
  - Thermal expansion as the ocean warms
  - Melting of glaciers
  - (Melting of sea ice does not change the sea level.)



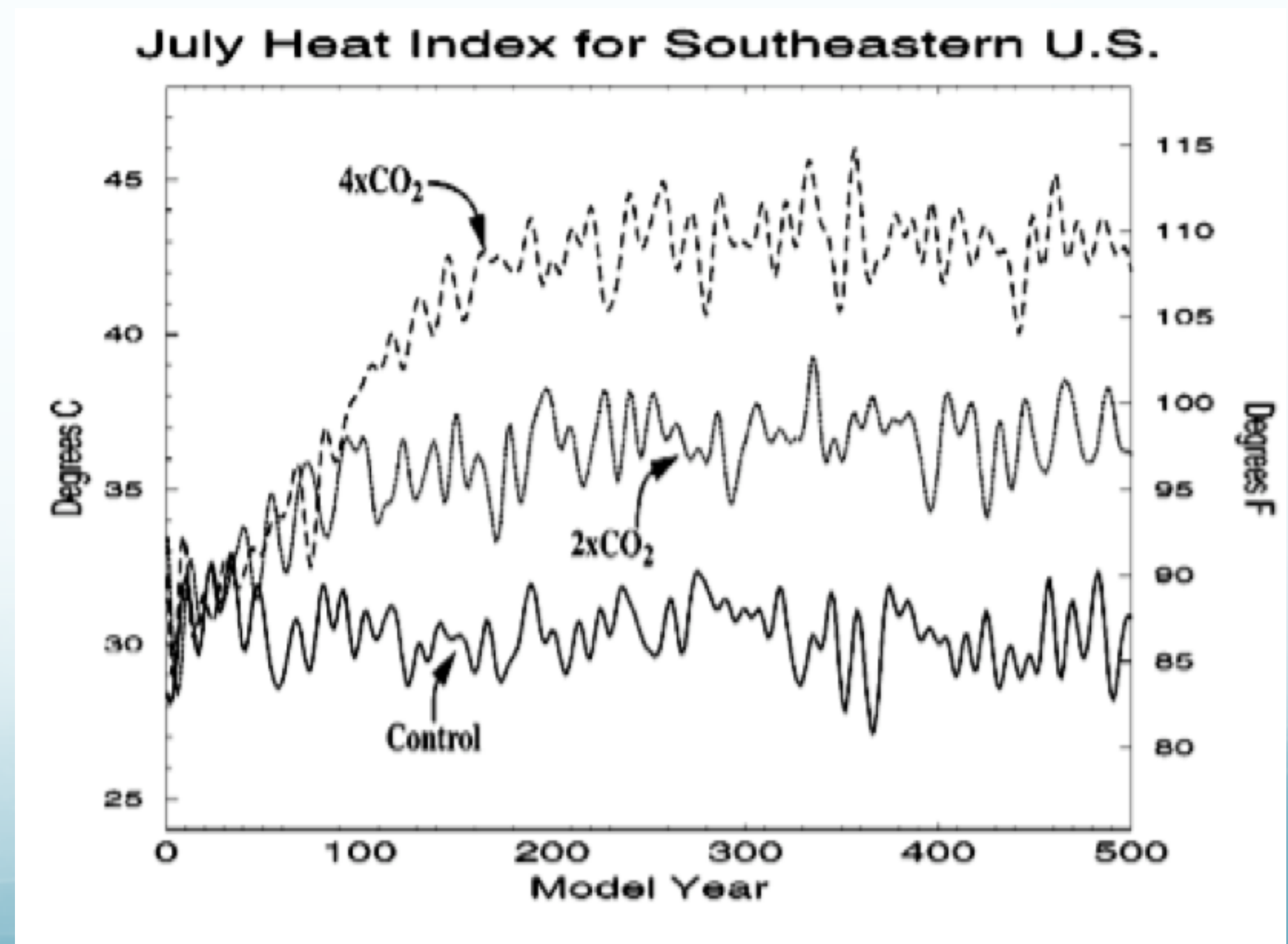
# Kenai Fjords National Park, Alaska





# Warmer air leads to higher humidity

- Warmer air can hold more moisture
  - Dew point temperature will increase globally
  - Exponential increase with temperature
- “Heat index” to rise
  - Days will feel much hotter

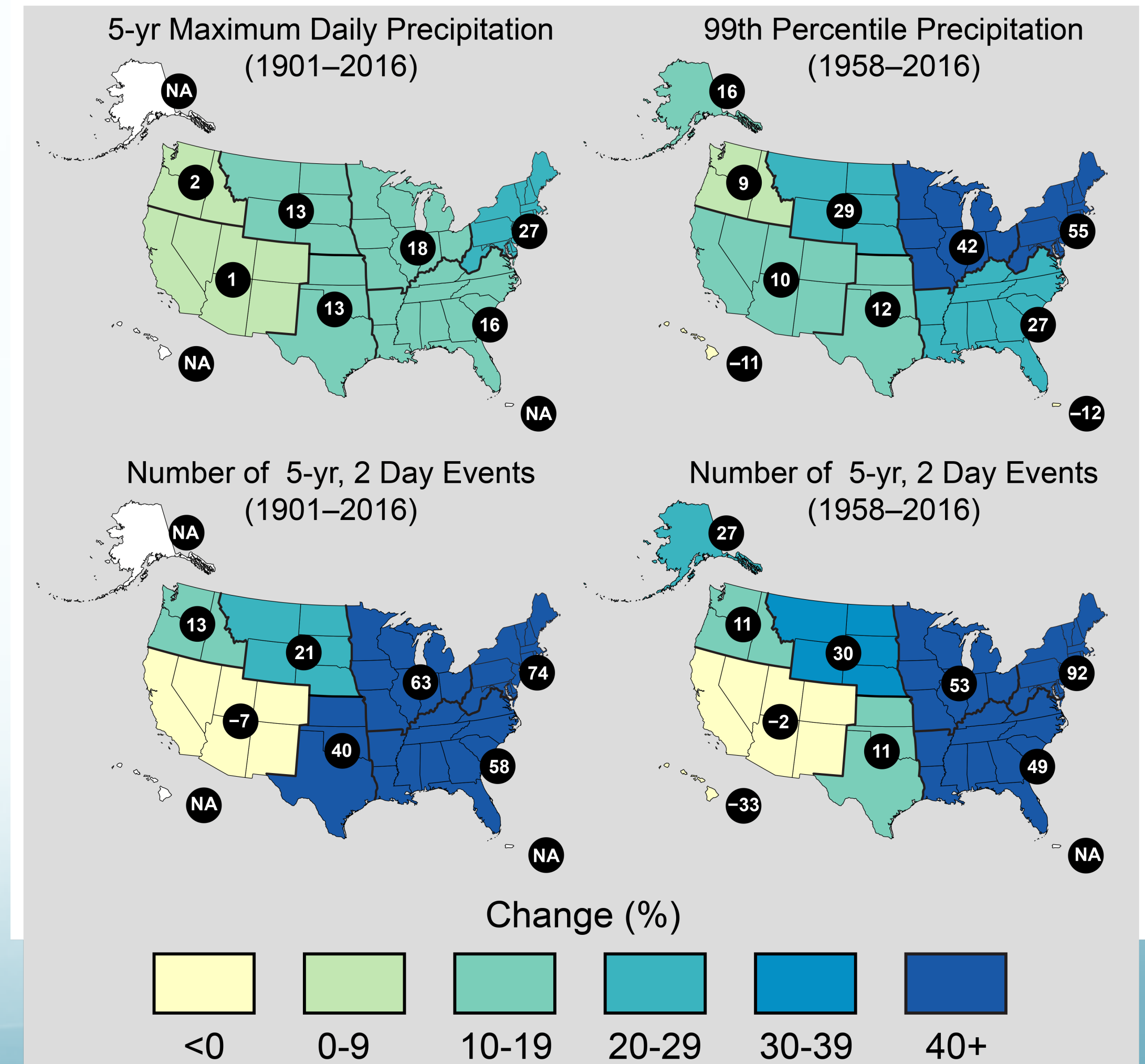




# More downpours

- More humidity leads to more extreme rainfall events
- Very heavy rain events have already increased in the US

## Observed Change in Heavy Precipitation

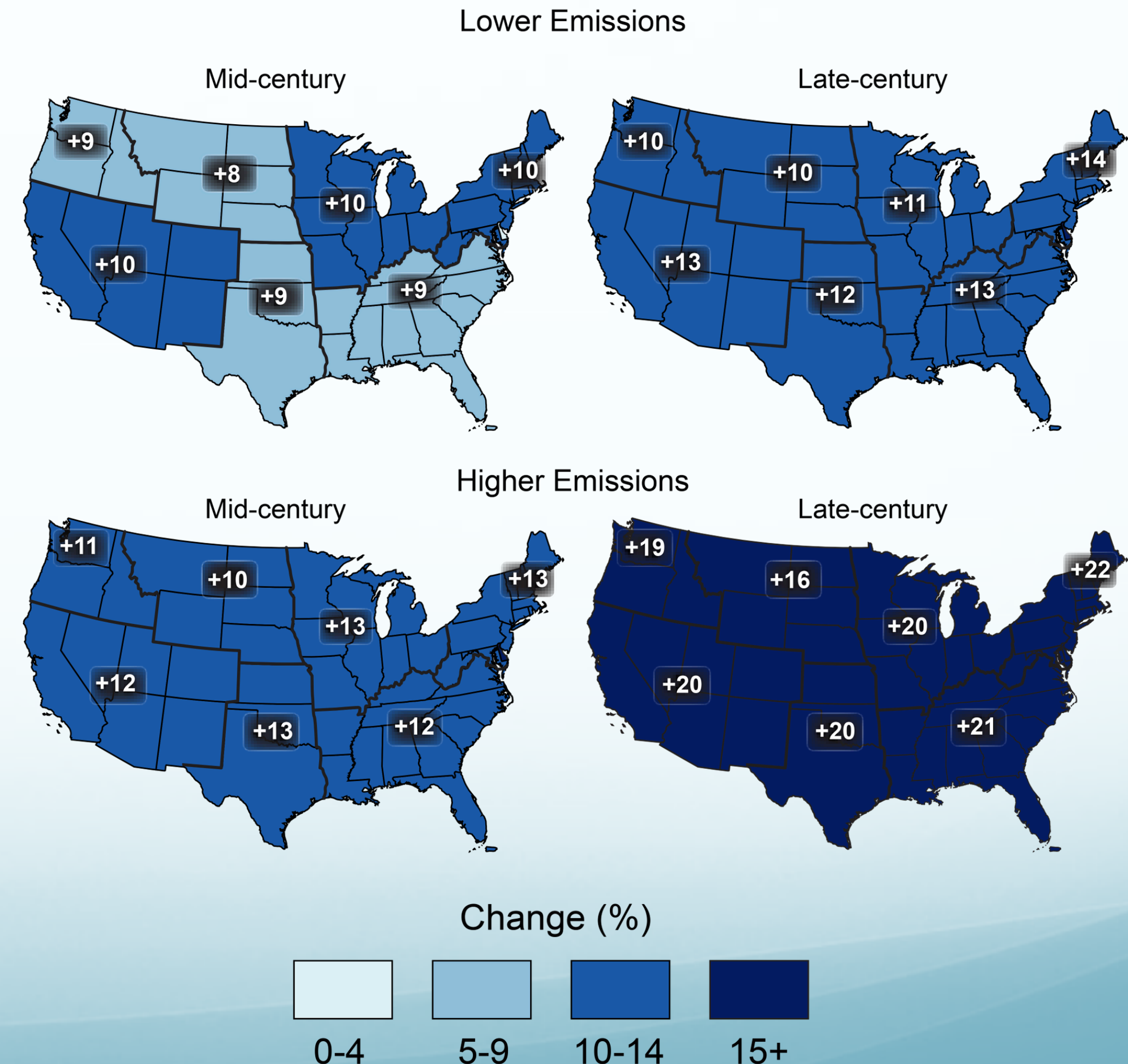




# More downpours

- More humidity leads to more extreme rainfall events
- Very heavy rain events have already increased in the US

## Projected Change in Daily, 20-year Extreme Precipitation





# How about thunderstorms?

- Very hard to look at trends from observations
- Likely that CAPE (convective available potential energy) will increase with more water vapor in the air
  - Especially in places like the Great Plains where dry air coming from over the Rockies collides with moist air from the Gulf

Wonkblog

## Global warming could increase U.S. lightning strikes by 50 percent

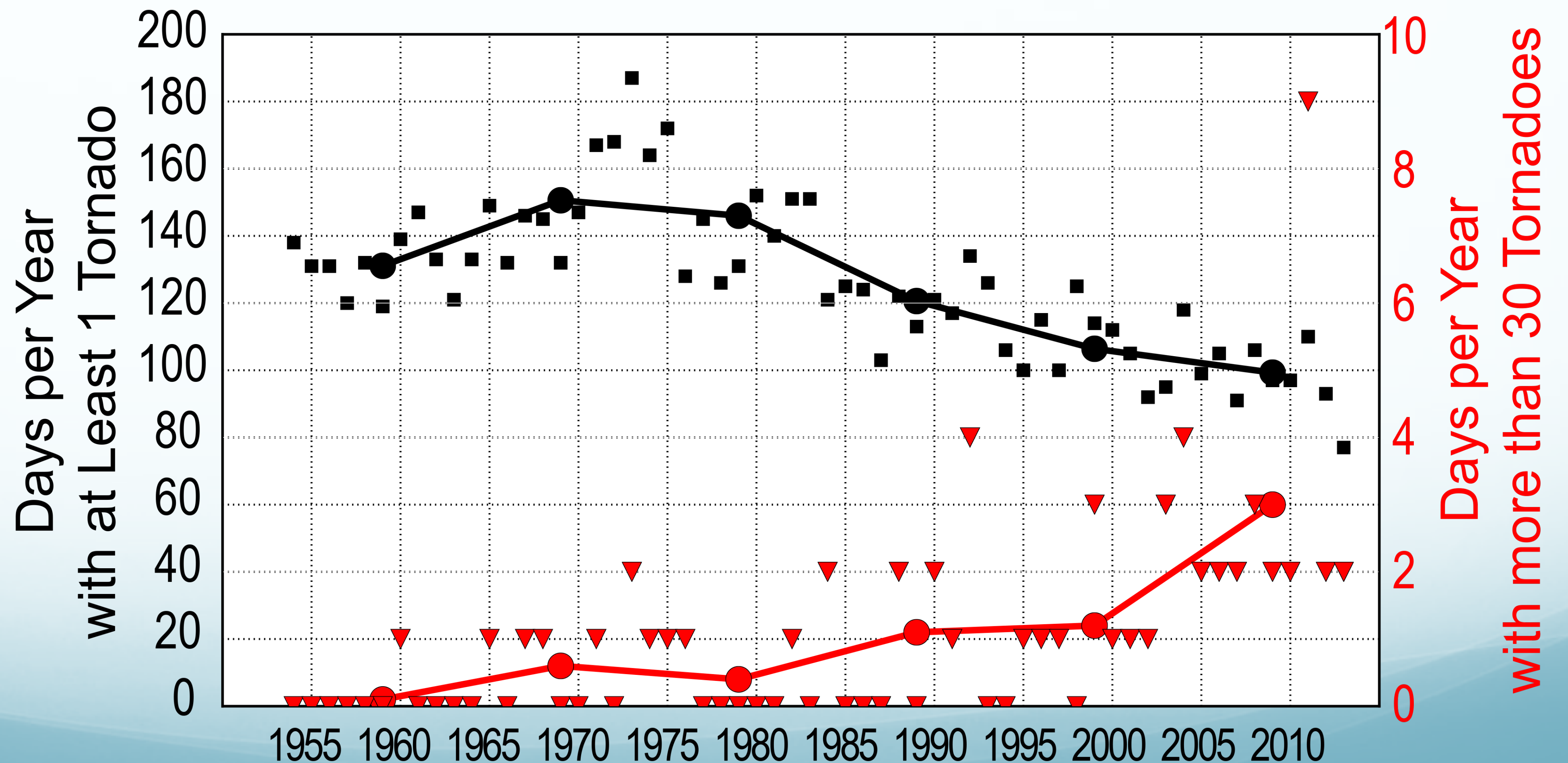
By **Chris Mooney** November 13, 2014 [Email the author](#)

This research group (Prof. David Romps) also claims from climate models that thunderstorms could increase by 50-150%



# Observed changes in tornado activity

Annual Tornado Activity in the U.S. (1955–2013)





# Hurricanes in a Warmer Climate

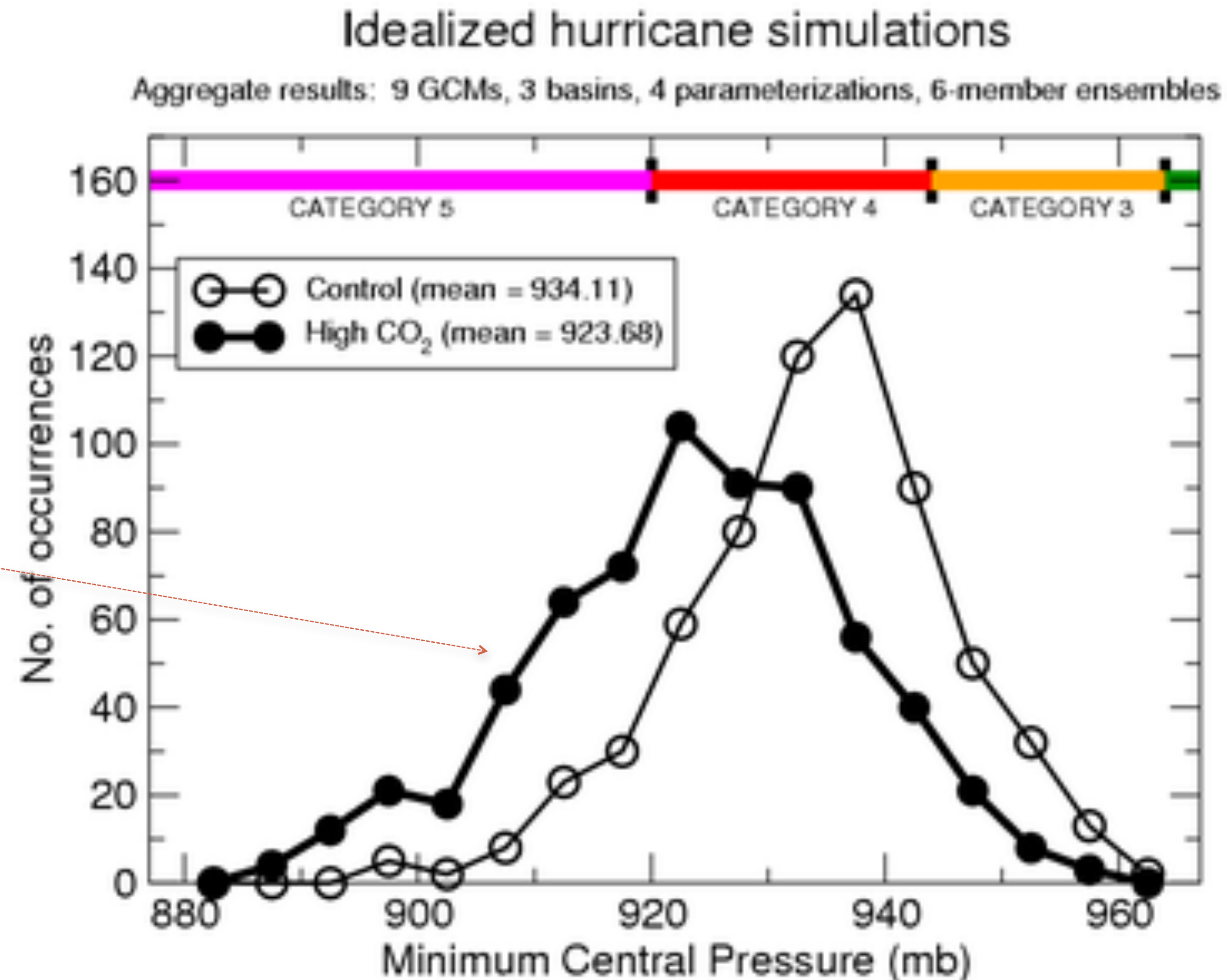
- Need to know the changes in
  - Sea surface temperatures (will rise)
  - Vertical wind shear (???)
  - Triggers (???)
- **Much uncertainty**, but some indication tropical cyclones will be
  - Bigger rain makers
  - More frequently intense (> Cat 3)
  - Less common overall



Recent model results are suggesting **fewer** but **more intense** storms

**More really strong storms** in warmer climate (darker line is high CO<sub>2</sub> climate)

Fewer storms overall though



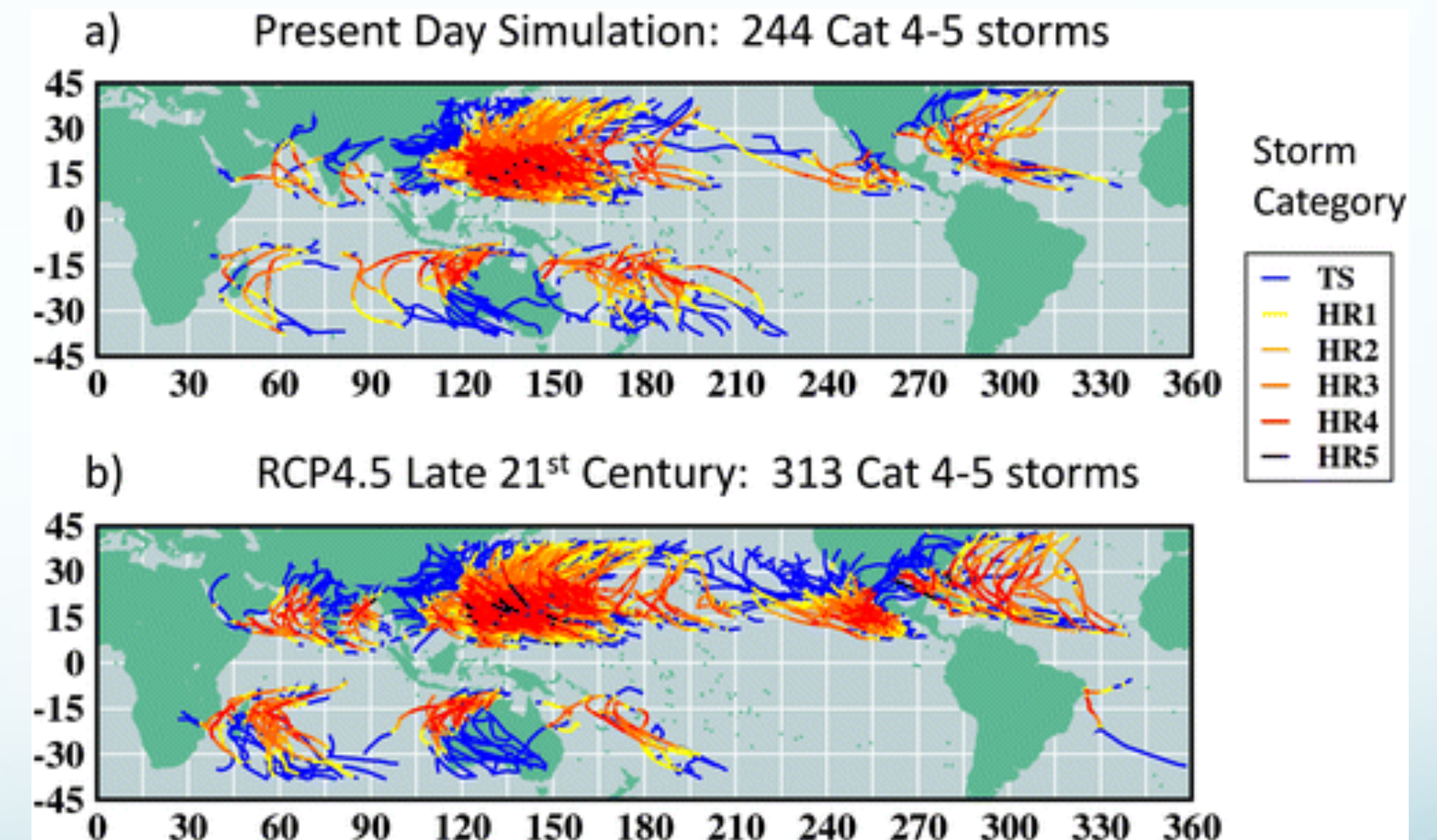
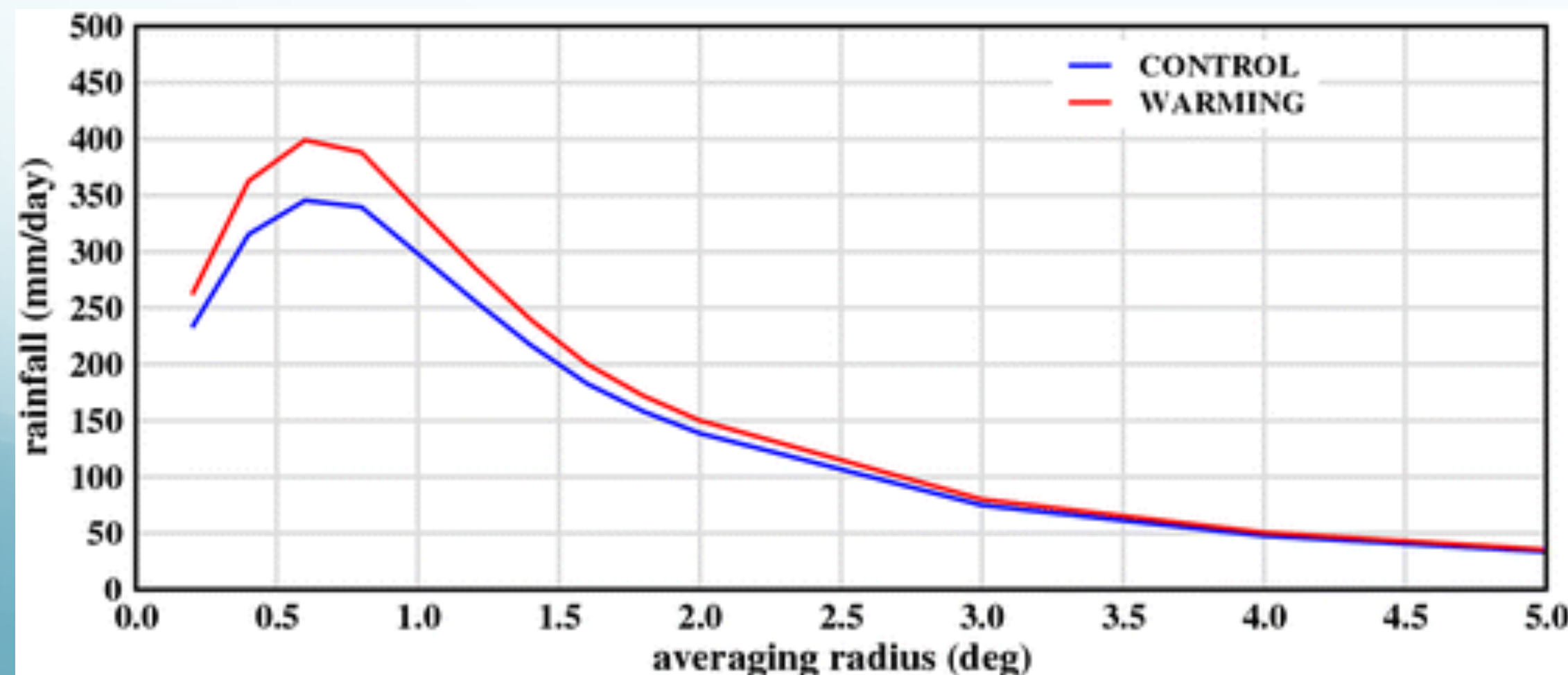
← Stronger

Weaker →



# Another Recent Modeling Study

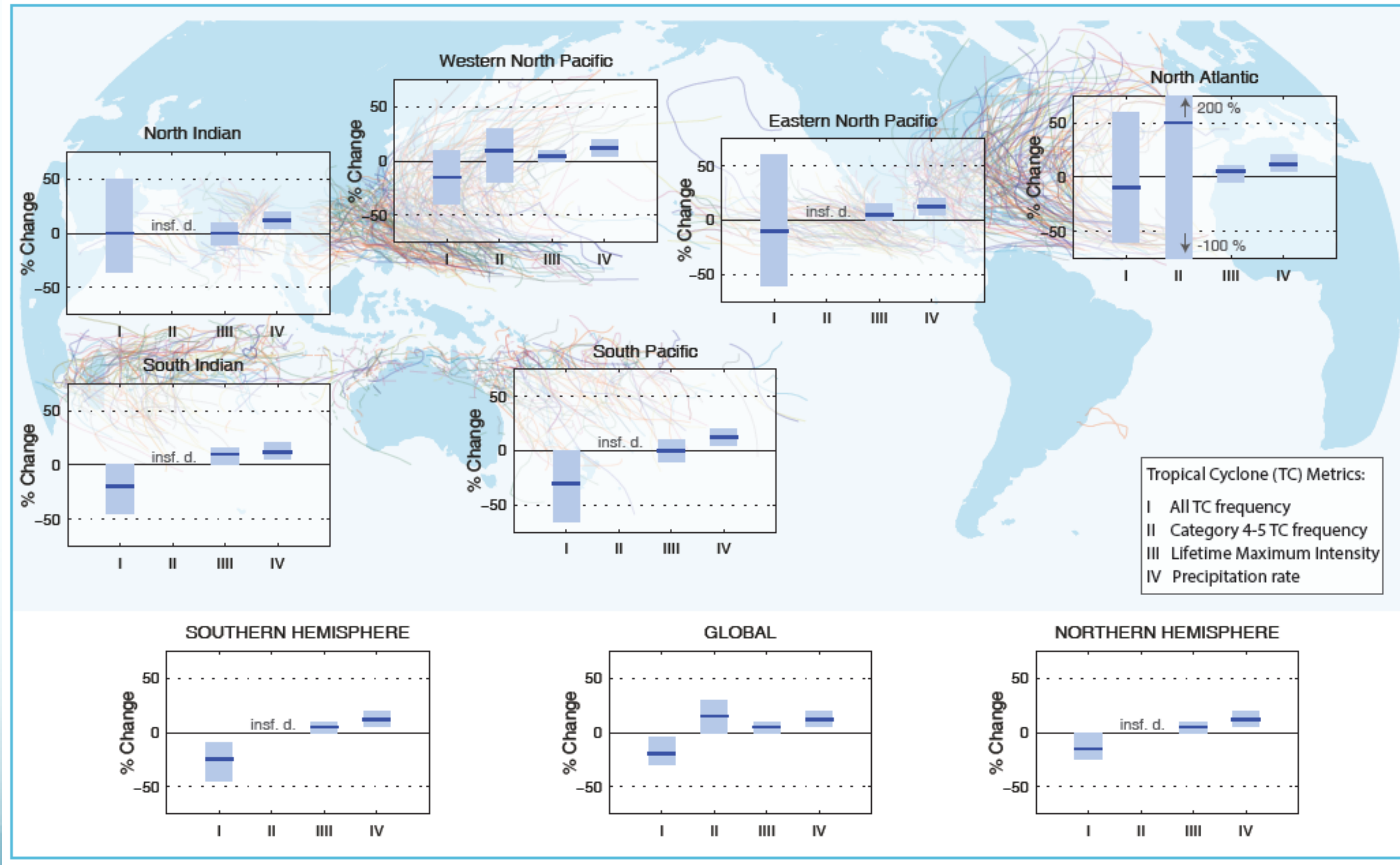
- 28% increase in cat 4-5 storms
- More rainfall in each storm as well



Knutson et al 2015



# Intergovernmental Panel on Climate Change (IPCC) 2013: The Physical Science Basis





W

What, besides intensity changes, might have a major influence on hurricane-induced destruction?

Changes in sea level

Changes in coastal land use

Both of the above



# Answer

Both sea level rise and increased coastal development are likely to have major influences on hurricane-induced destruction.

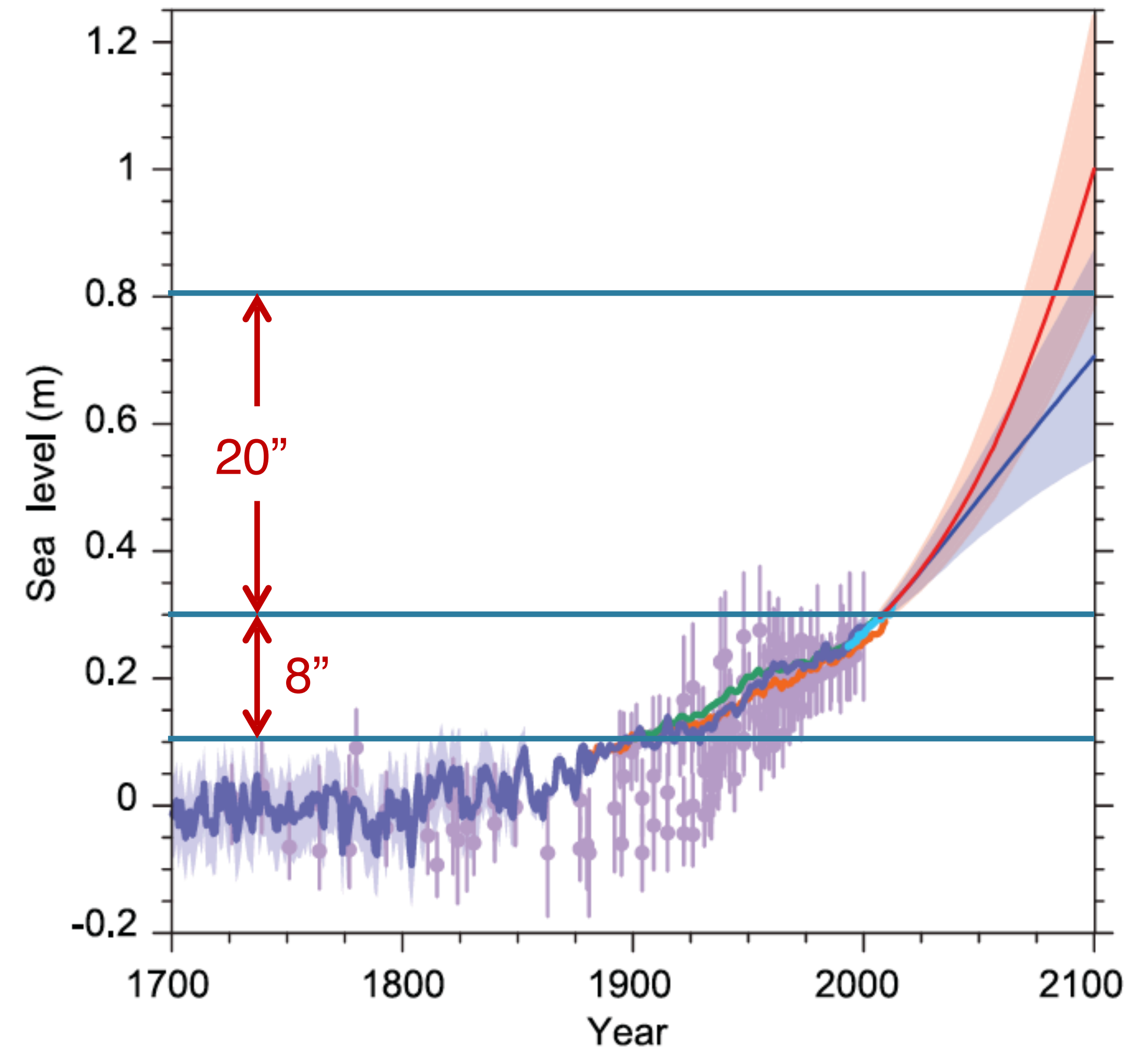
Sea level rise is far more certain than the possible changes in tropical cyclone frequency or intensity!



# Global Mean Sea-Level Change

## IPCC 2013

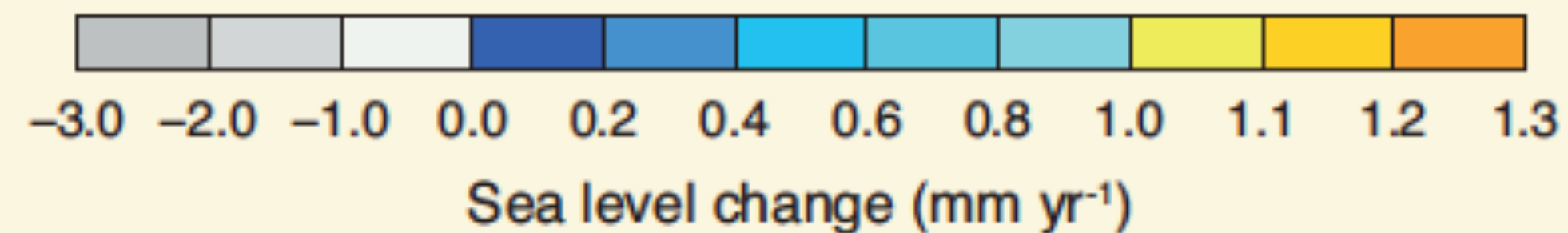
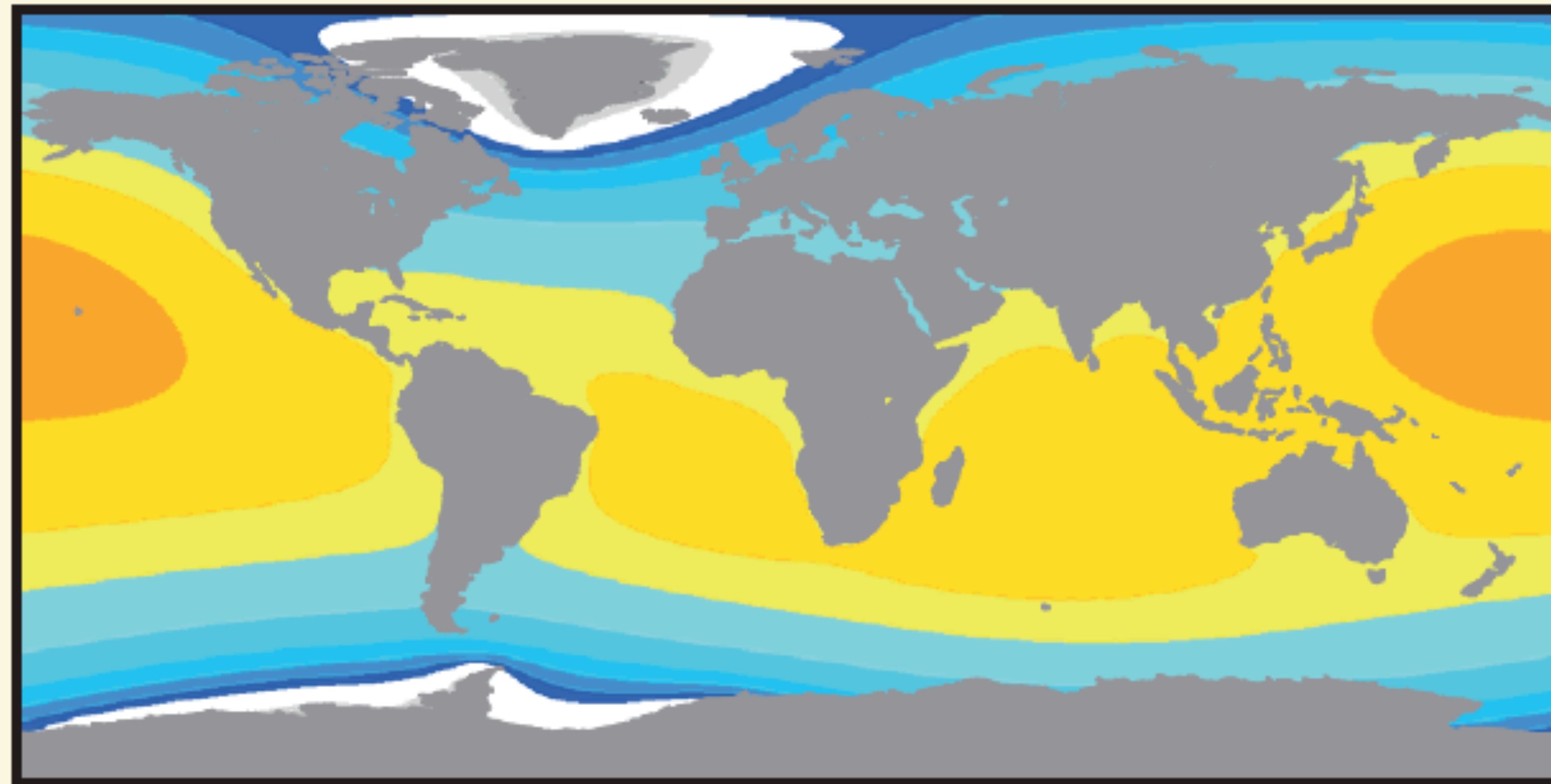
- Thermal expansion of the warming oceans
- Melting of ice on land



**Figure 13.27** | Compilation of paleo sea level data, tide gauge data, altimeter data (from Figure 13.3), and central estimates and *likely* ranges for projections of global mean sea level rise for RCP2.6 (blue) and RCP8.5 (red) scenarios (Section 13.5.1), all relative to pre-industrial values.



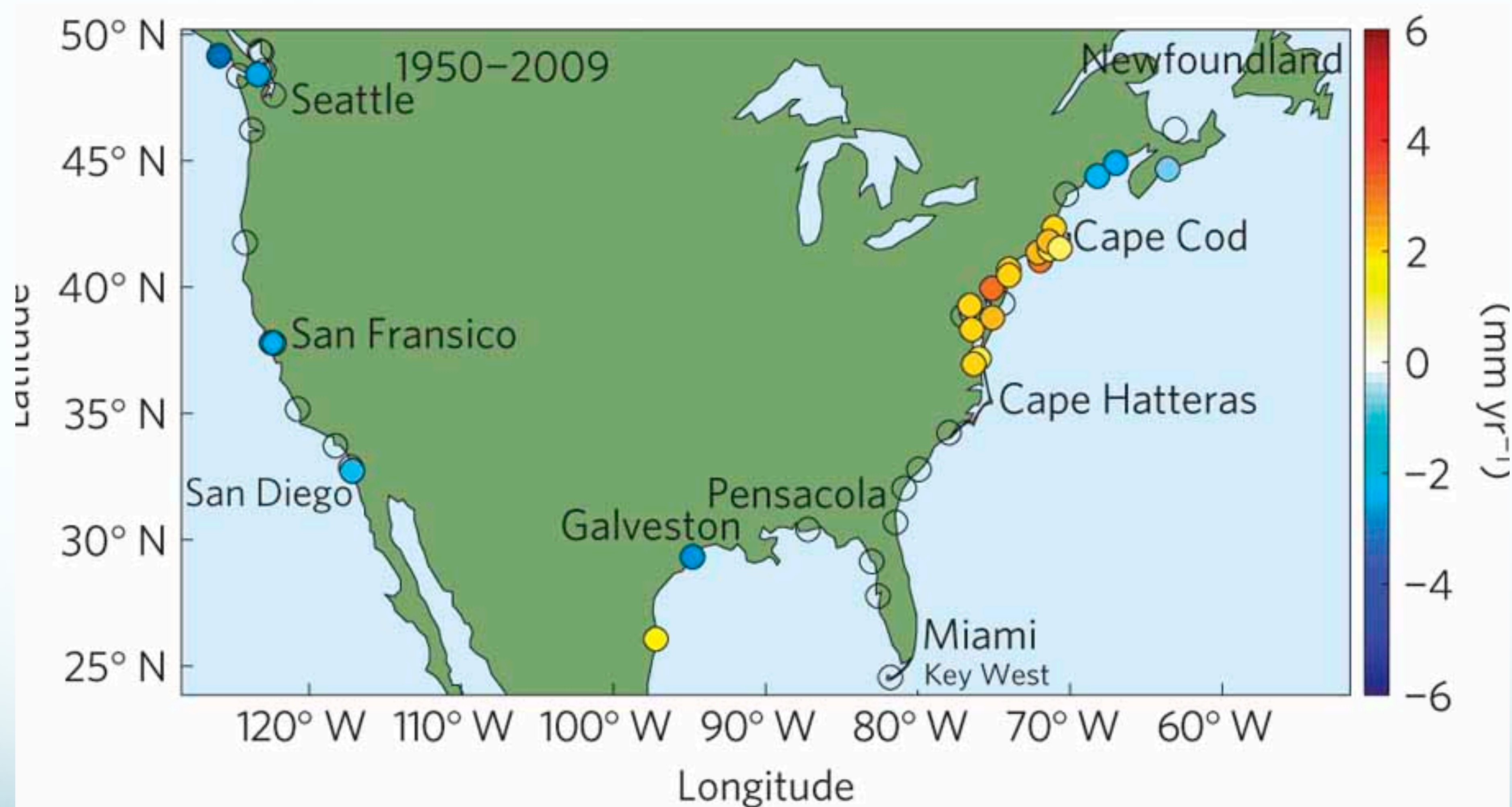
# Distribution of Sea-Level Rise (IPCC 2013)



**FAQ13.1, Figure 2** | Model output showing relative sea level change due to melting of the Greenland ice sheet and the West Antarctic ice sheet at rates of 0.5 mm yr<sup>-1</sup> each (giving a global mean value for sea level rise of 1 mm yr<sup>-1</sup>).



# Non-uniform Sea Level Rise: 1950-2009



2 mm per year x 59 years = 4.5" of rise



# Class Overview

- Goal: To explore science, history, and impacts of thunderstorms and hurricanes
  - Clouds (Weeks 1-2)
  - Thunderstorms (Weeks 3-5)
  - TORNADOS (Weeks 6-7)
  - Hurricanes/Tropical Cyclones (Weeks 8-10)



# Course evaluations

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- Open through 11:59 PM June 11<sup>th</sup>
- Suggestions for improving the course are particularly encouraged