

# You're Still Not Sure Global Warming is Real?

Panelists:

- **Dr. Judith Curry**

Professor in the School of Earth and Atmospheric Sciences,  
Georgia Institute of Technology

- **Dr. Joe Casola**

Staff Scientist and Program Dir. Sciences & Impacts,  
Center for Climate and Energy Solutions

Moderator: **Dr. Rajnish Barua**

Executive Director, NRRI

# President Obama

“The best scientists in the world are all telling us that our activities are changing the climate, and if we do not act forcefully, we’ll continue to see rising oceans, longer, hotter heat waves, dangerous droughts and floods, and massive disruptions that can trigger greater migration, conflict, and hunger around the globe”

State of the Union address, 1/20/15

# Is Global Warming Real?

- The National Academy of Sciences, the U.S. Global Change Research Program, and the Intergovernmental Panel on Climate Change agree: manmade greenhouse gases are changing the world's climate
- Yet, seemingly contradictory information is not hard to find
- Federal initiatives to cut greenhouse gas emissions from power plants are placing this issue on the regulators' desks

# Dr. Judith Curry

- Professor and former Chair of the School of Earth and Atmospheric Sciences, Georgia Institute of Technology
- Ph.D. in atmospheric science from the University of Chicago
- Previously held faculty positions at the University of Colorado, Penn State University and Purdue University
- Fellow of the
  - American Meteorological Society
  - American Association for the Advancement of Science
  - American Geophysical Union
- Testified before the Senate Committee on Environment and Public Works and the House Subcommittee on the Environment
- Research interests span a variety of topics in climate. Current interests include:
  - climate dynamics of the Arctic
  - climate dynamics of extreme weather events
  - reasoning about climate uncertainty



# Dr. Joe Casola

- Staff Scientist and Program Director, Science and Impacts, Center for Climate and Energy Solutions (C2ES)
- Ph.D. and MS in atmospheric sciences, University of Washington; BS in chemistry, Duke University
- C2ES works with decision makers in government and large corporations to identify policy options for lowering emissions and improving resilience
- Contributed to scientific reports at the National Research Council/National Academy of Science
- Worked with water, energy, transportation, and natural resource managers to address climate risks at ICF International

# Climate Change: Our BIG PICTURE understanding

Joe Casola  
Staff Scientist; Program Director, Science and Impacts  
C2ES

*NARUC Winter Meeting  
Electricity Committee*

*February 17, 2015*



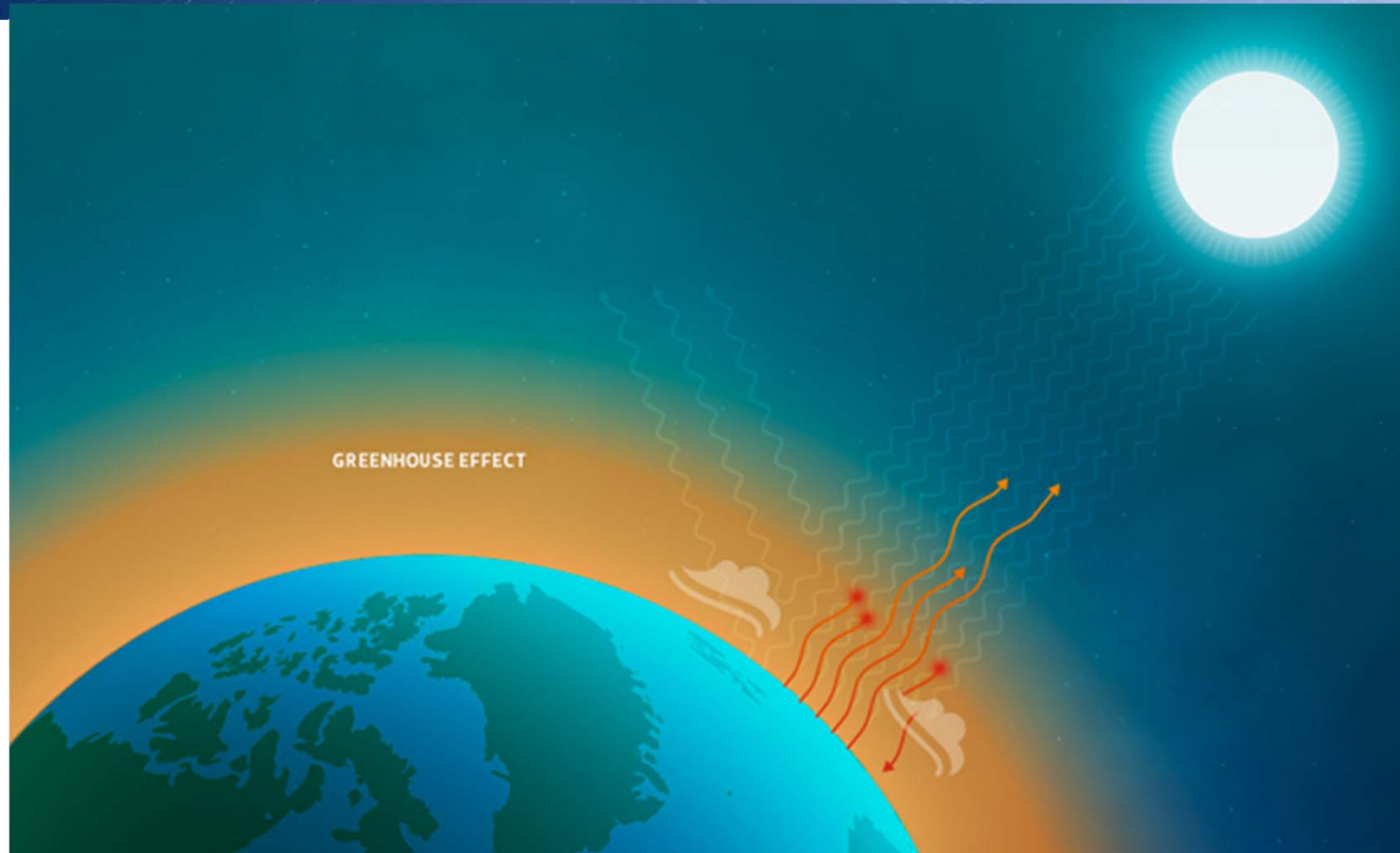
**C2ES.ORG**

## The BIG picture



- 1) Carbon dioxide (CO<sub>2</sub>) and other greenhouse gases make the planet warmer**
- 2) CO<sub>2</sub> is accumulating in the atmosphere**
- 3) The planet is warming**
- 4) Warming is best explained by humans' emissions of CO<sub>2</sub> and other greenhouse gases**
- 5) Future warming should be expected**

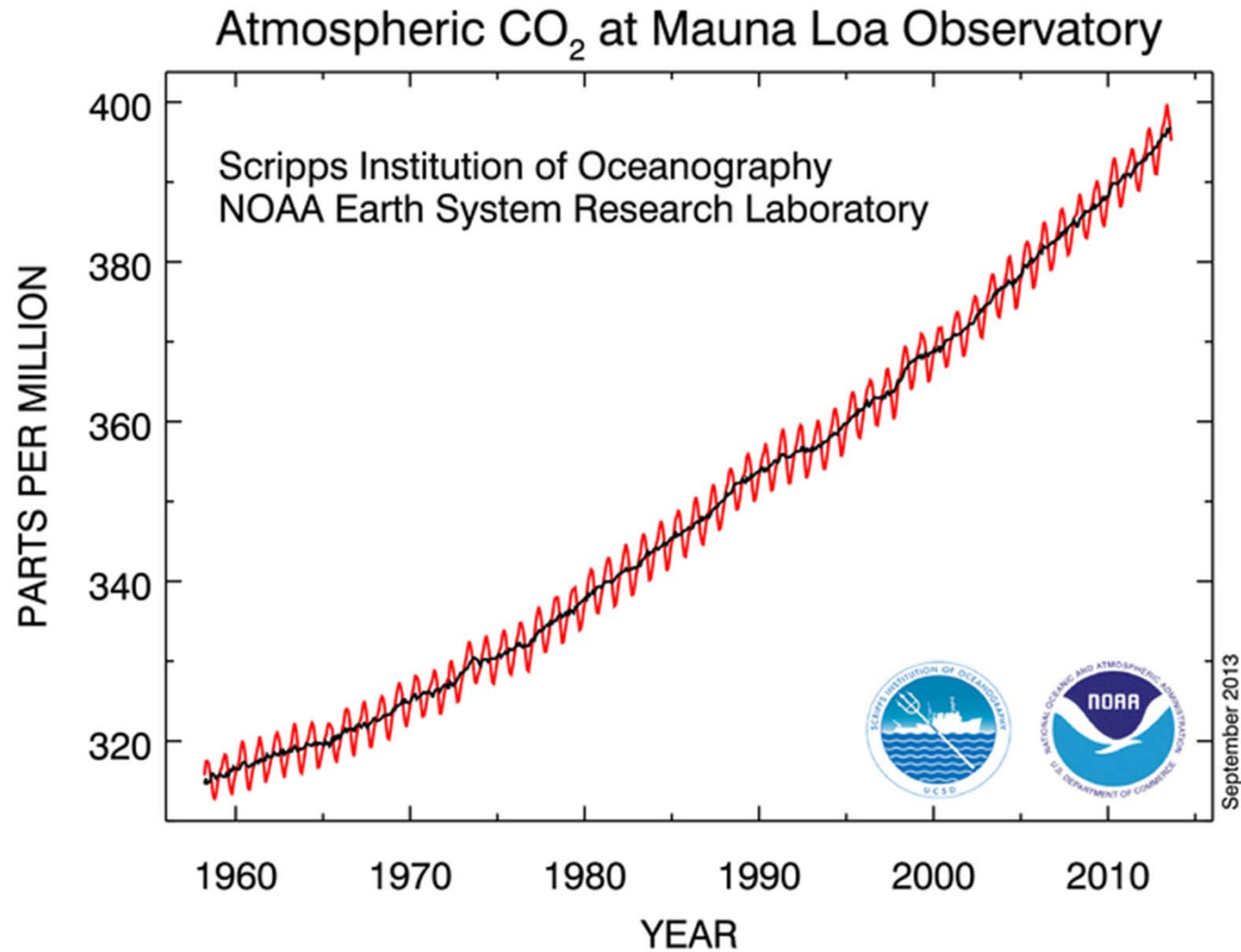
# 1) Greenhouse gases (GHGs) warm the planet



<http://www.epa.gov/climatechange/science/causes.html>

- **GHGs absorb and re-emit infrared radiation back to the surface**
- **GHGs “naturally” keep the Earth about 60°F warmer than it would be without them**

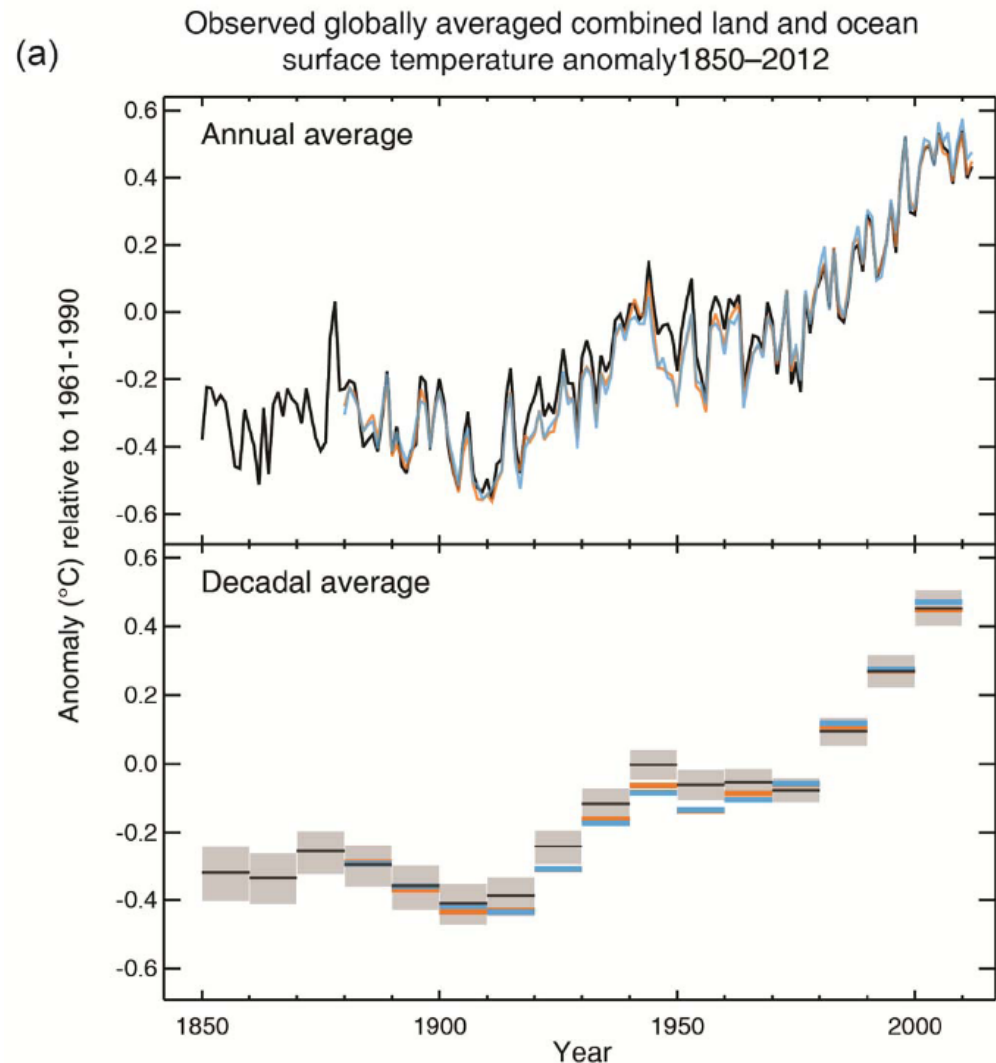
## 2) CO<sub>2</sub> is accumulating in the atmosphere



### 3) The Earth is warming



- **2000's were the warmest decade in the data record**
- **Every decade has been warmer than the previous one since the 1970s**

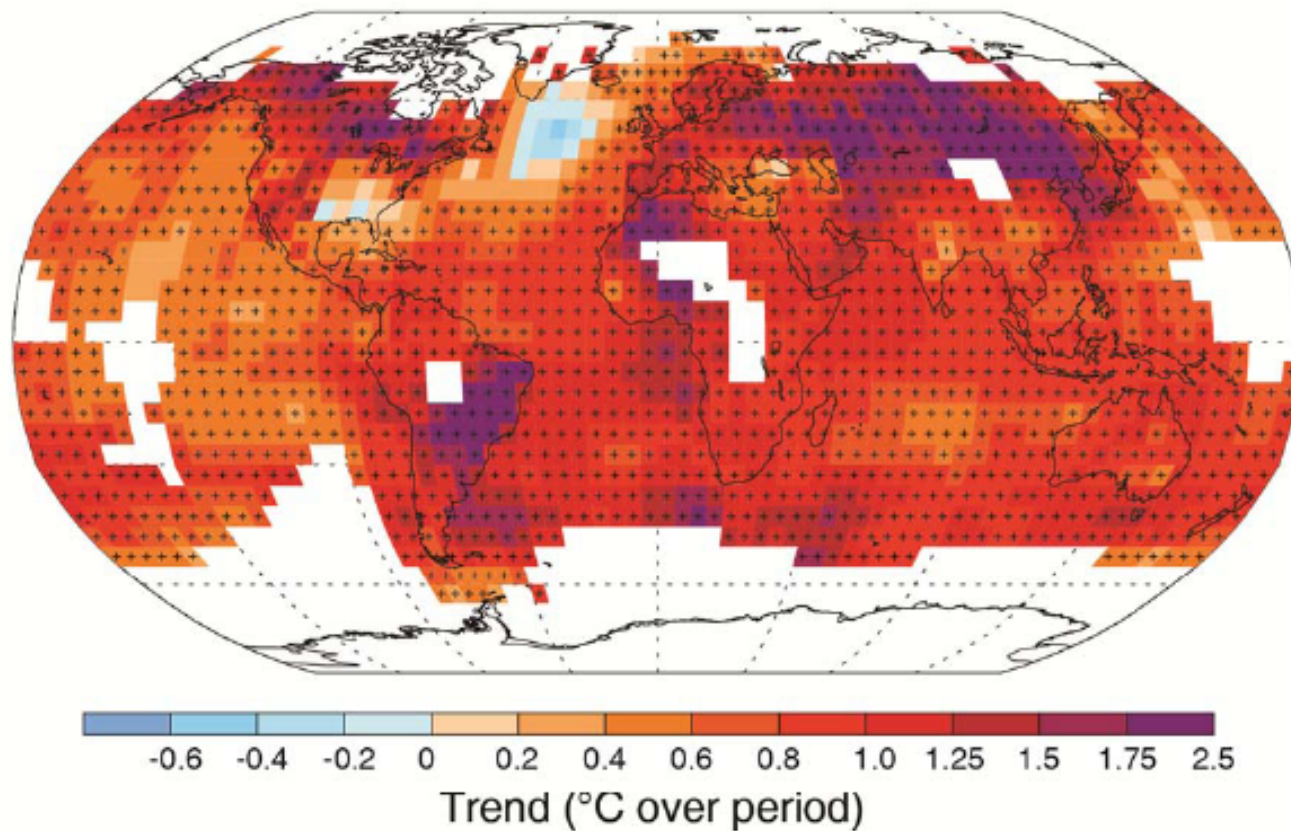




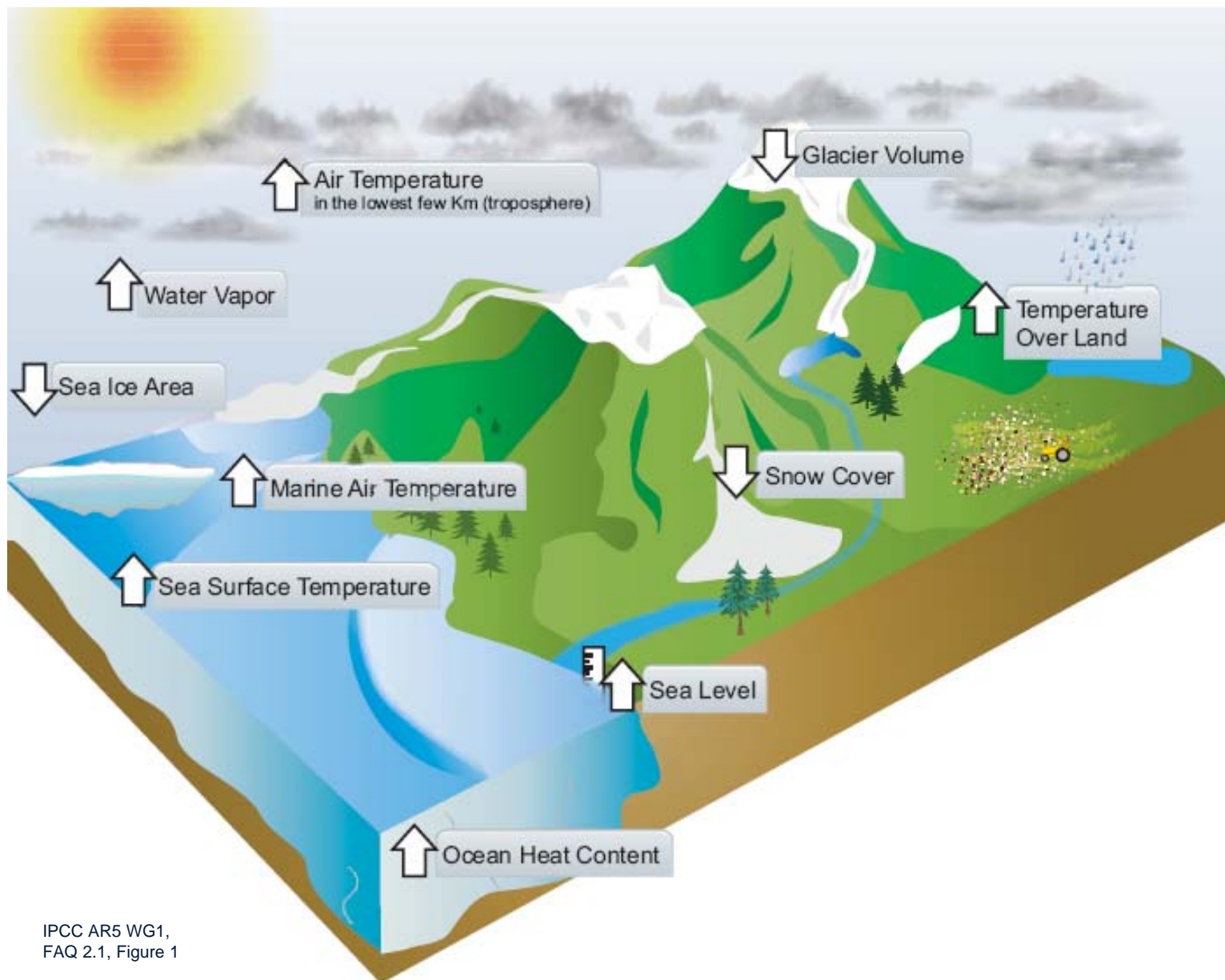
# Warming nearly everywhere throughout 20<sup>th</sup> century



(b) Observed change in average surface temperature 1901–2012



# Warming is consistent with other global changes



IPCC AR5 WG1,  
FAQ 2.1, Figure 1



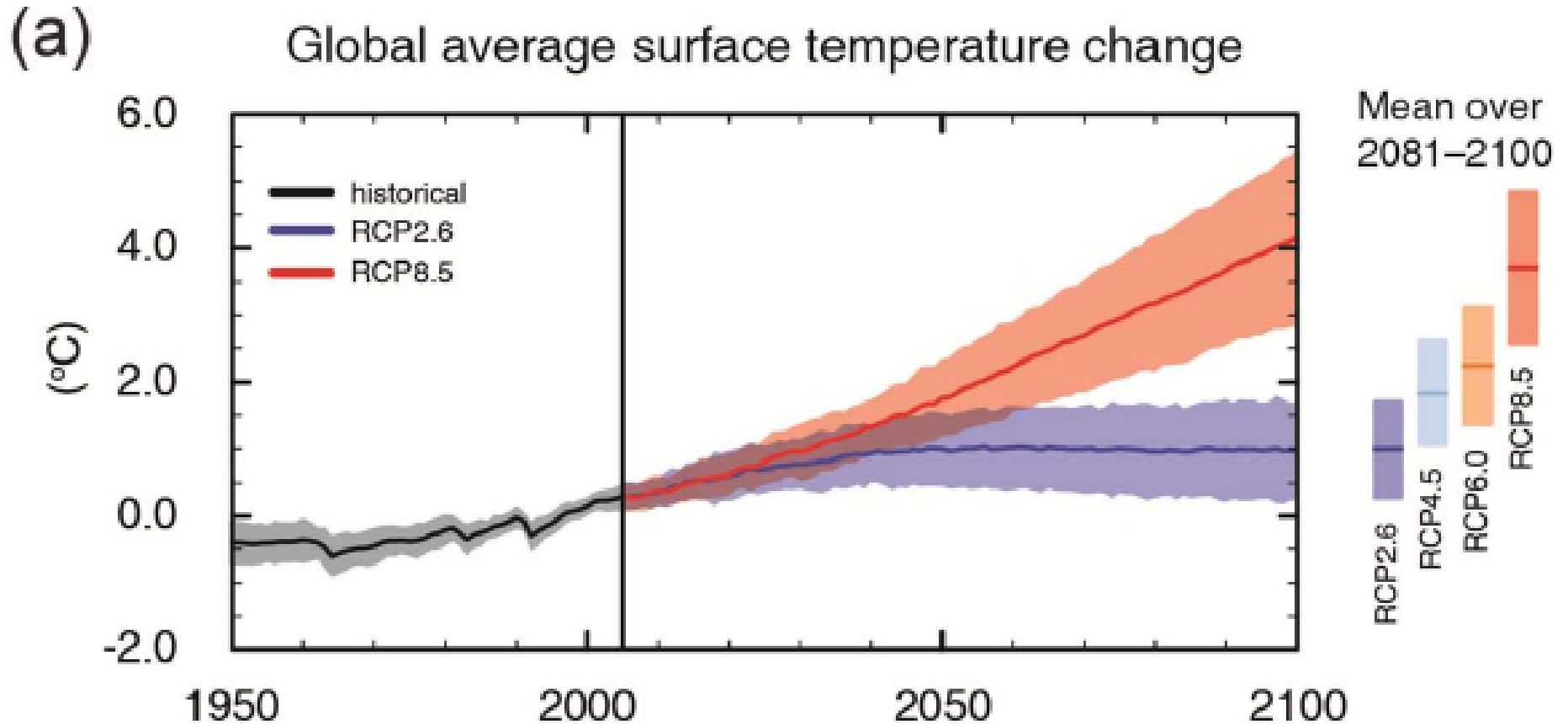
## 4) Warming is unusual; best explained by our emissions



- Magnitude and rate of warming is large (warmer than in last 400 years, at least; ice ages only +/- 5°C)
- Spatial and vertical pattern of warming matches what greenhouse gases “should” do
- Changes in other factors that drive climate (like the Sun) don’t explain warming
- Models can only replicate 20<sup>th</sup> century warming when greenhouse gases are included



## 5) Future climate likely to be much warmer

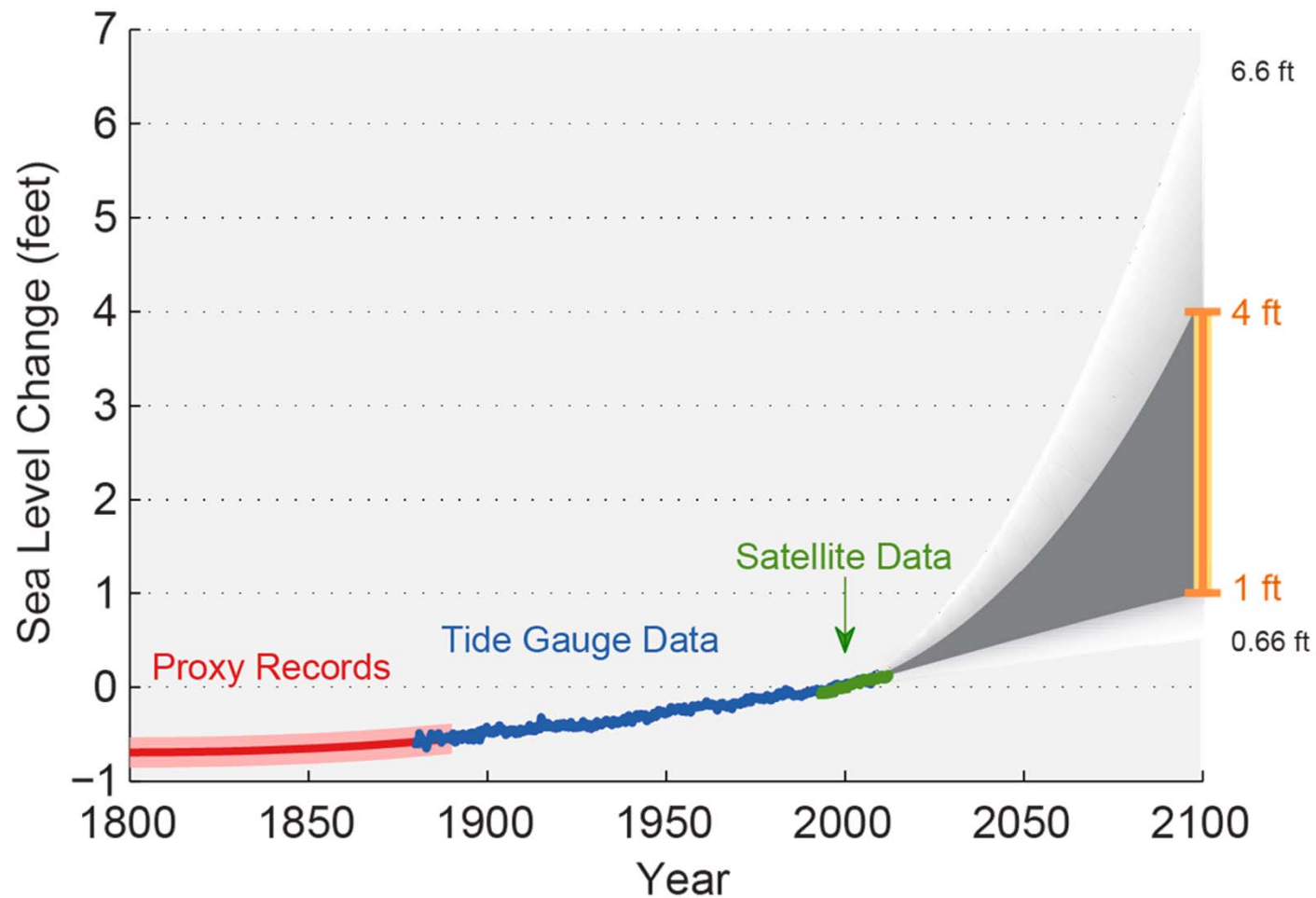


**“RCP” - Representative Concentration Pathways [in  $\text{W}/\text{m}^2$ ]**

# Potential for dramatic sea level rise in 21<sup>st</sup> century



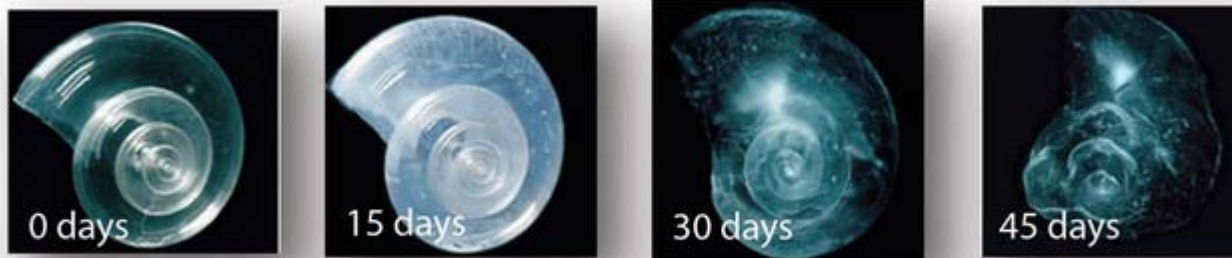
## Past and Projected Changes in Global Sea Level



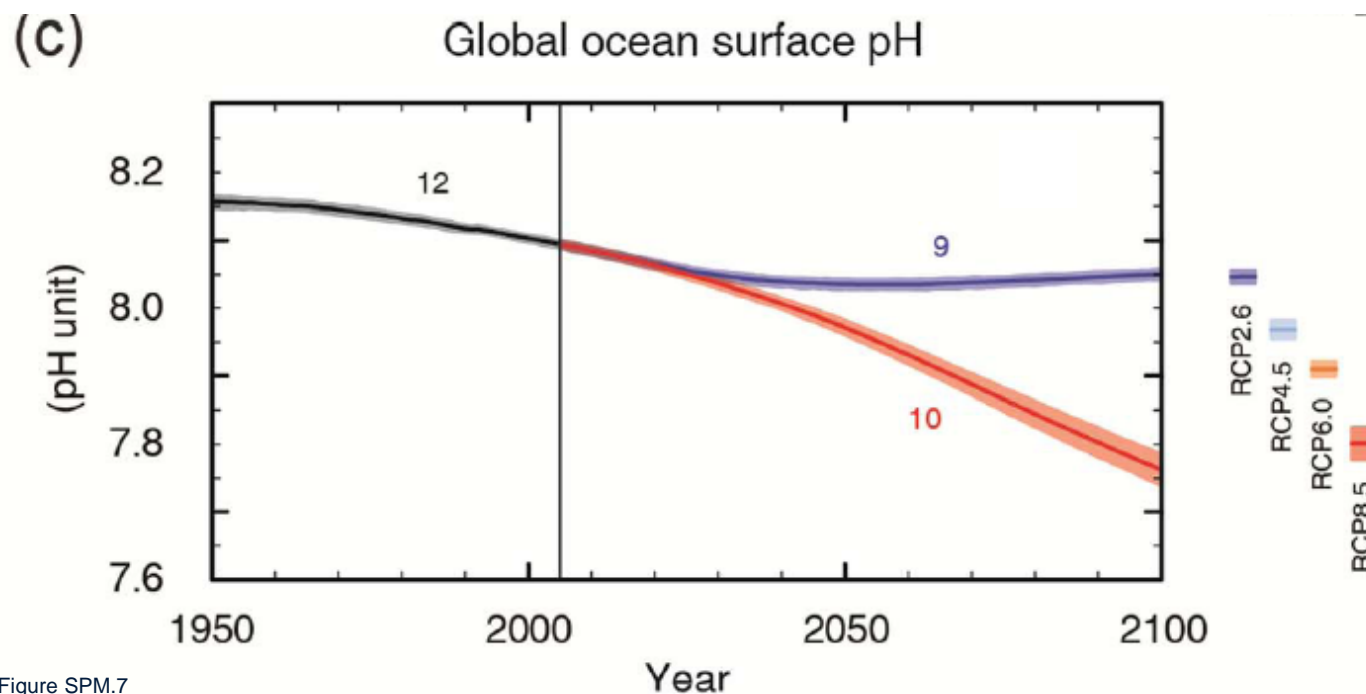
# Increasing CO<sub>2</sub> → More acidic oceans



Pteropod exposed to “2100 seawater” (water that is 50% more acidic than present day)



National Geographic and NOAA Pacific Marine Environmental Lab  
<http://ngm.nationalgeographic.com/2007/11/marine-miniatures/acid-threat-text>  
<http://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F>



- **Evidence for \*some types\* of extreme events grows stronger**
  - ↑ Heat Waves (frequency and severity)
  - ↓ Cold Waves (frequency and severity)
  - ↑ Amount of Rainfall during Heaviest Rains
  - ↑ Area burned by wildfires
- **We have some physical or statistical information for changes in other types of extremes, but the evidence is weaker**
  - Changes in seasonal rainfall → regionally variable
  - Hurricanes potentially more intense, but frequency changes could be small or negative
  - Tornadoes??



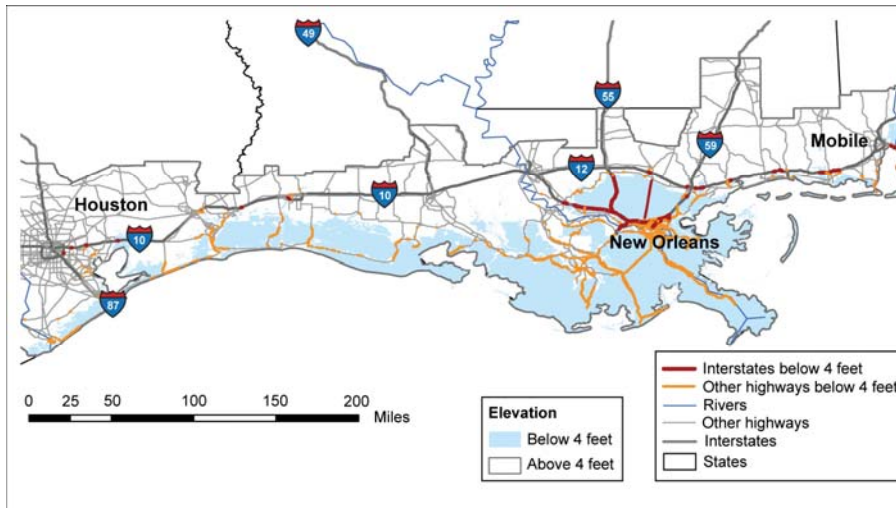
# Communities and businesses are sensitive to climate variations



- Transportation
- Energy
- Public Health
- Agriculture
- Water Resources
- Ecosystems



LEADING BY EXAMPLE: THE CITY OF CHICAGO  
URBAN HEAT ISLAND POLICIES



## What does this mean for regulators and the electricity sector?



- The BIG PICTURE is not a subject of debate within the scientific community
- There ARE many aspects of climate that are not completely understood, but do not undermine the BIG PICTURE understanding
- Best translation into a policy context = **RISK MANAGEMENT** approach
- Compared to other business and environmental risks, we actually have lots of information about climate change!

# State of the Climate Debate

Judith Curry

Georgia Institute of Technology

Climate Forecast Applications Network

Confusion

•

Uncertainty

•

Disagreement





# Sense of the Senate Resolution 1/20/15

“Climate change is real and not a hoax” (98-1)

“Climate change is real; and human activity significantly contributes to climate change.” (50-49)

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Confusion between the scientific and political definition:

- Scientific definition: Climate change may be due to natural processes, or to persistent anthropogenic changes.
- Political definition equates ‘climate change’ with human-caused climate change (UNFCCC)

**Natural climate variability versus human-caused climate change is at the heart of scientific and policy debate**



# Agreement:

- Surface temperatures have increased since 1880
- Humans are adding carbon dioxide to the atmosphere
- Carbon dioxide and other greenhouse gases have a warming effect on the planet

# Disagreement:

- Whether the warming since 1950 has been dominated by human causes
- How much the planet will warm in the 21<sup>st</sup> century
- Whether warming is 'dangerous'
- Whether we can afford to radically reduce CO<sub>2</sub> emissions, and whether reduction will improve the climate



# Why do scientists disagree?

- Insufficient observational evidence
- Disagreement about the value of different classes of evidence (e.g. global climate models)
- Disagreement about the appropriate logical framework for linking and assessing the evidence
- Assessments of areas of ambiguity & ignorance
- **Belief polarization as a result of politicization of the science**

Uncertainty • Doubt • Ignorance

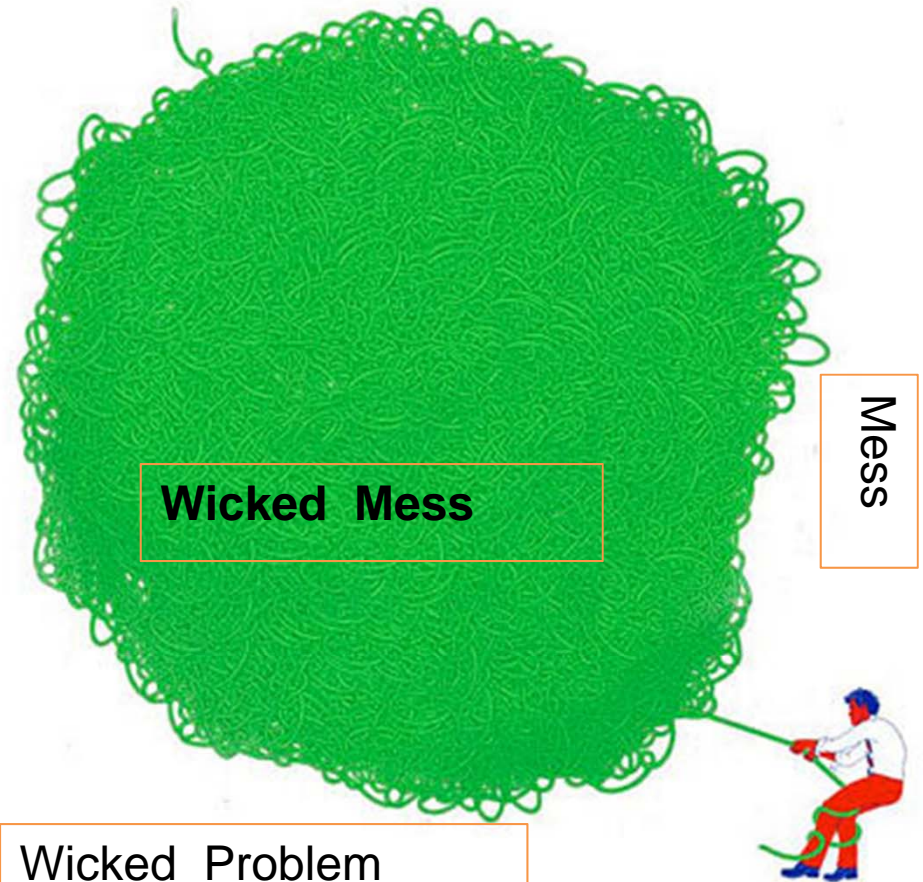
Tame Problem



versus

**President Obama:** “We don’t have time for a meeting of the Flat Earth Society”

**JC:** The climate change problem and its solution have been vastly oversimplified.



**Wicked Mess**

Mess

Wicked Problem

2/17/15

Judith Curry

# You find what you shine a light on . . .

Solar indirect effects

Unknown unknowns

Long-term ocean  
oscillations

Volcanoes

Greenhouse gases

Underwater volcanoes

Land use

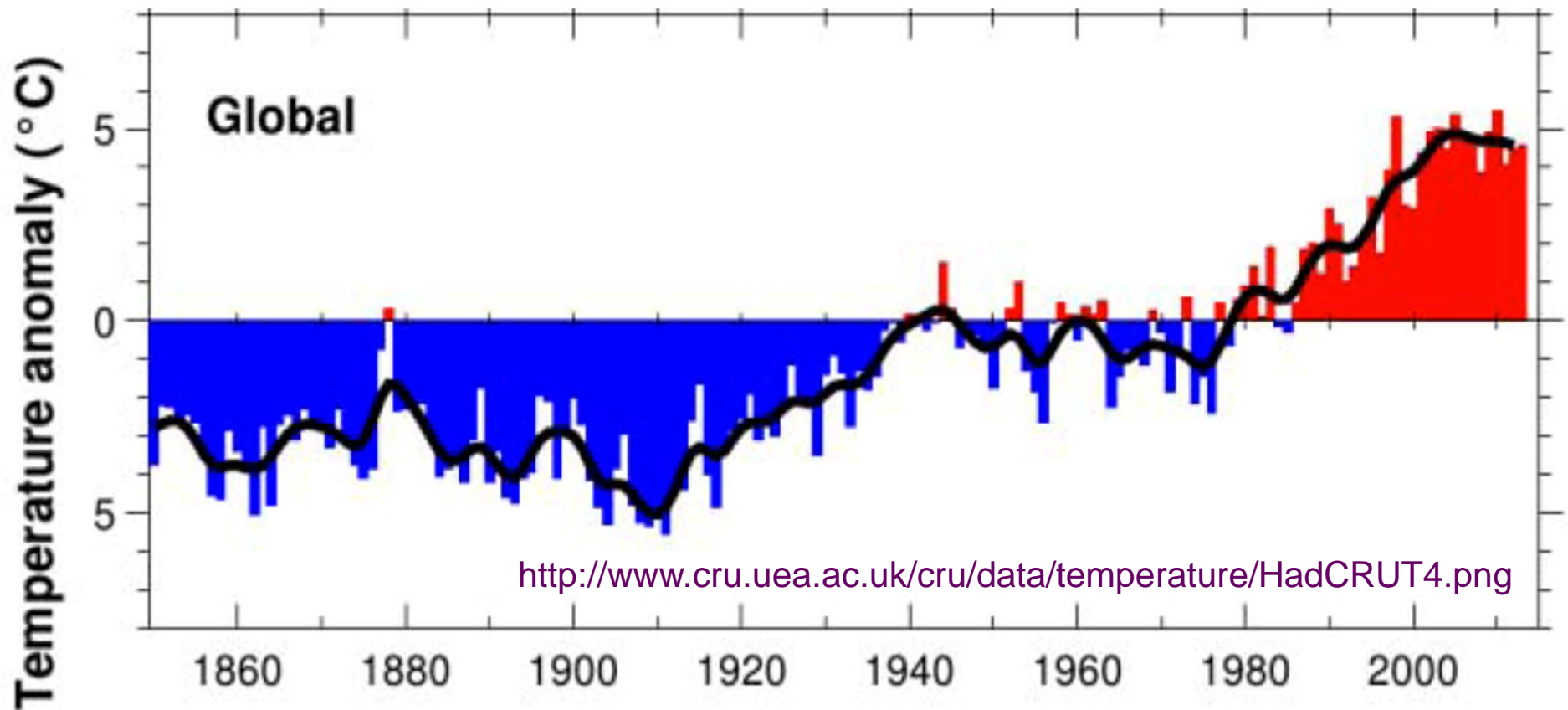
Solar system gravitational  
& magnetic interactions

Aerosols



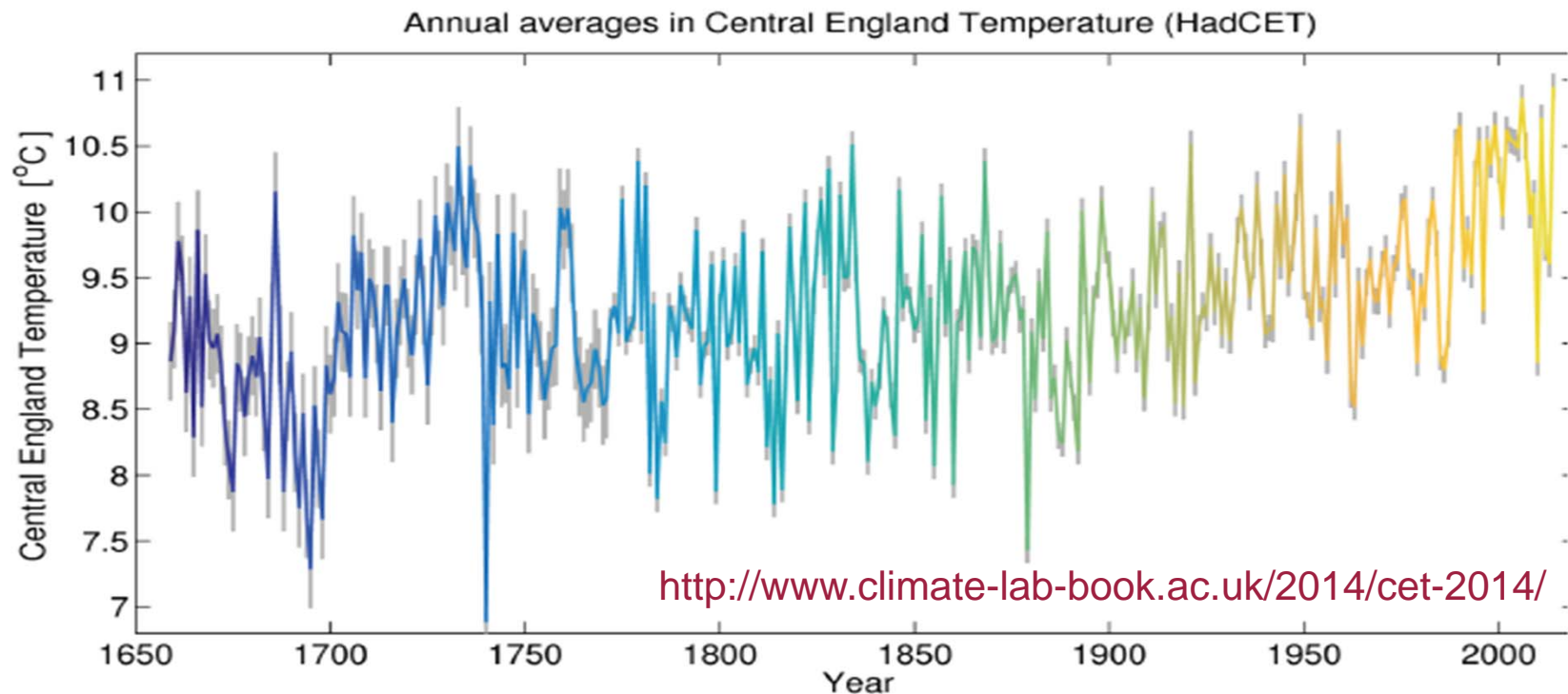


# Global surface temperature anomaly



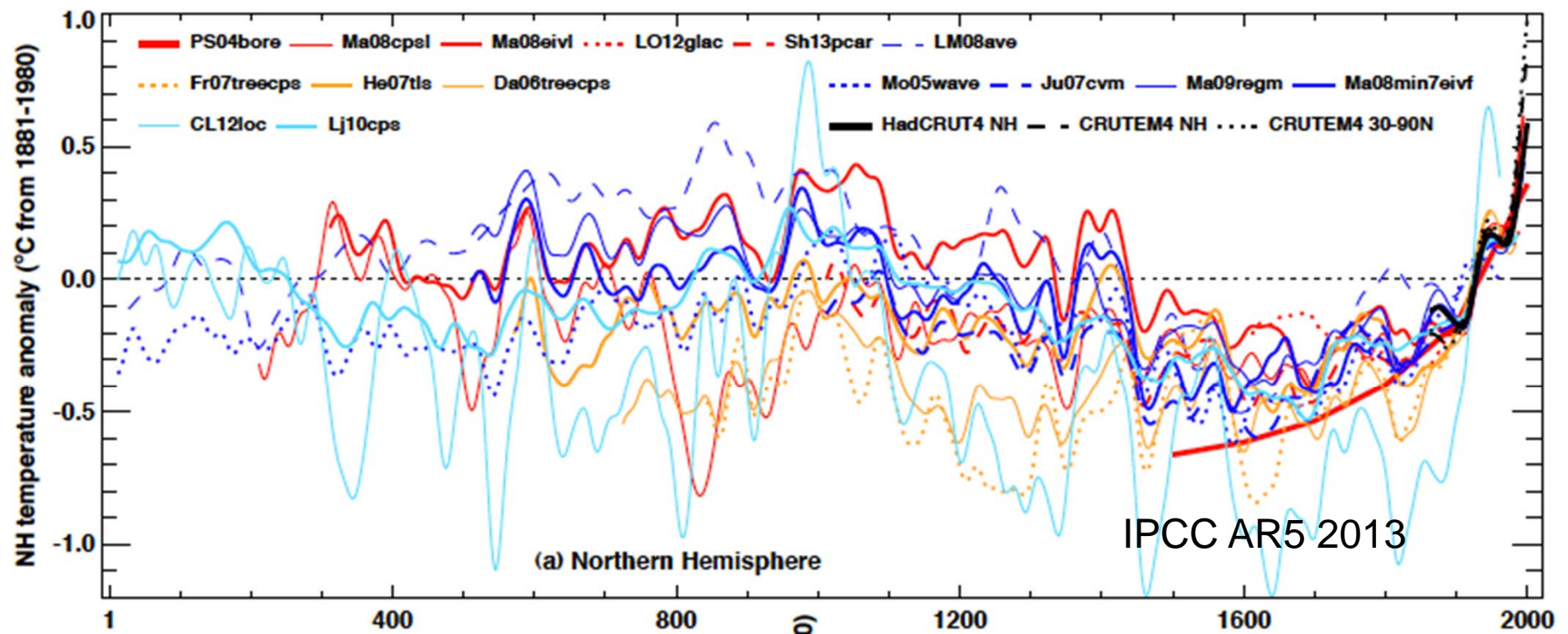
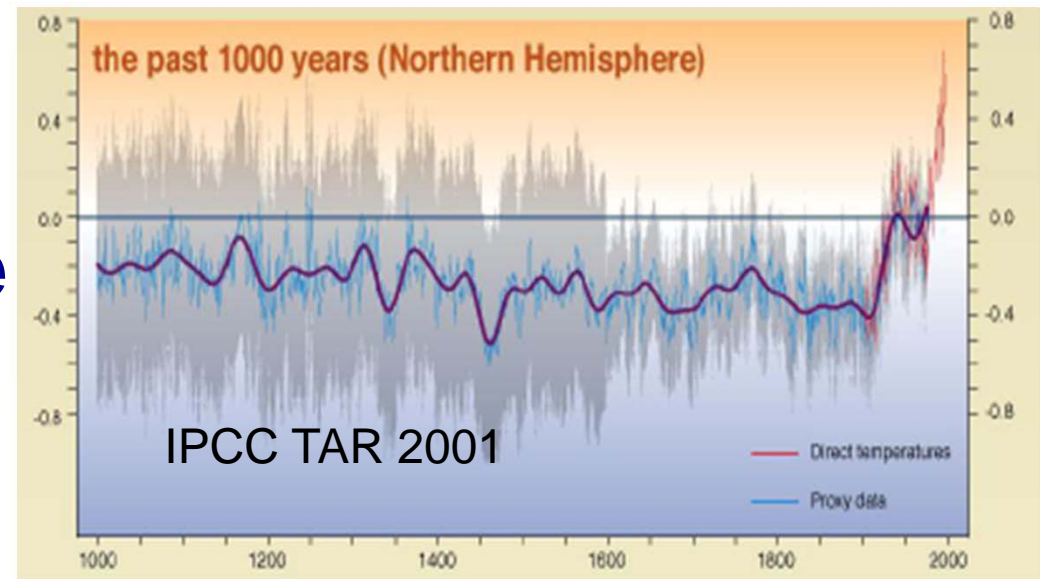
**IPCC AR5:** *It is **extremely likely** that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by [humans]. The best estimate of the human induced contribution is similar to the observed warming over this period.*

# Is the warming since 1950 unusual?



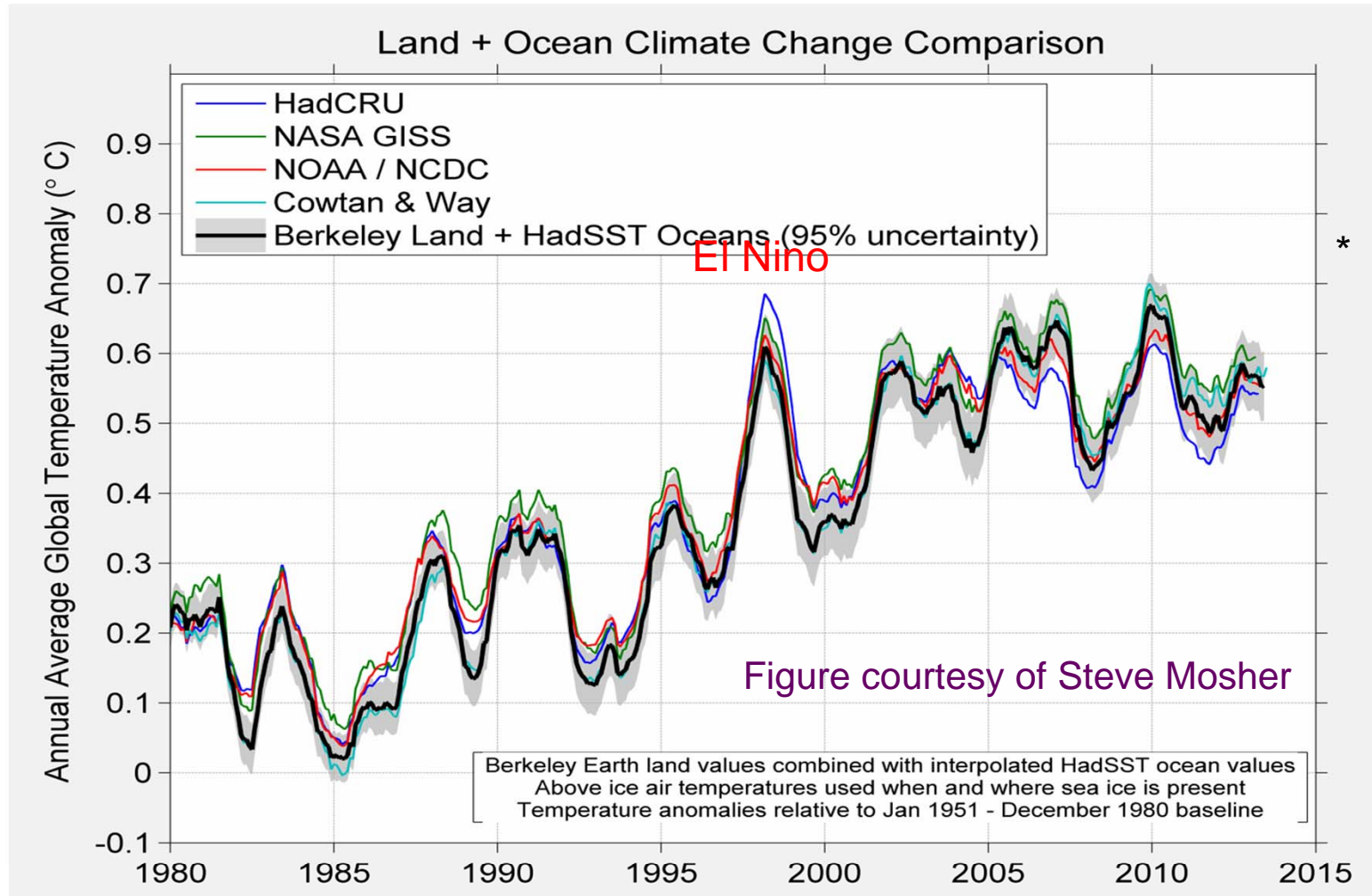
- Long-term warming trend: fossil fuel contribution since 1950
- Year-to-year variations: volcanoes, El Nino
- Multi-decadal variations: solar, ocean circulations

# NH paleoclimate surface temperature reconstructions



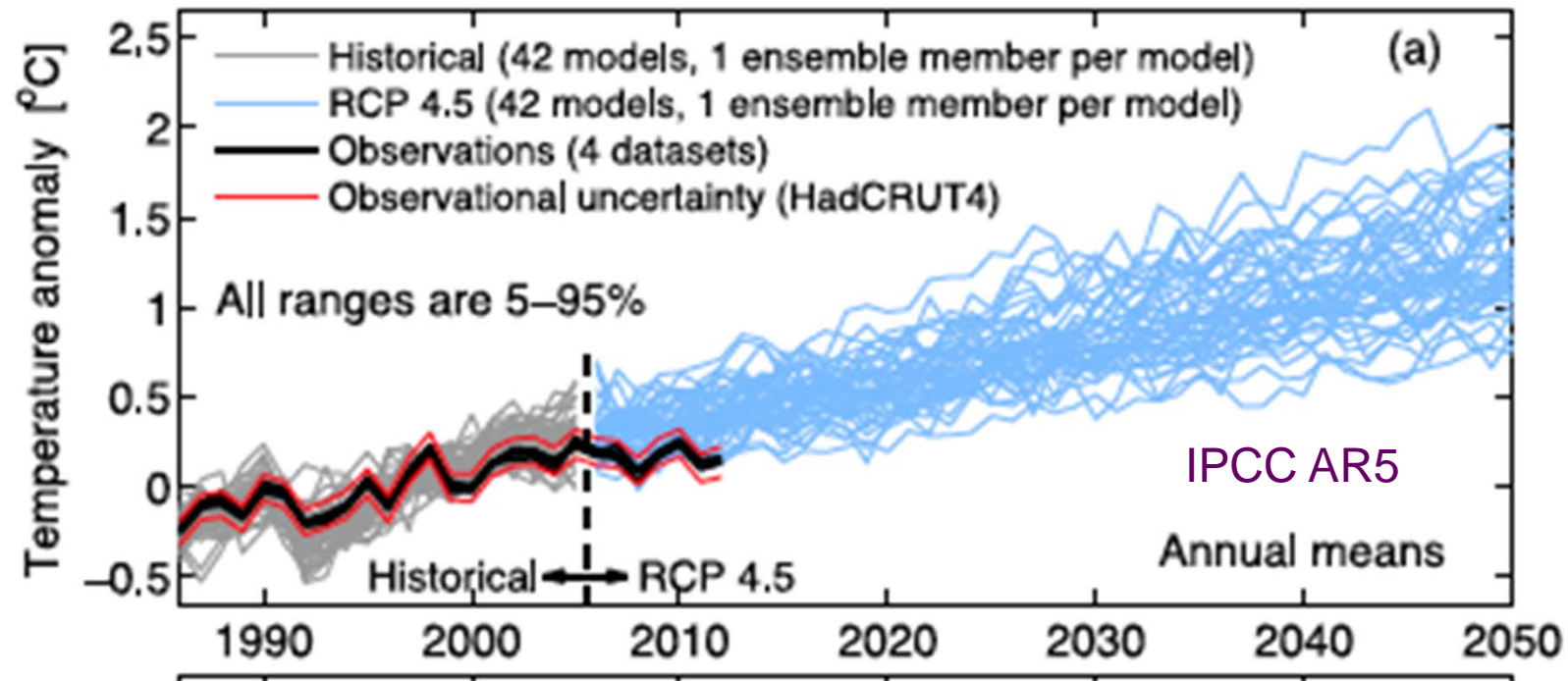


# Warming 'pause' or 'hiatus'



IPCC AR4: Surface temperature expected to increase  $0.2^{\circ}\text{C}/\text{decade}$  in early 21<sup>st</sup> century

# Significance of the 'pause' since 1998



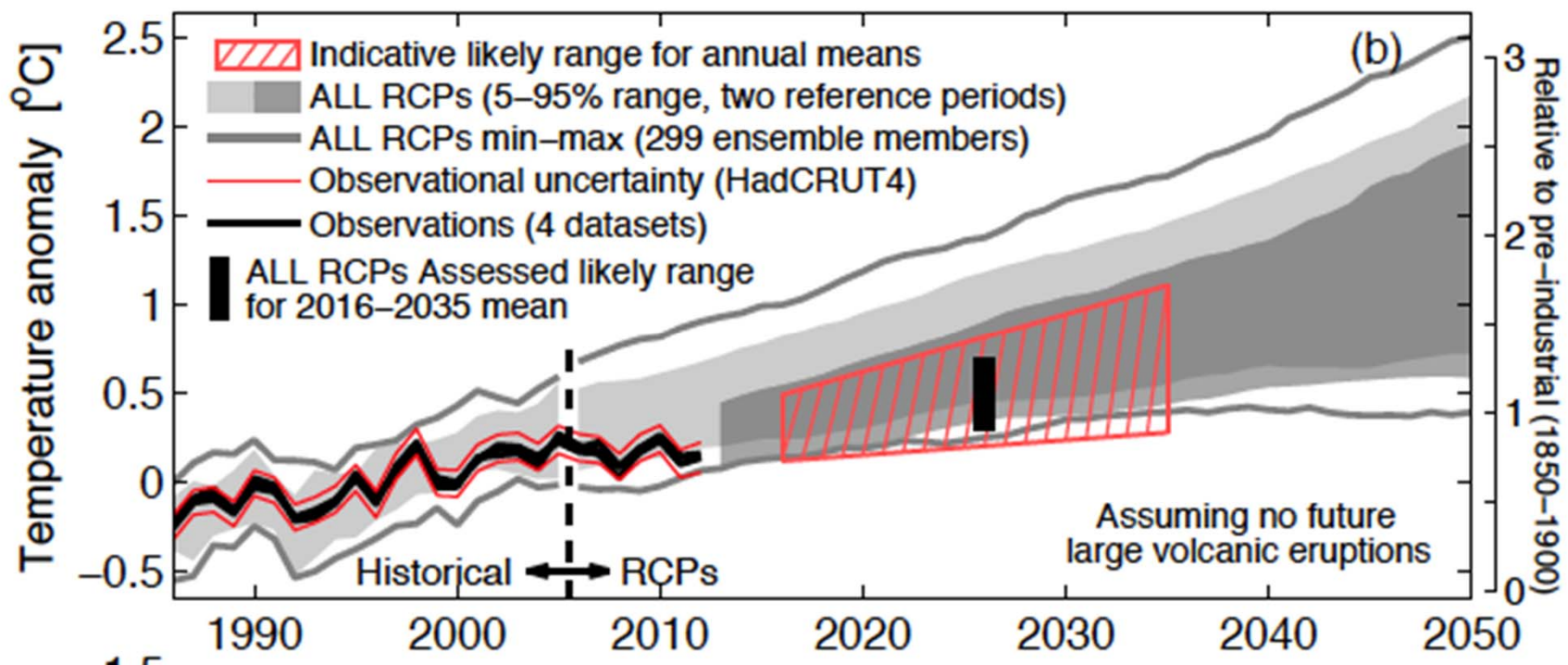
Growing divergence between models & observations:

- Are climate models too sensitive to greenhouse impact?
- Is modeled treatment of natural climate variability inadequate?
- Are model projections of 21<sup>st</sup> century warming too high?

# Implications for the future:

## I. Consensus IPCC view

- The 'pause' will end soon, with the next El Nino



IPCC AR5 Ch 11

# Implications for the future:

## II. View emphasizing natural variability

- The 'pause' will continue at least another decade (into the 2030's?); El Ninos weak and infrequent
- Climate models are too sensitive to human impact; 21<sup>st</sup> century warming will be on the low end of IPCC projections (or even below)
- Solar variations & volcanoes: wild card. Most are predicting solar cooling in the near term
- Can't rule out unforeseen surprises



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# Implications for utility regulators

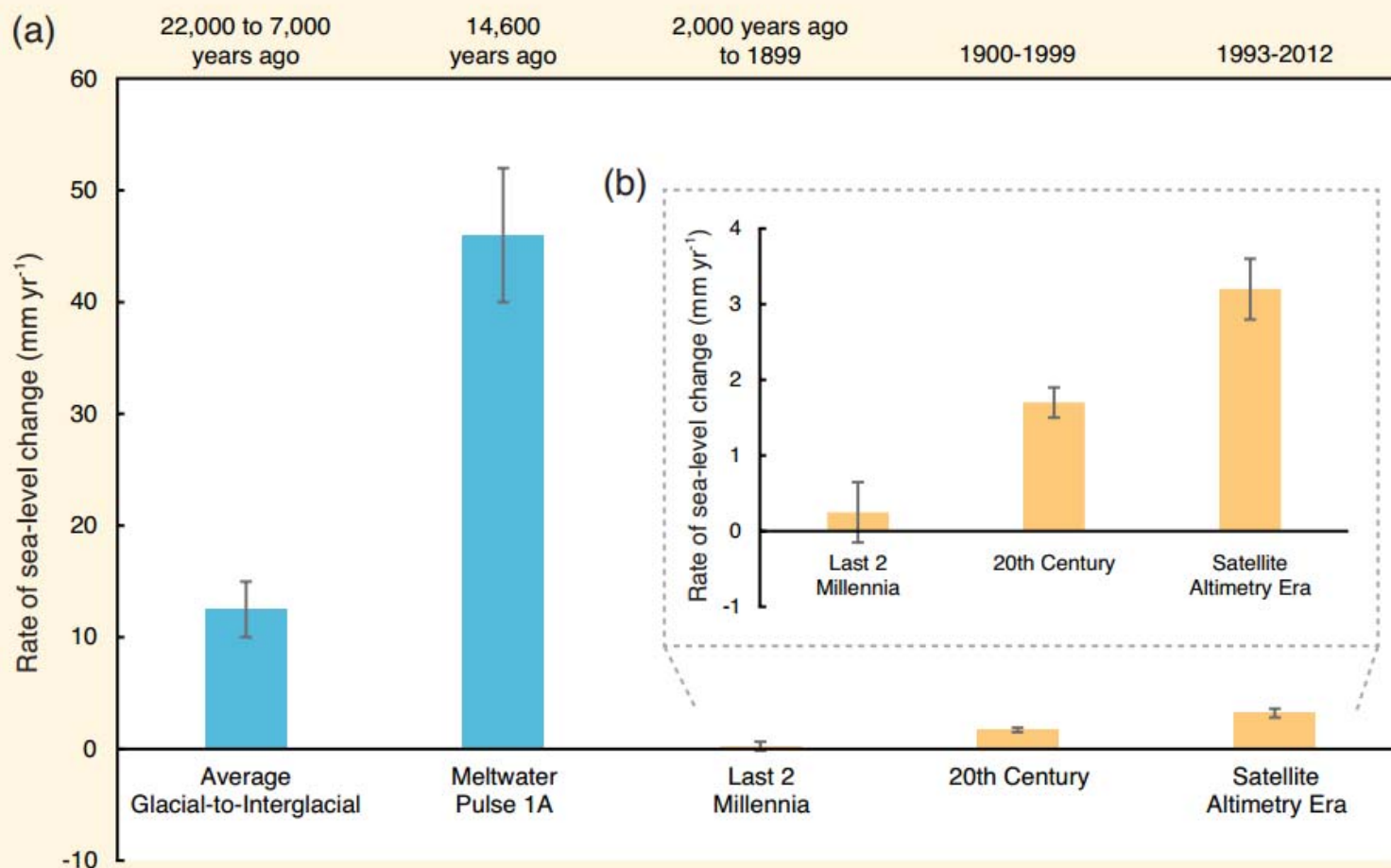
- There is a great deal of uncertainty in our understanding of what has caused the 20<sup>th</sup> century warming and how the 21<sup>st</sup> century climate might evolve.
- We need to prepare for surprises – including ‘cold’ ones
- We need to stop treating ‘climate change’ as a tame problem, and need to adopt a decision making framework that seeks flexible, robust and anti-fragile policies

# Oceans Rising?

- When the ice ages ended, sea level rose substantially over several thousand years.
- Is the more-recent resumption in sea level rise caused by human-caused global warming?
- Has human-caused climate change increased the threats to our coasts?

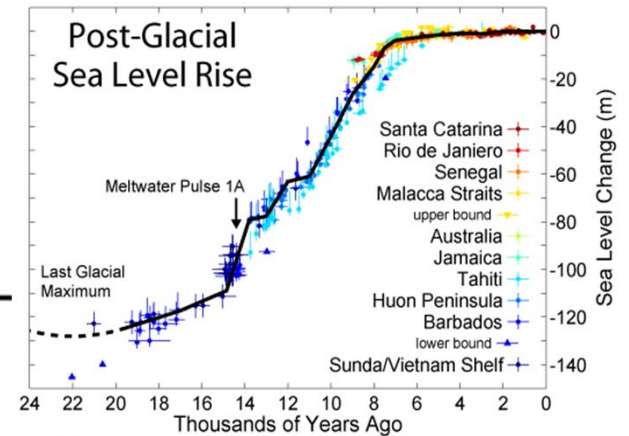
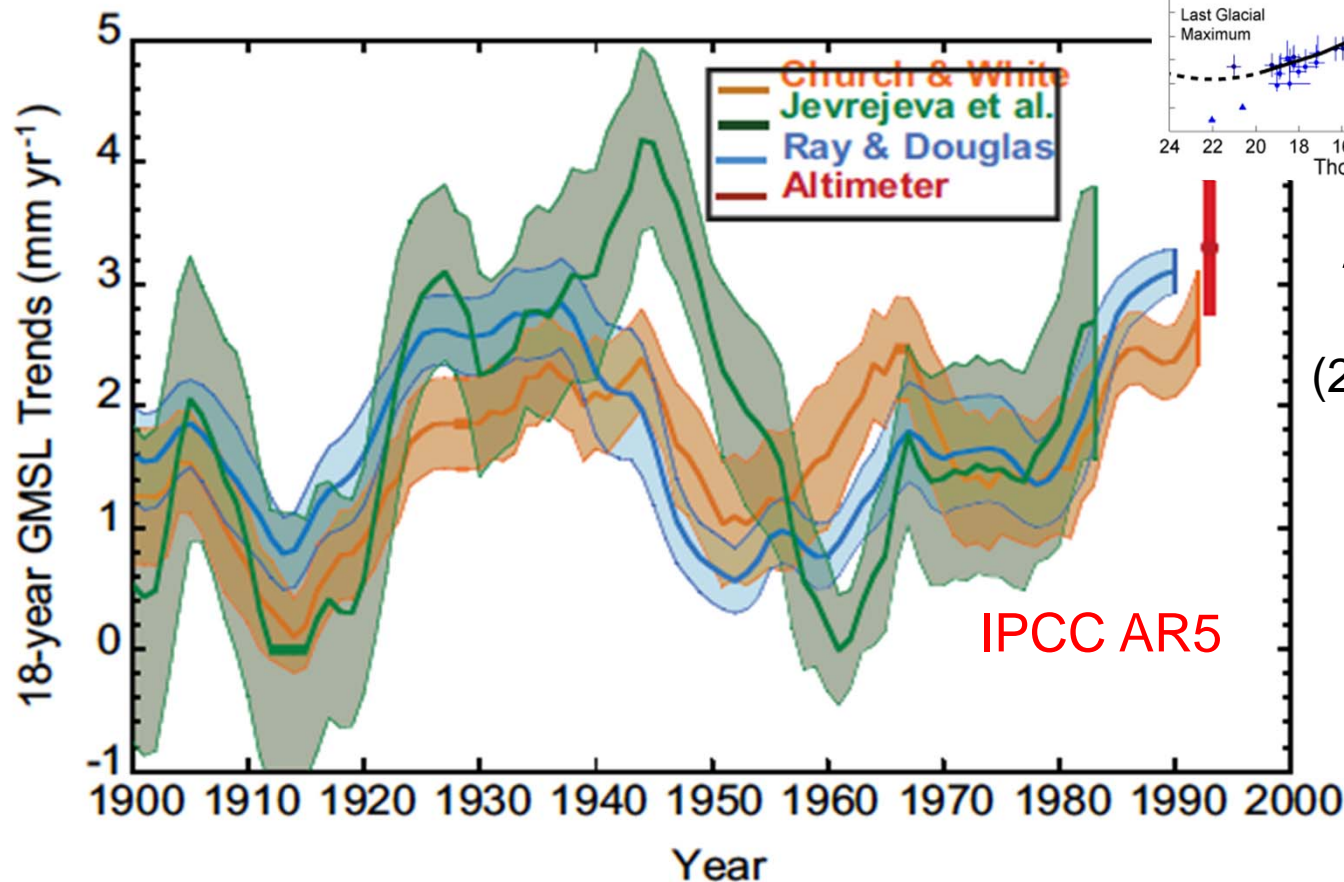


# Q1: Sea level was stable during last several thousand years; Recent acceleration is dramatic



**FAQ 5.2, Figure 1 |** (a) Estimates of the average rate of global mean sea level change (in  $\text{mm yr}^{-1}$ ) for five selected time intervals: last glacial-to-interglacial transition; Meltwater Pulse 1A; last 2 millennia; 20th century; satellite altimetry era (1993–2012). Blue columns denote time intervals of transition from a glacial to an interglacial period, whereas orange columns denote the current interglacial period. Black bars indicate the range of likely values of the average rate of global mean sea level change. Note the overall higher rates of global mean sea level change characteristic of times of transition between glacial and interglacial periods. (b) Expanded view of the rate of global mean sea level change during three time intervals of the present interglacial.

# Is the IPCC's sea level rise conclusion justified?



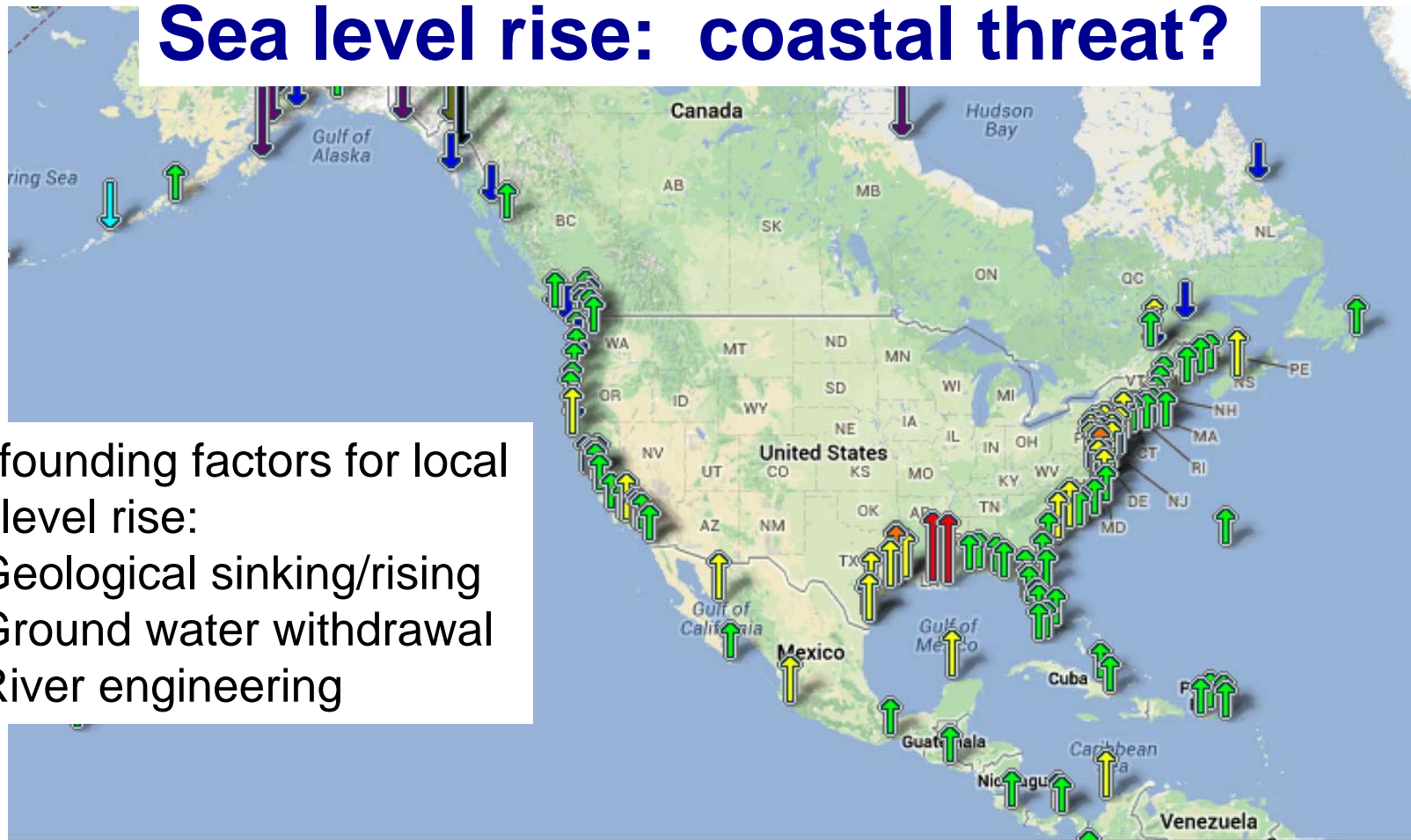
**IPCC AR5:** “Since the early 1970’s, glacier mass loss and ocean thermal expansion from warming together explain about 75% of the observed global sea level rise (high confidence)”



# Sea level rise: coastal threat?

Confounding factors for local sea level rise:

- Geological sinking/rising
- Ground water withdrawal
- River engineering



with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that s

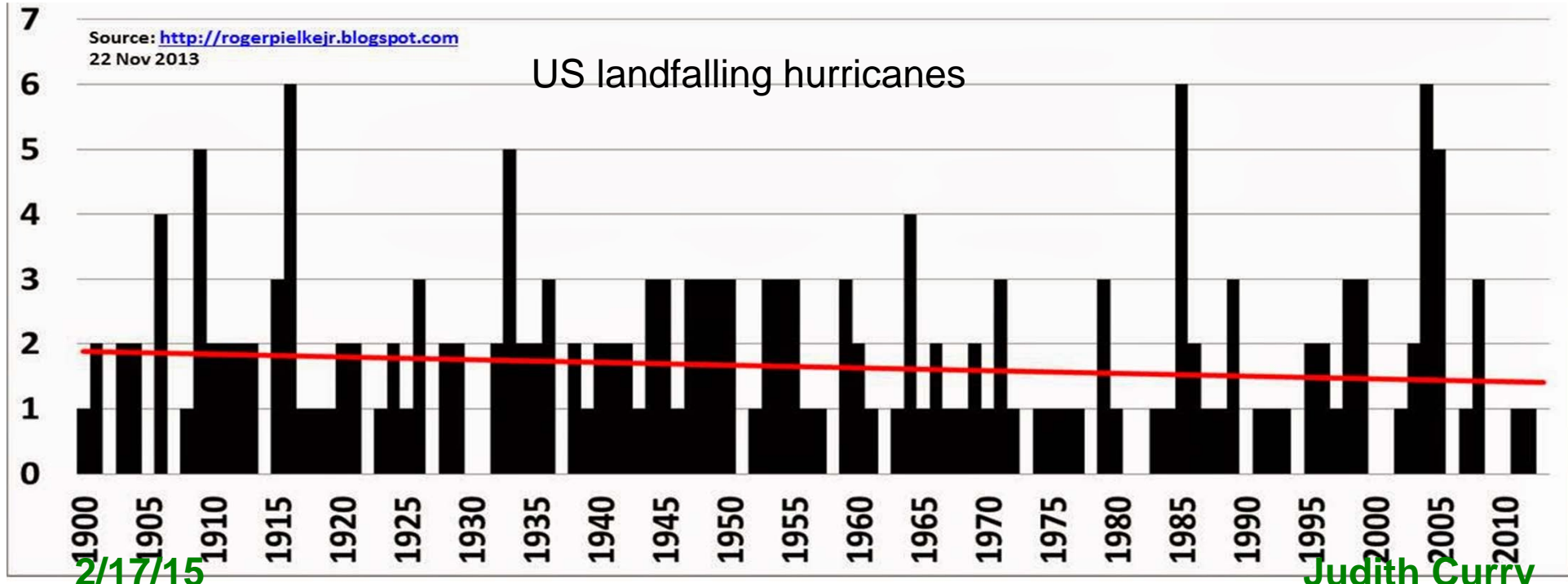
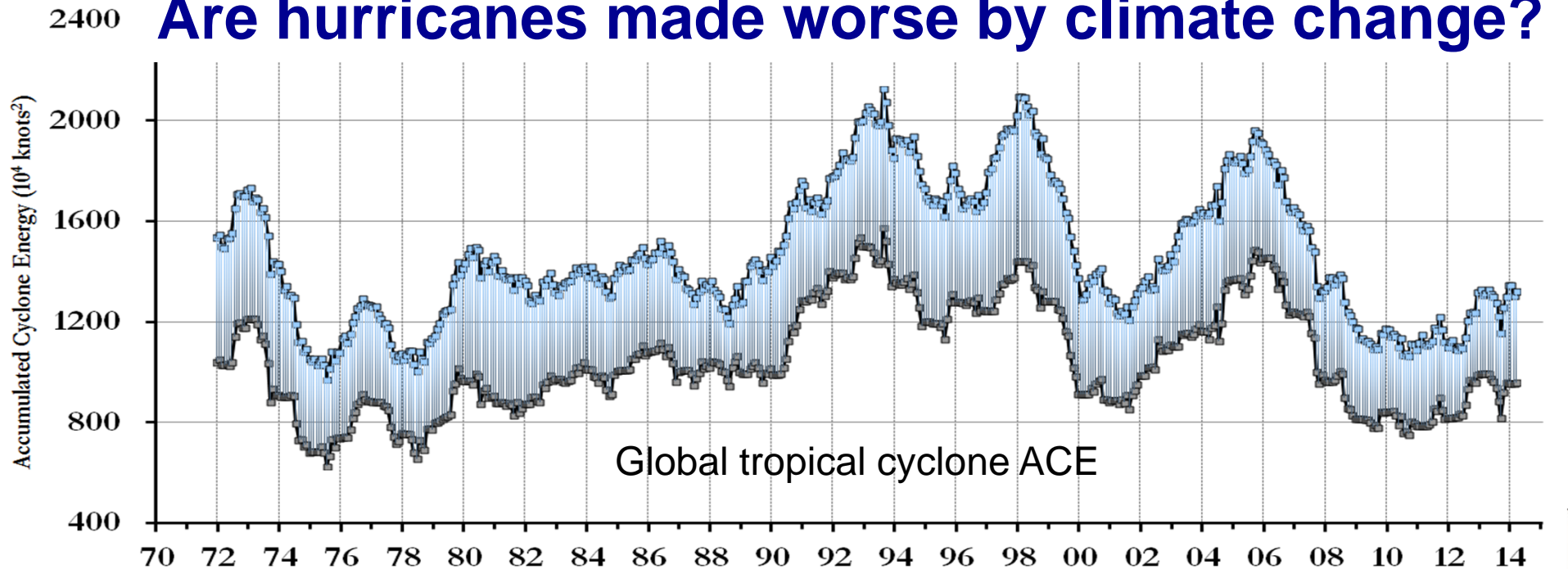
## Sea Level Trends mm/yr (feet/century)

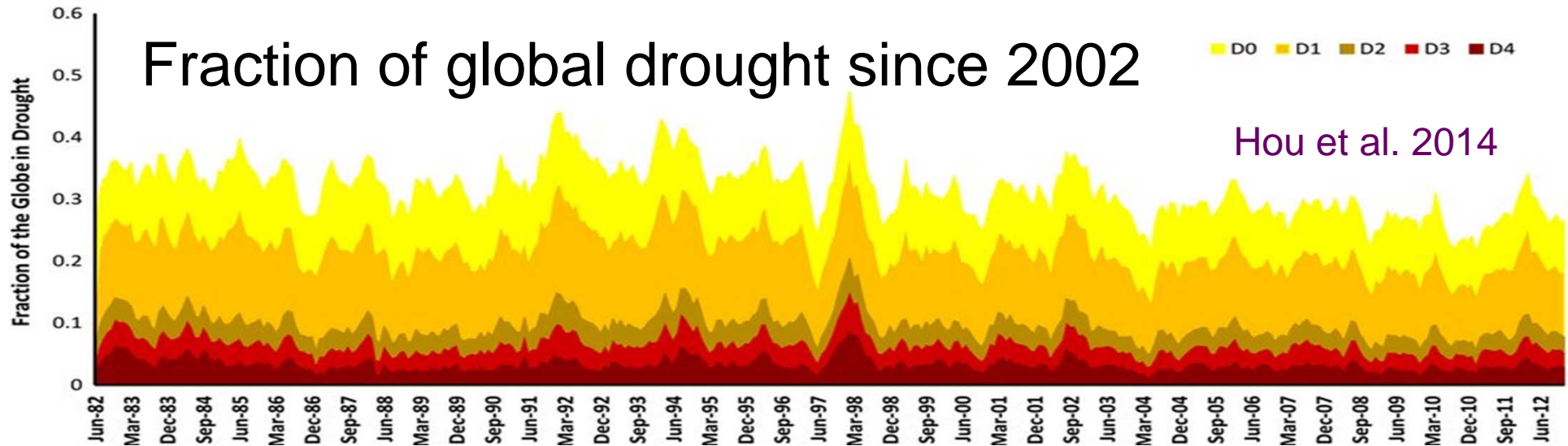
15 to 21 (5 to 7)	6 to 9 (2 to 3)	-3 to 0 (-1 to 0)	-12 to -9 (-4 to -3)
12 to 15 (4 to 5)	3 to 6 (1 to 2)	-6 to -3 (-2 to -1)	-15 to -12 (-5 to -4)
9 to 12 (3 to 4)	0 to 3 (0 to 1)	-9 to -6 (-3 to -2)	-18 to -15 (-6 to -5)

# Extreme Weather Events

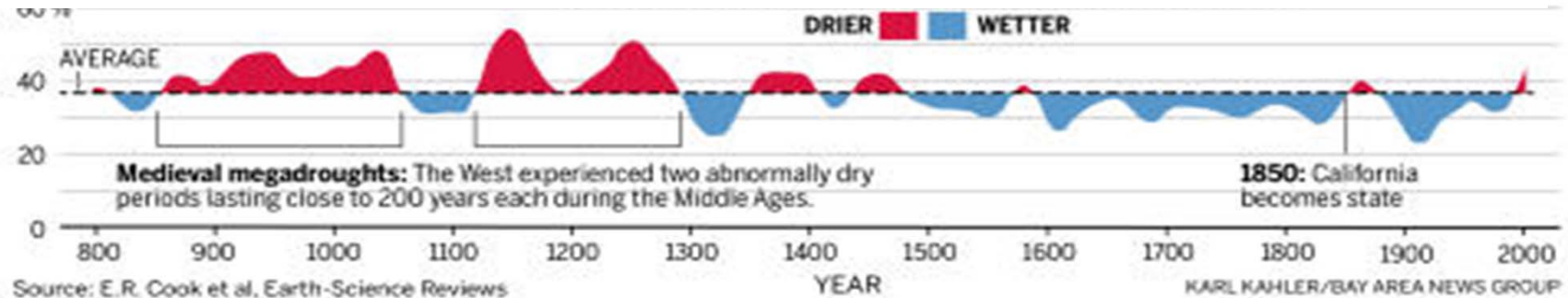
- Were recent extreme weather events made worse by man-made climate change? e.g, Hurricane Sandy
- Is vulnerability to extreme weather events increasing because of human-caused climate change?

# Are hurricanes made worse by climate change?





## Drought in the western U.S.



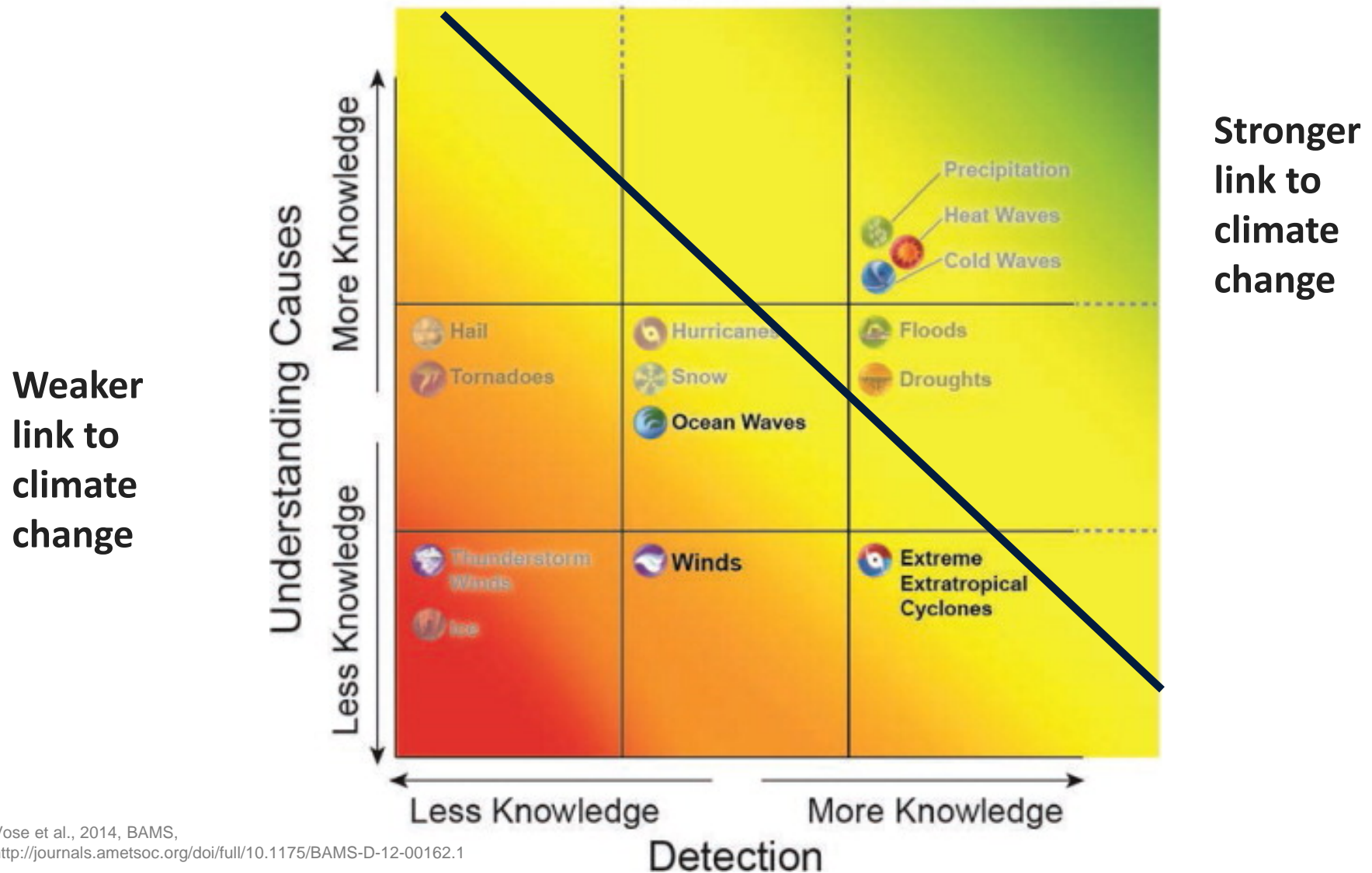
- California drought: comparable drought in 1890's
- Massive droughts in U.S. west during Middle Ages
- Climate models predict MORE rain in western U.S.



## Q2: Evidence for more heat waves, fewer cold snaps, and more intense heavy rainfall



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



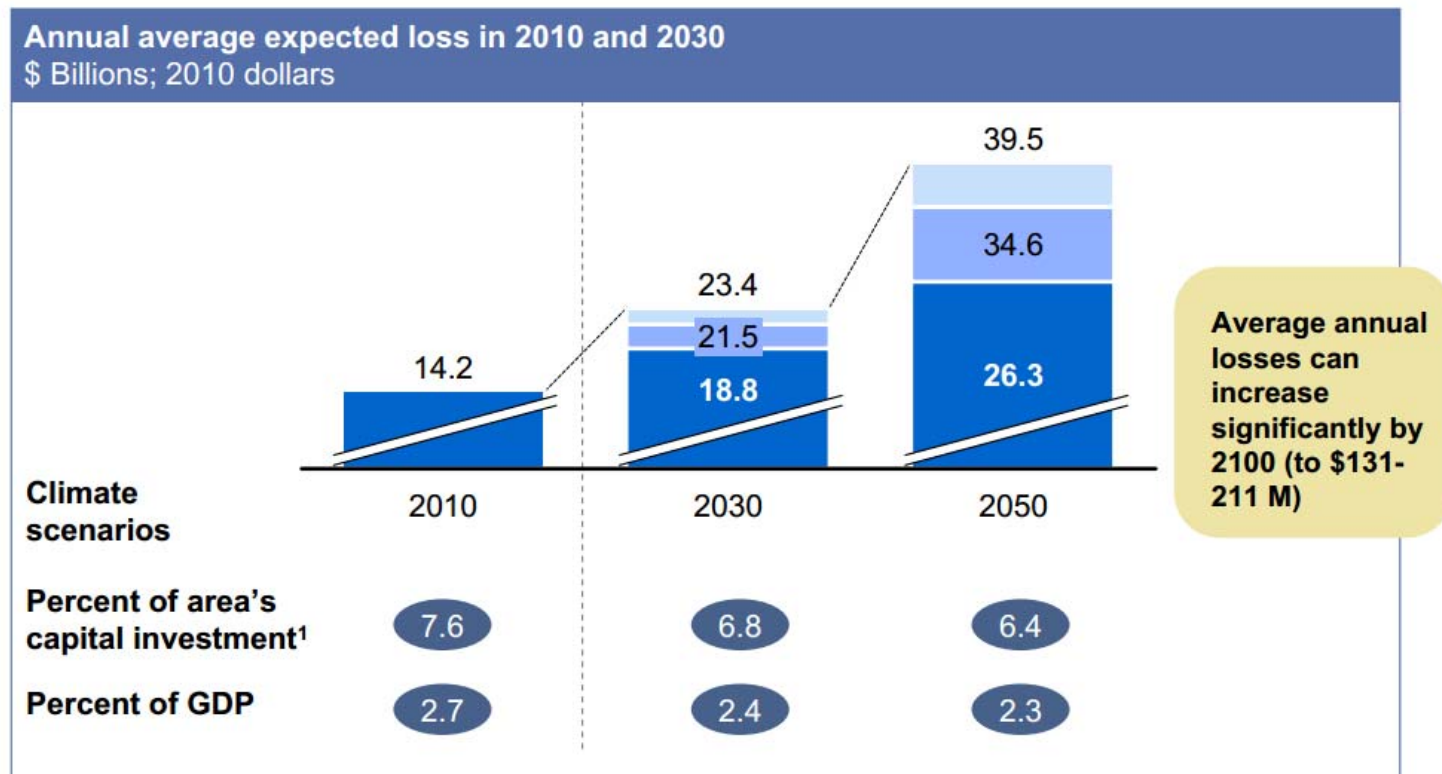


## Q2: “Location, location, location” + Climate change = Substantial current and future risk



### 3 | Extreme storms drive significant economic damage with losses increasing going forward

- Extreme climate scenario
- Average climate scenario
- No climate change



<sup>1</sup> No climate change; includes impact of subsidence

<sup>2</sup> Based on BEA historical average of capital investment (private and total government expenditures) as a percentage of GDP

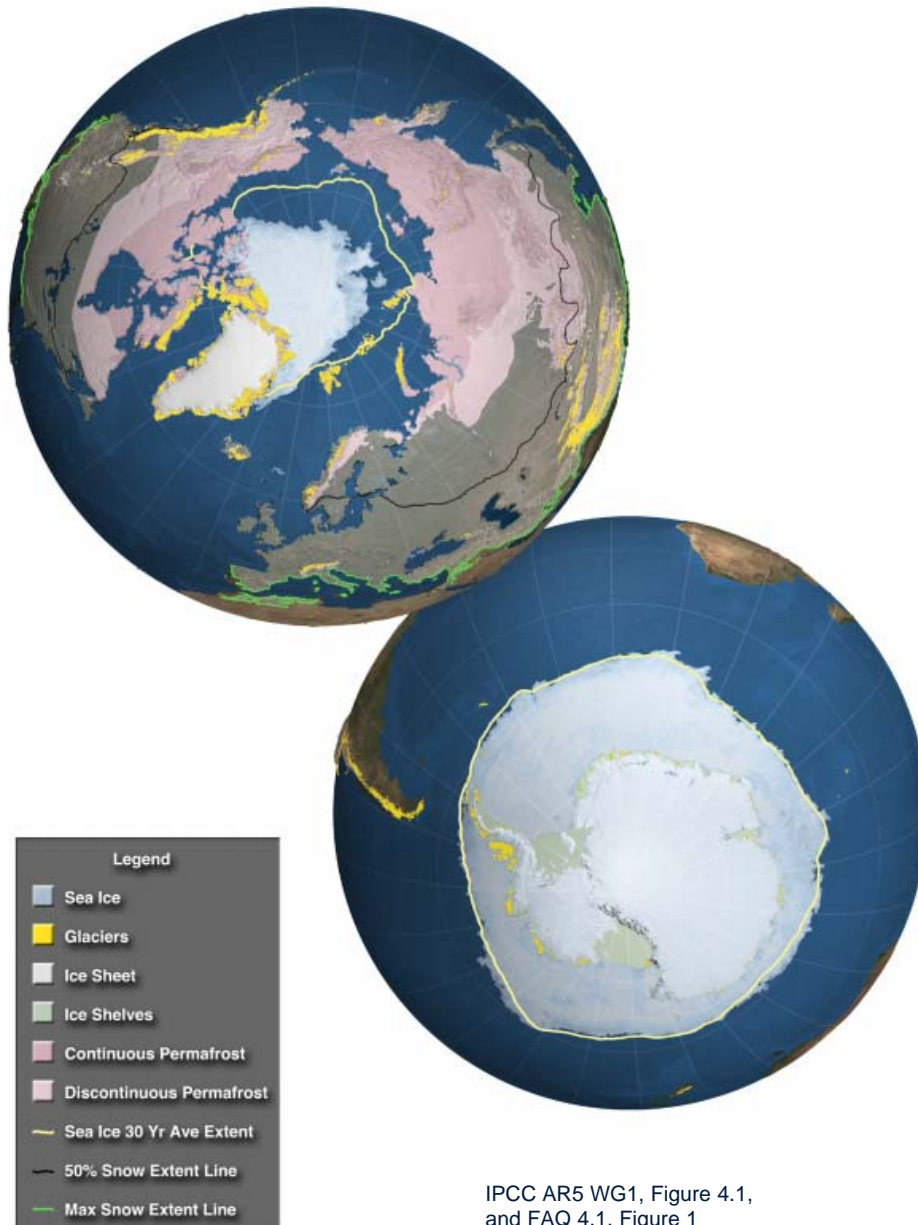
Source: Swiss Re

[http://www.energy.com/content/our\\_community/environment/GulfCoastAdaptation/Building\\_a\\_Resilient\\_Gulf\\_Coast.pdf](http://www.energy.com/content/our_community/environment/GulfCoastAdaptation/Building_a_Resilient_Gulf_Coast.pdf)

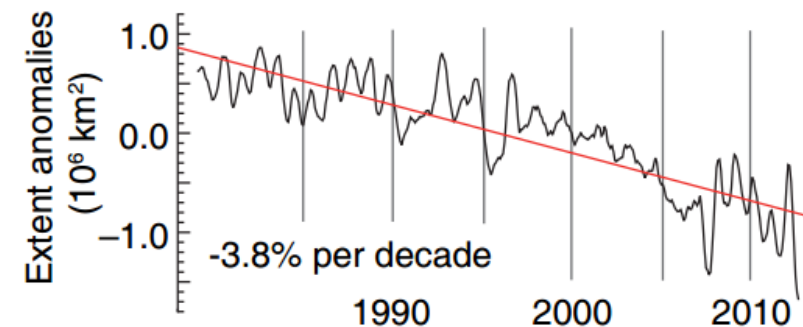
# Sea Ice Melting?

- Since satellite records began in 1979, Arctic sea ice at the end of summer has been retreating. But in Antarctica, the extent of the sea ice has been increasing recently.
- Are these changes due to human-caused global warming?
- Do scientists understand what is going on and why?

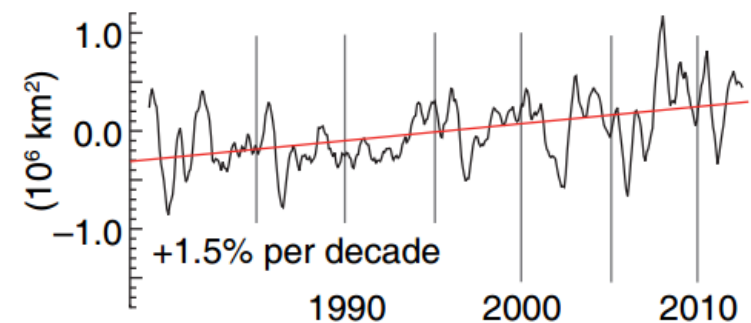
### Q3: Contrasting Arctic sea ice loss with Antarctic sea ice increases



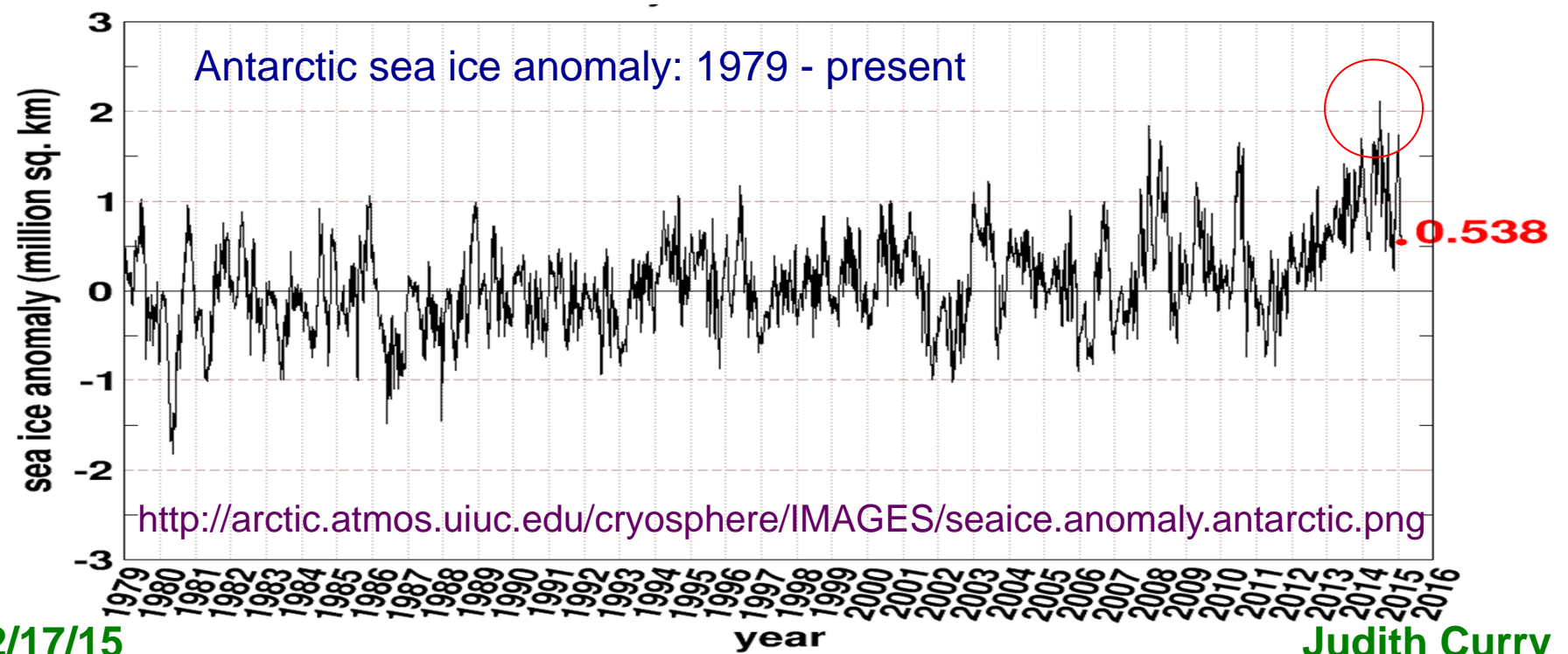
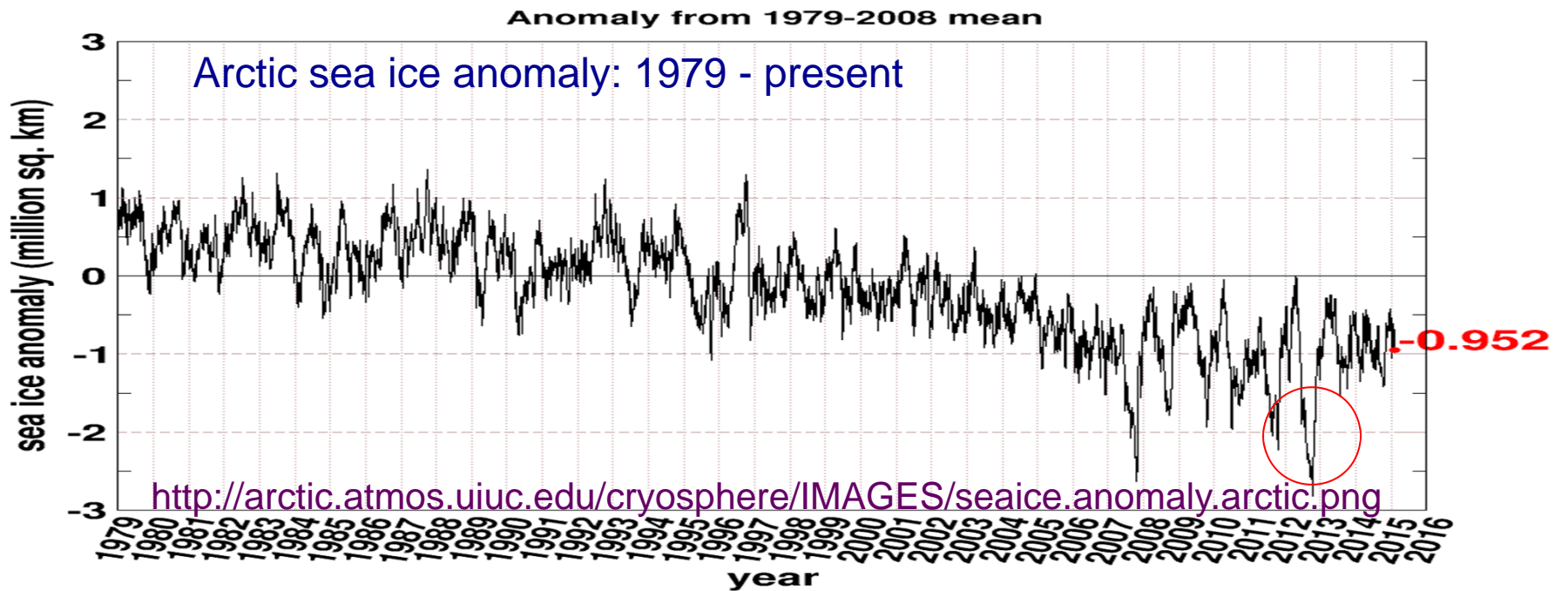
IPCC AR5 WG1, Figure 4.1,  
and FAQ 4.1, Figure 1



**ARCTIC: Geometry of the Arctic Ocean enables temperature to play a big role**



**ANTARCTIC: Physical processes more complicated; regional changes are in different directions**



# IPCC AR5 statements on causes of sea ice changes (Ch 10)

- “Anthropogenic [impacts] are very likely to have **contributed** to Arctic sea ice loss since 1979.”
- “There is **low confidence** in the scientific understanding of the observed increase in Antarctic sea ice extent since 1979, due to the incomplete and competing scientific explanations for the causes of change and low confidence in estimates of internal variability.”
- “Arctic temperature anomalies in the 1930s were apparently as large as those in the 1990s and 2000s. There is still considerable discussion of the ultimate causes of the warm temperature anomalies that occurred in the Arctic in the 1920s and 1930s.”



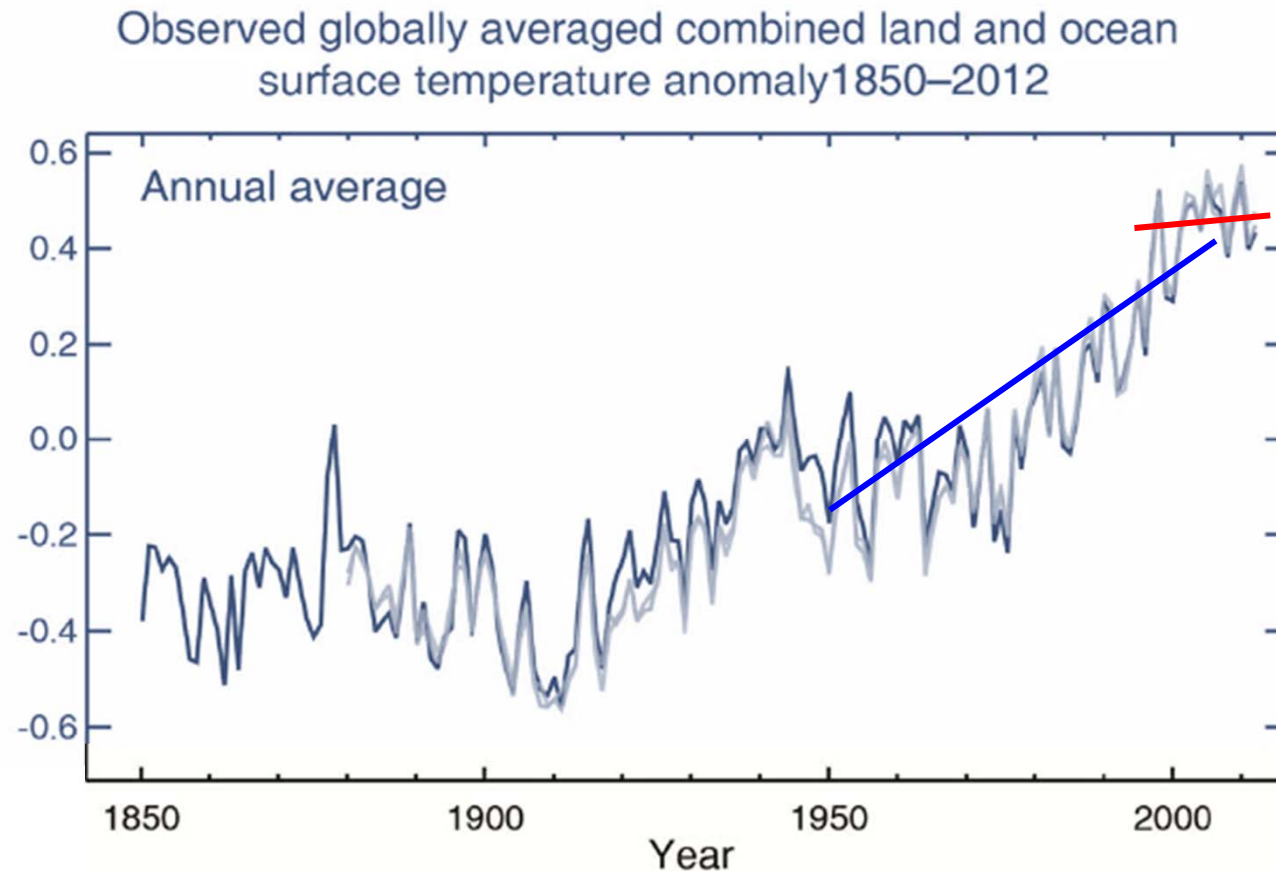
# Is the Earth Warming or Cooling?

- Some assert that the earth has not warmed in the last 16 years
- According to NOAA and NASA data, 2014 was the warmest year on record
- How should we interpret recent temperature, relative to longer-term trends?
- Is the earth entering a cycle of global cooling due to a slowing in solar activity?

# Recent global temperature record

- 'Warmest year': 2014 is in a statistical tie with 9 other years since 1998 (uncertainty is  $0.1^{\circ}\text{C}$ )
- No statistically significant trend for past 16+ years. Compare with major warming trend 1976-1998 (22 yrs)
- Since 1998, 25% of human  $\text{CO}_2$  has been emitted
- Climate models predicted a trend of  $0.2^{\circ}\text{C}/\text{decade}$  in early part of 21<sup>st</sup> century: growing discrepancy between climate models and observations
- Changes in ocean circulation seems to be dominant reason for 'pause', with solar & volcanoes
- Growing discrepancy raises serious questions about utility of climate models, the cause of warming in the 20<sup>th</sup> century, and predictions of 21<sup>st</sup> century warming.

## Q4: Putting the warming “hiatus” in context

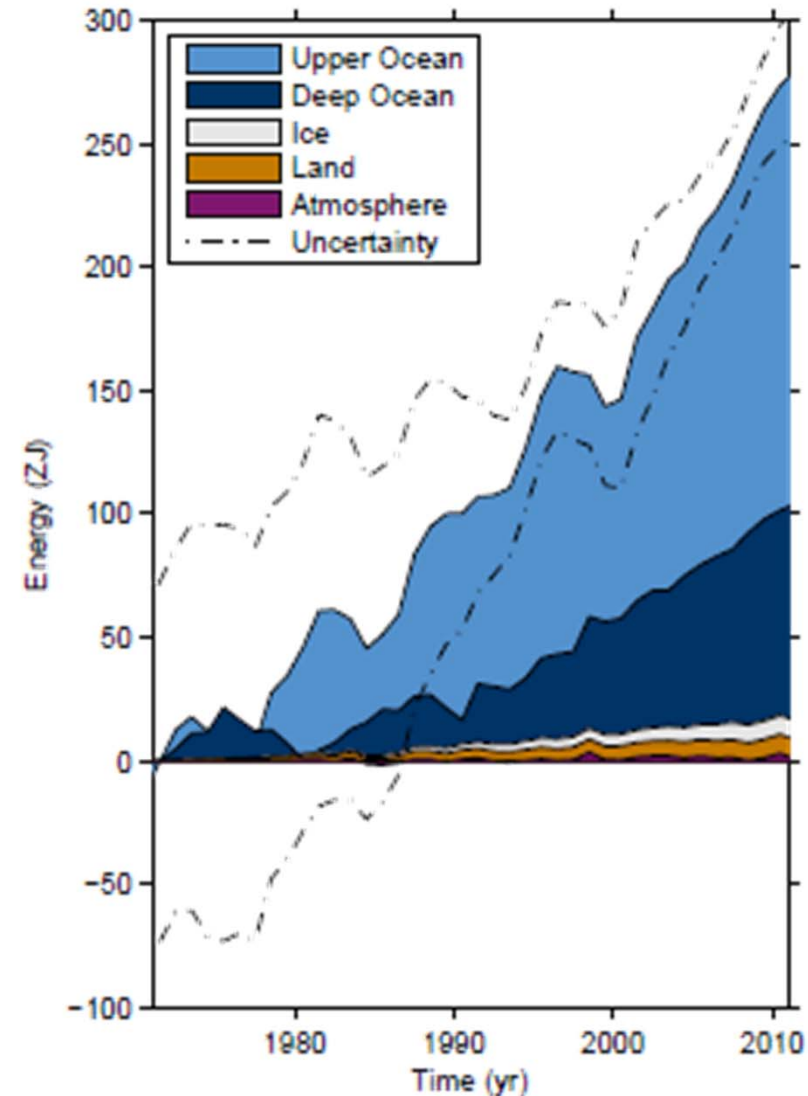


- Warming rate since the **late 1990's** is less than the rate **since the 1950's** (or since 1900)
- There is a LOT of variation in temperature on year-to-year timescales...
- ...trends over short periods of time should not undermine our understanding of the big picture

## Q4: Diagnosing the cause of the “hiatus”



- “Roughly equal measure”
  - aerosols/Sun
  - internal variability
- Heat still accumulating in the Earth System



# Glaciers Melting?

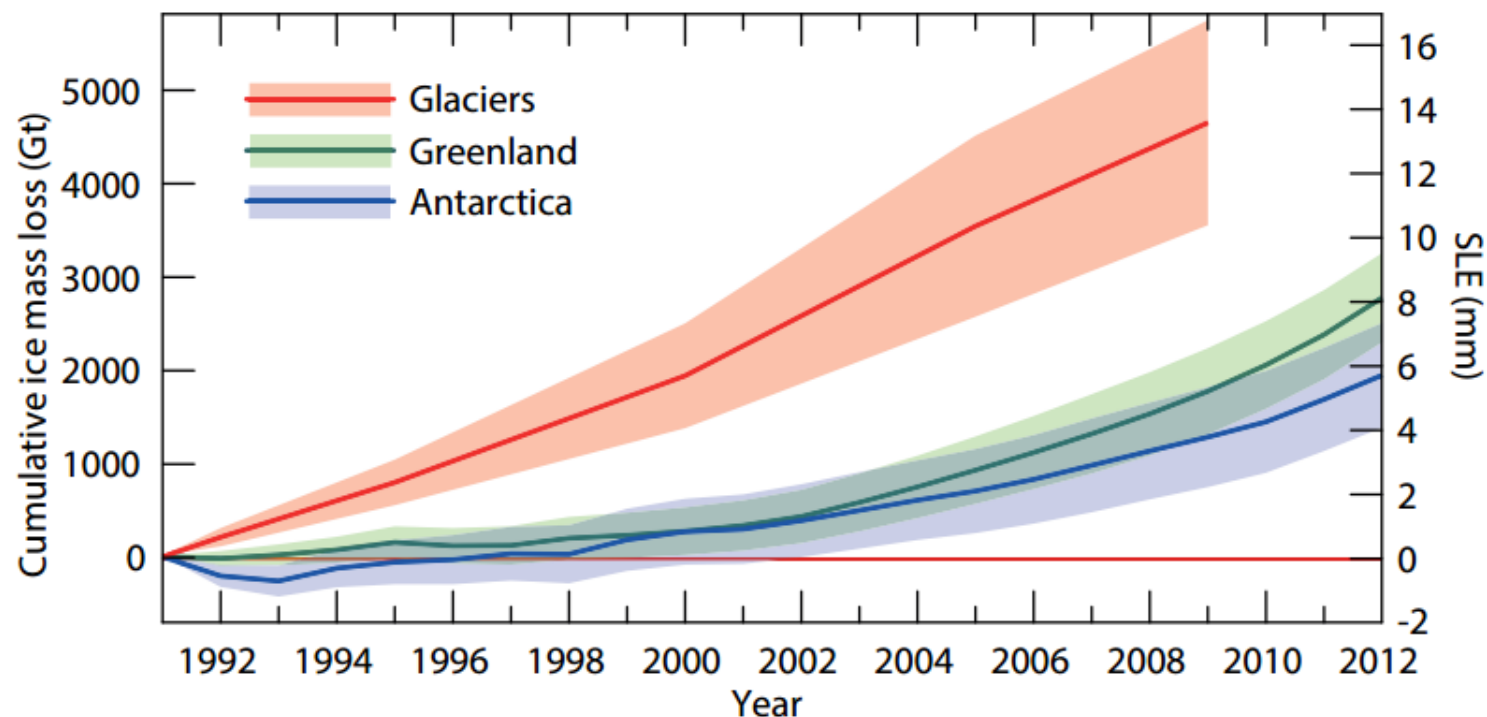
- Many (but not all) glaciers are melting, including Greenland and Antarctica!
- How confident are we that humans are causing some glaciers to melt?



## Q5: Rate of melt in Greenland and Antarctica accelerating



### Contribution of Glaciers and Ice Sheets to Sea Level Change

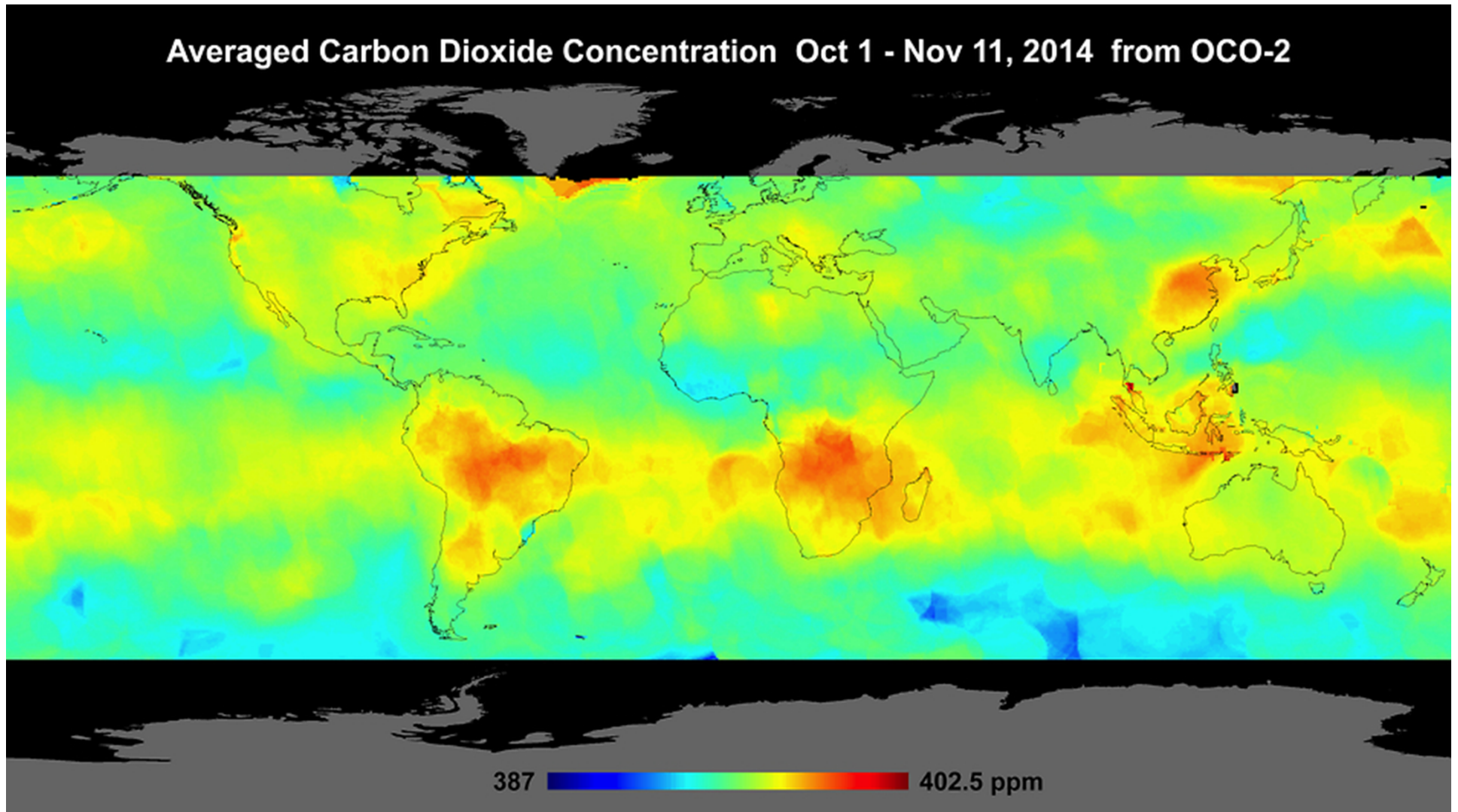


Cumulative ice mass loss from glacier and ice sheets (in sea level equivalent) is  $1.0$  to  $1.4 \text{ mm yr}^{-1}$  for 1993-2009 and  $1.2$  to  $2.2 \text{ mm yr}^{-1}$  for 2005-2009.

## Are there benefits to CO<sub>2</sub>?

- Doesn't CO<sub>2</sub> help crops grow?
- How well do scientists understand the sources and sinks of CO<sub>2</sub> in the atmosphere?

# How well do scientists understand sources and sinks of CO<sub>2</sub>?



## In Closing . . .

- How much consensus exists in the scientific community that man-made greenhouse gases are changing the earth's climate?
- What area of climate science would most benefit from additional research?

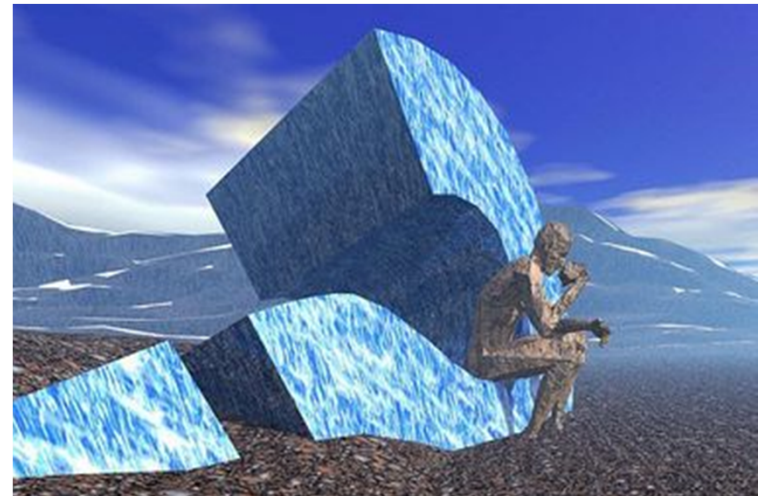
# Consensus among scientists as to whether humans are dominant cause of 20<sup>th</sup> century warming?

- The much vaunted '97% consensus' was based on a deeply flawed study that examined the abstracts of published papers.
- Actual surveys of scientists found:
  - American Meteorological Society (2014): **52%**
  - Verheggan et al. (2014) survey of climate scientists: **85%**



# Summary of major uncertainties

- Deep ocean heat content variations and mechanisms of vertical heat transfer in the ocean
- Uncertainties in aerosol impact
- Sensitivity of the climate system to CO<sub>2</sub>
- Clouds: trends, feedbacks, & aerosol – cloud interactions
- Nature and mechanisms of multidecadal natural ‘internal’ variability (ocean-atmosphere circulations)
- Unknowns – solar indirect effects, magnetic and electric field effects, orbital (tidal and other) effects, core-mantle interactions, etc.



**Q7: Statements about the veracity of climate change  
have only gotten stronger in the last 50 years**



Air pollution is no longer confined to isolated places. This generation has altered the composition of the atmosphere on a global scale through radioactive materials and a steady increase in carbon dioxide from the burning of fossil fuels.

***President Lyndon Johnson***

***February 8, 1965***

***Special Message to the Congress on Conservation and Restoration of Natural Beauty***

## Q7: Statements about the veracity of climate change have only gotten stronger in the last 50 years



We now have incontrovertible evidence that the atmosphere is indeed changing and that we ourselves contribute to that change. Atmospheric concentrations of carbon dioxide are steadily increasing, and these changes are linked with man's use of fossil fuels and exploitation of the land.

When it is assumed that the CO<sub>2</sub> content of the atmosphere is doubled...the more realistic of the modeling efforts predict a global surface warming of between 2°C and 3.5°C, with greater increases at high latitudes...It is significant, however, that none of the model calculations predicts negligible warming.

***National Research Council  
Carbon Dioxide and Climate: A Scientific Assessment  
1979***

## Q7: Statements about the veracity of climate change have only gotten stronger in the last 50 years



Climate change is occurring, is very likely caused by human activities, and poses significant risks for a broad range of human and natural systems. Each additional ton of greenhouse gases emitted commits us to further change and greater risks.

In the committee's judgment there are many reasons why it is imprudent to delay actions that at least begin the process of substantially reducing emissions.

***National Research Council  
America's Climate Choices  
2011***

## Q7: Statements about the veracity of climate change have only gotten stronger in the last 50 years



Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.

Anthropogenic greenhouse gas emissions have increased...driven largely by economic and population growth...Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century.

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems.

***IPCC Synthesis Report, Summary for Policymakers  
2014***



## **Q7: Areas for further research**



- **Improved understanding of factors (like El Niño) that drive year-to-year and decade-to-decade variations in climate**
- **Better understanding of changes in the jet stream that can be tied to greenhouse gases (in other words, linking weather to climate)**
- **More knowledge about ice (the cryosphere)**
- **Better translation of climate information at the regional scale, especially for adaptation/resilience planning**

# THANK YOU!

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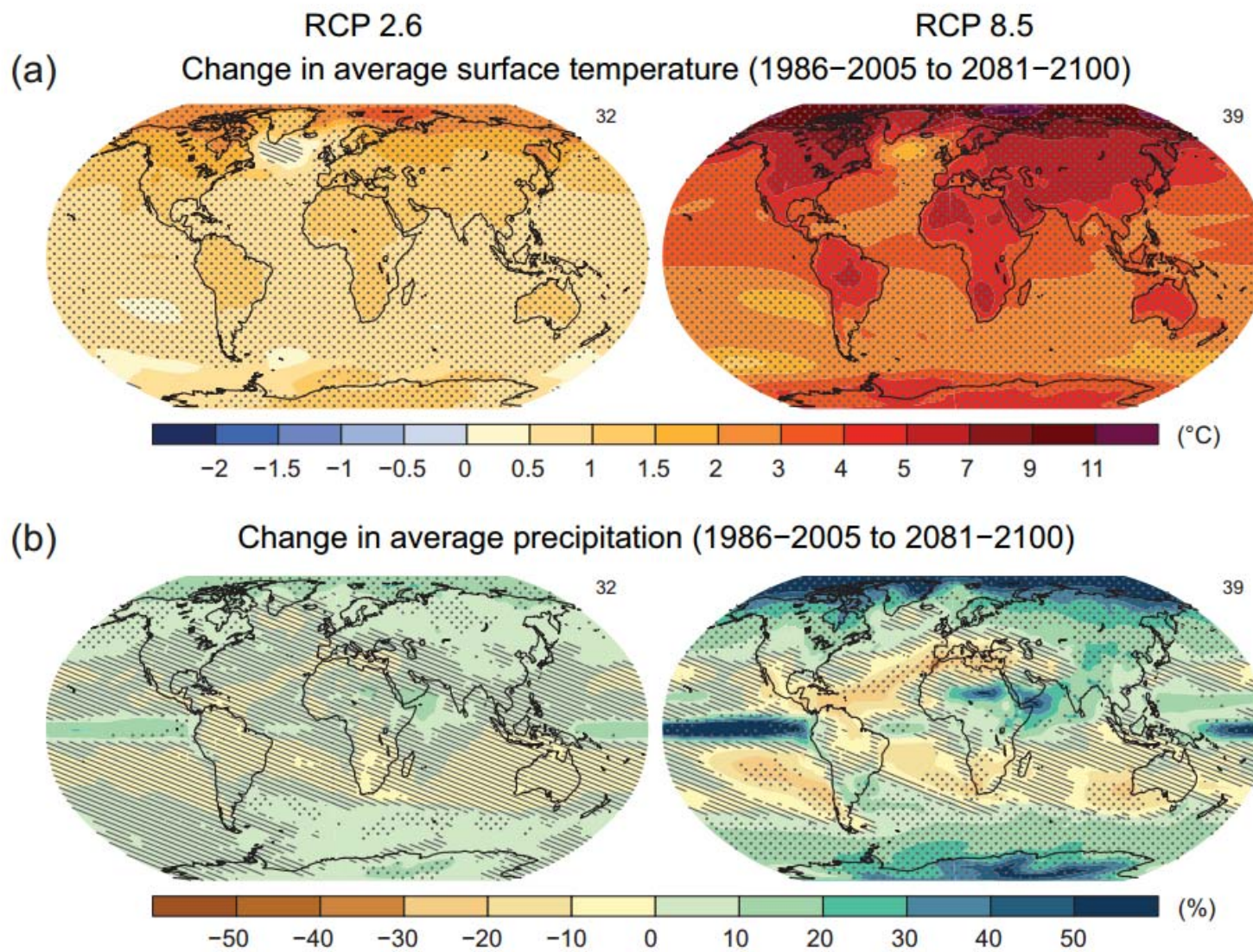
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- **National Climate Assessment:**  
<http://nca2014.globalchange.gov/>
- **IPCC Fifth Assessment Report (Working Groups I and II)**  
<https://www.ipcc.ch/report/ar5/wg1/>  
<https://www.ipcc.ch/report/ar5/wg2/>
- **IPCC Synthesis Report**  
<http://www.ipcc.ch/>
- **NOAA sea level trends:**  
<http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml>



# Sea ice vs. Land ice

