



# Climate Change Science Fact, Fiction & the Unsettled

Judith Curry



Georgia Institute  
of Technology



# President Obama on Climate Change

The U.S. is leading global efforts to the threat of climate change.

[www.whitehouse.gov/climate-change](http://www.whitehouse.gov/climate-change)

“For all the challenges we face, the growing threat of climate change could define the contours of this century more dramatically than any other.”

“The United States of America not only recognizes our role in creating this problem, we embrace our responsibility to do something about it.”







**United Nations**  
Framework Convention on  
Climate Change



## **UNFCCC Treaty (1992):**

The UNFCCC established a goal of stabilization of atmospheric greenhouse gases to prevent dangerous climate change

## **Intergovernmental Panel on Climate Change (IPCC):**

1. Human-caused climate change is real
2. Human-caused climate change is dangerous
3. Action is needed to prevent dangerous human caused climate change



# Paris Climate Agreement



PARIS2015

- Reaffirm the goal of limiting global temperature increase well below 2°C, while urging efforts to limit the increase to 1.5°
- Establish binding commitments by all parties to make “nationally determined contributions” (NDCs), and to pursue domestic measures aimed at achieving them
- Commit all countries to submit new NDCs every five years, with the clear expectation that they will represent a progression beyond previous ones



**United Nations**  
Framework Convention on  
Climate Change

## Nationally Determined Contributions (NDCs)

### U.S. NDC:

- Reduce emissions by 26-28% below 2005 levels by 2025
- Economy-wide emission reductions of 80% by 2050



# The ‘treaty’ problem



U.S. Constitution Treaty Clause:

“ [The President] shall have Power, by and with the Advice and Consent of the **Senate**, to make Treaties, **provided two thirds of the Senators present concur . . .** “

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)**

Legend:

- None
- DEQ/PSC
- AG
- Gov
- Gov+AG
- Suing EPA
- Legislation

The logo for SPE International, featuring two overlapping blue circles. The left circle contains a white silhouette of the world map. The right circle contains a white silhouette of the Americas. The text "SPE" is in large, bold, white letters, and "International" is in smaller, white letters below it. A registered trademark symbol (®) is at the bottom right.

<http://assets.inhabitat.com/wp-content/blogs.dir/1/files/2015/06/epa-map.jpg>

# To what extent is President Obama's Climate Commitment enforceable?

In the absence of State and Congressional support, the Plan is being enforced through the Executive Branch via the Environmental Protection Agency (EPA).

Challenges:

- 24 states have challenged the Clean Power Plan; Supreme Court has issued a 'stay' on EPA enforcement
- The next President may choose not to enforce.





# Donald Trump on Climate Change

“I believe in clean air. Immaculate air. But I don’t believe in climate change.”

“I believe there’s weather. I believe there’s change, and I believe it goes up and it goes down, and it goes up again.

And it changes depending on years and centuries, but I am not a believer, and we have much bigger problems.”



# Agreement:

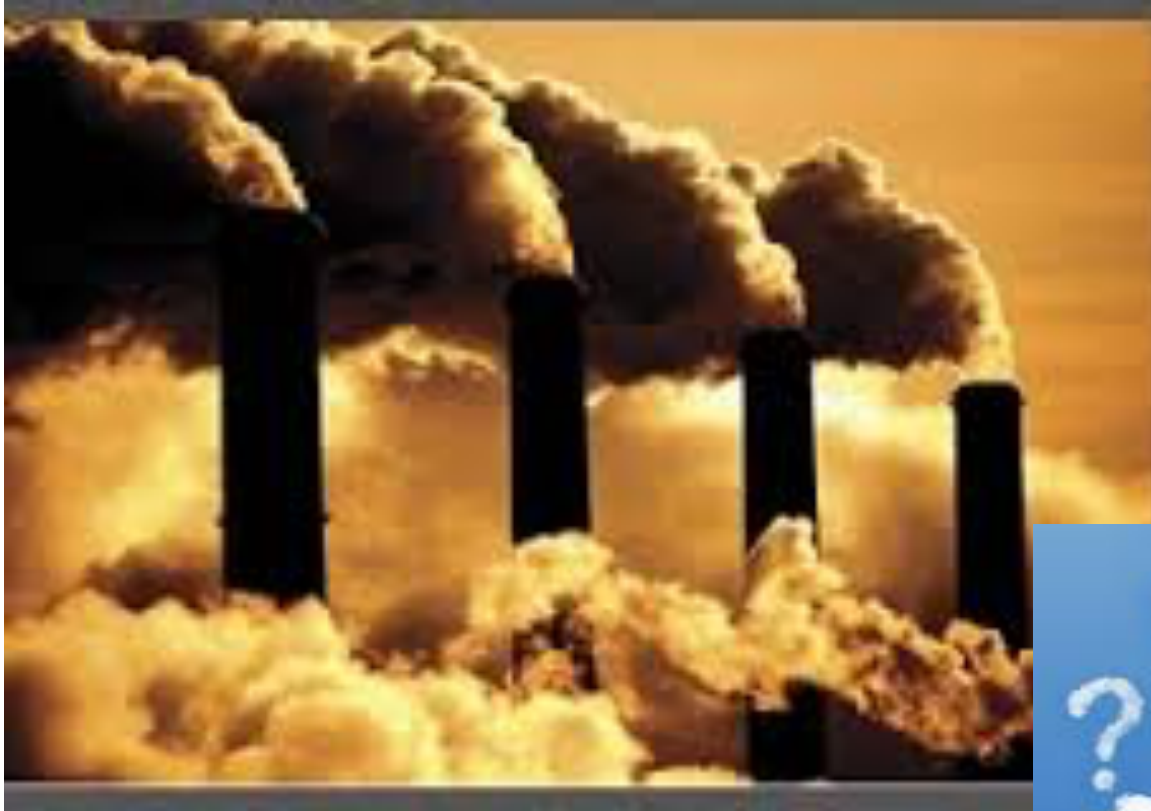
- Surface temperatures have increased since 1880
- Humans are adding carbon dioxide to the atmosphere
- Carbon dioxide and other greenhouse gases have a warming effect on the planet

# 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 well-being

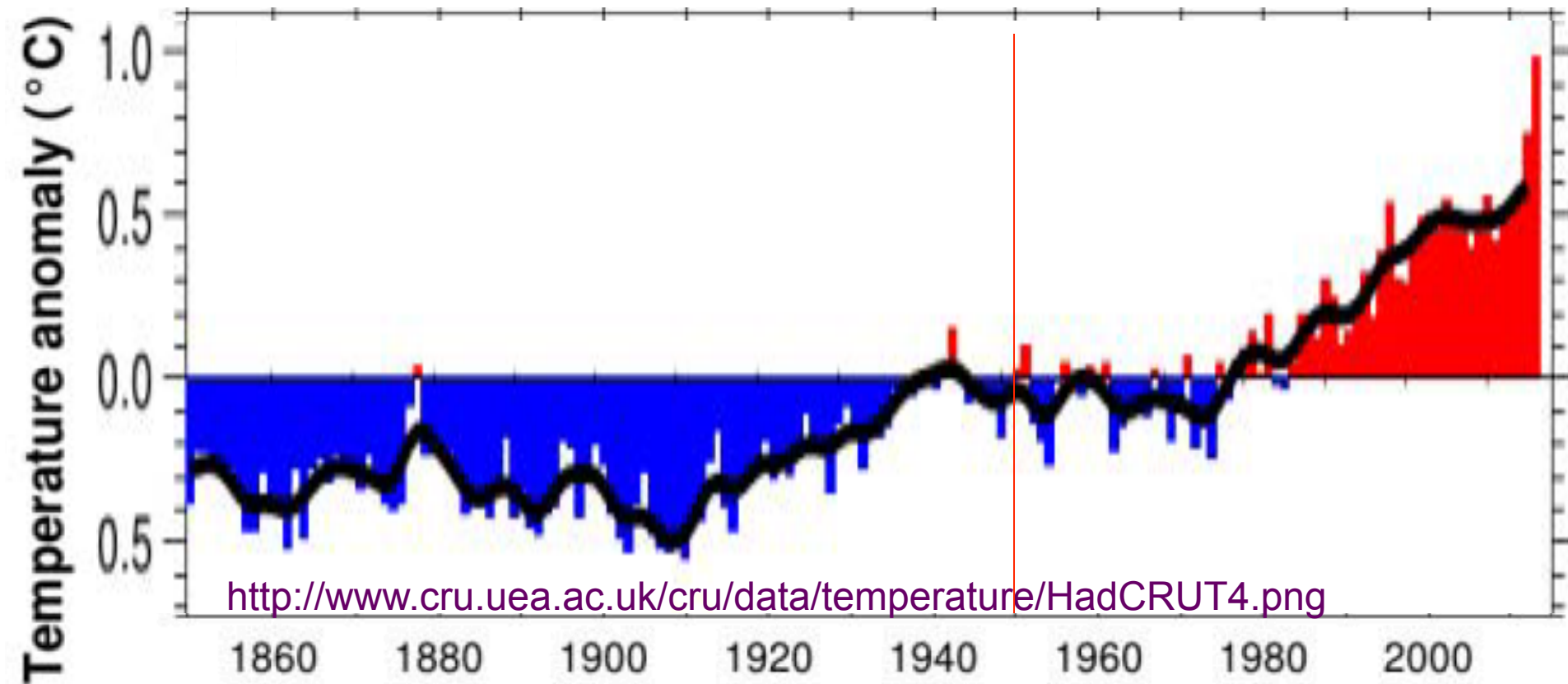


# Are humans causing global warming?



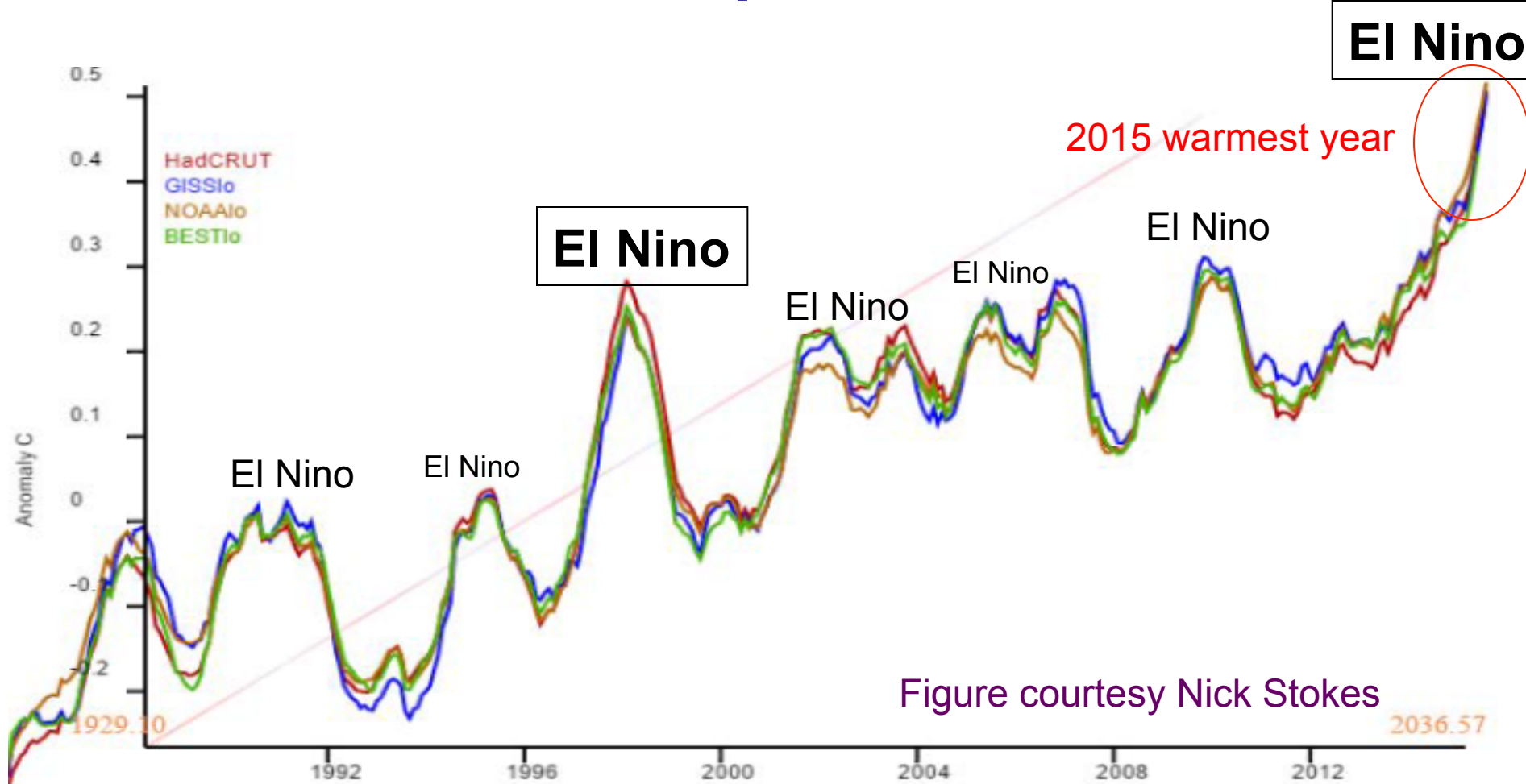


# Global surface temperature anomaly



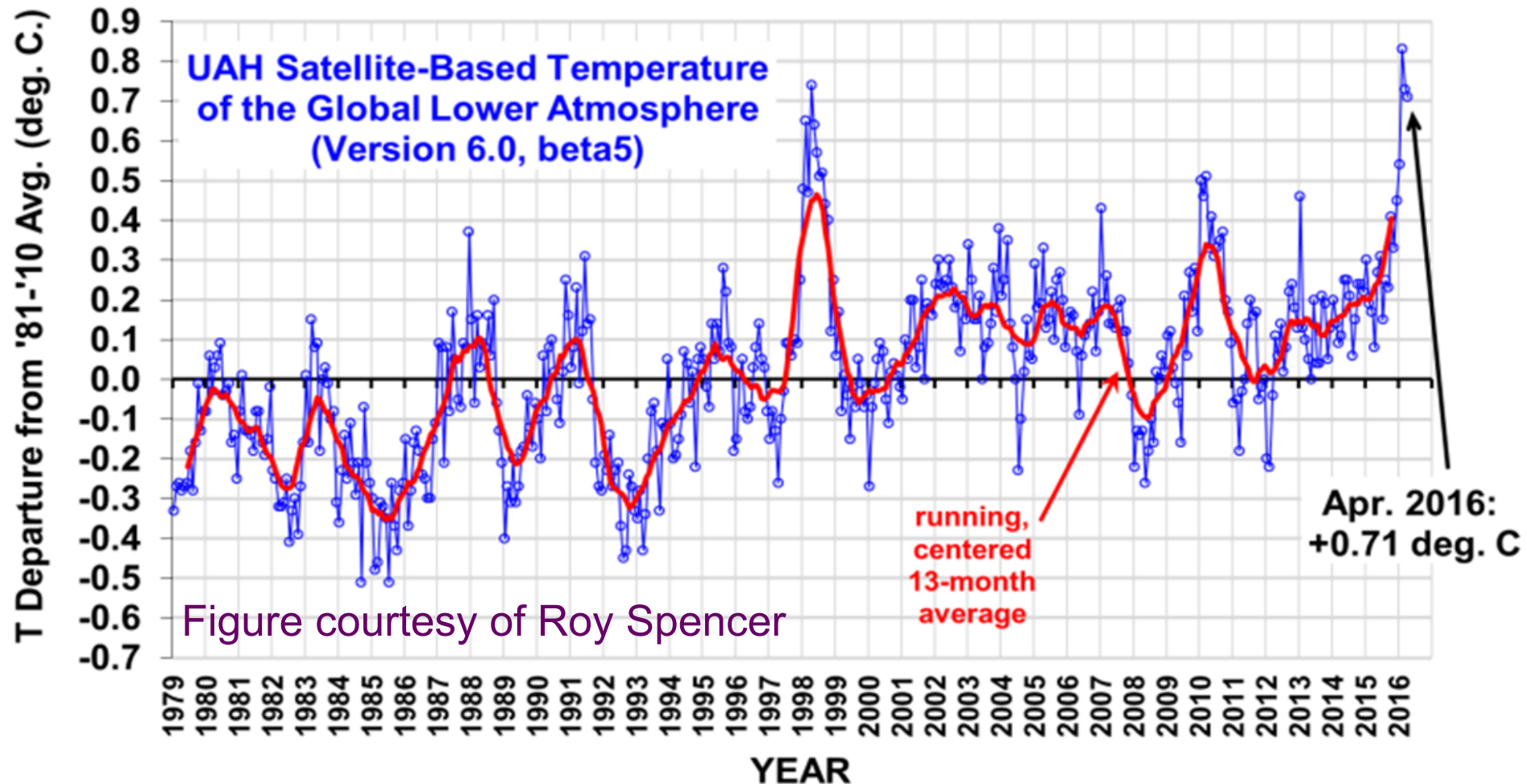
**IPCC AR5:** “It is **extremely likely** that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by [humans]. The **best estimate of the human induced contribution is similar to the observed warming over this period.**”

# Global surface temperature anomalies



2015 was striking as 'warmest year,' since there had been very little warming since 1998

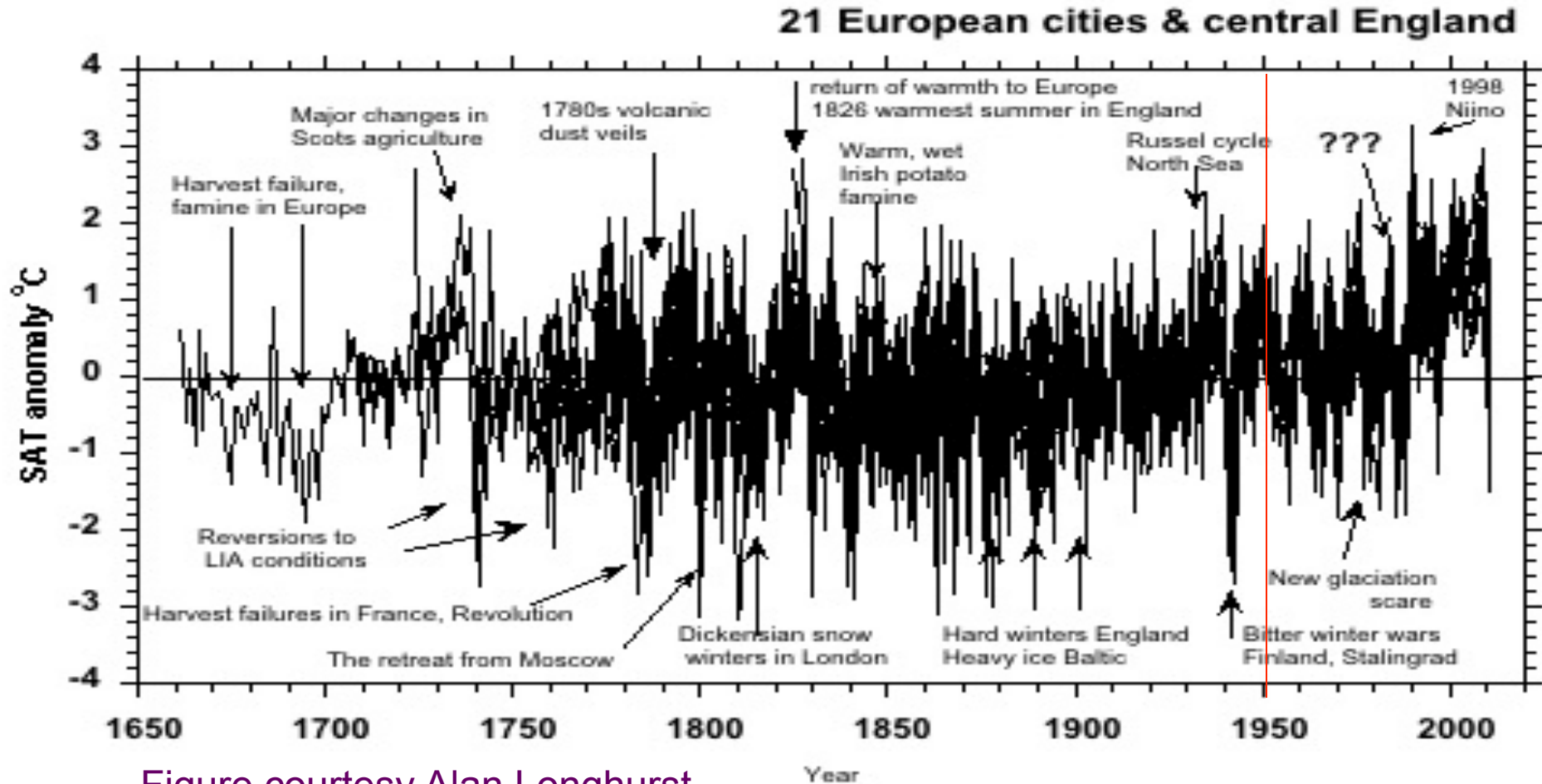
# Lower atmospheric temperatures from satellite



2015 was 3<sup>rd</sup> warmest year in the satellite data set, with a large spike for Feb 2016 from El Nino

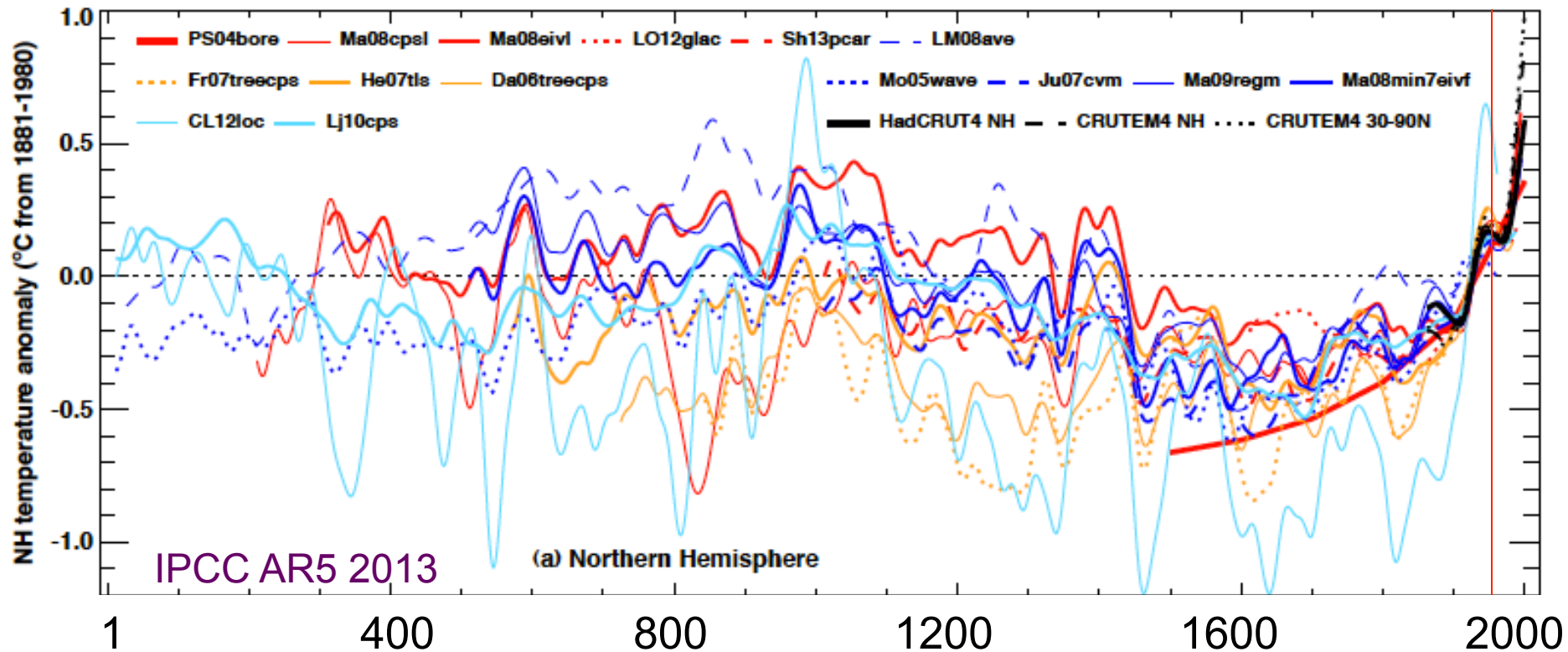


# Is the warming since 1950 unusual?



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

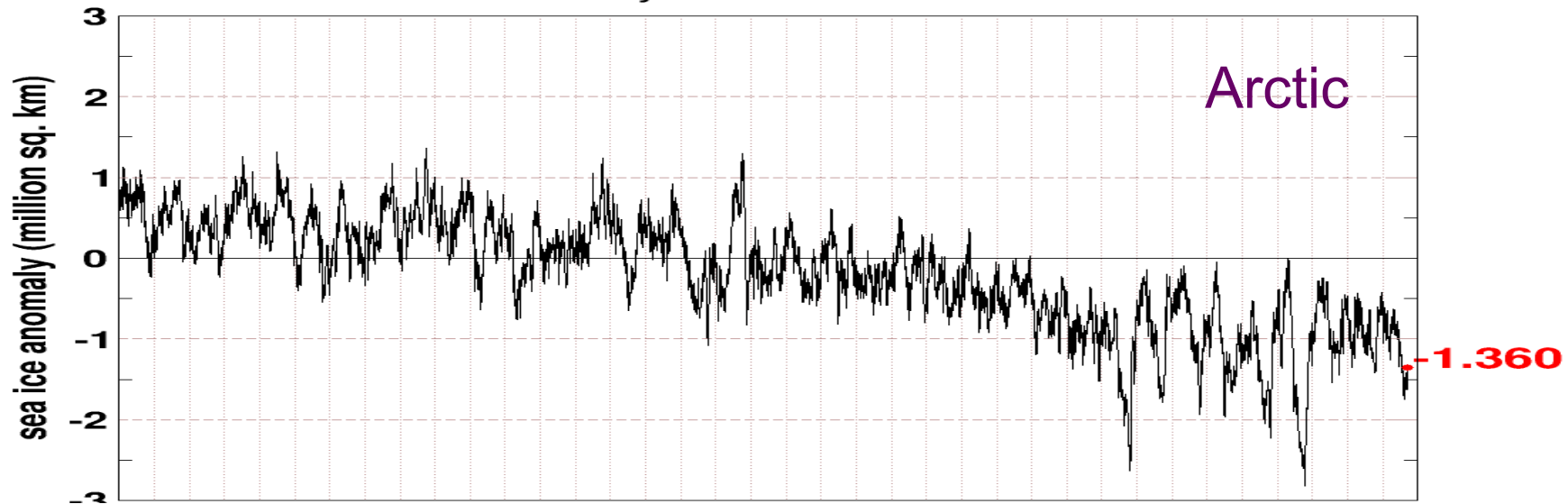
# Northern Hemisphere paleoclimate surface temperature reconstructions



Temperatures have been warming for the past 200-400 years; only the warming since 1950 is being attributed to humans

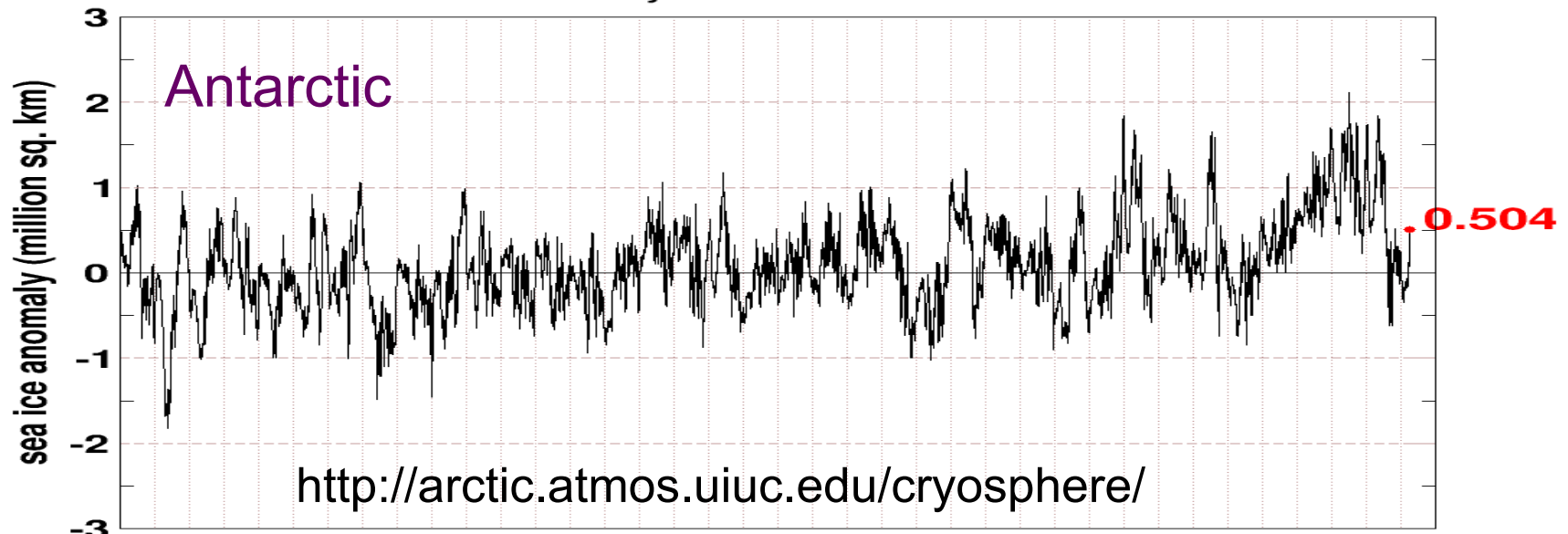
## Northern Hemisphere Sea Ice Anomaly

Anomaly from 1979-2008 mean



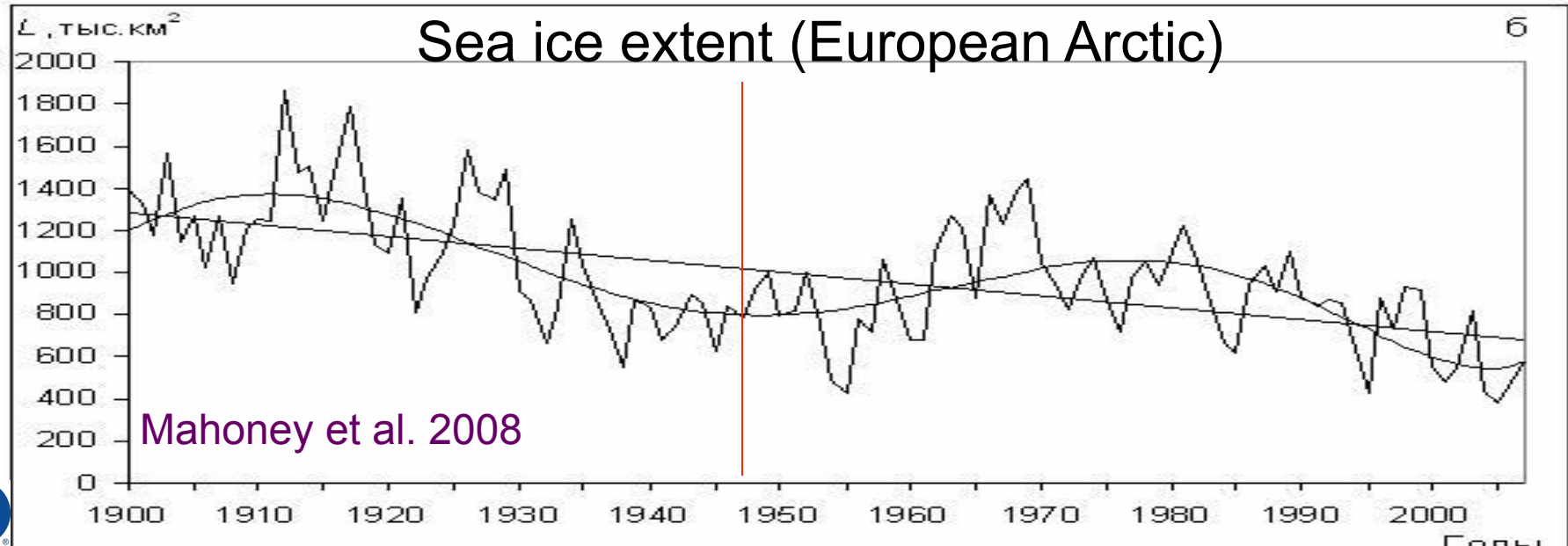
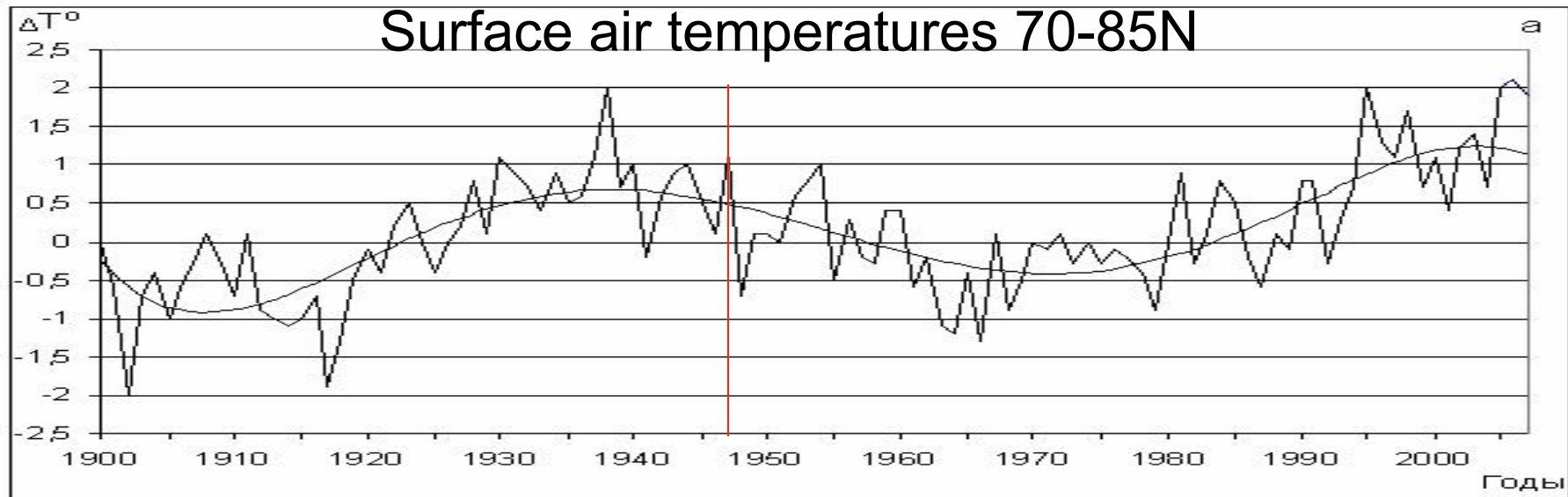
## Southern Hemisphere Sea Ice Anomaly

Anomaly from 1979-2008 mean

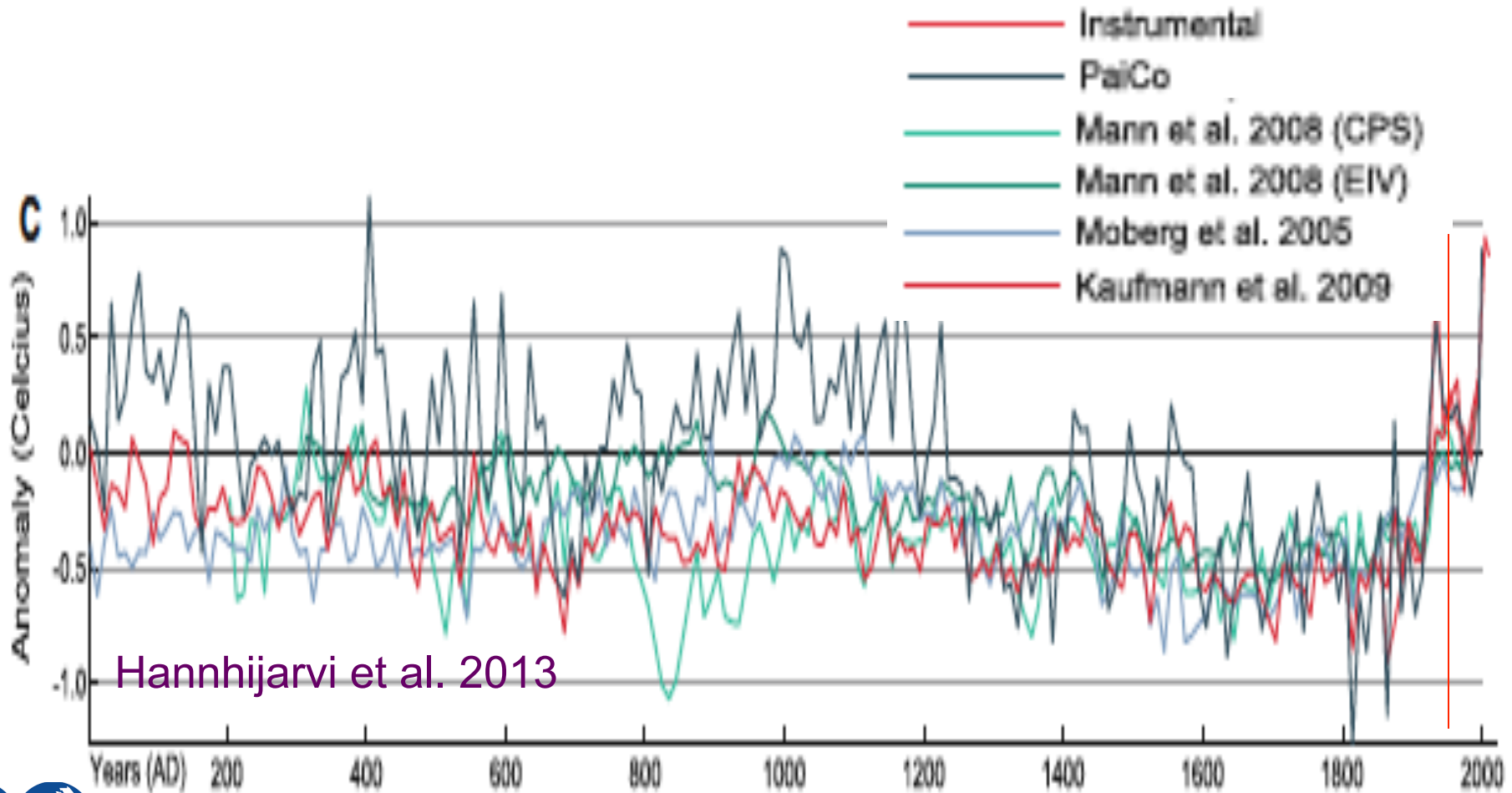


<http://arctic.atmos.uiuc.edu/cryosphere/>

*“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 anomalies in the 1920s and 1930s.” (IPCC AR5)*

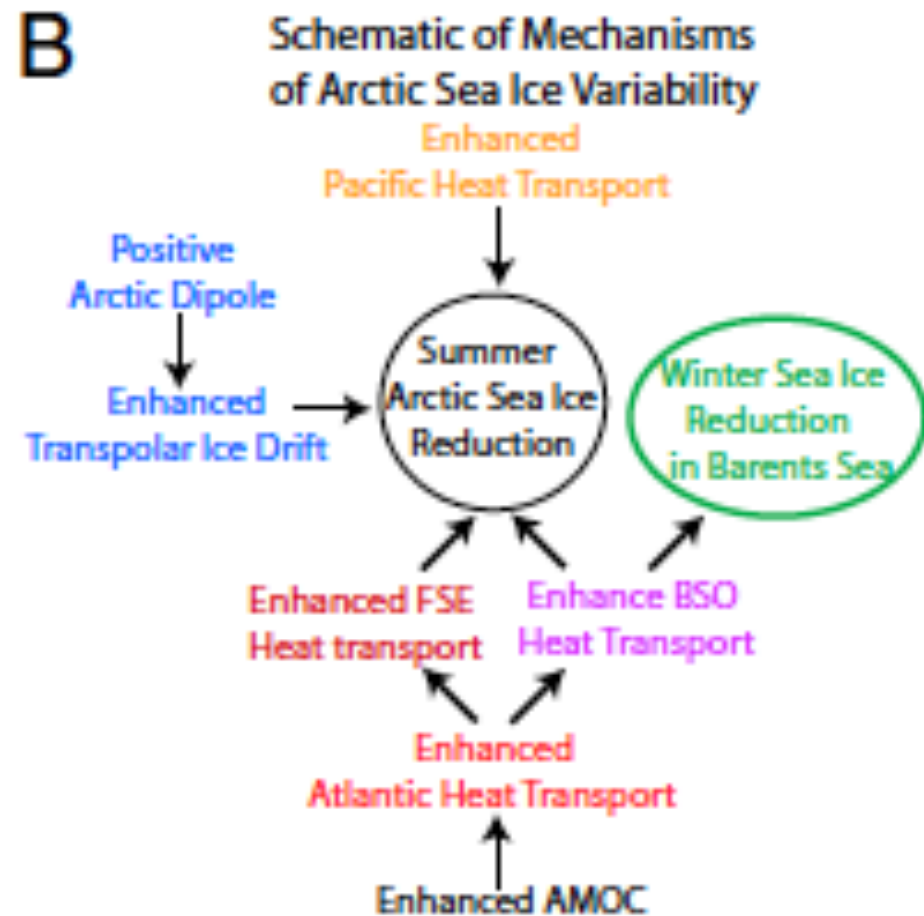
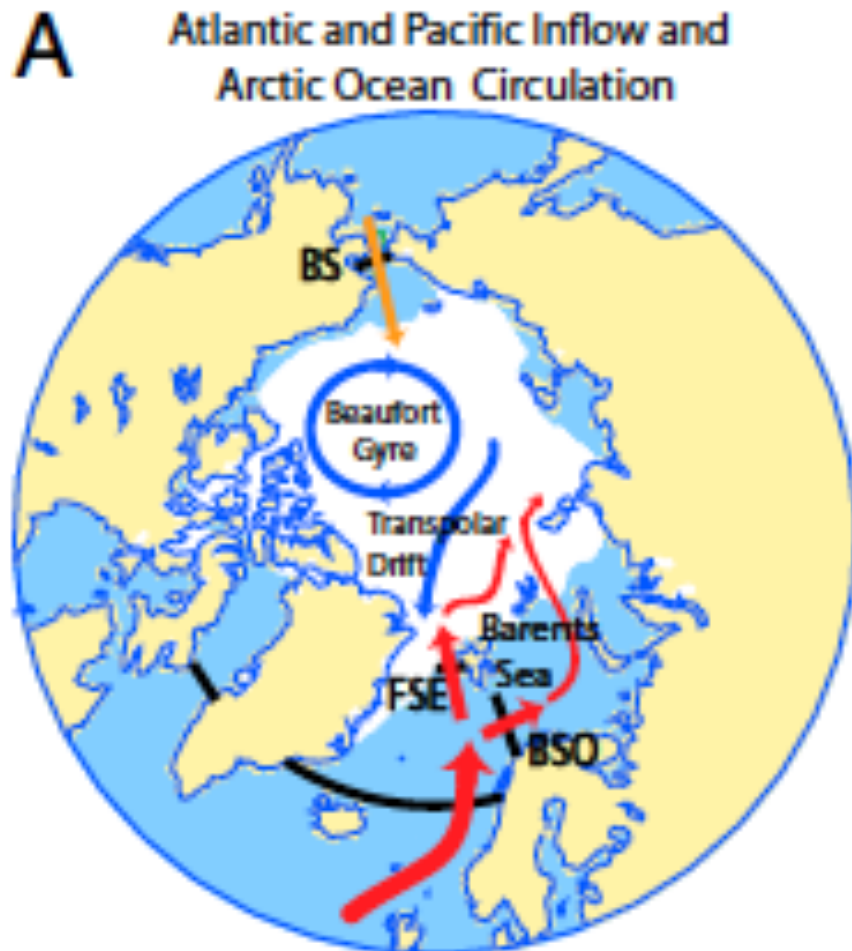


IPCC AR5: “A recent multi-proxy 2000-year Arctic temperature reconstruction shows that temperatures during the first centuries were comparable or even higher than during the 20th century.”





# Mechanisms of Arctic sea ice variability



# Extraterrestrial Factors

Solar  
Output

Earth-Sun  
Geometry

Interstellar  
Dust

**Earth's  
Climate**

Volcanic  
Emissions

Atmospheric  
Composition

Mountain  
Building

Atmospheric  
Reflectivity

Continental  
Drift

Atmosphere/Ocean  
Heat Exchange

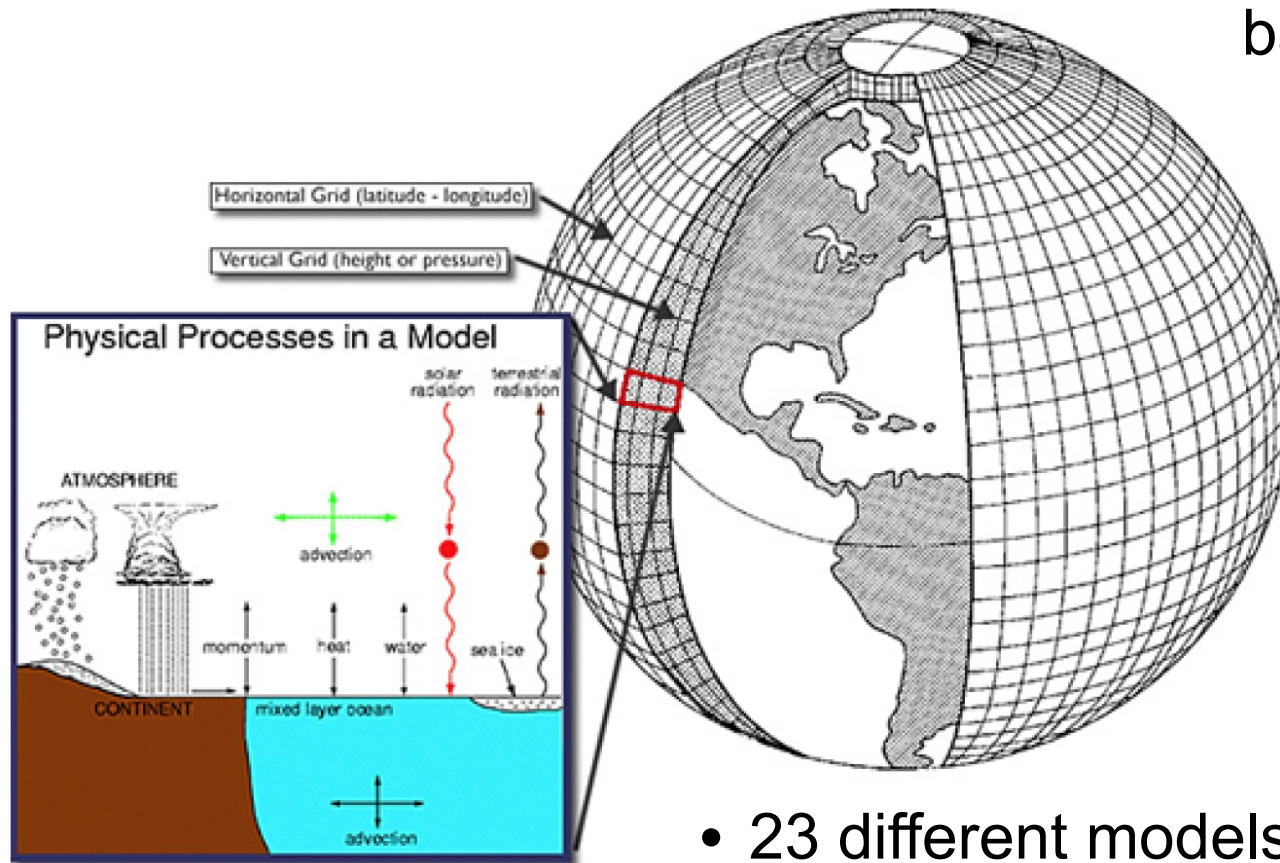
Surface  
Reflectivity

Ocean, Atmosphere, and Land Factors

# Climate Models

- Climate models represent the atmosphere, land surface, the ocean and the cryosphere on thousands of gridpoints in the atmosphere and the ocean. The model framework is

based on the laws of physics

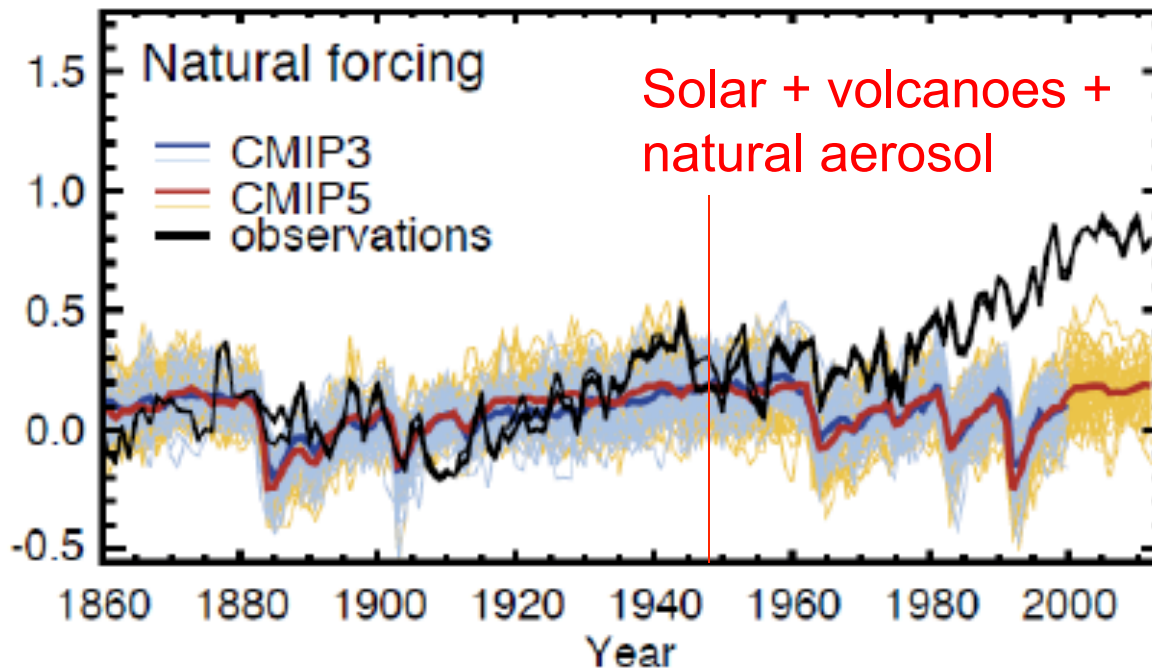


- Grid points in the atmosphere of the best models are ~ 100 km apart

- 23 different models were used by the IPCC in their assessment



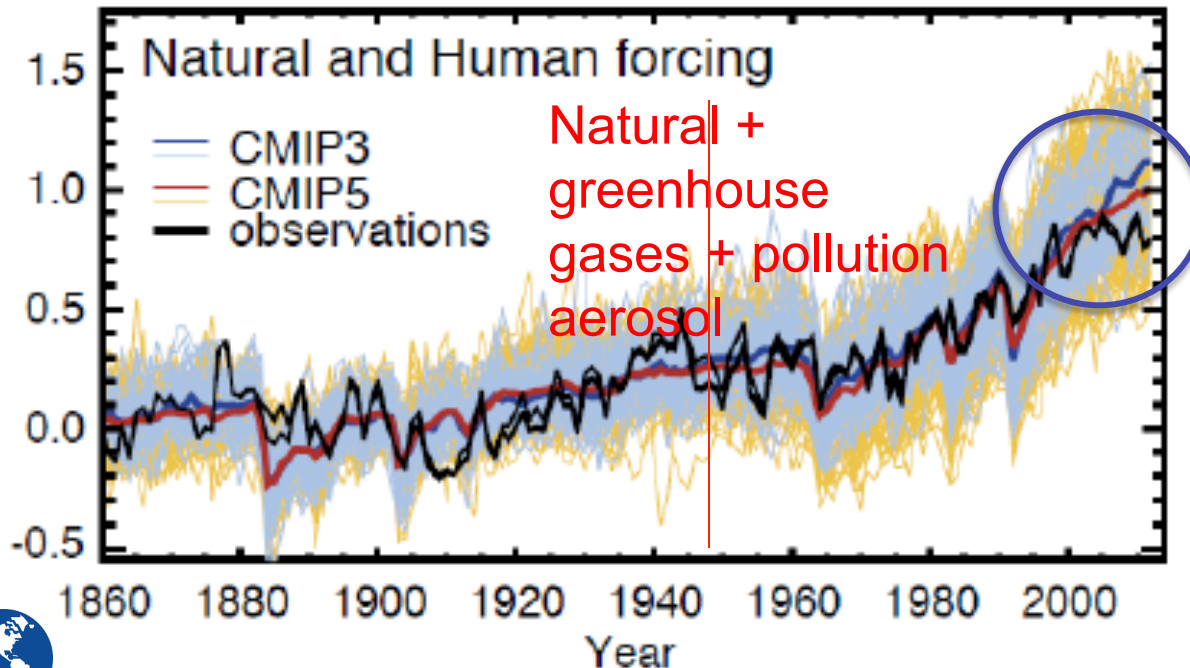
# What has caused the warming?



**Warming since 1950:**  
Human forcing

**Warming 1910-1940:**  
Models produce slight warming due to reduced volcanic activity and small human effects

**Cooling 1940-1975:**  
Not reproduced by the models



# Growing divergence: climate models vs surface temperature observations

CMIP5 near-term global temperature projections: updated from IPCC AR5 Fig. 11.25

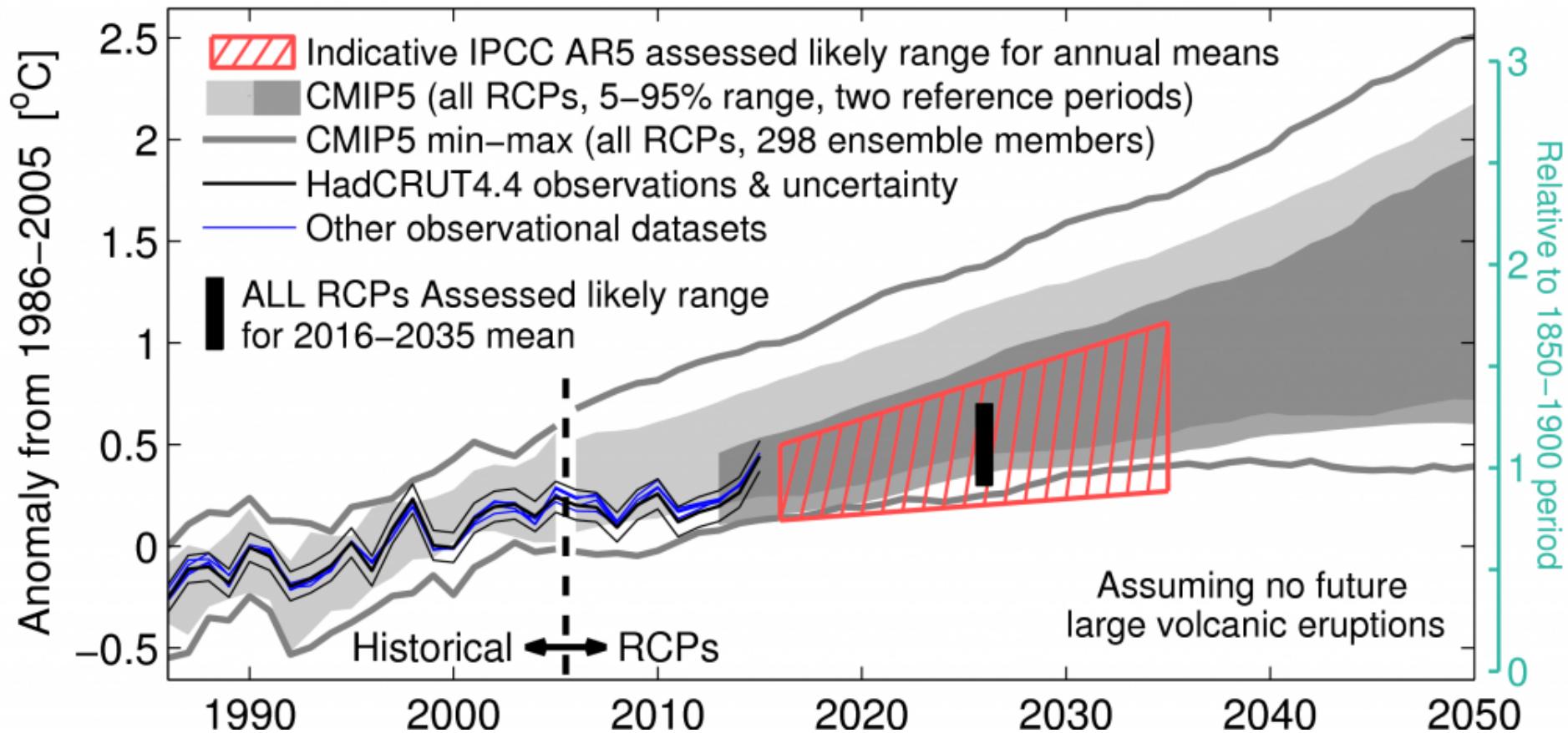


Figure courtesy of Ed Hawkins



# Growing divergence: climate models vs tropical mid-troposphere observations

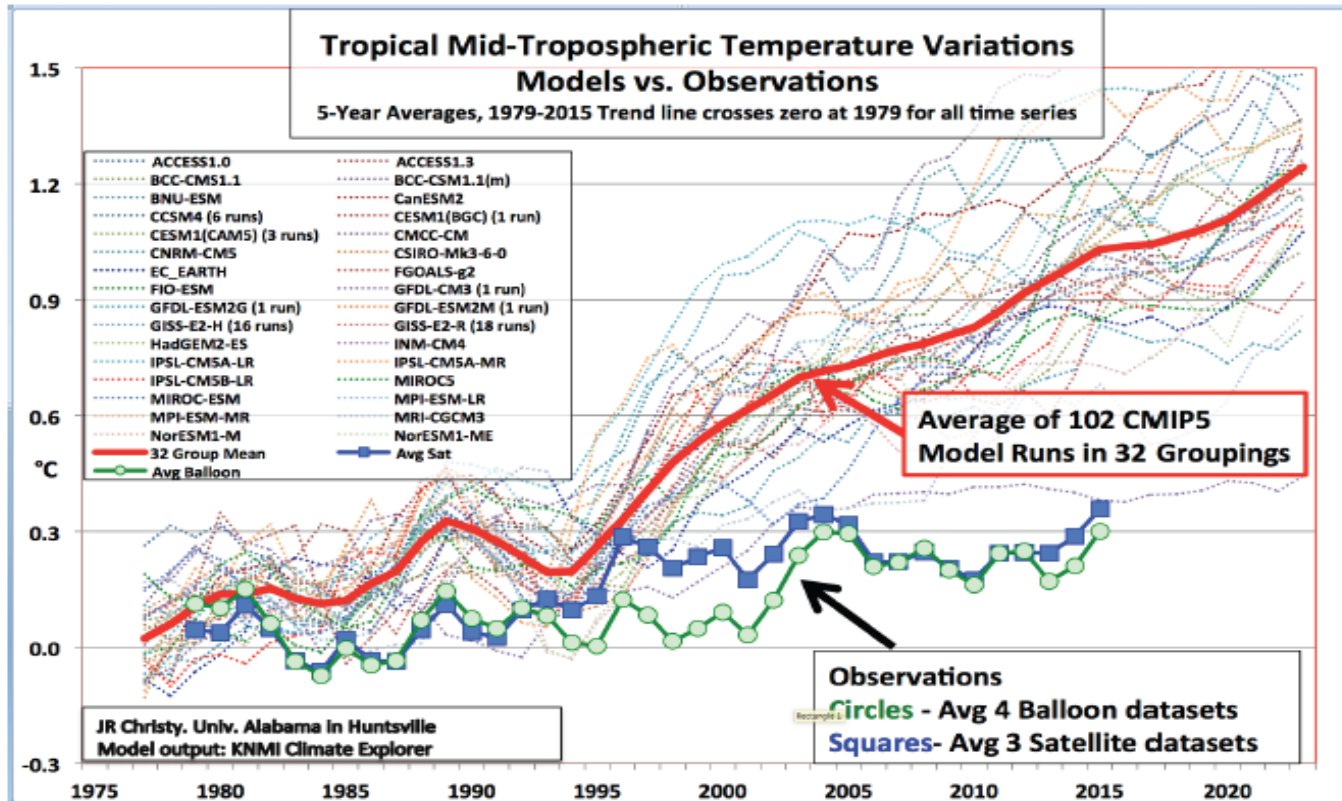


Figure courtesy John Christy

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

# Whither the climate of the 21<sup>st</sup> century?

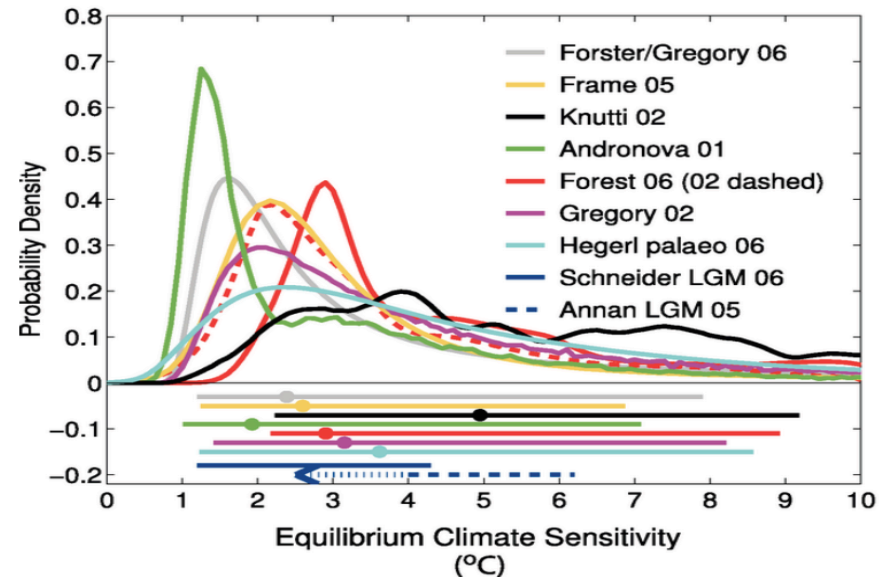


# Equilibrium Climate Sensitivity

**Definition:** Global surface temperature change following a doubling of atmospheric CO<sub>2</sub> concentration

Determined from:

- global climate models
- historical observations
- paleoclimate reconstructions



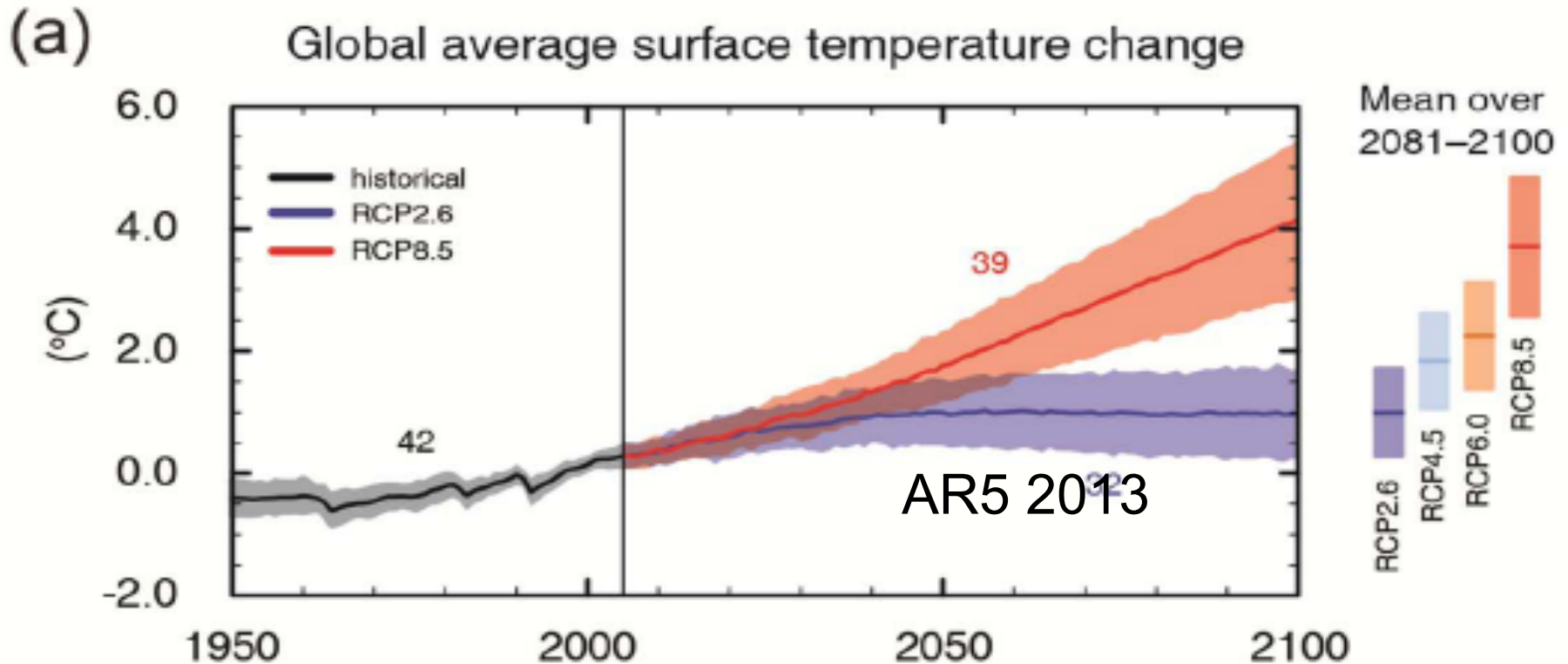
# Equilibrium Climate Sensitivity (°C)

	Median	5 <sup>th</sup> pctl	95 <sup>th</sup> pctl
IPCC AR4 (2007)	3.0	1.5	-
IPCC AR5 (2013)	-	1.0	6.0
Climate models	3.2	2.1	4.7
Observations	1.7	1.1	4.4
Observations*	1.5	1.1	2.4
*incorporates lower aerosol forcing			

Costs of warming are dominated by the **extreme tail values**

# Implications for the future:

## I. IPCC AR5 view



The amount of warming depends on the emission of greenhouse gases



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

**Solar effects**

Unknown unknowns

**Long-term ocean  
oscillations**

Volcanoes



**Greenhouse gases**

Underwater volcanoes

**Land use**

Solar system gravitational  
& magnetic interactions

**Aerosols**

# Scenarios of future climate

**CO2 emissions**

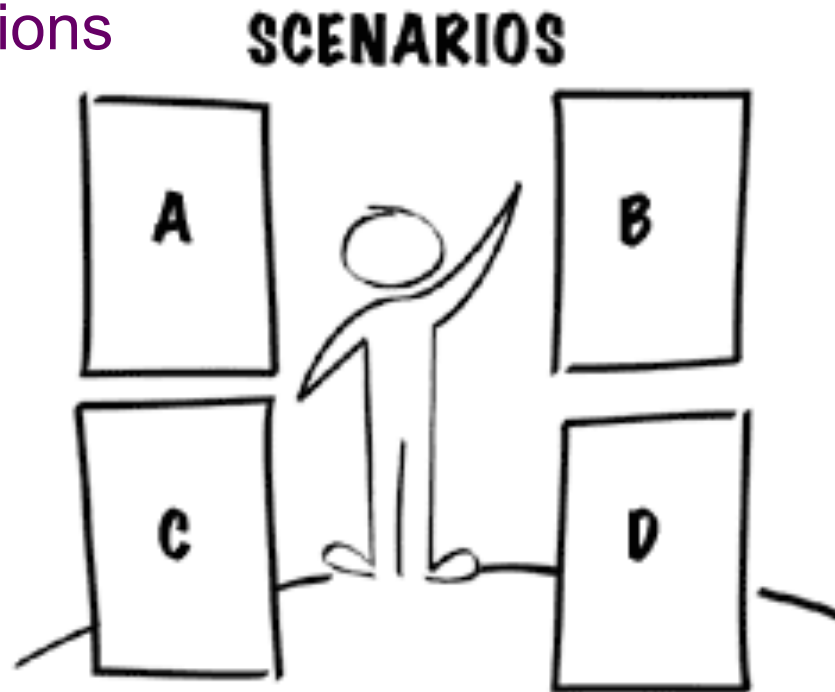
Long range  
ocean oscillations

Solar effects

Geologic  
processes

Volcanic  
eruptions

Unknowns



**20 YEARS FROM NOW...**

**50 YEARS, 100 YEARS**

# Implications for the future:

## II. View emphasizing natural variability

- The slowdown in warming since 1998 will continue at least another decade (into the 2030's?)
- Climate models are too sensitive to human forcing; 21<sup>st</sup> century warming will be on the low end of IPCC projections (or even below)
- Solar variations & volcanoes: wild card. Some are predicting solar cooling in the near term
- Can't rule out unforeseen surprises



# Why do scientists disagree?

- Insufficient & inadequate 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

# Is global warming dangerous?

The UNFCCC has defined 'dangerous' as  $2^{\circ}\text{C}$  post industrial warming; we have already warmed more than  $0.9^{\circ}\text{C}$

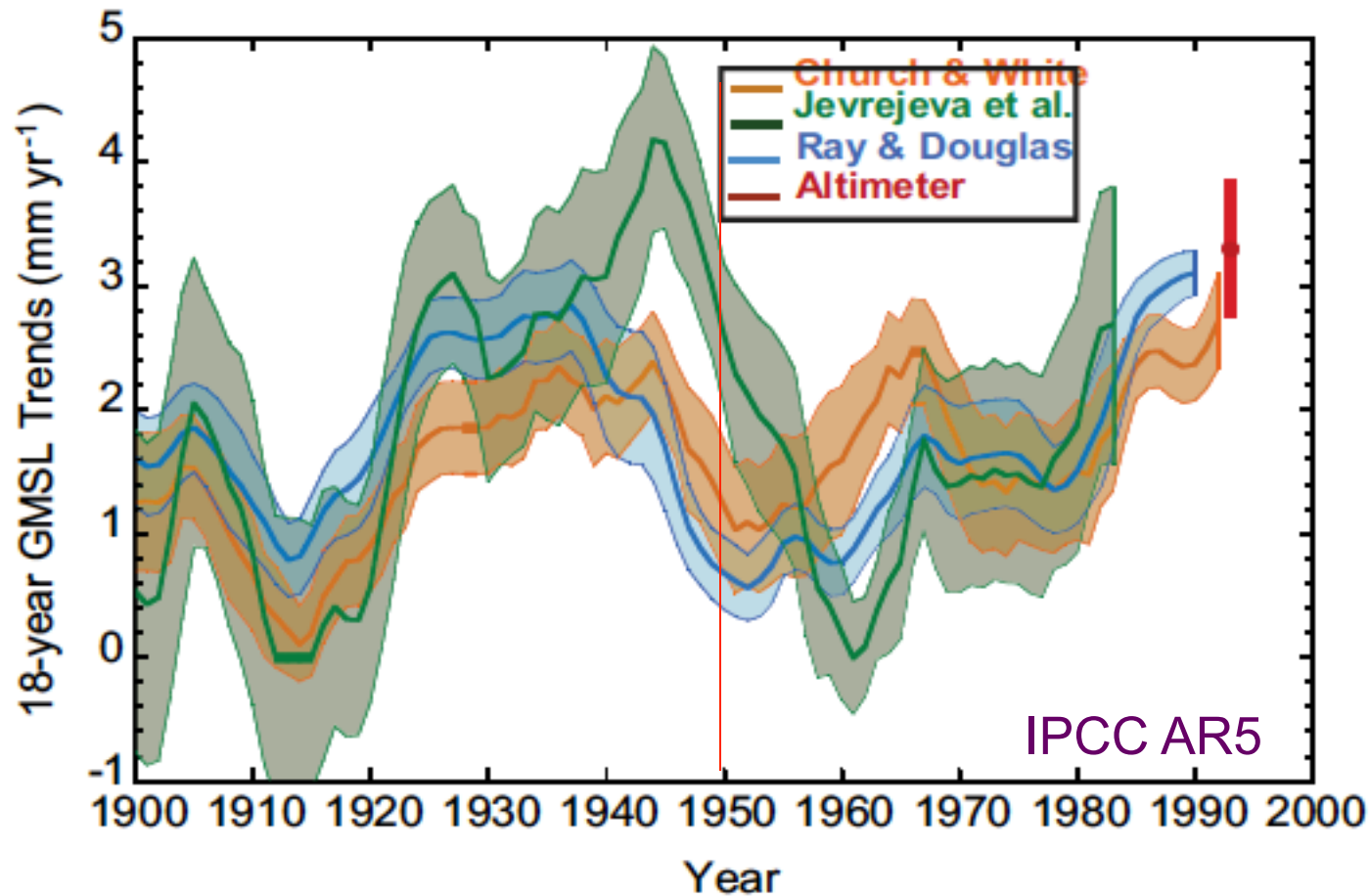
When we will reach  $2^{\circ}\text{C}$  depends not only on ECS, but also on natural climate variability

Efforts to redefine 'dangerous' as  $1.5^{\circ}\text{C}$  post industrial warming are underway



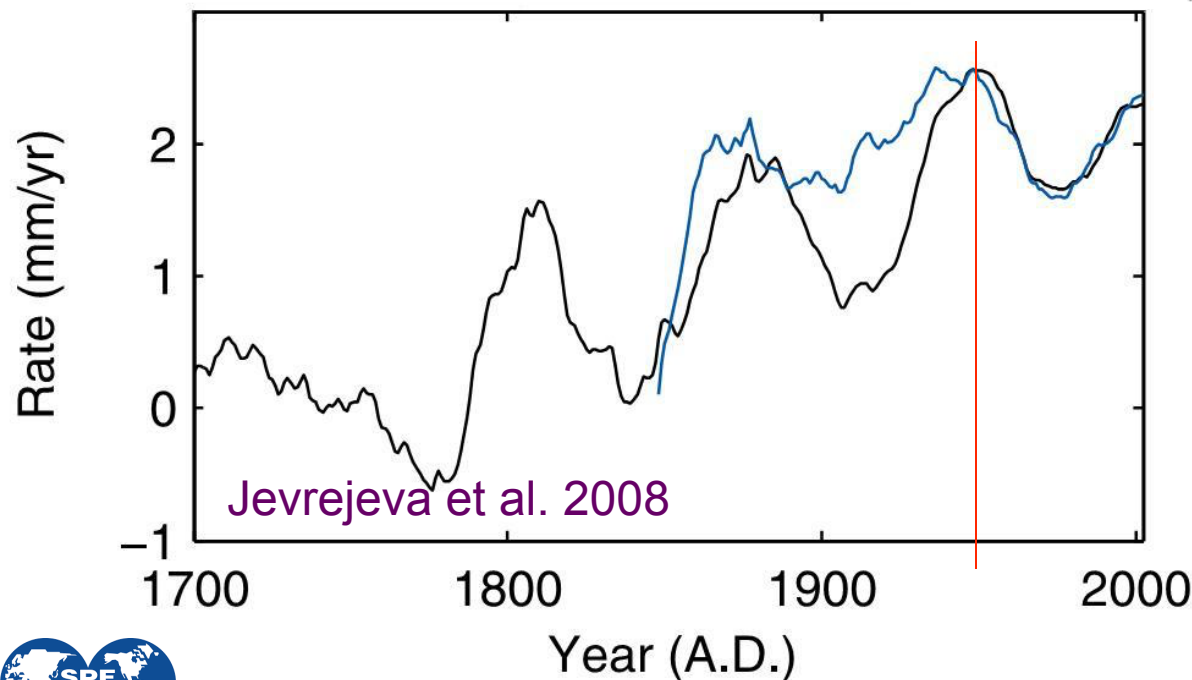
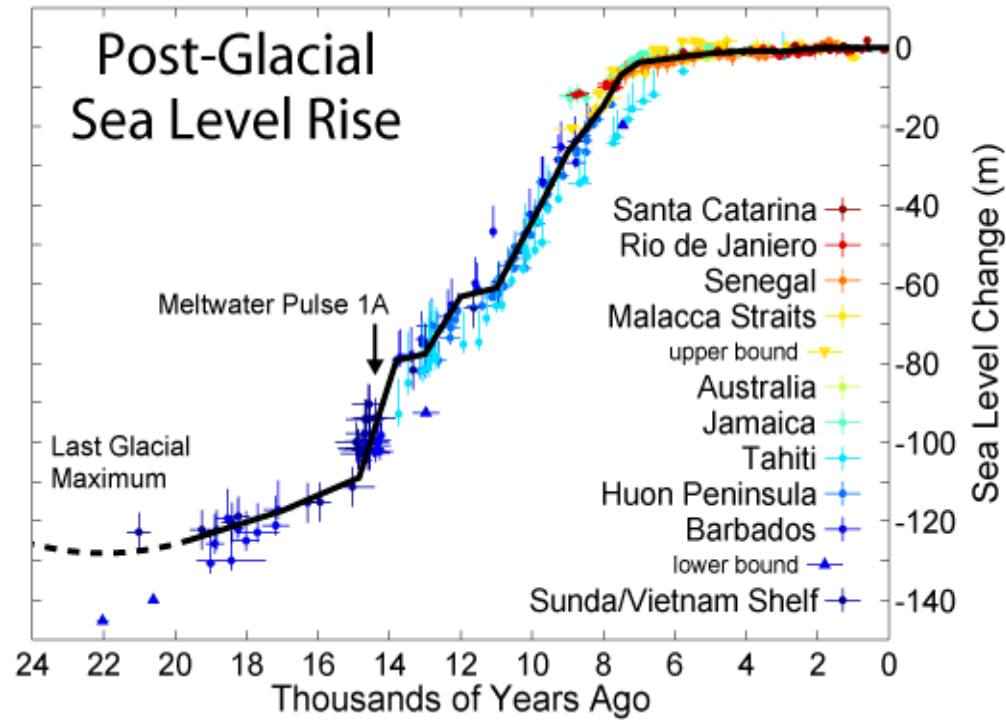


# Is the IPCC's sea level rise conclusion justified?



**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)”

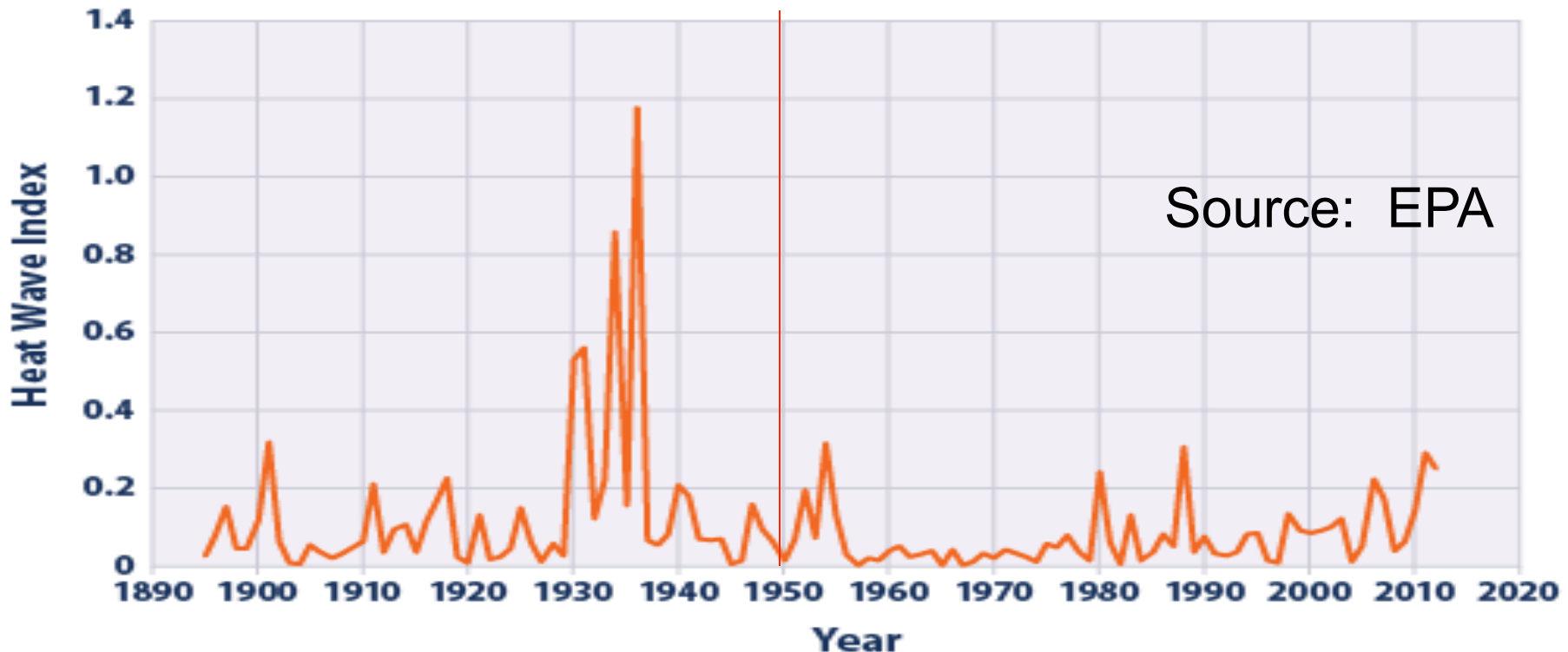
Sea level has been rising since the end of the last ice age



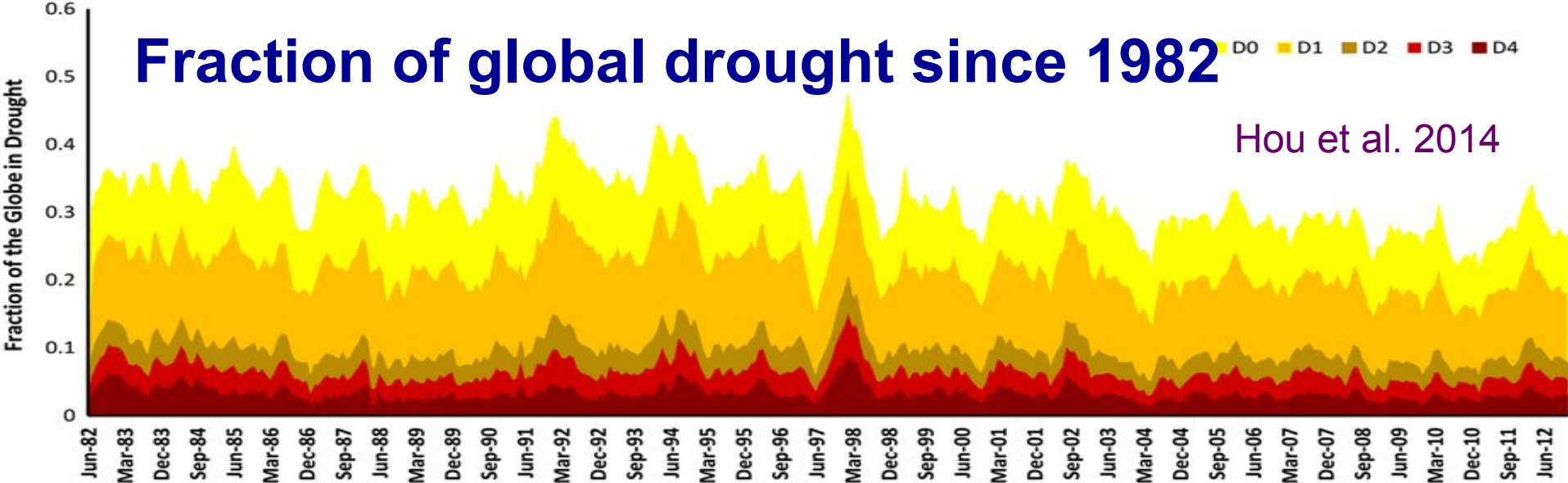
Debate: did recent sea level rise acceleration begin over 200 years ago?

# US Annual Heat Wave Index, 1895-2012

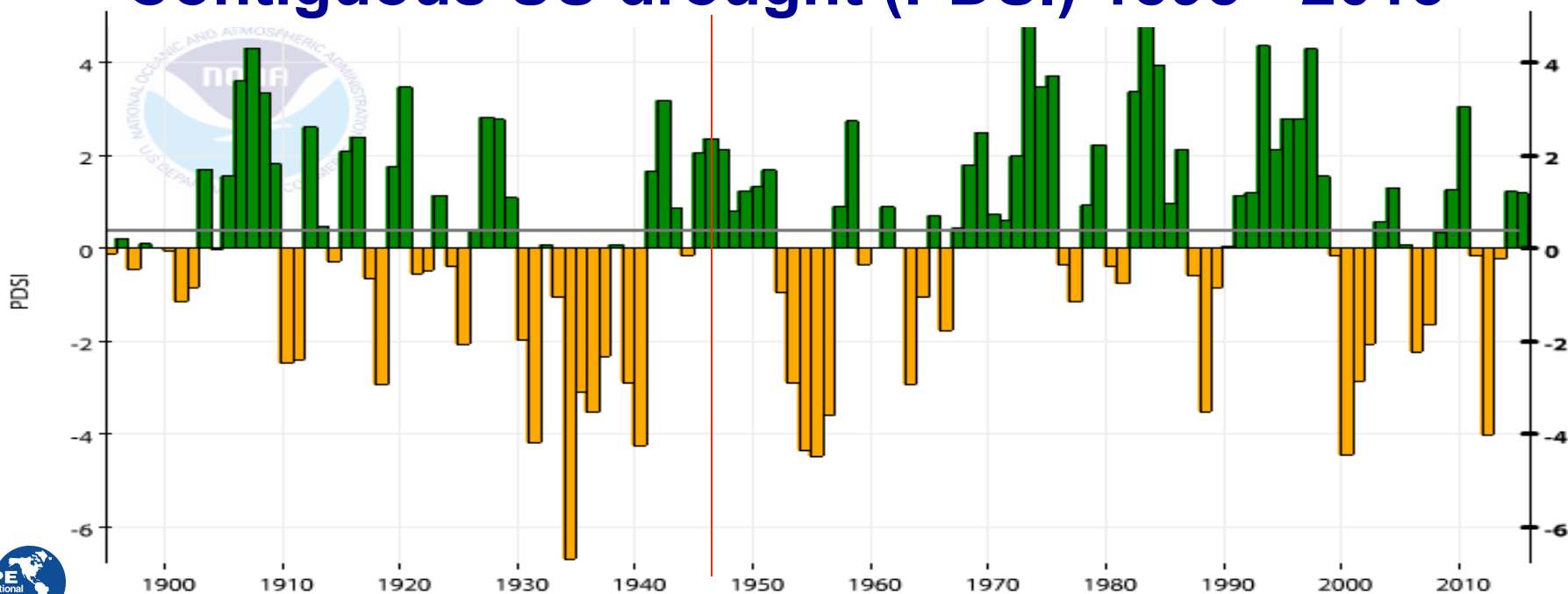
Figure 1. U.S. Annual Heat Wave Index, 1895–2012



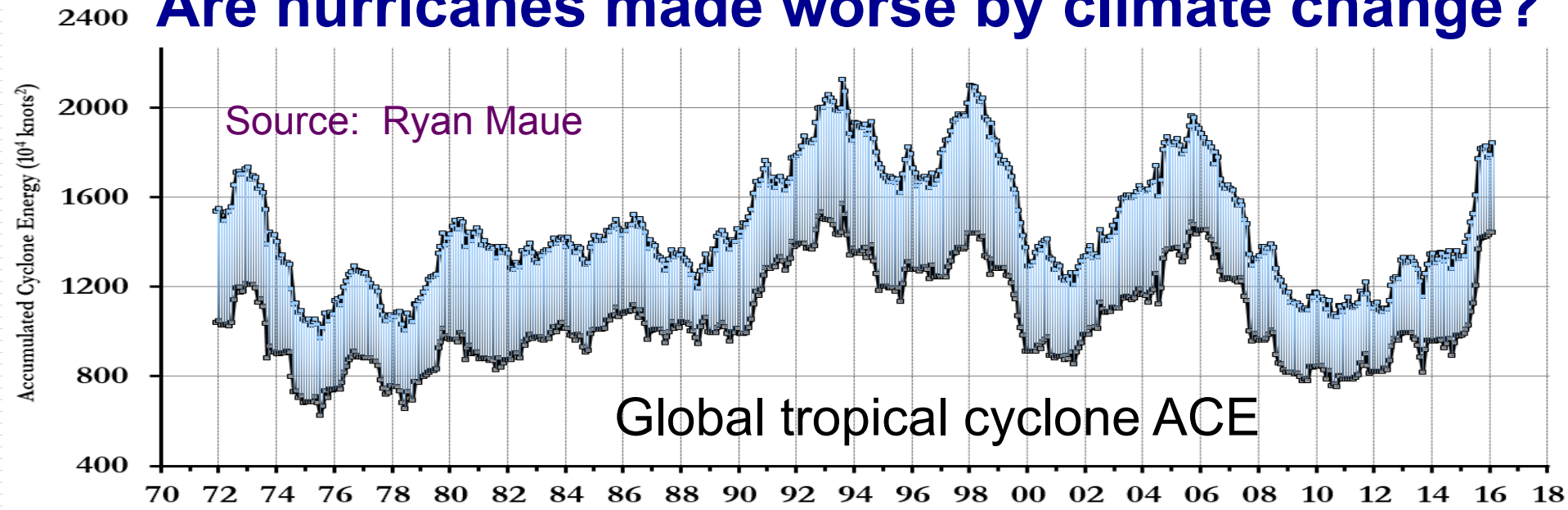
“It is *likely* that the frequency of heat waves has increased in large parts of Europe, Asia and Australia.” (since 1950)  
IPCC AR5



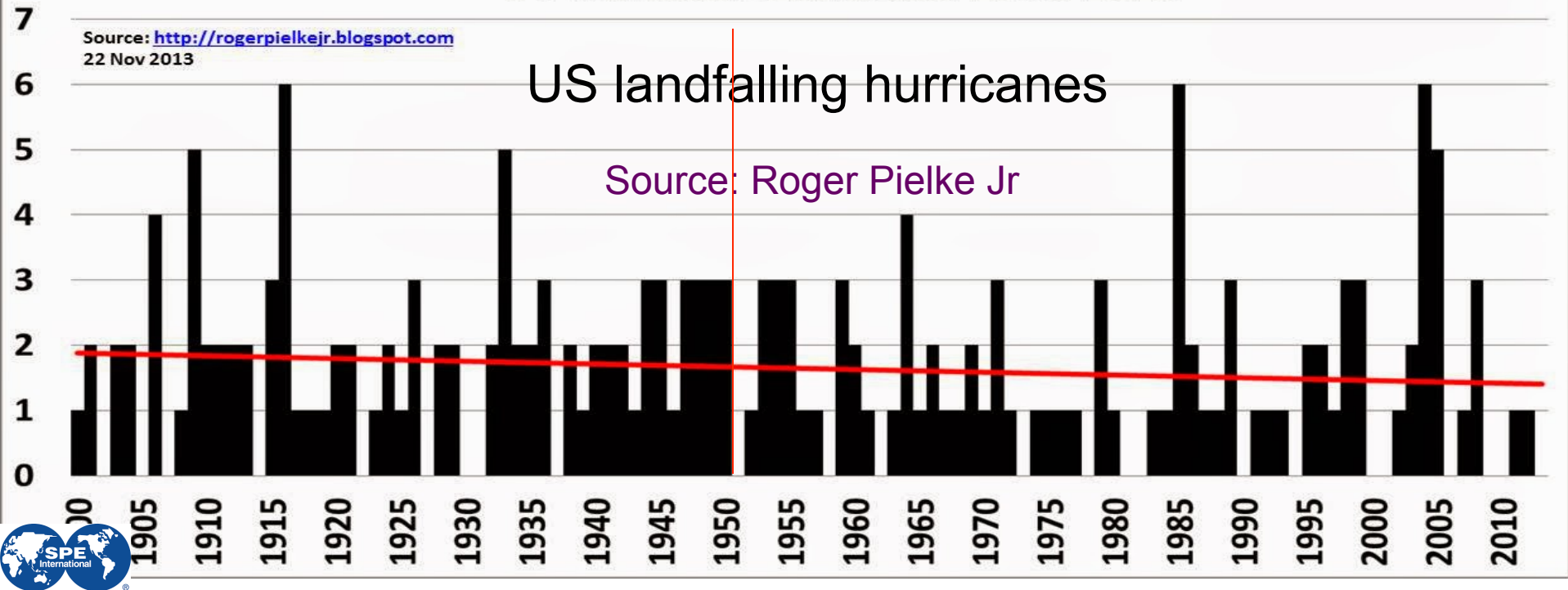
## Contiguous US drought (PDSI) 1895 - 2015



# Are hurricanes made worse by climate change?

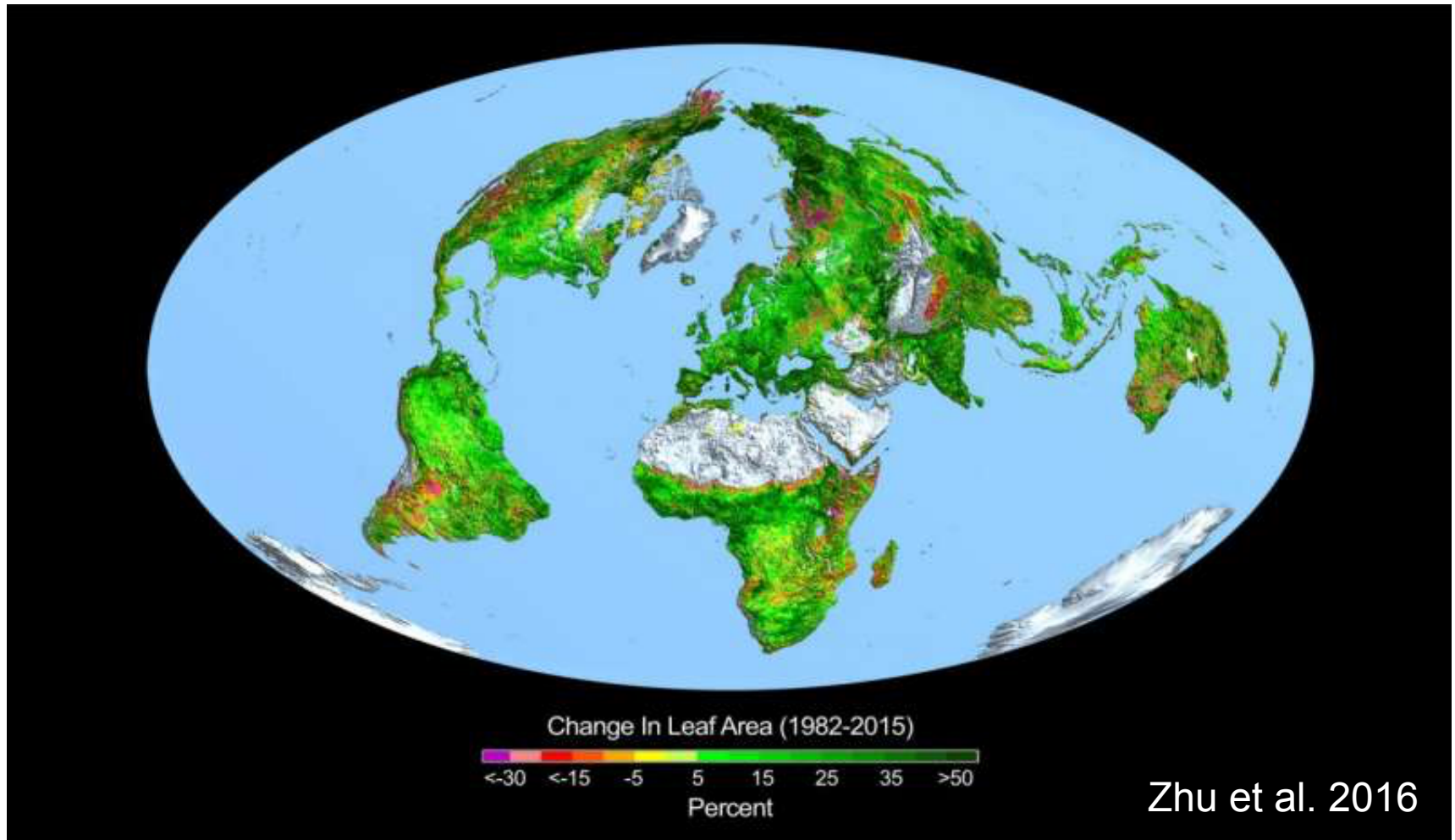


## US Hurricane Landfalls: 1900-2013





# Rise in CO<sub>2</sub> greening Earth since 1982



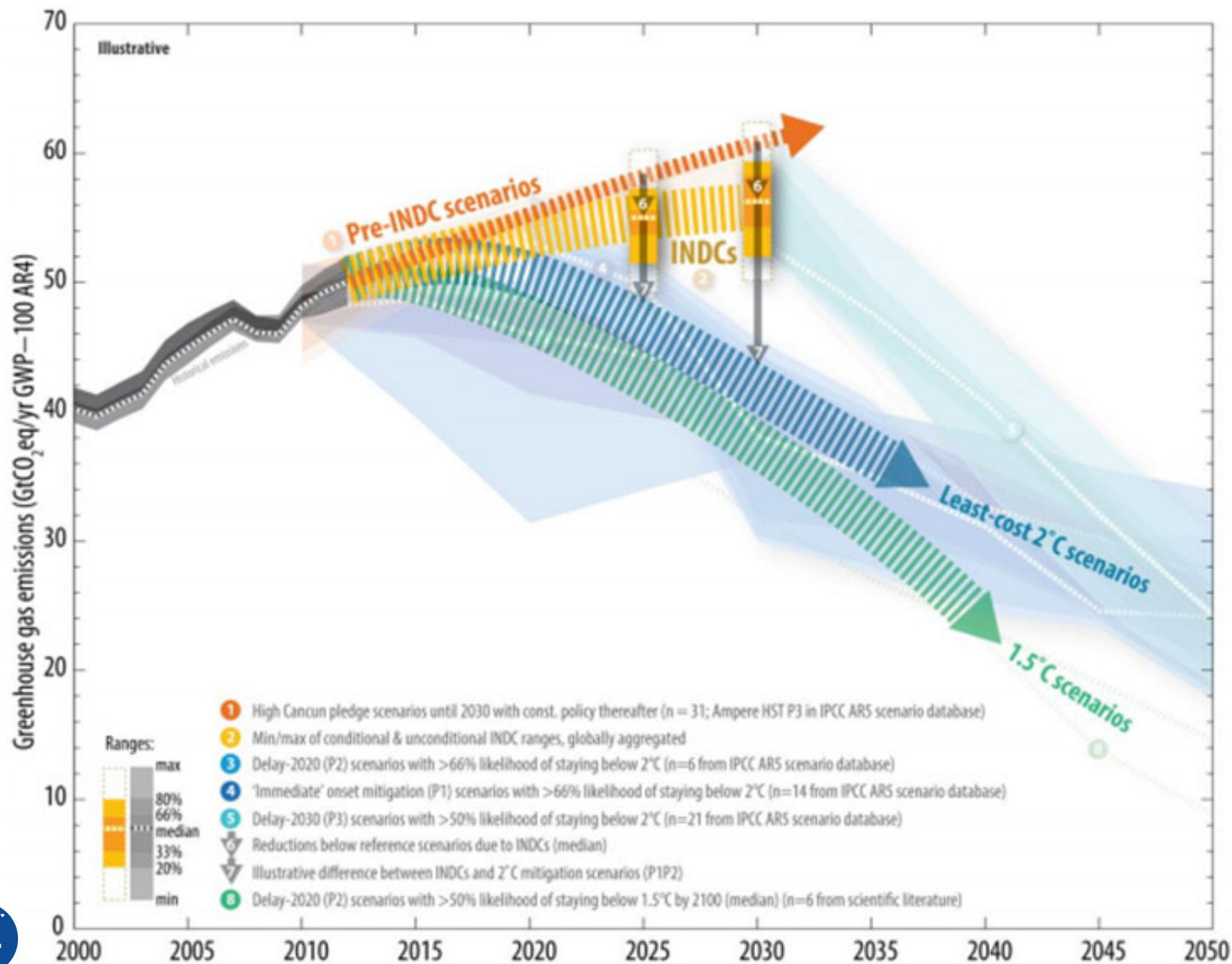
Greening over 25-50% of global vegetated area; 4% browning  
CO<sub>2</sub> fertilization effects explain 70% of the greening trend

# How should we respond to climate change?

- There is increasing evidence that the threat from global warming is overstated
- However, if the threat is not overstated, there are major shortfalls in current and proposed solutions.



# Comparison of global emission levels in 2025 and 2030 resulting from the implementation of the intended nationally determined contributions and under other scenarios



# How much warming will emissions reductions commitments to 2025-2030 (sustained) prevent in the 21<sup>st</sup> century?

U.S.: (ECS = 3°C)

- The U.S. NDC of 28% reduction of emissions below 2005 levels by 2025 will prevent **0.03°C** in warming by 2100

Global estimates

- **0.17 - 0.2°C** is optimistic target
- India's NDC will double - triple emissions by 2030



# Can we limit the warming to 2°C?

**Yes**, if the climate sensitivity is at lower end of estimates  
(emissions reductions will make little difference)

**No**, if natural climate variability is dominating the warming  
(emissions reductions will make little difference)

If the IPCC climate model projections are correct: even dramatic reductions in CO<sub>2</sub> emissions by 2050 would have small impact on temperatures in the 21<sup>st</sup> century

(Some) economists: Missing the 2°C target will not lead to a large welfare loss.



# Concerns about the Paris Agreement

**In-country legal, political & economic issues** – nonbinding agreement and voluntary compliance by developing countries ensures that emissions will continue to rise

**Technical feasibility:** no known technologies that are feasible, economic, scalable & politically acceptable to substantially reduce CO<sub>2</sub> emissions from power, transportation, agriculture, cement on the timescale of a few decades

## **Confounding factors:**

- Global population increase
- Bringing grid electricity to undeveloped countries
- Rapid economic development in developing and undeveloped countries

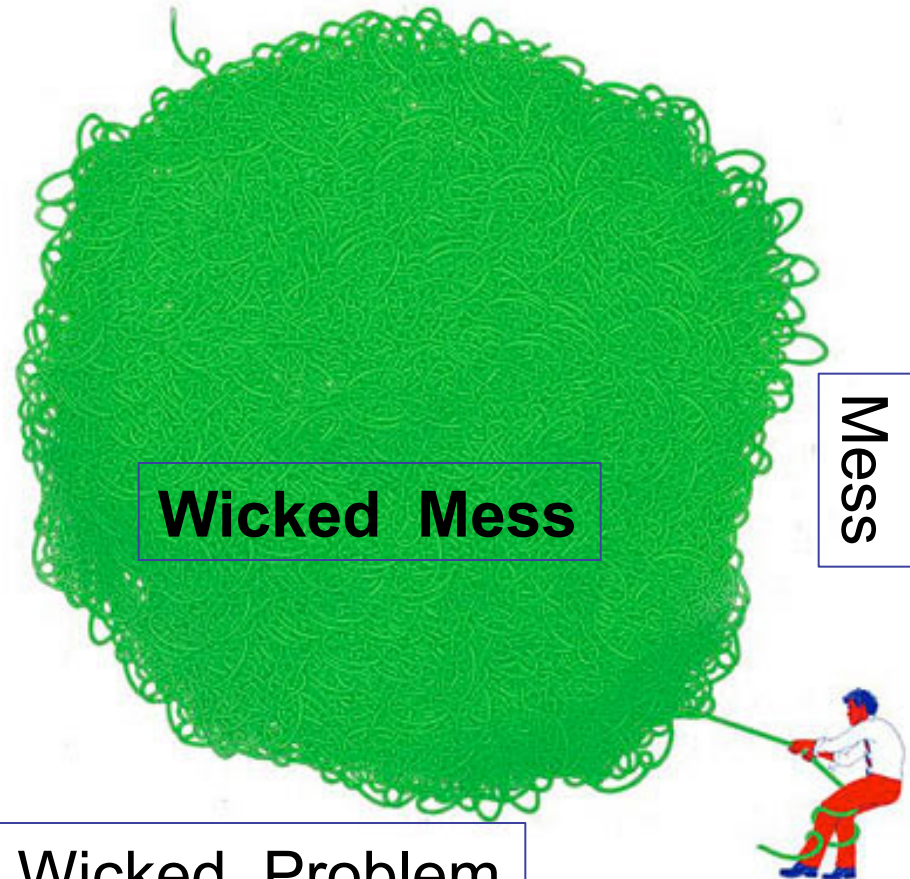
## Tame Problem



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

**versus**

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



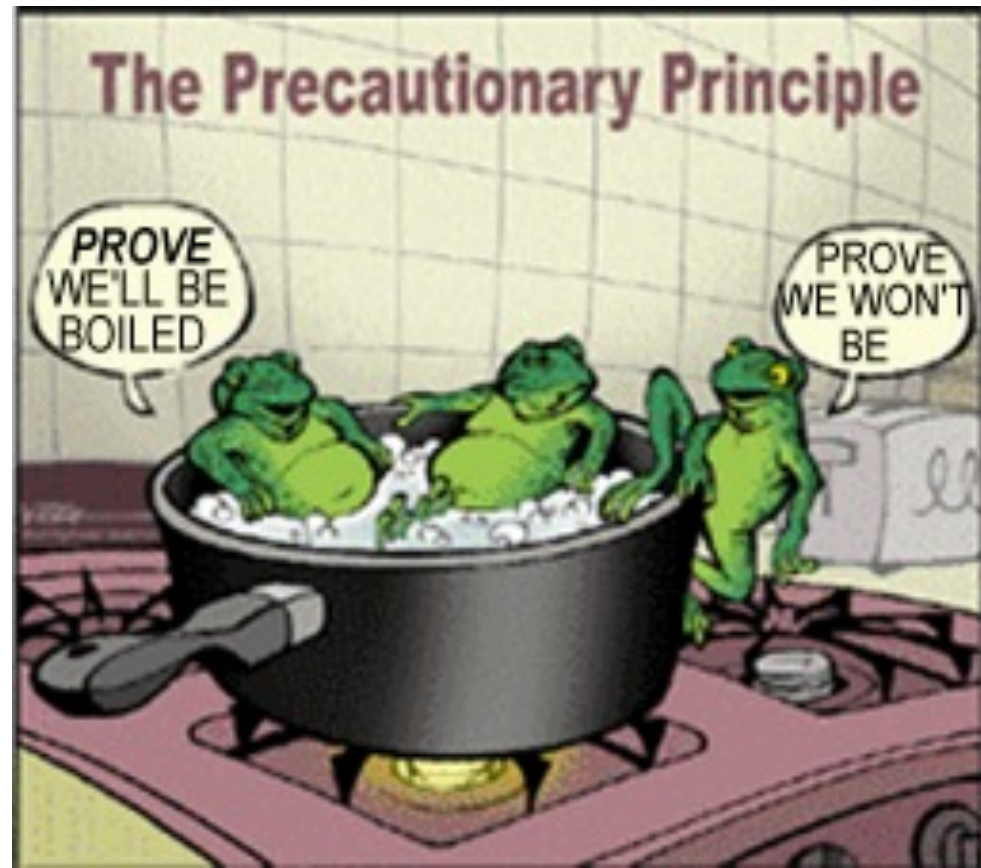
**Wicked Problem**

# The Precautionary Principle

"Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

Based upon the precautionary principle, the UNFCCC established a goal of stabilization of atmospheric greenhouse gases to prevent dangerous climate change

Stabilization targets are set at the lowest critical threshold value

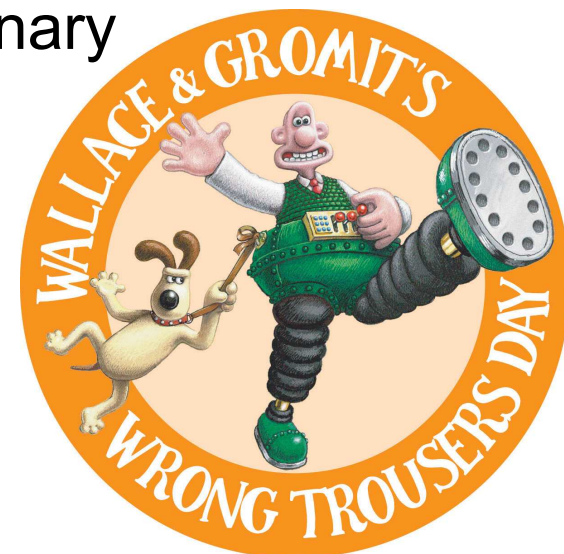


# Precautionary Principle: 'Wrong Trousers'

## A mismatch between problem and solution:

For a wicked problem, the precautionary principle is an oversimplification that can lead to overreactions that cause more harm than benefits and introduce new systemic risks. (Prins and Rayner)

Current thinking focuses on **risk management** (e.g. cost/benefit) rather than the precautionary principle. However, UNFCCC policies are still framed by the precautionary principle.





# Options for decision makers confronted with deep uncertainty and wicked messes:



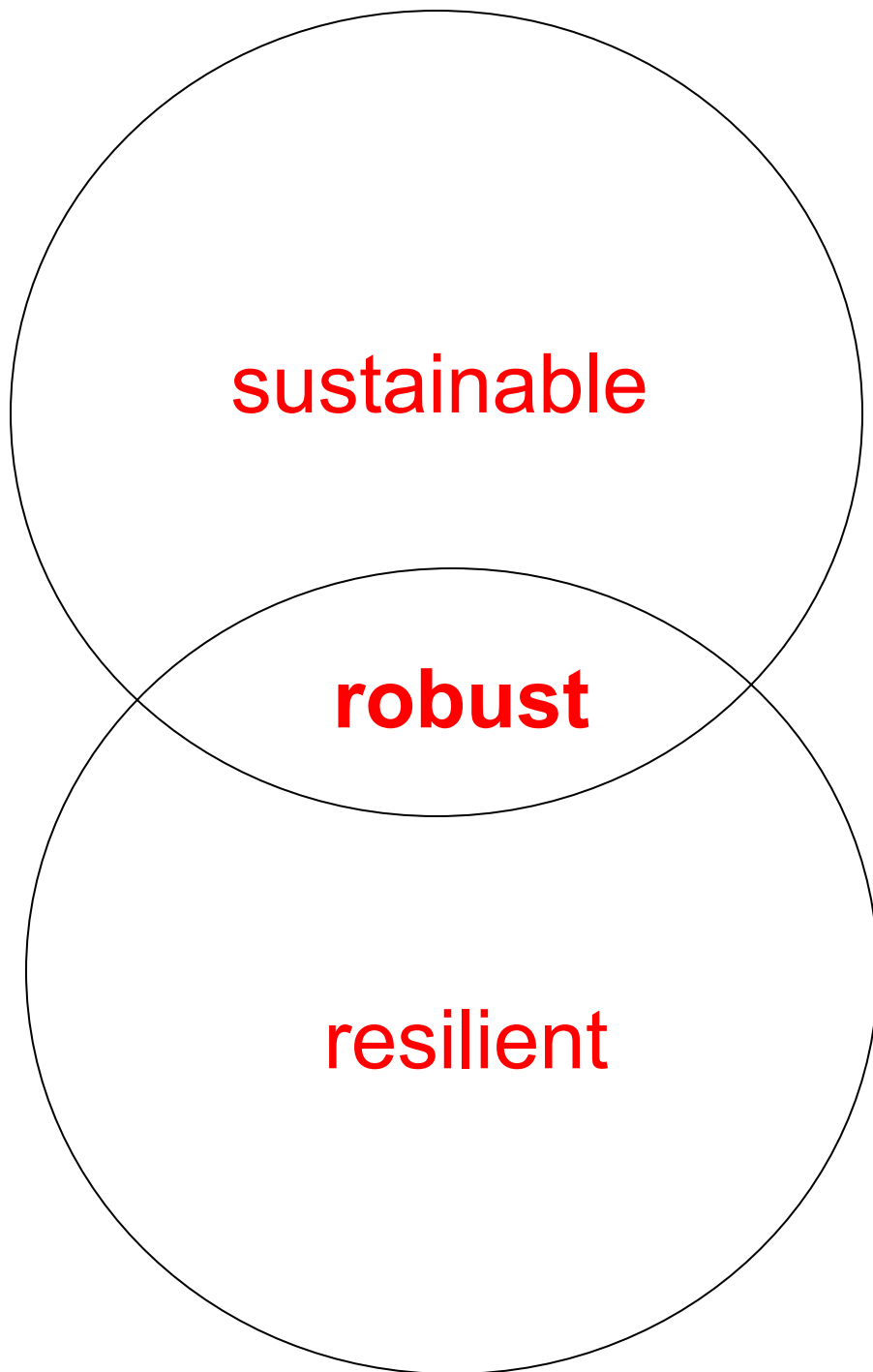
- Do nothing
- Enlarge the knowledge base for decisions
- Adaptive management
- Build a resilient society

"OK, all those in favour of delegating decision-making, shrug your shoulders"



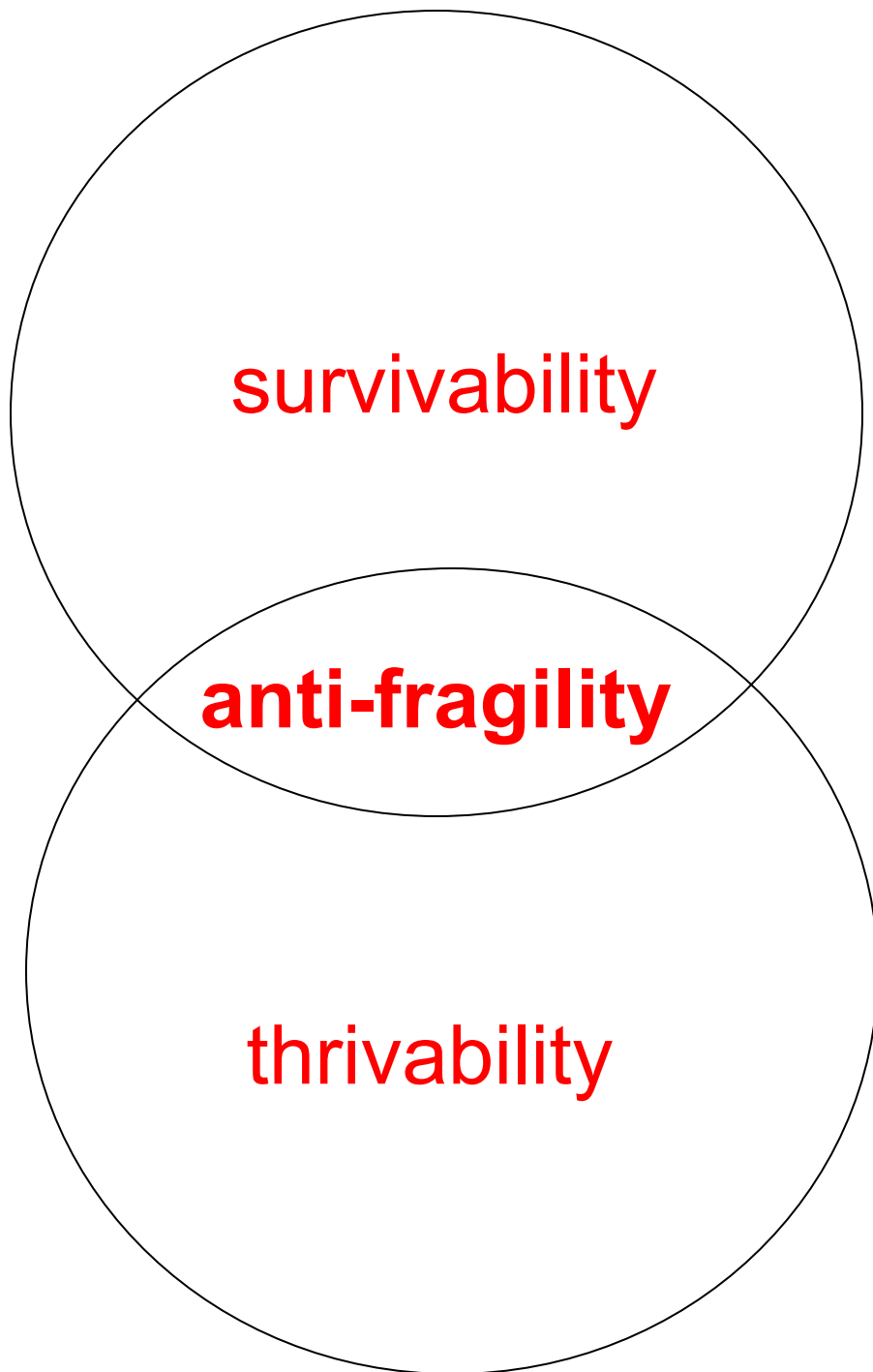
# Conflict of values

Survival	Sustainable	Resilience	Thrivability
Outlast	Maintain	Bounce back	Bounce forward
Better than dead	Endure in a stable world	Recover quickly from difficult conditions	Prosper, thrive, develop vigorously
Try for personal survival: group or nation	Able to maintain at a given rate, level over time	Survive longer in changing world	Strive for greatness
Meet basic Needs	Mitigate damage Sacrifice, austerity	Adaptation, redundancy	Anti-fragile, generate, transform
	Obligations		



**Robust strategies** (multiple benefits with little downside):

- Water resource management
- Infrastructure security
- Agricultural productivity
- Ecological conservation and restoration
- Resource conservation & reuse
- Energy research



**Antifragility** learn and grow from volatility and unexpected events:

- Economic development
- Reduce the downside from volatility
- Optionality
- Small experiments; tinker
- Transformative ideas

# Challenges for the energy sector

Provide reliable power economically:

- Growing demand
- Need for rapid 3<sup>rd</sup> world development
- Aging infrastructure
- Desire/demand for clean, green energy
- Uncertain and changing federal climate policy



# Weather & Climate Prediction for the Energy Sector



Tactical adaptation:

- Probabilistic prediction of ***high impact extreme events*** on daily to seasonal time scales
- Support energy trading, economic development, risk management, disaster mitigation, regional stability, long-range asset planning

[www.cfانclimate.net](http://www.cfانclimate.net)

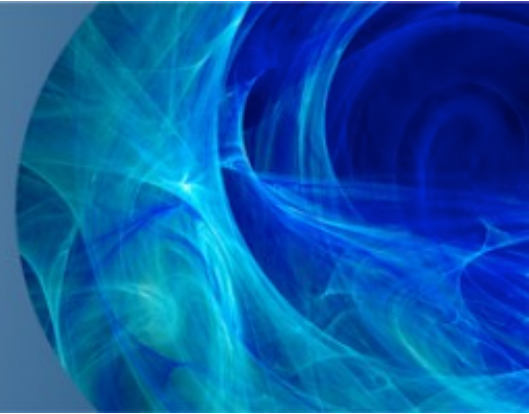


We have oversimplified both  
the problem and its solution



<http://judithcurry.com>

# Climate Etc.



**Climate Etc.** provides a forum for technical experts and the interested public to engage in a discussion on topics related to climate science, its impacts and policy options.

twitter: @curryja