



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

“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



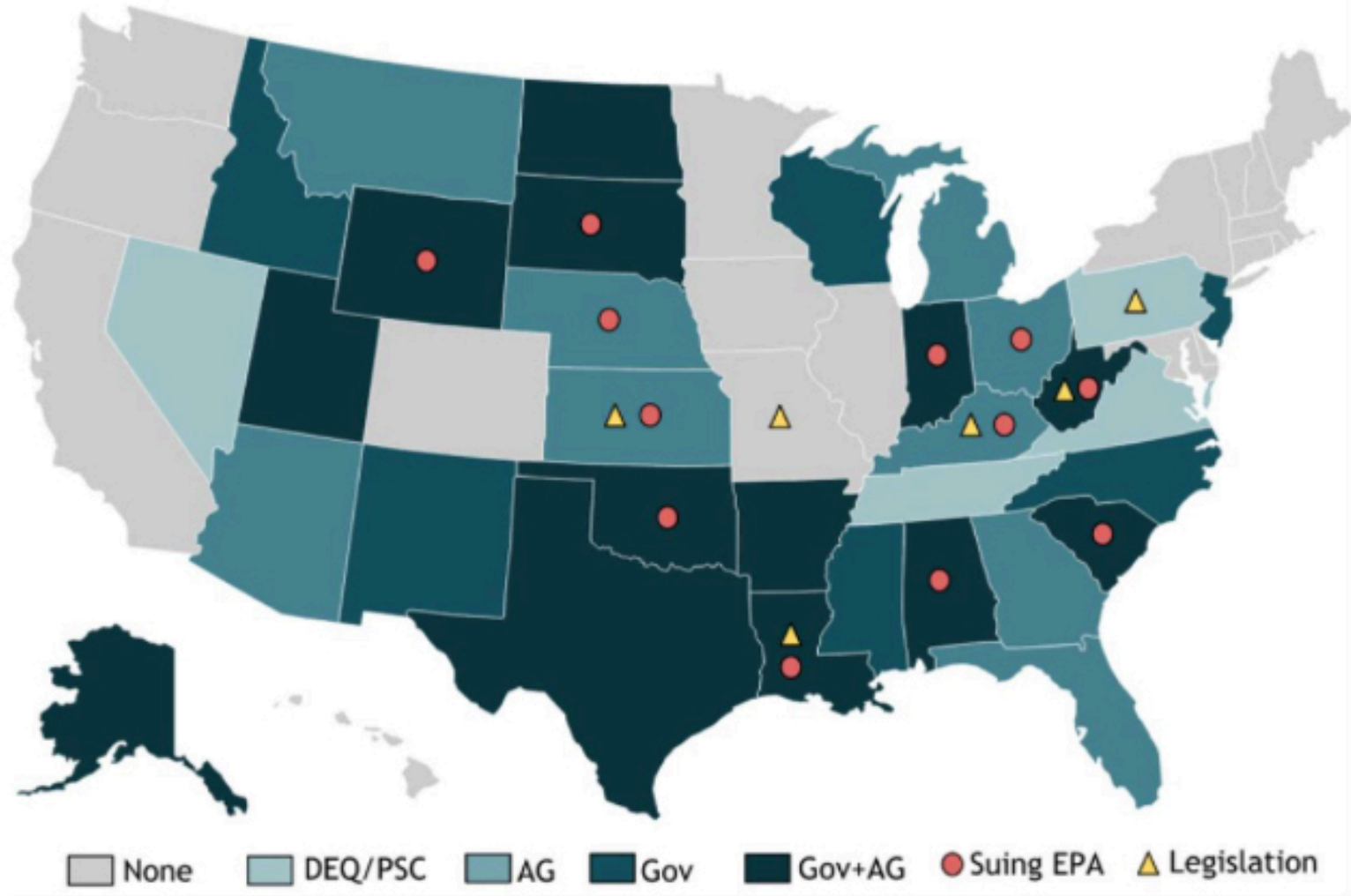
U.S. Constitution Treaty Clause:

“ [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)**

State Legal Objections to EPA Carbon Regulations



Note: Map compiled as of January 9, 2015 based on official comments in regulatory docket as well as other public letters and statements. Objections from state environmental agencies or public service commissions are shown only in absence of objections from governor or attorney general.

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:

- Ongoing legal challenges: win some, lose some
- The next President may choose not to enforce, or even to abolish the EPA.



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:

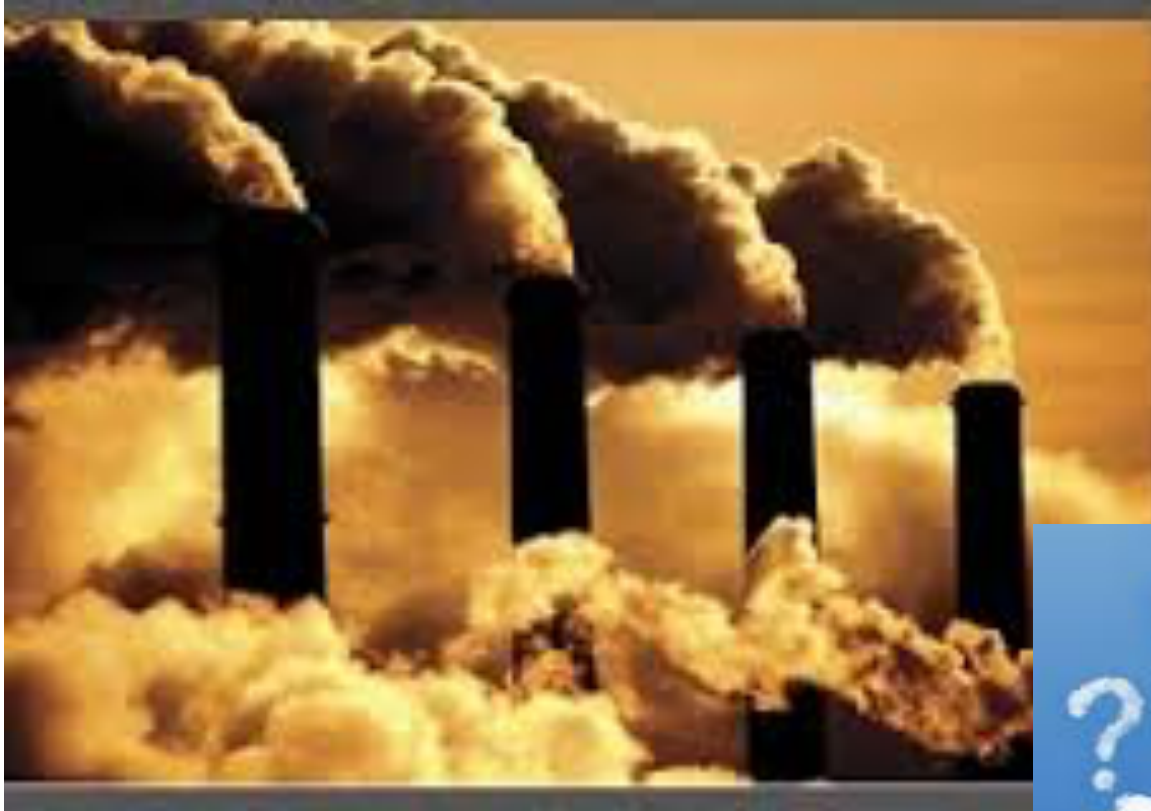
- Surface temperatures have increased since 1880
- Humans are adding carbon dioxide to the atmosphere
- Carbon dioxide and other greenhouse gases have a warming effect on the planet

Disagreement:

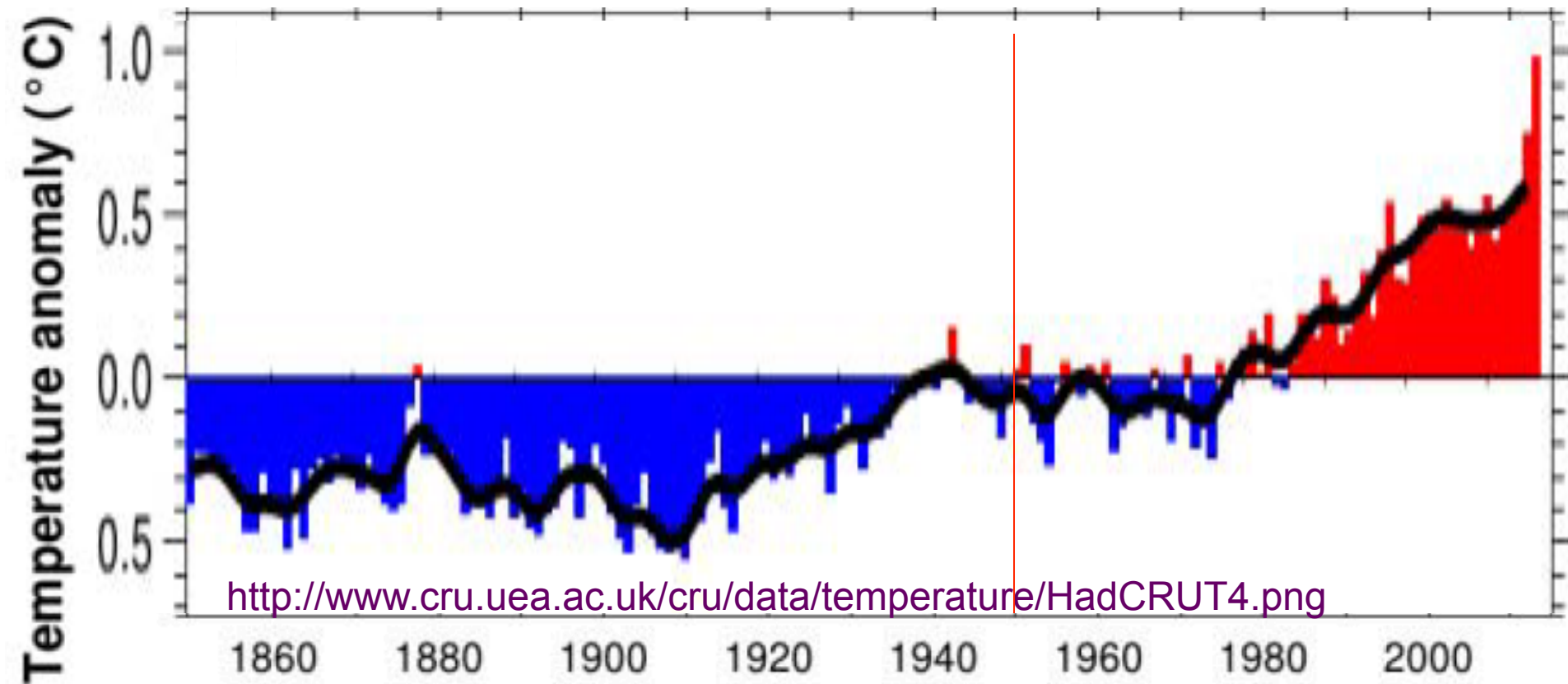
- Whether the warming since 1950 has been dominated by human causes
- How much the planet will warm in the 21st century
- Whether warming is ‘dangerous’
- Whether we can afford to radically reduce CO₂ emissions, and whether reduction will improve well-being



Are humans causing global warming?

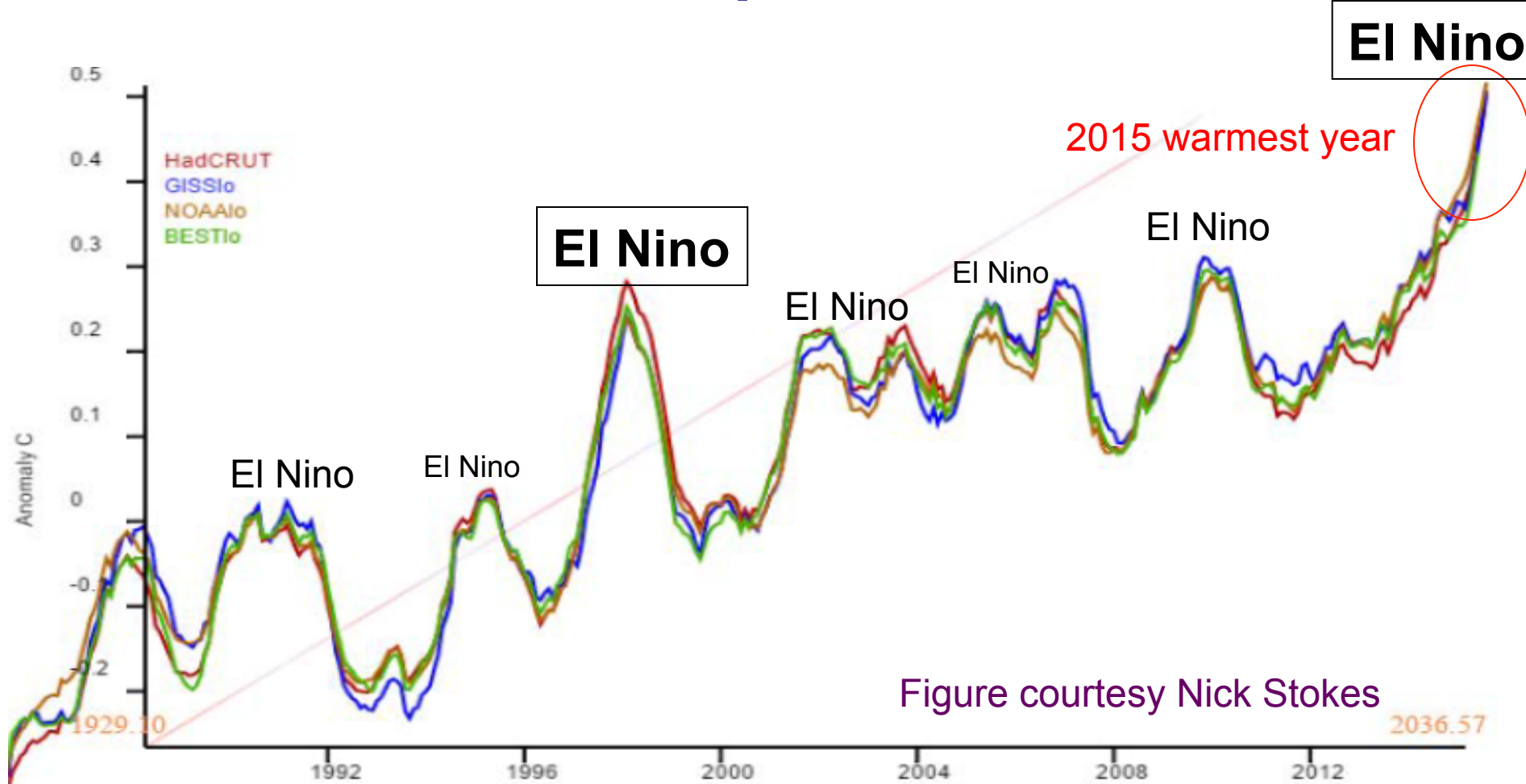


Global surface temperature anomaly



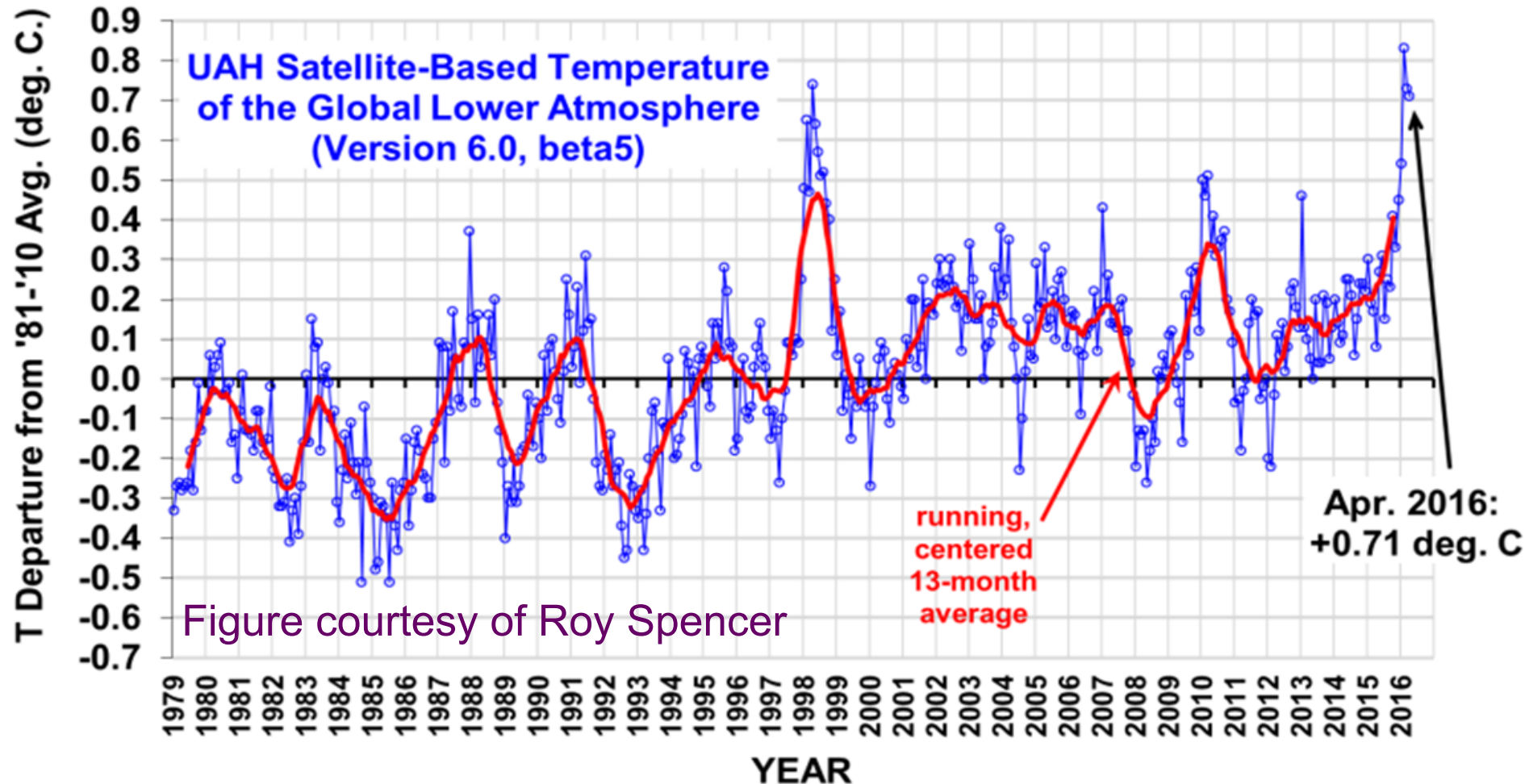
IPCC AR5: *It is **extremely likely** that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by [humans]. The best estimate of the human induced contribution is similar to the observed warming over this period.*

Global surface temperature anomalies



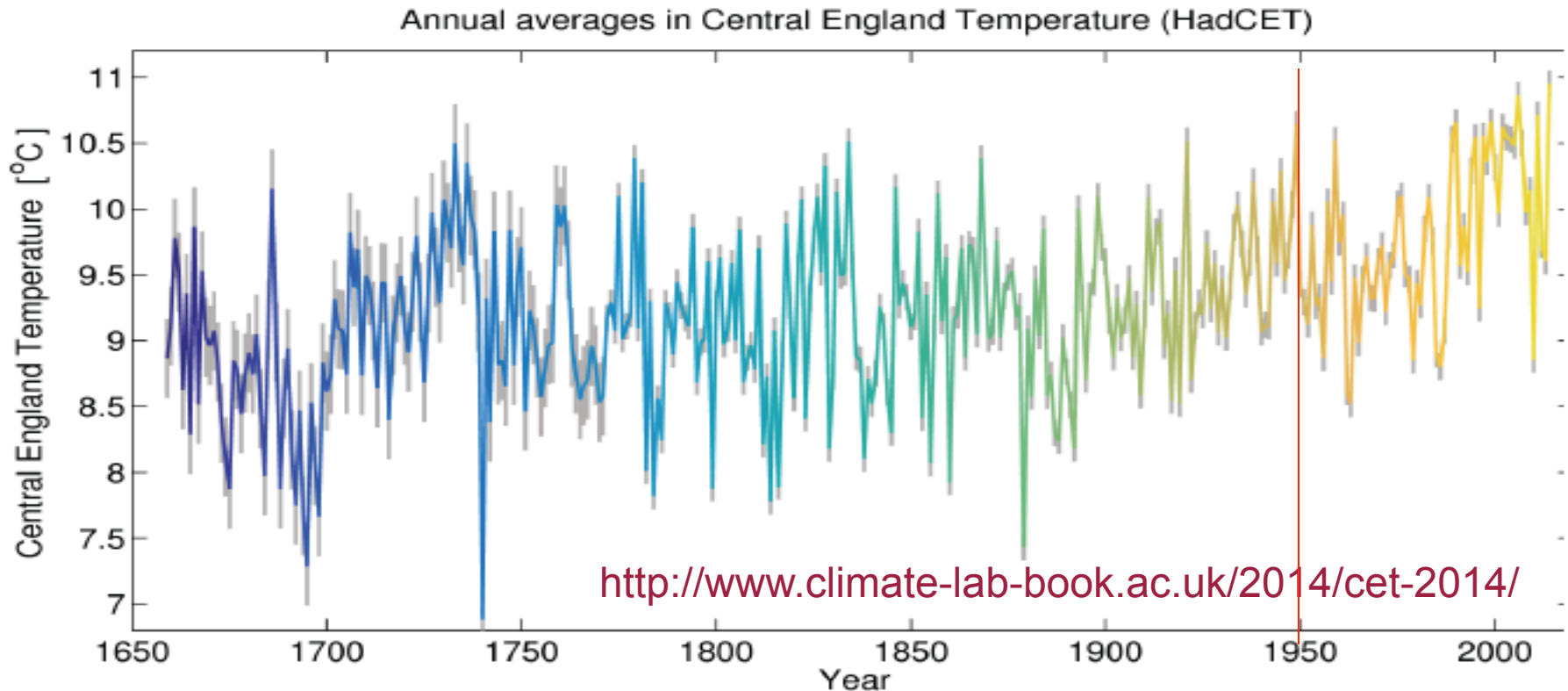
2015 was striking as 'warmest year,' since there had been very little warming after 1998

Lower atmospheric temperatures from satellite



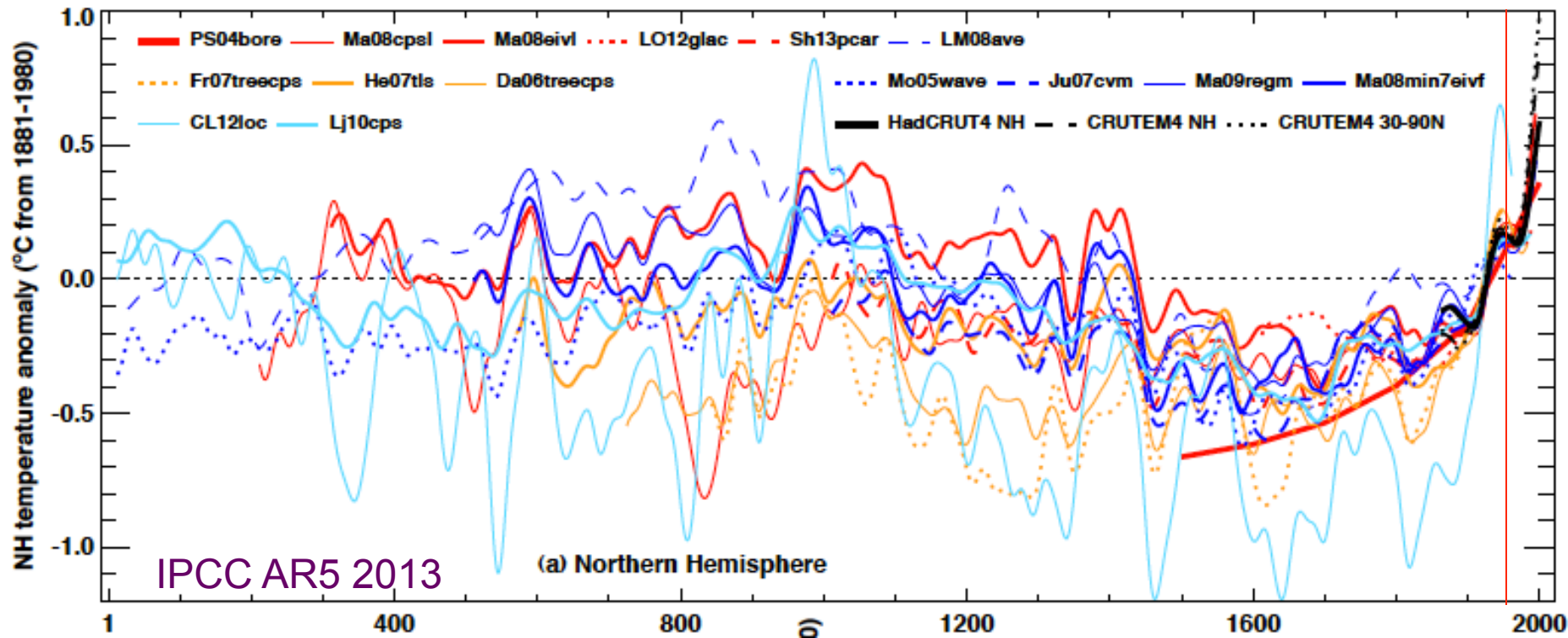
2015 was 3rd warmest year in the satellite data set, with a large spike for Feb 2016 from El Nino

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

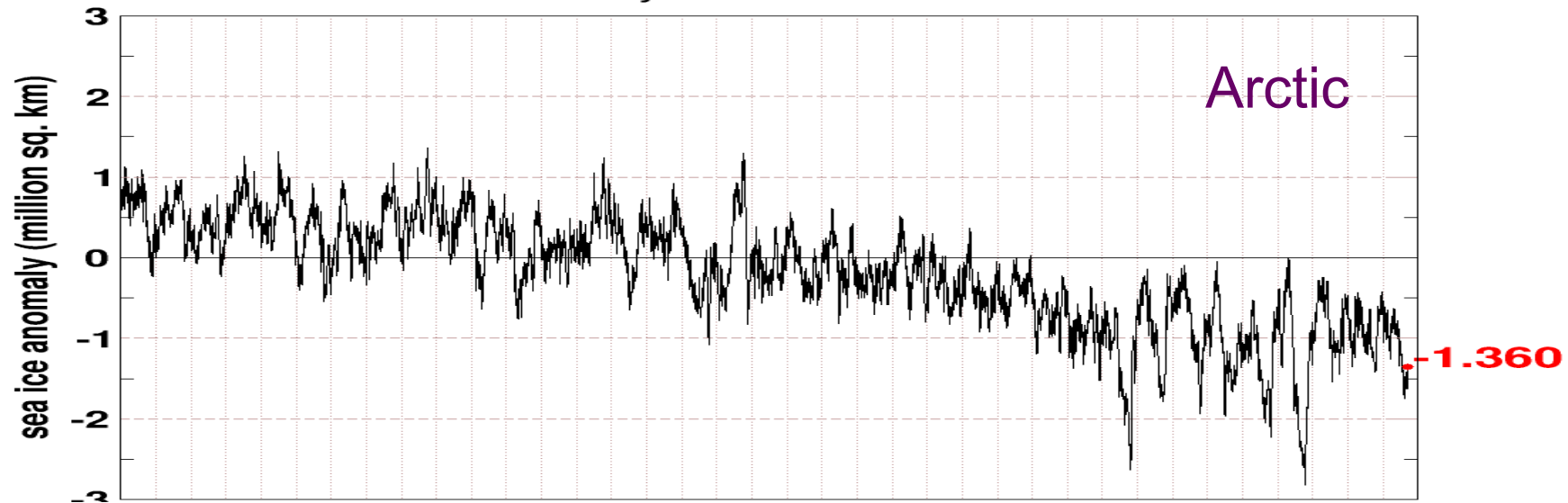
Northern Hemisphere paleoclimate surface temperature reconstructions



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

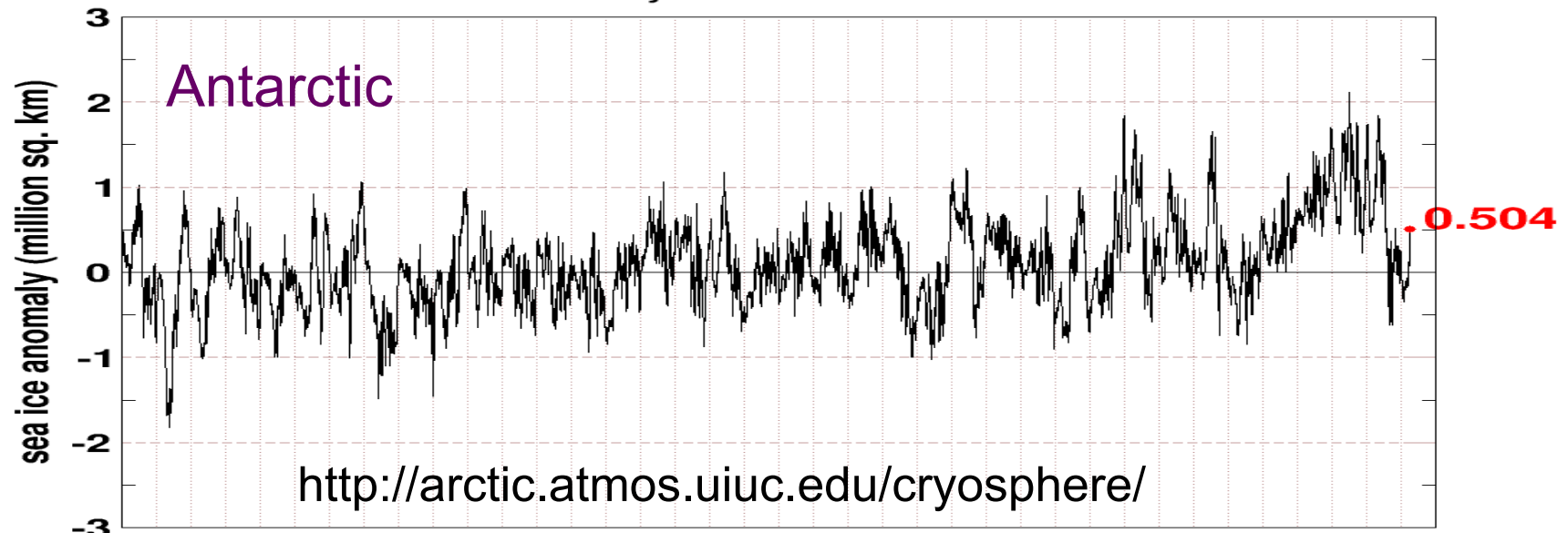
Northern Hemisphere Sea Ice Anomaly

Anomaly from 1979-2008 mean



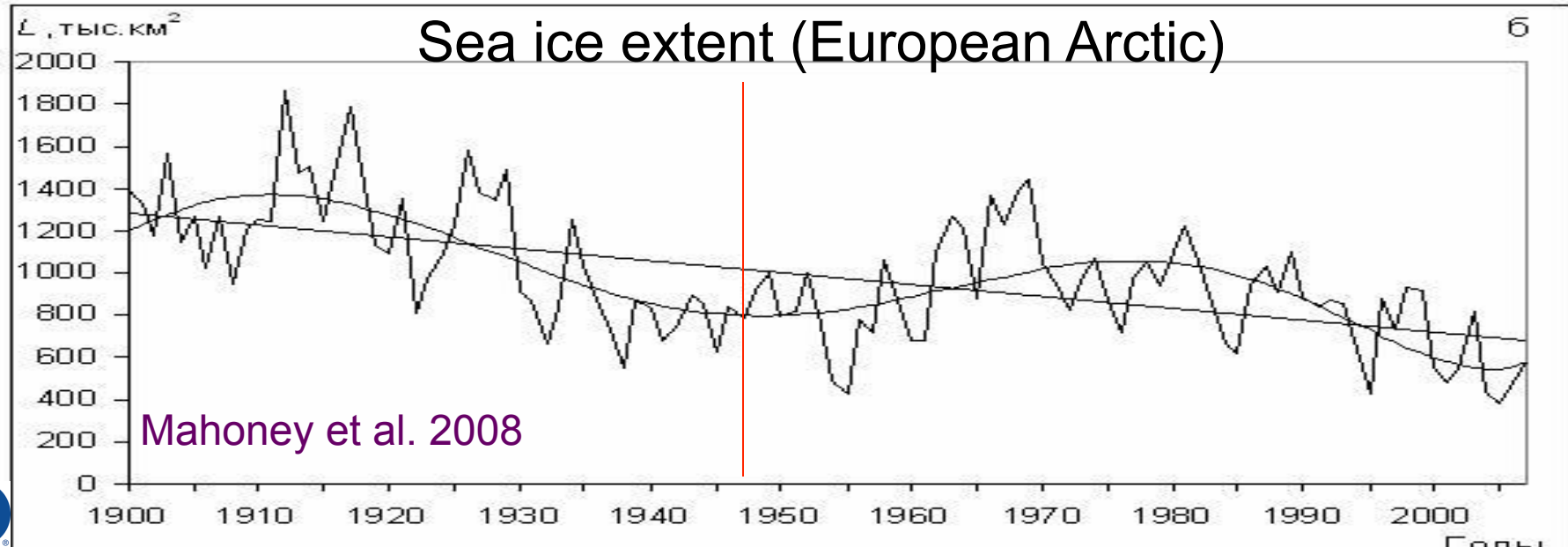
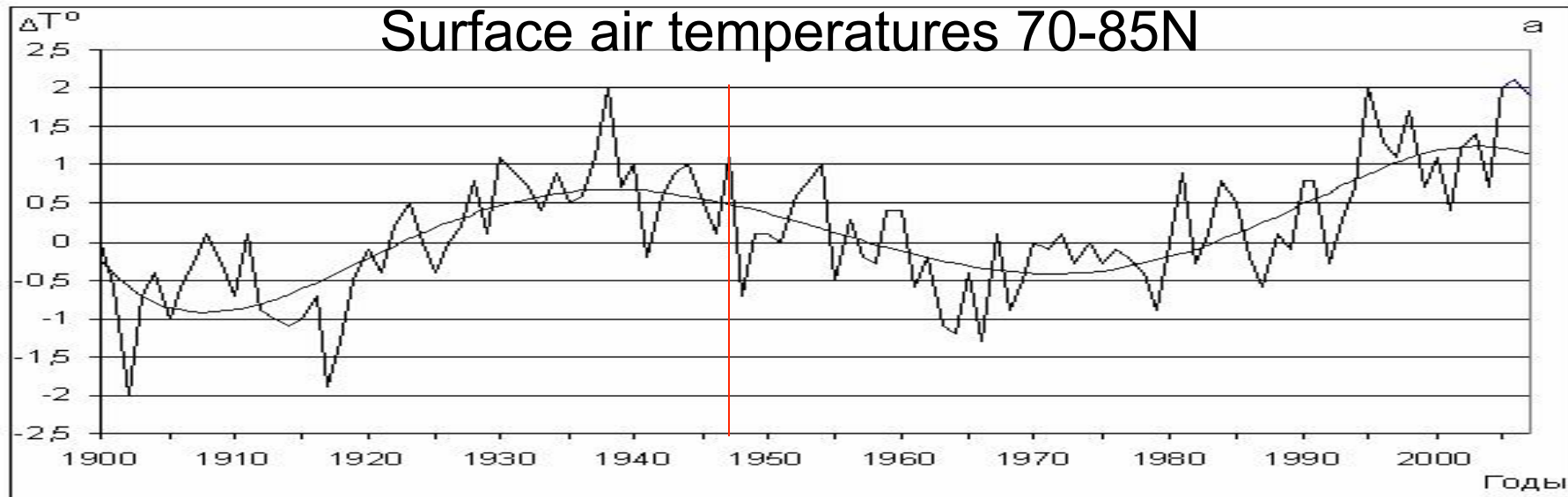
Southern Hemisphere Sea Ice Anomaly

Anomaly from 1979-2008 mean

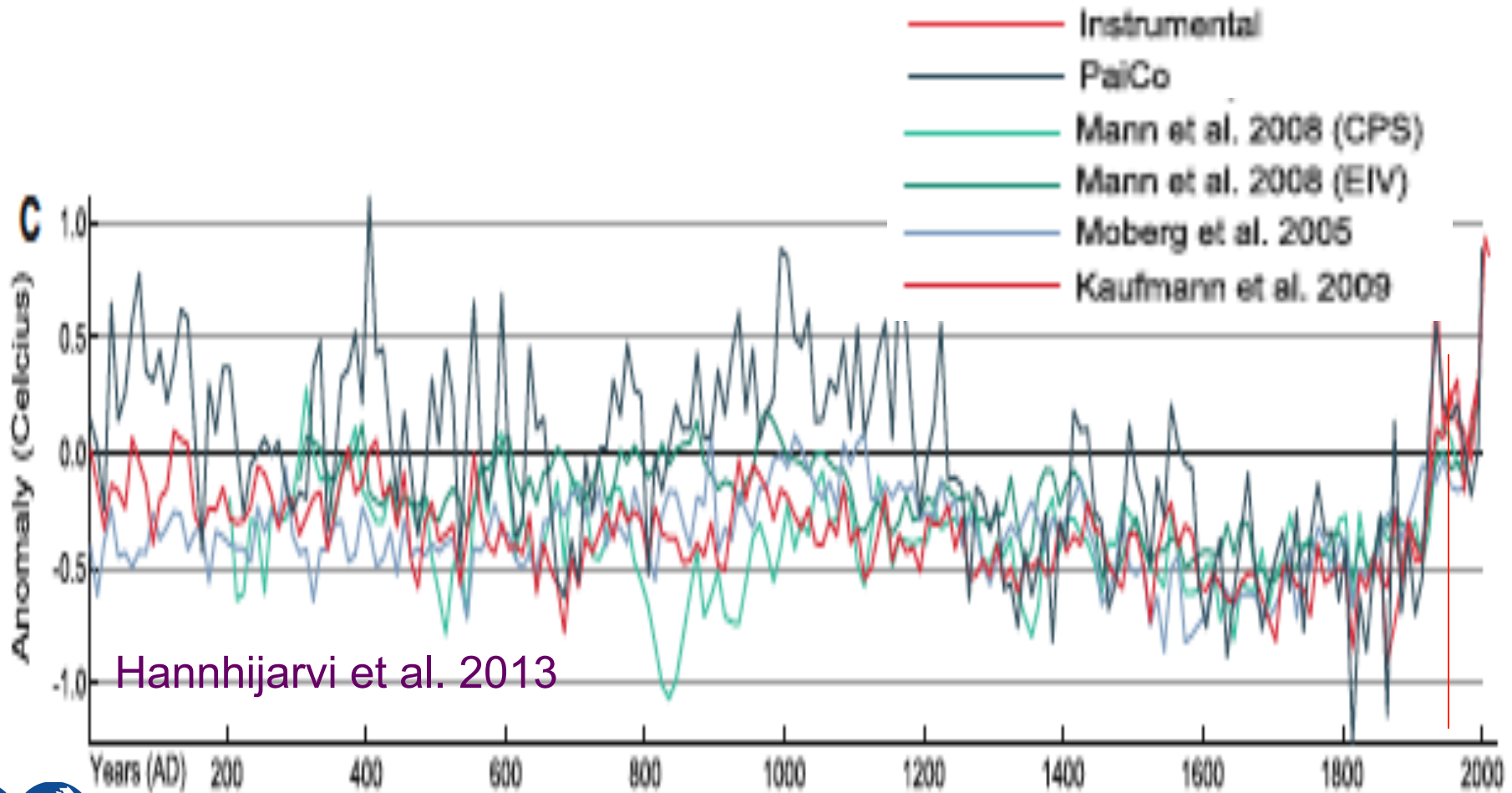


<http://arctic.atmos.uiuc.edu/cryosphere/>

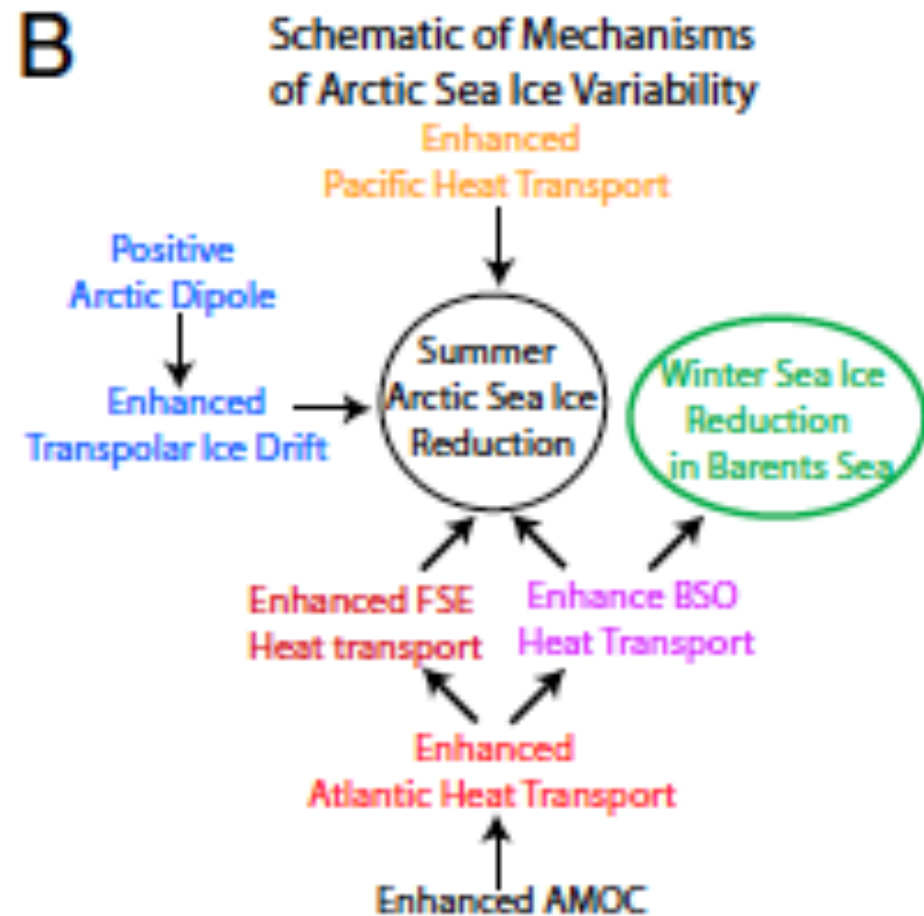
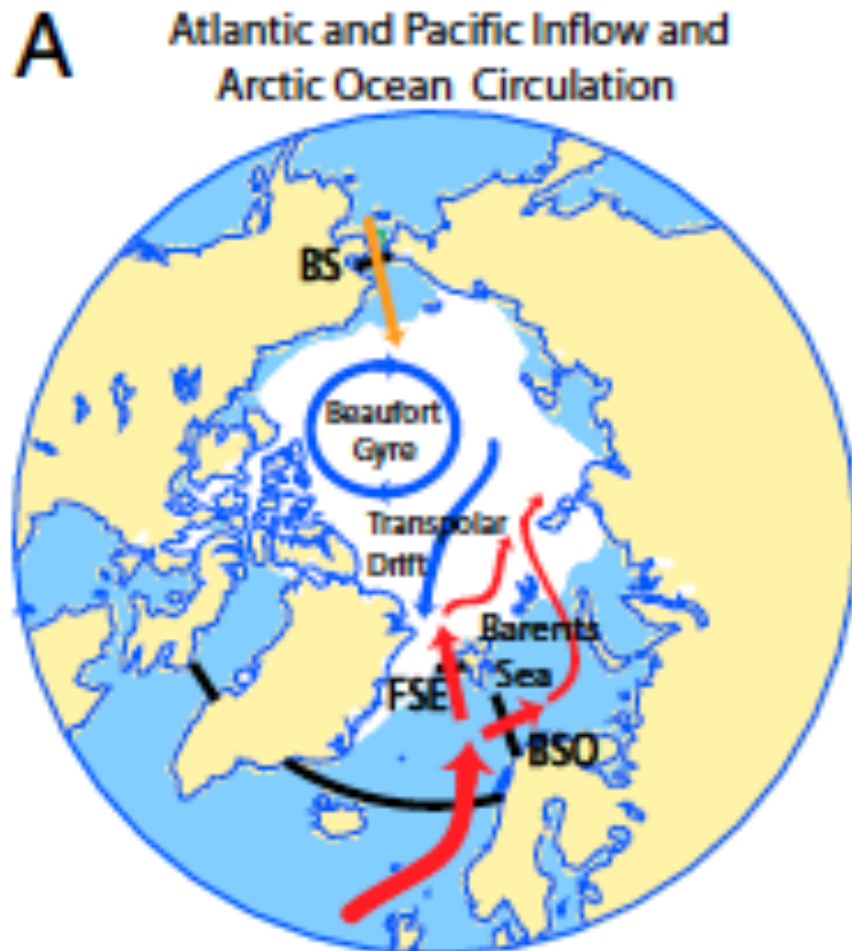
“Arctic temperature anomalies in the 1930s were apparently as large as those in the 1990s and 2000s. There is still considerable discussion of the ultimate causes of the warm anomalies in the 1920s and 1930s.” (IPCC AR5)



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

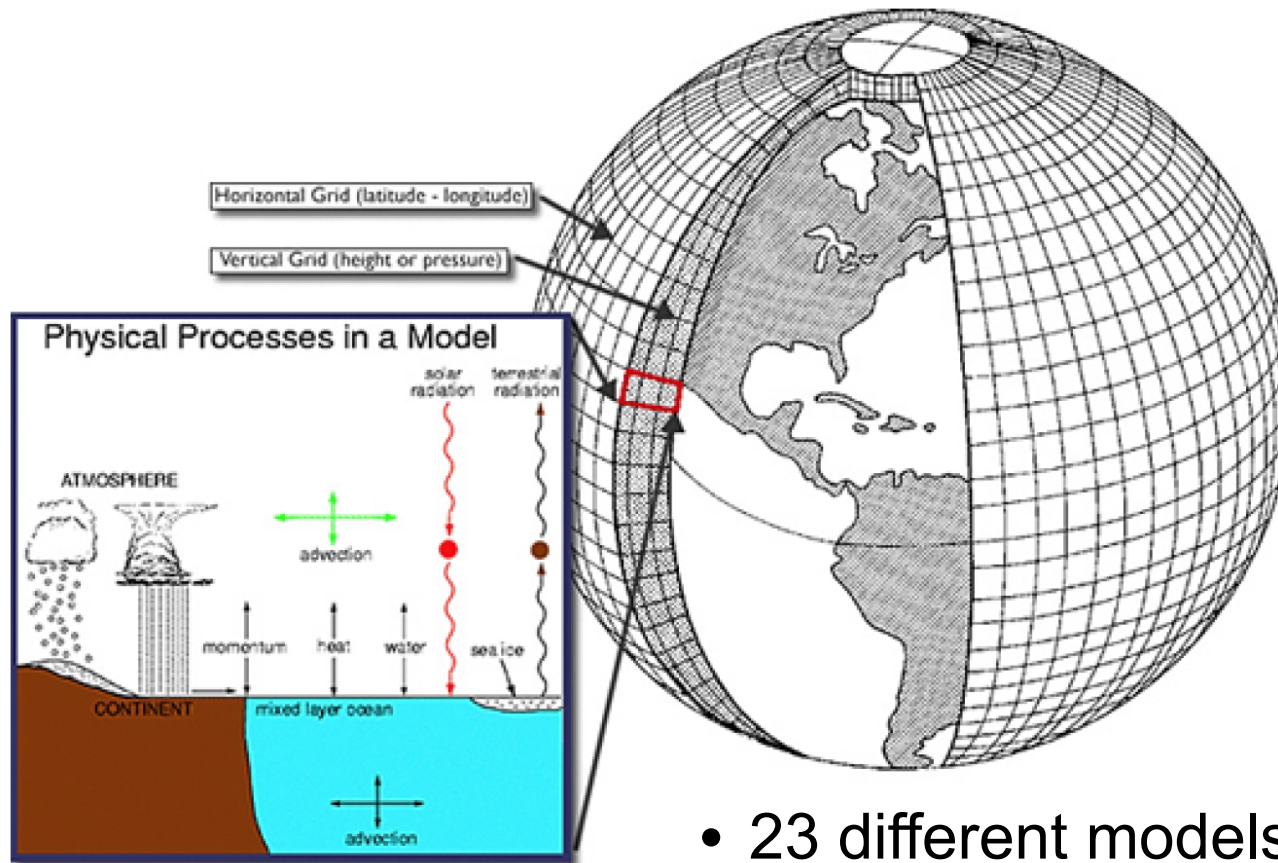
Surface
Reflectivity

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 is based on

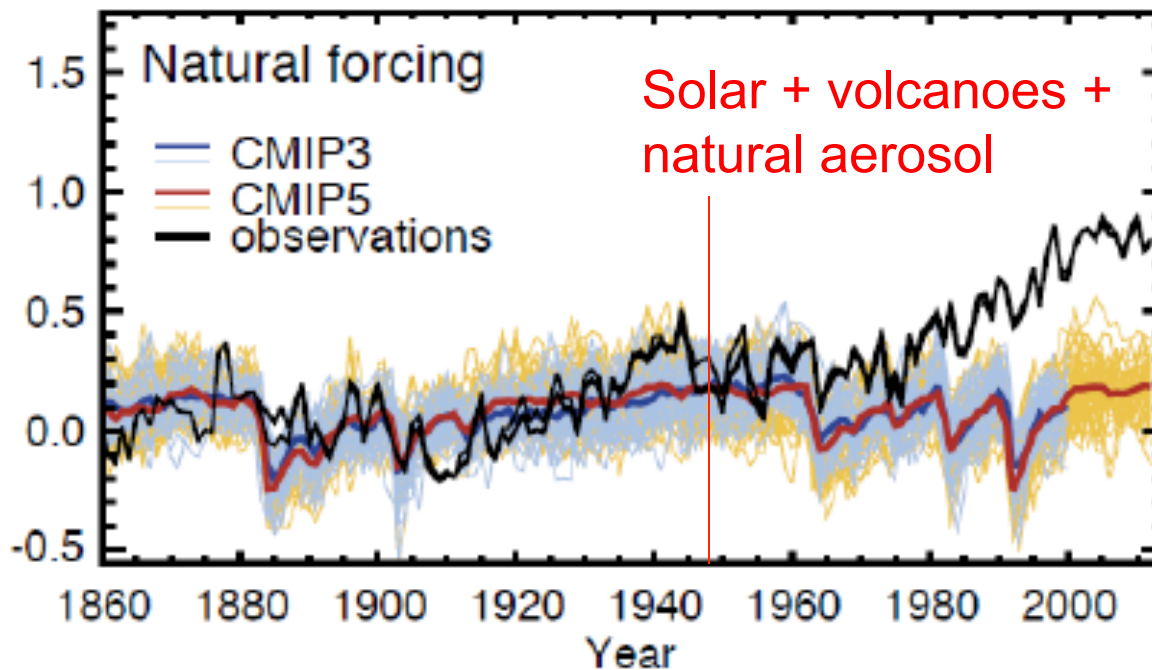
the laws of physics



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

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

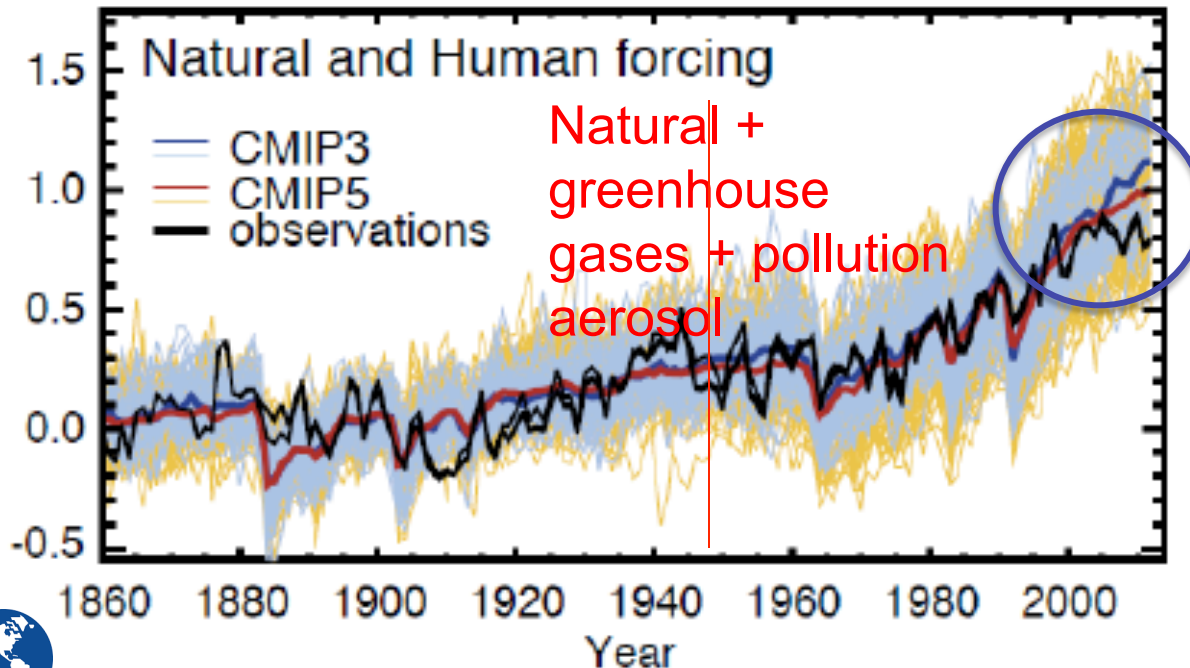
What has caused the warming?



Warming since 1950:
Human forcing

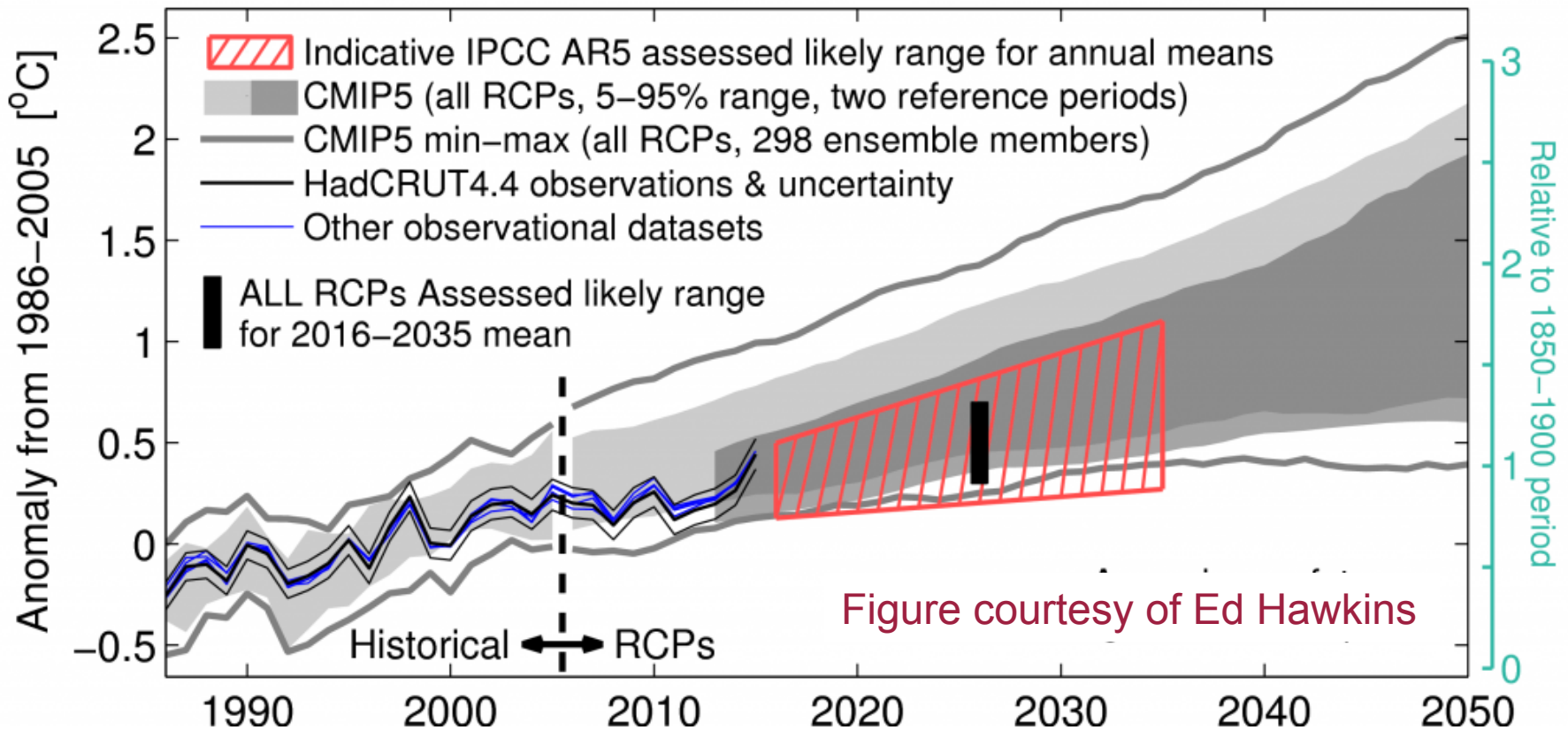
Warming 1910-1940:
Models produce slight warming due to reduced volcanic activity and small human effects

Cooling 1940-1975:
Not reproduced by the models



Growing divergence: models vs observations

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



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

Whither the climate of the 21st century?

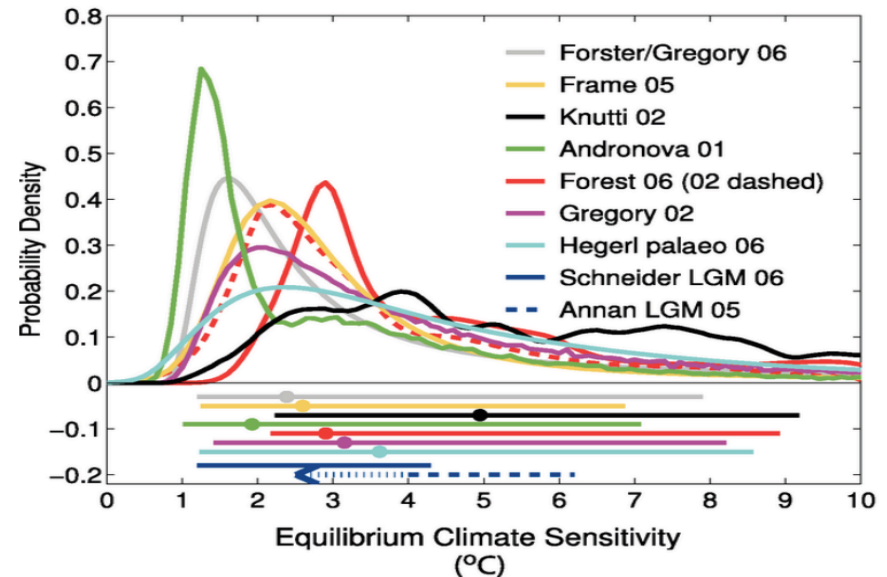


Equilibrium Climate Sensitivity

Definition: Global surface temperature change following a doubling of atmospheric CO₂ concentration

Determined from:

- global climate models
- historical observations
- paleoclimate reconstructions



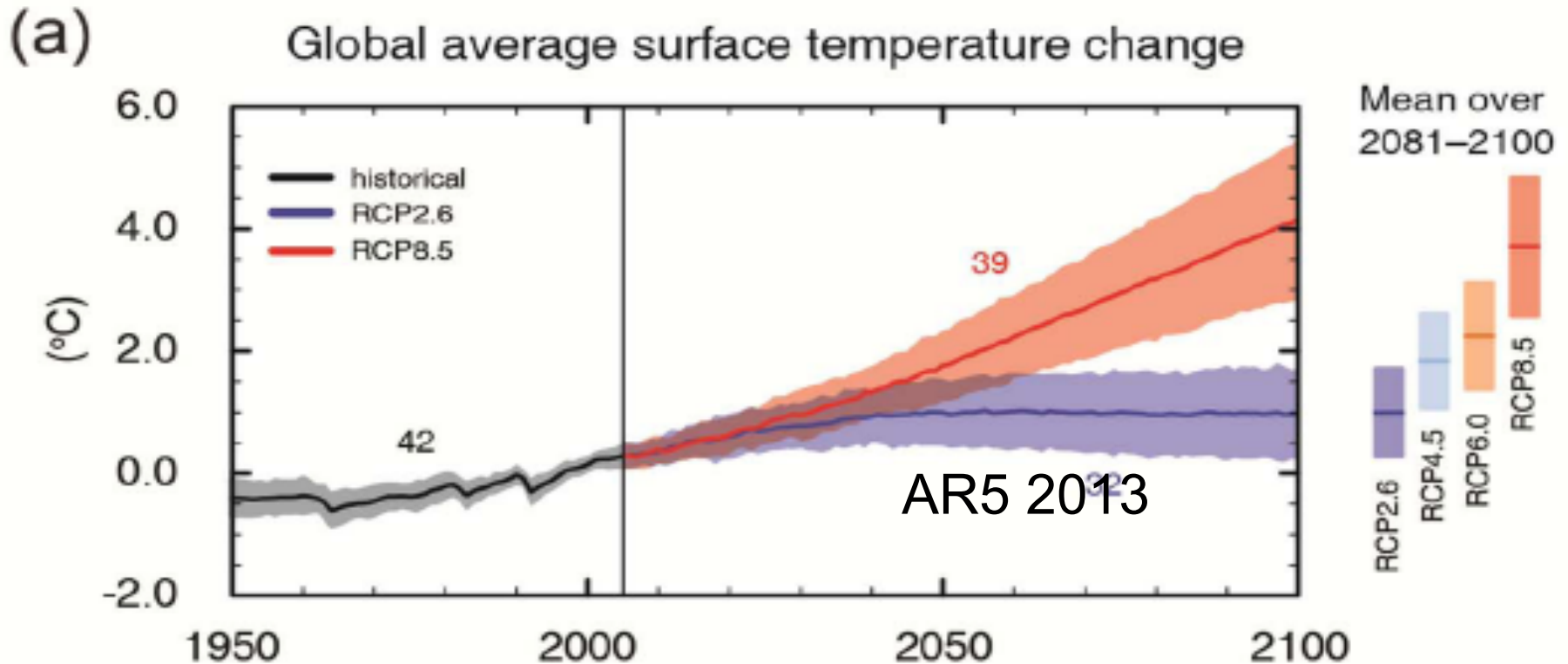
Equilibrium Climate Sensitivity (°C)

	Median	5 th pctl	95 th pctl
IPCC AR4 (2007)	3.0	1.5	-
IPCC AR5 (2013)	-	1.0	6.0
Climate models	3.2	2.1	4.7
Observations	1.6	1.1	4.1
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

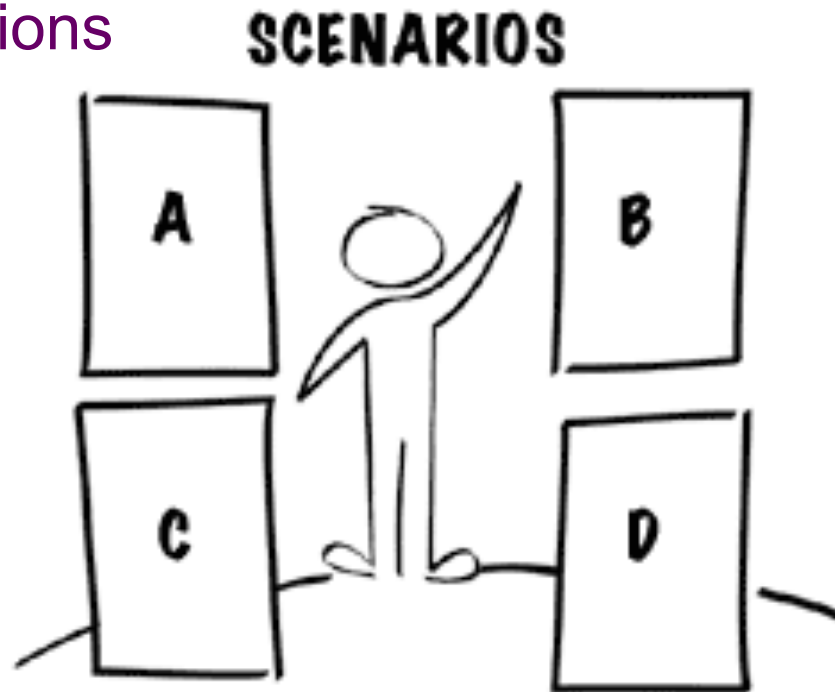
Long range
ocean oscillations

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 will continue at least another decade (into the 2030's?)
- Climate models are too sensitive to human forcing; 21st 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?

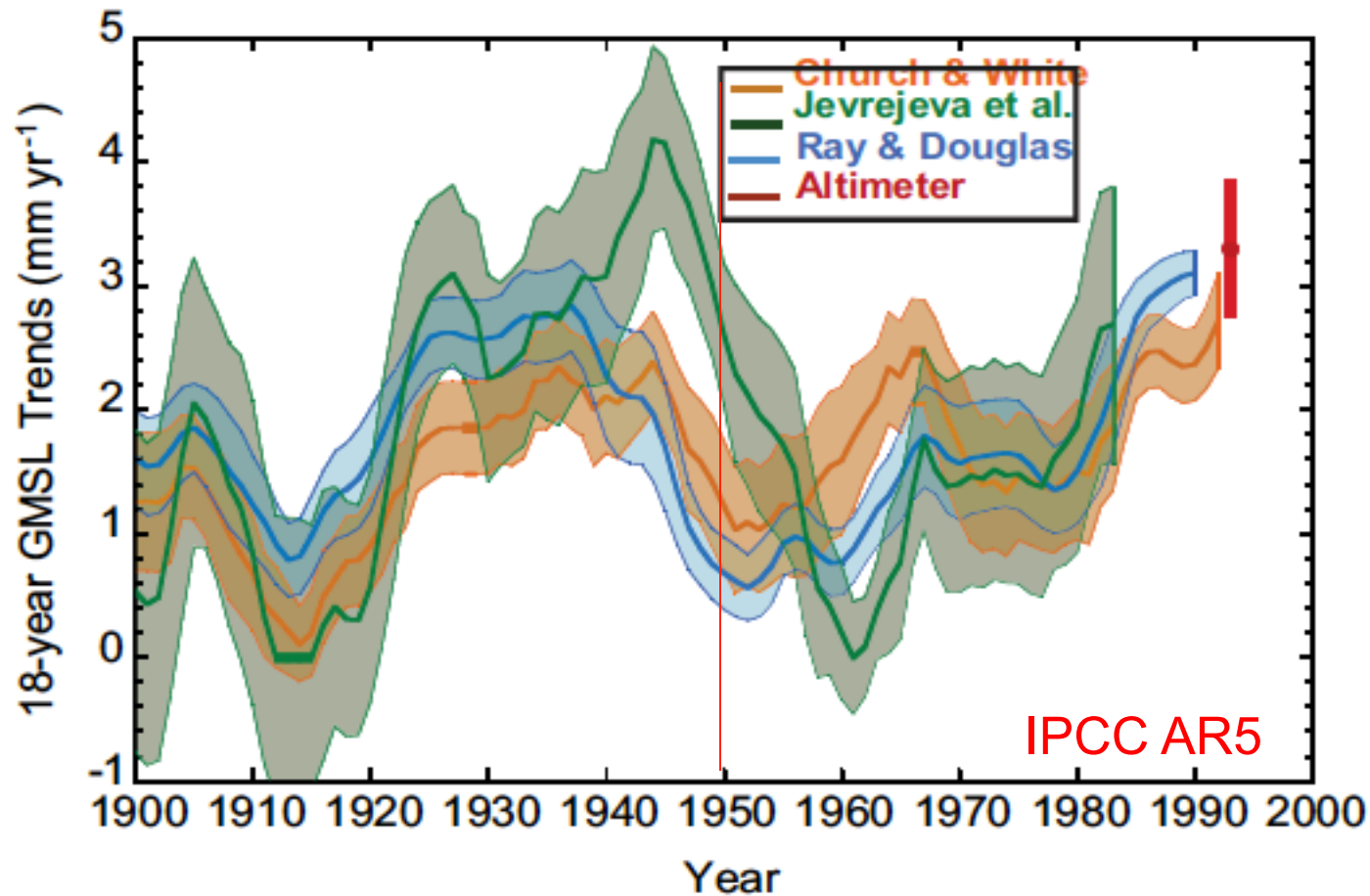
The UNFCCC has defined 'dangerous' as 2°C post industrial warming; we have already warmed more than 0.9°C

When we will reach 2°C depends not only on ECS, but also on natural climate variability

Efforts to redefine 'dangerous' as 1.5°C post industrial warming are underway

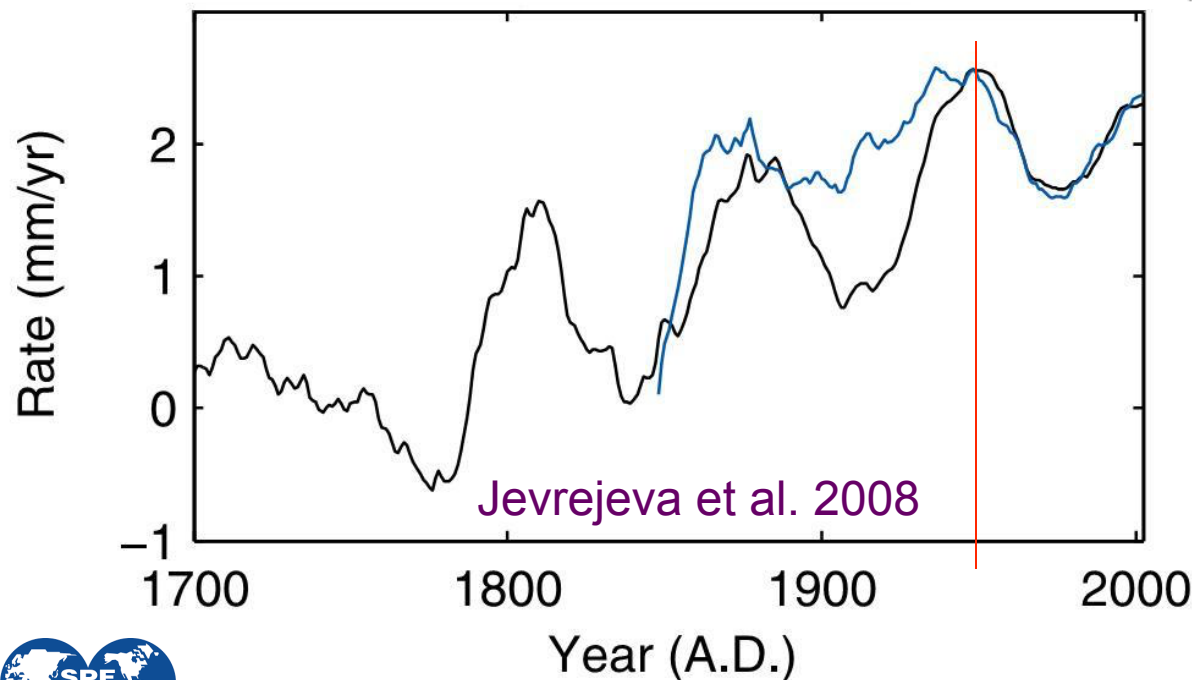
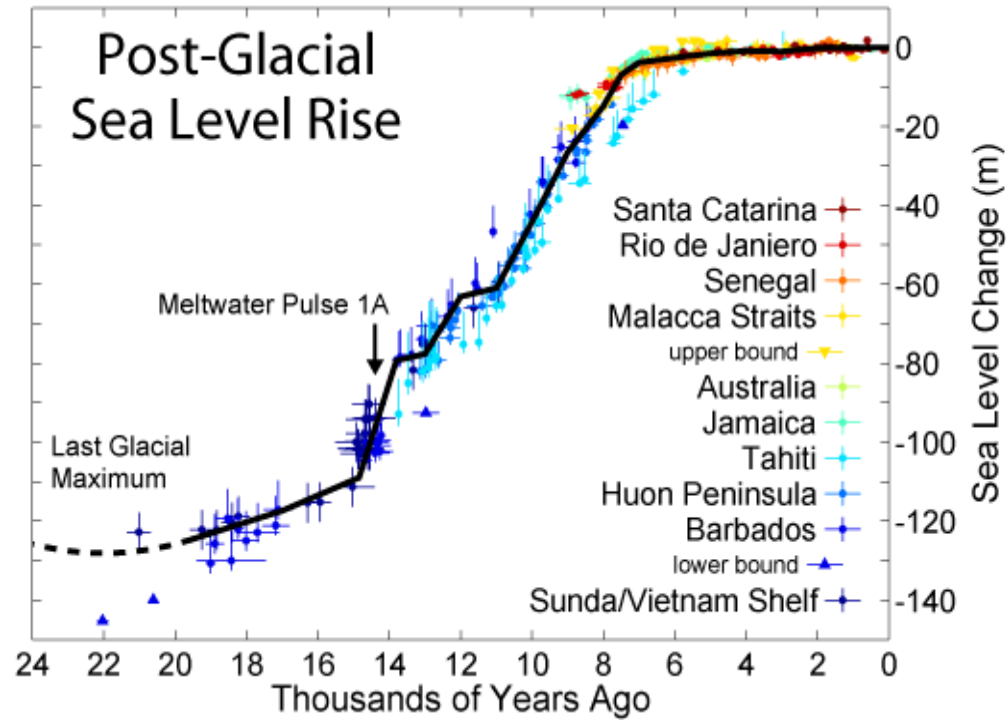


Is the IPCC's sea level rise conclusion justified?



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)”

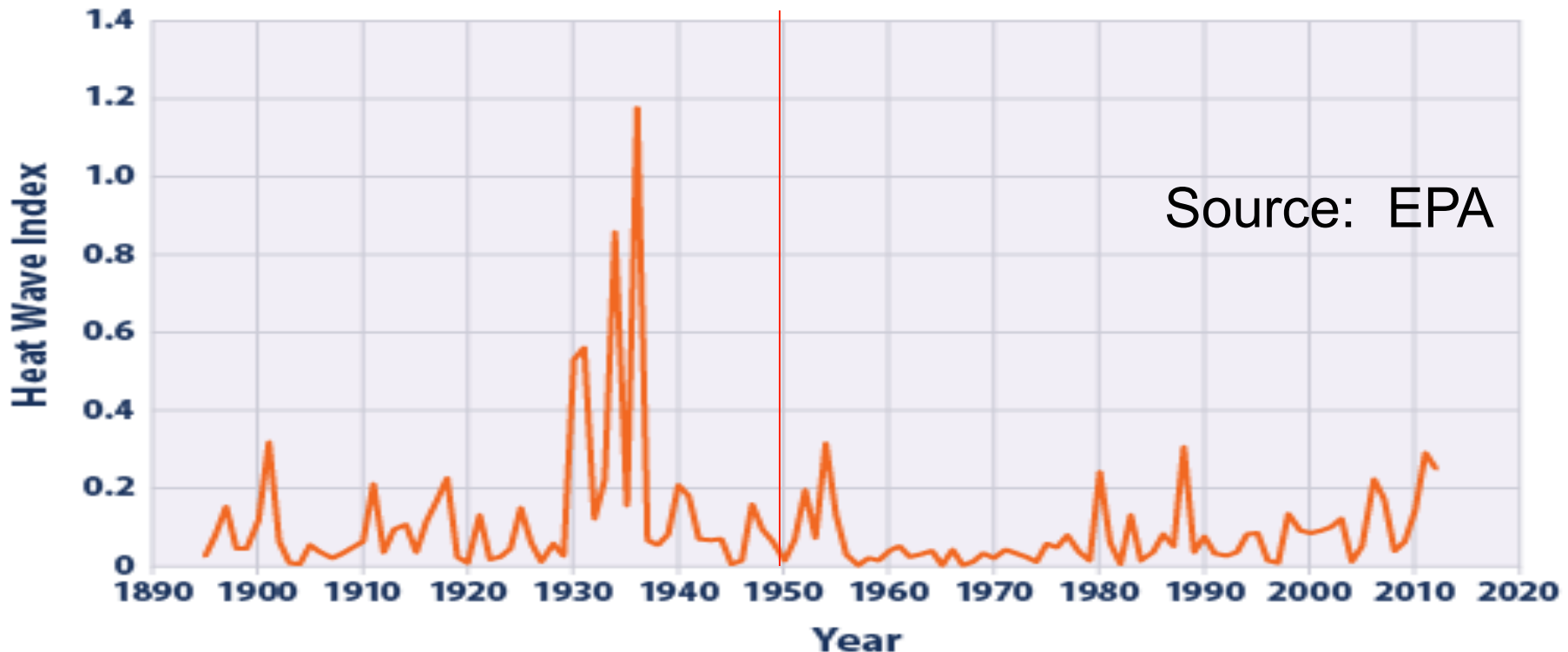
Sea level has been rising since the end of the last ice age



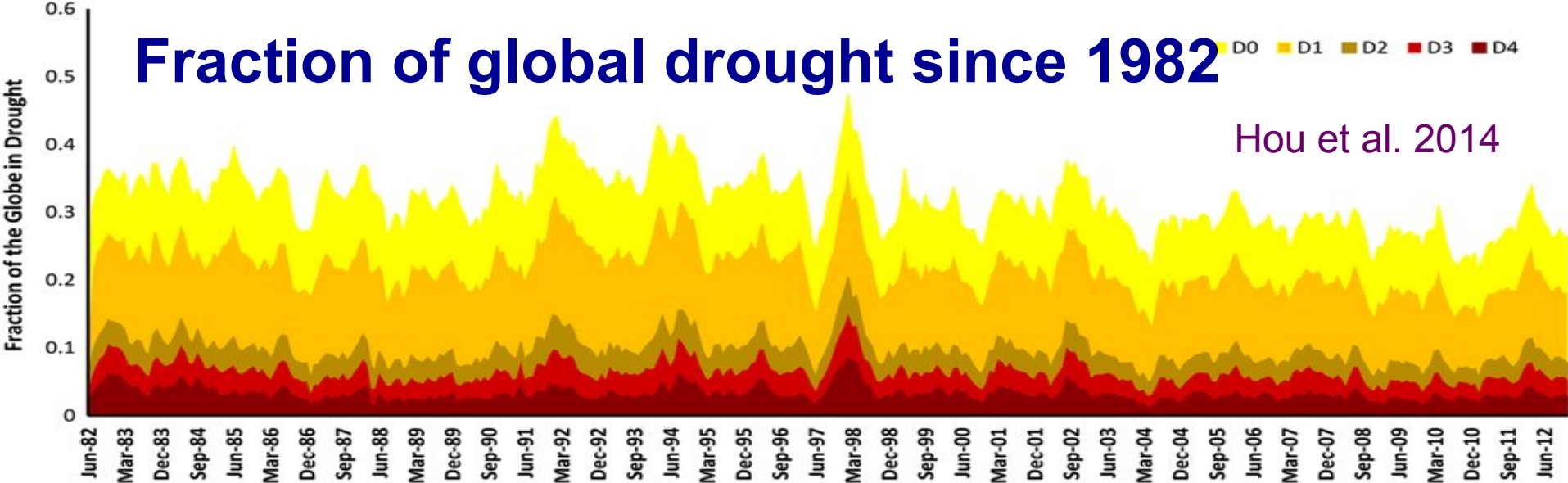
Recent sea level rise acceleration started over 200 years ago

US Annual Heat Wave Index, 1895-2012

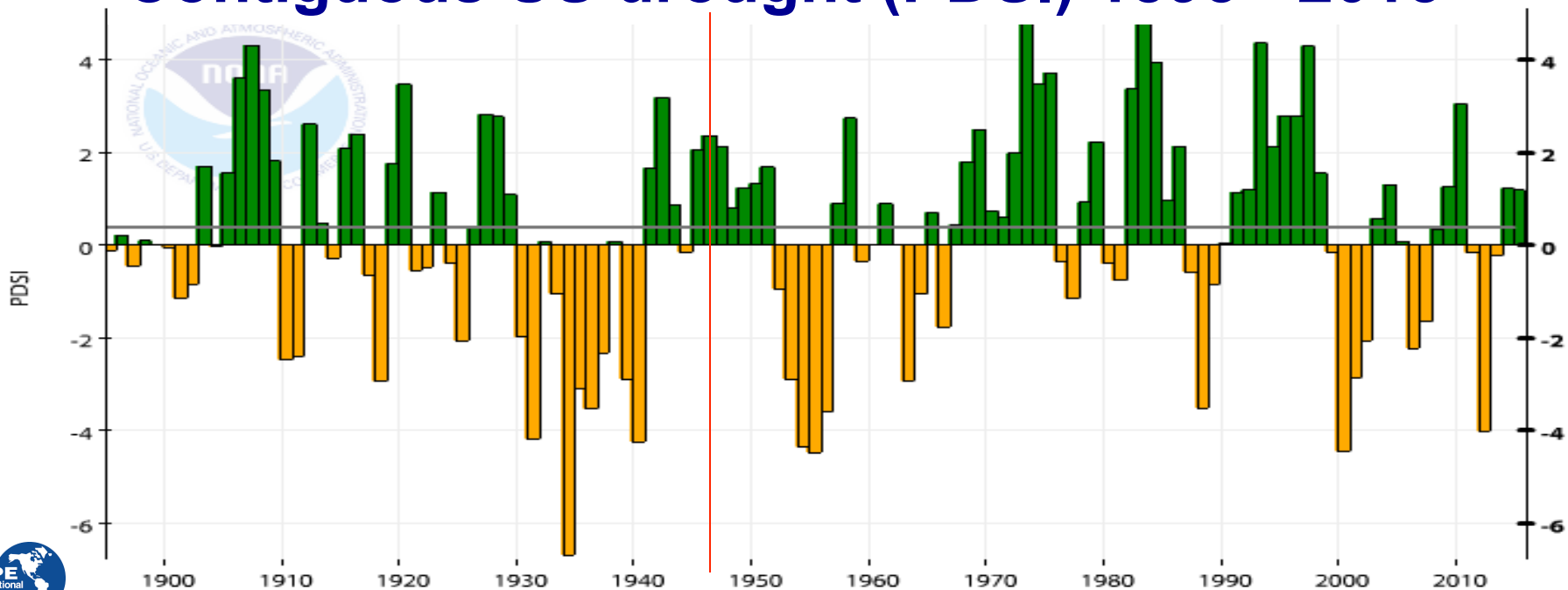
Figure 1. U.S. Annual Heat Wave Index, 1895–2012



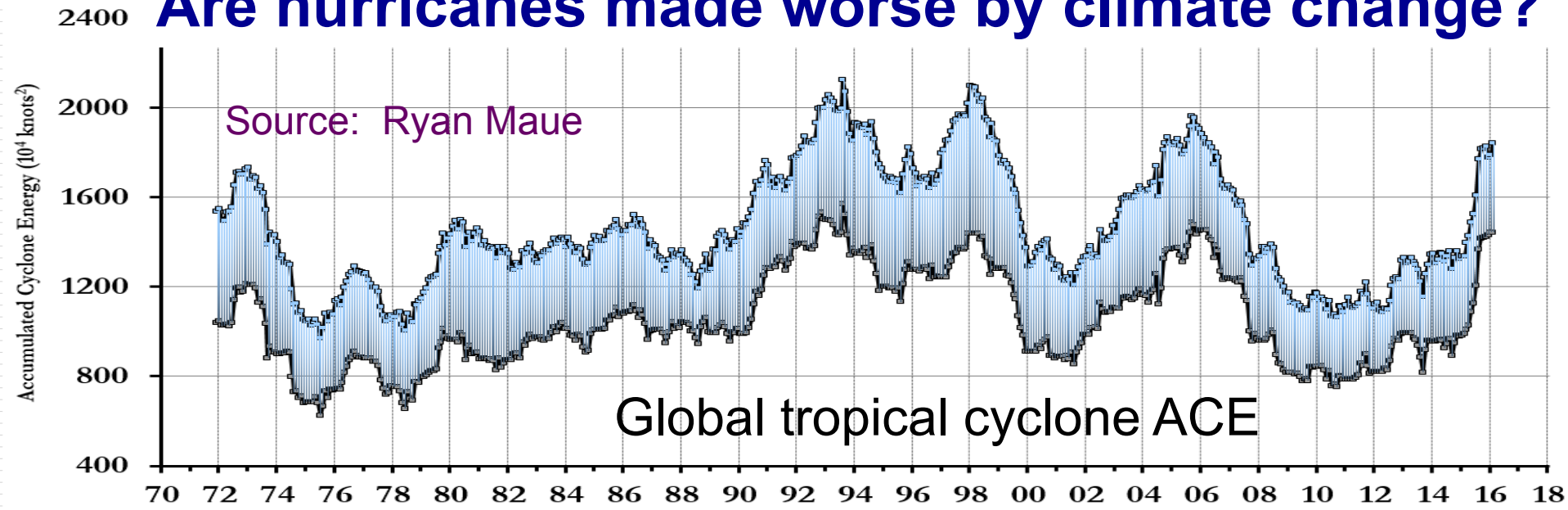
“It is *likely* that the frequency of heat waves has increased in large parts of Europe, Asia and Australia”. (since 1950)
IPCC AR5



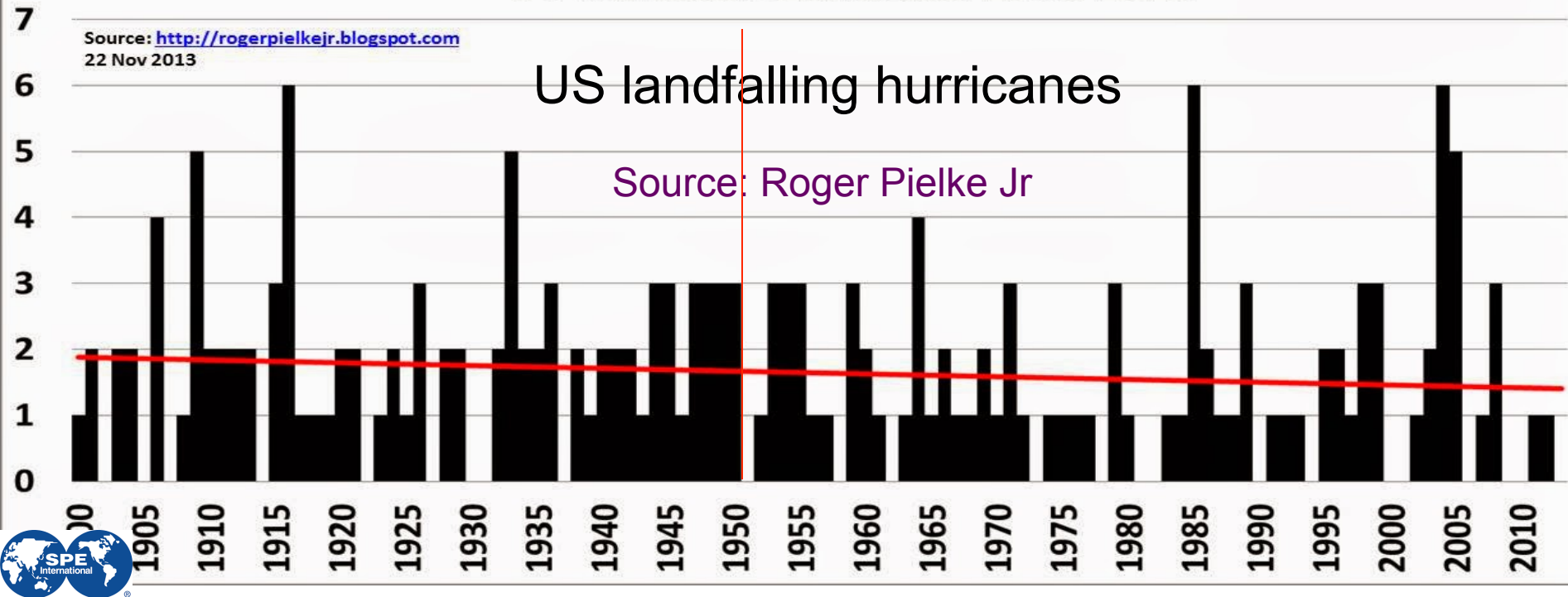
Contiguous US drought (PDSI) 1895 - 2015



Are hurricanes made worse by climate change?

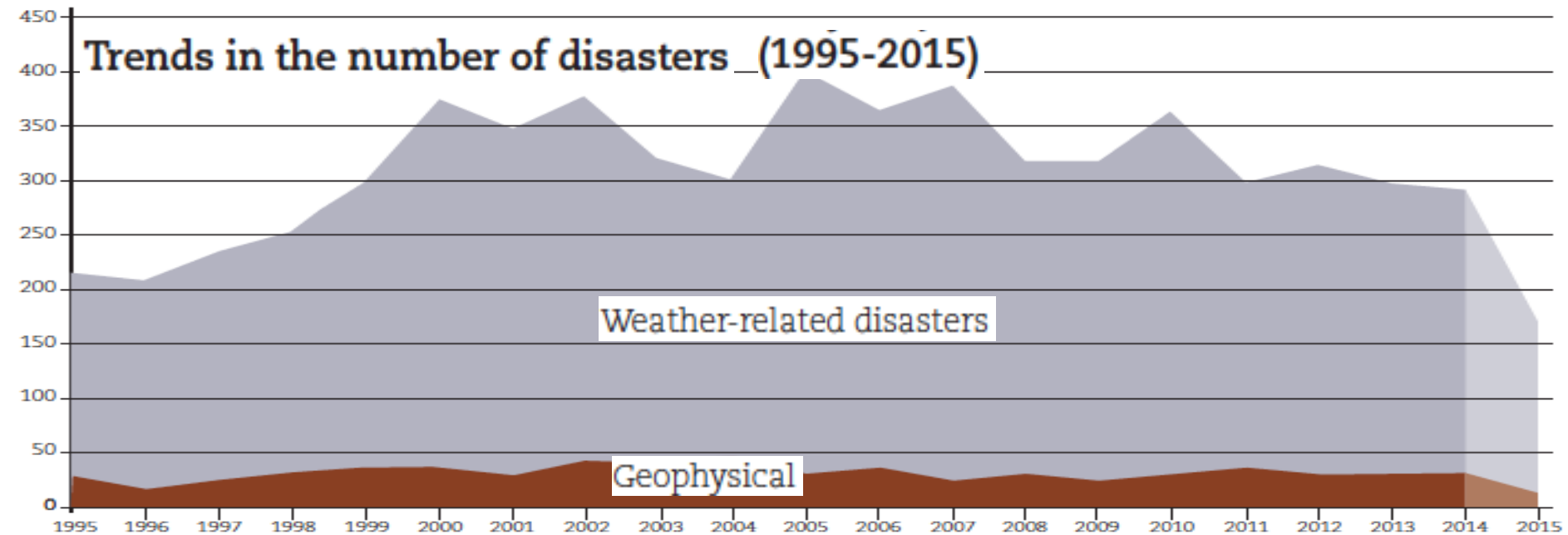


US Hurricane Landfalls: 1900-2013



Human Cost of Weather Related Disasters - UNISDR

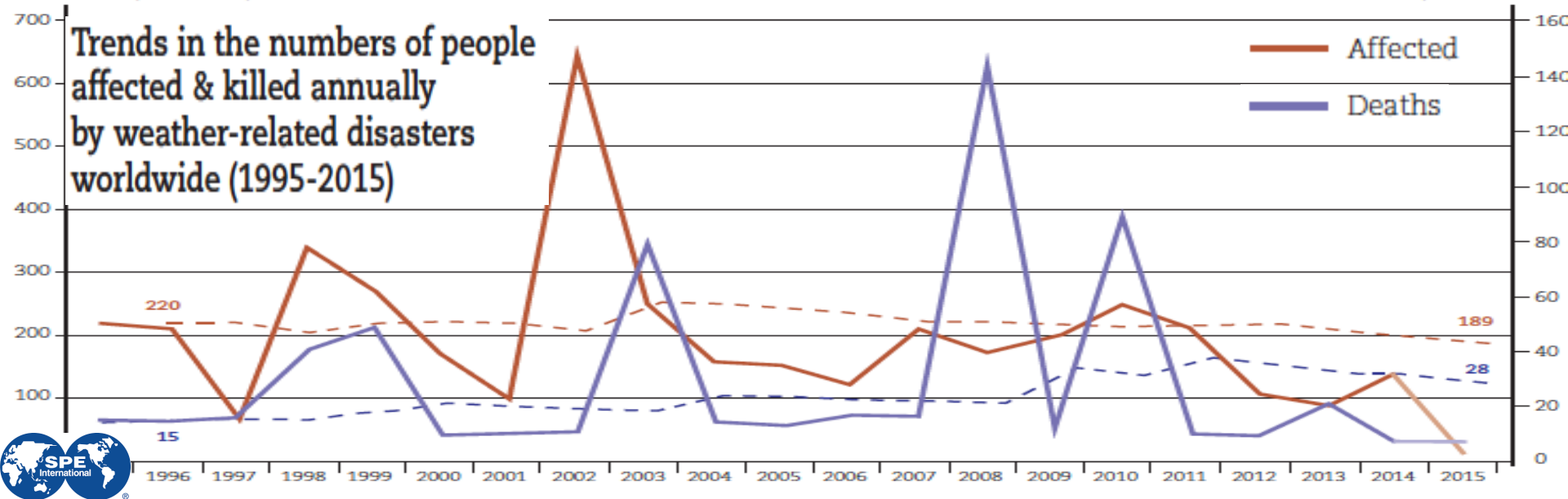
Trends in the number of disasters (1995-2015)



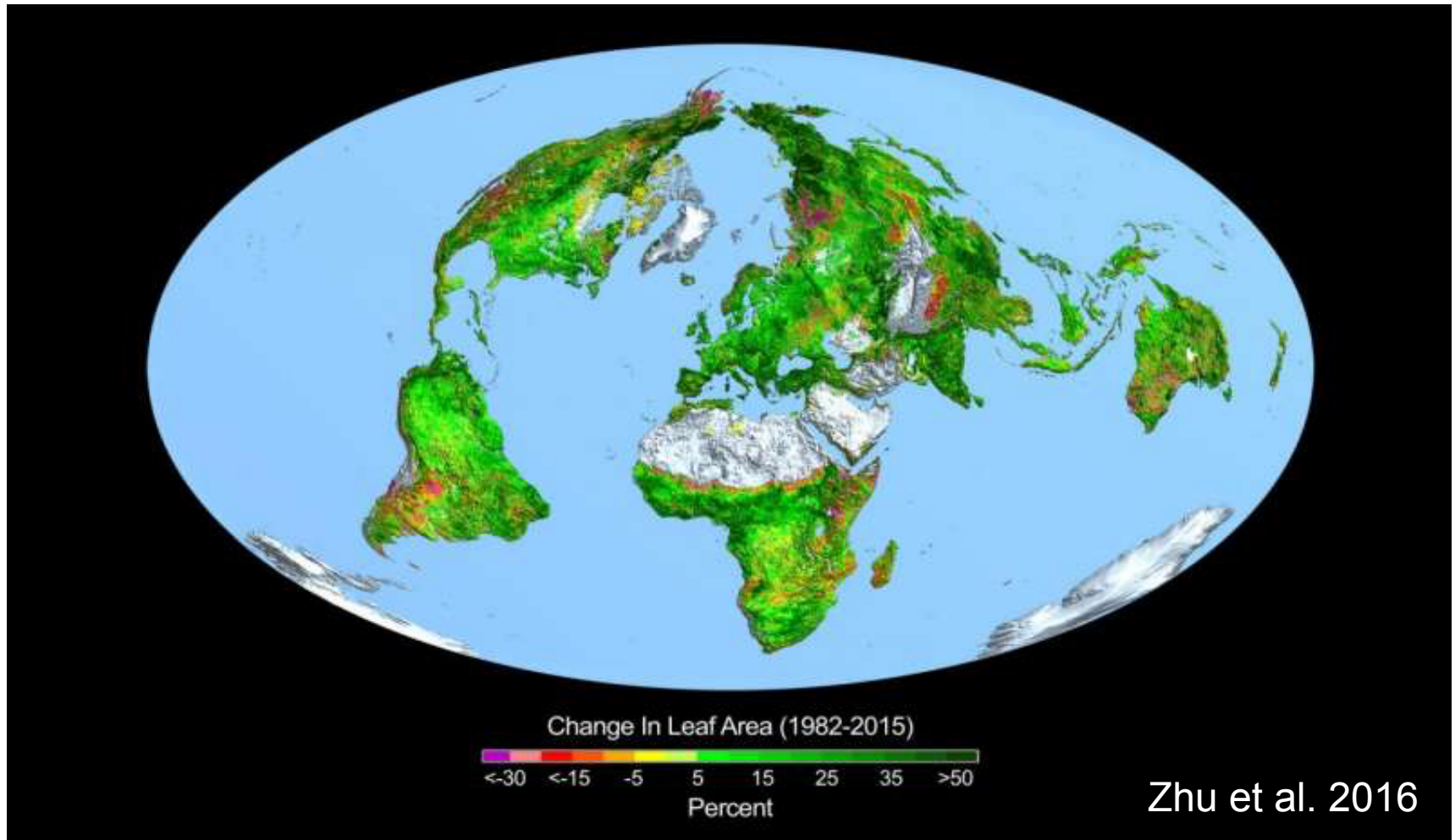
Number of people affected (Millions)

Number of deaths (Thousands)

Trends in the numbers of people affected & killed annually by weather-related disasters worldwide (1995-2015)



Rise in CO₂ greening Earth since 1982



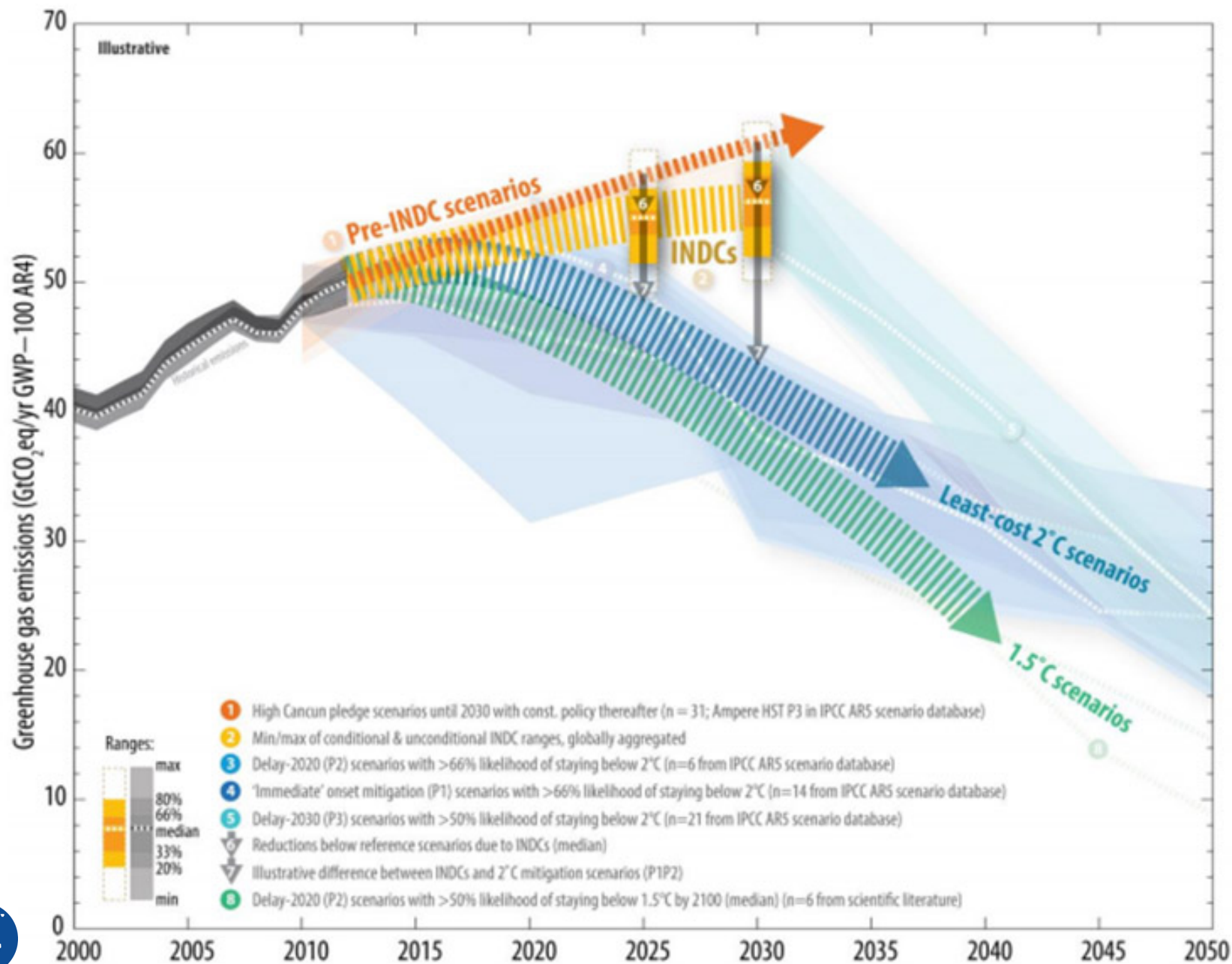
Greening over 25-50% of global vegetated area; 4% browning
CO₂ fertilization effects explain 70% of the greening trend

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 21st 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 CO₂ emissions by 2050 would have small impact on temperatures in the 21st 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 and scalable to substantially reduce CO₂ emissions from power, transportation, agriculture, cement on the timescale of a few decades

Confounding factors:

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

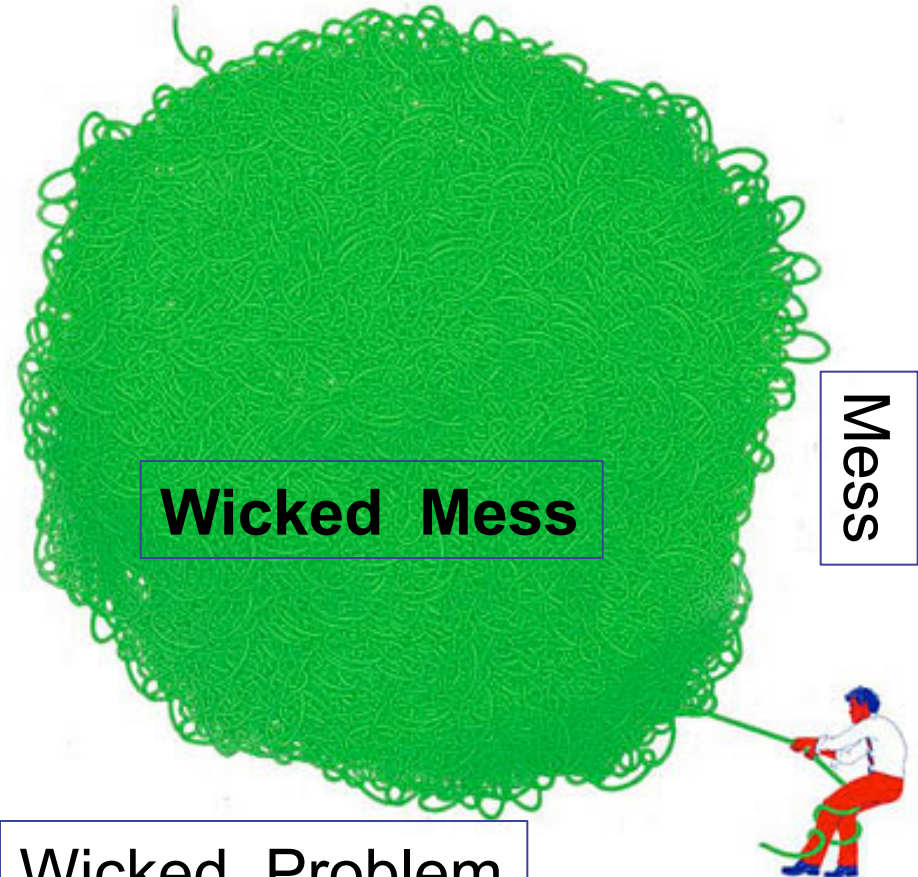
Tame Problem



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 Mess

Mess

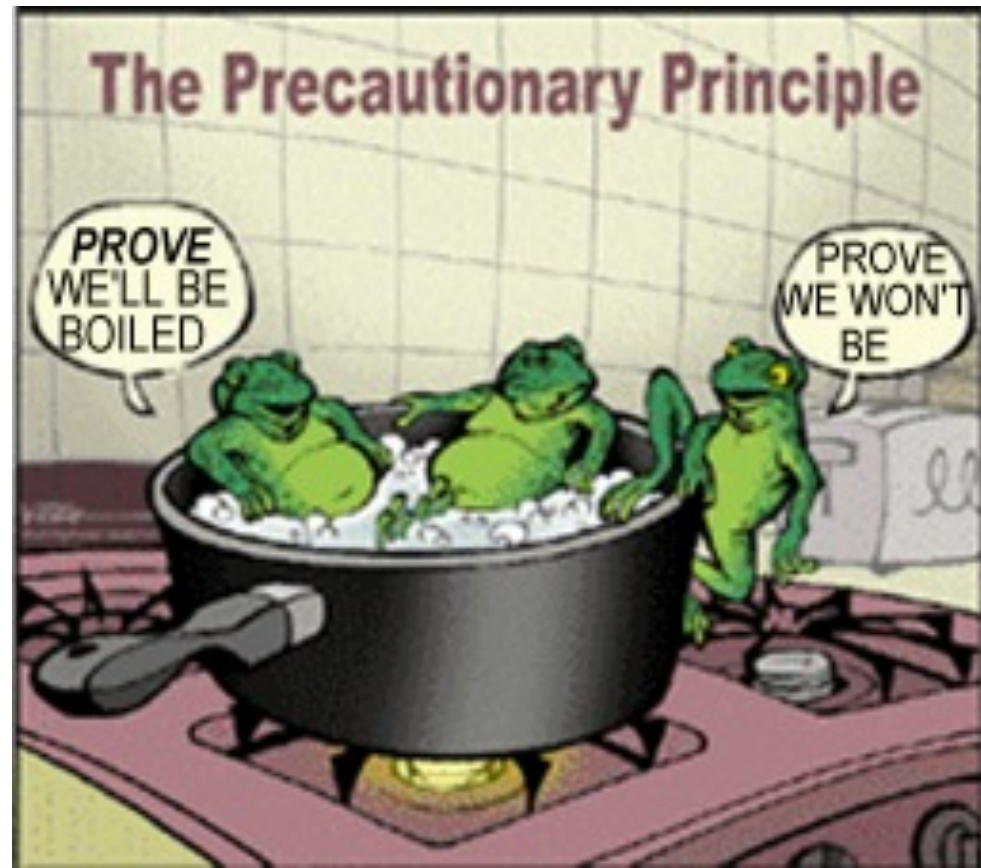
Wicked Problem

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

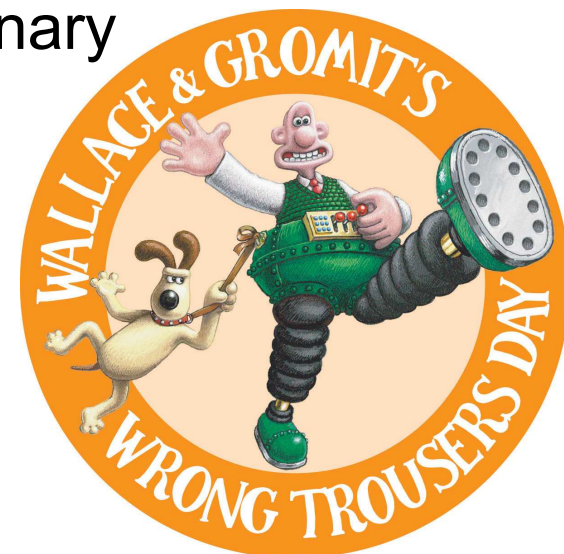
Stabilization targets are set at the lowest critical threshold value



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
- Delay, gather more info
- Target critical uncertainties
- 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

Outlast

Better than
dead

Try for personal
survival: group
or nation

Meet basic
Needs

Sustainable

Maintain

Endure in a
stable world

Able to maintain
at a given rate,
level over time

Mitigate damage
Sacrifice,
austerity

Obligations

Resilience

Bounce back

Recover quickly
from difficult
conditions

Survive longer in
changing world

Adaptation,
redundancy

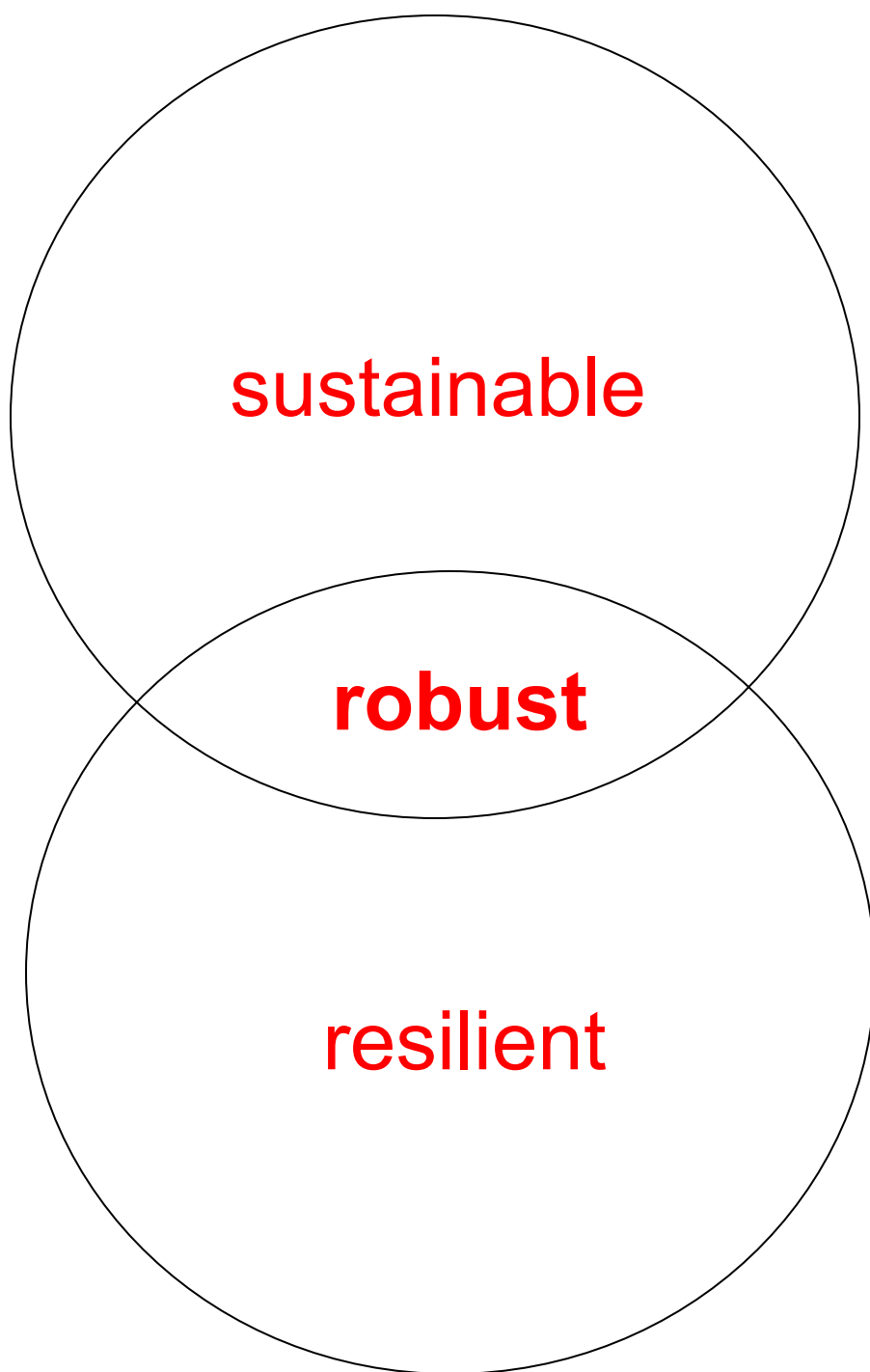
Thrivability

Bounce forward

Prosper, thrive,
develop
vigorously

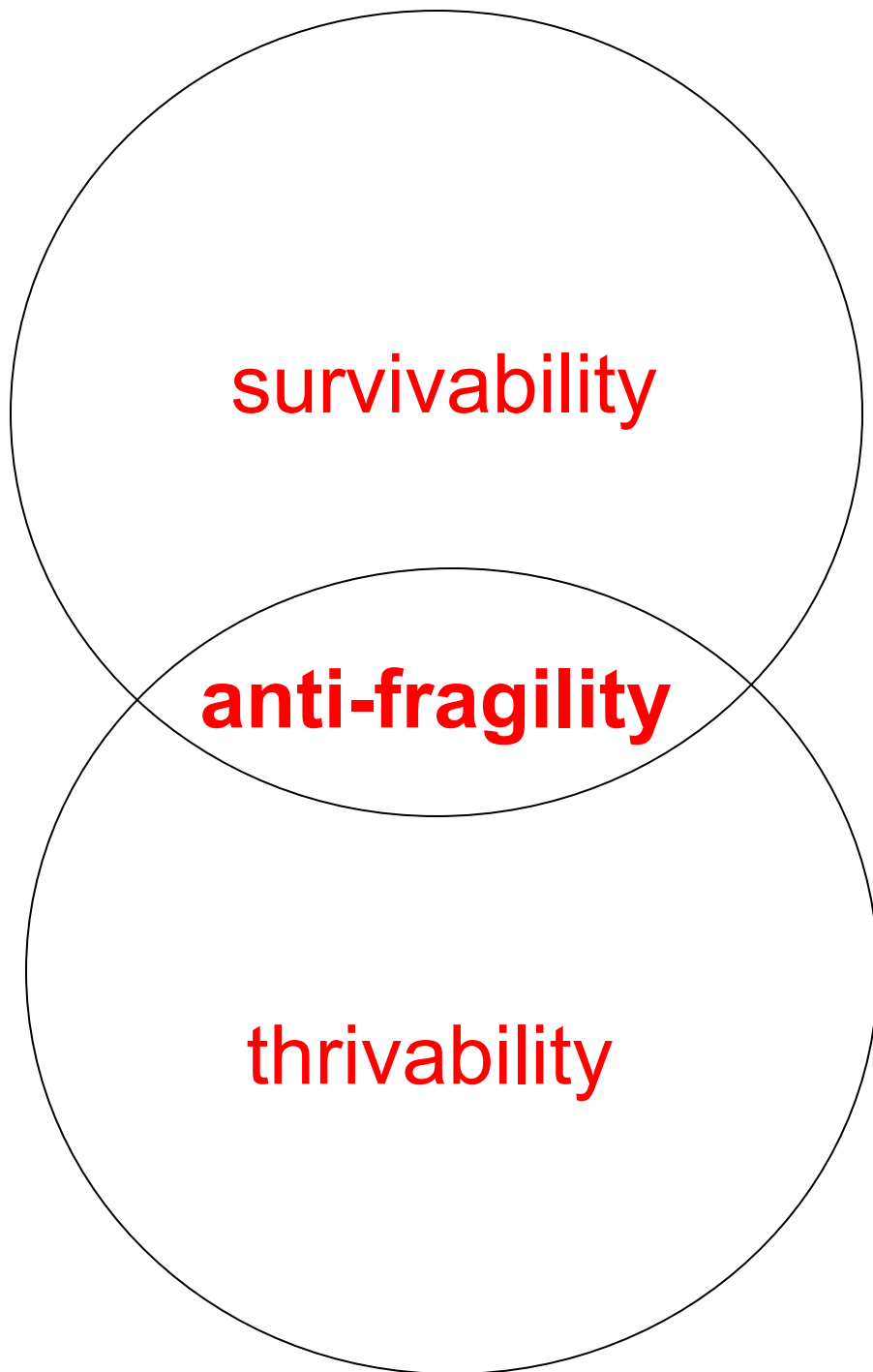
Strive for
greatness

Anti-fragile,
generate,
transform



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
- Aging infrastructure
- Desire 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

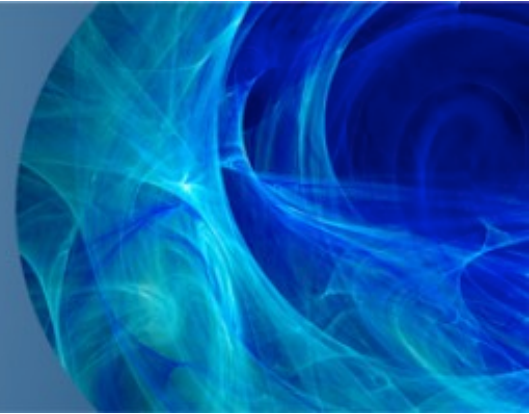
www.cfانclimate.net

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