

Certainties and Uncertainties in Our Energy and Climate Futures

Steven E. Koonin, NYU

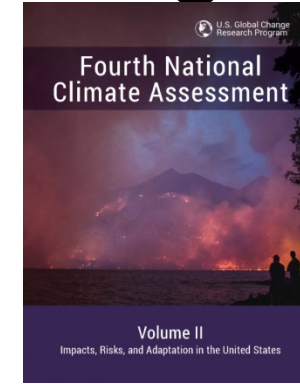
Purdue Discovery Park Distinguished Lecture

4/16/16




The consensus position on Climate Change



UN IPCC Fifth Assessment Report (AR5, 2014)



US Climate Science Special Report (CSSR, 2017)
US Fourth National Climate Assessment Vol II (2018)

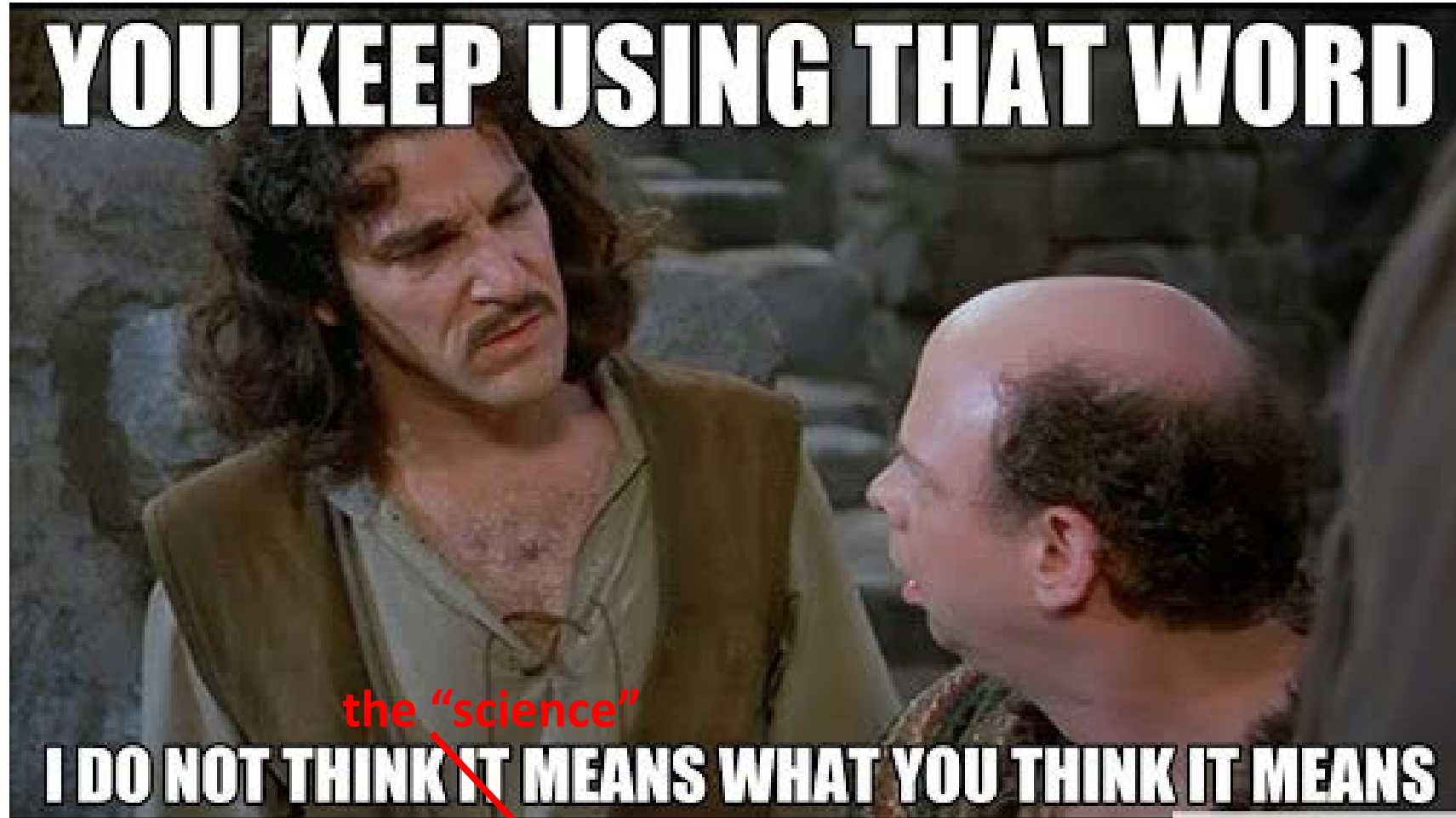
 **Katharine Hayhoe** 
@KHayhoe 

Our 600 page climate report in one tweet:
It's real
It's us
It's serious
And the window of time to prevent dangerous impacts is closing fast

5:36 AM - 11 Aug 2017

- The climate is changing (**Detection**)
- Due to humans (**Attribution**)
- **Impacts** now, with worse to come (**Projection**)
- We must act now (**Response**)

From *The Princess Bride*



Presentation outline

- The **“Consensus view”** on the science

- Detection
- Attribution (and models)
- Projection

} **“... But”**
interspersed

- **Impacts observed and impacts projected**

- **Response (and But’s)**

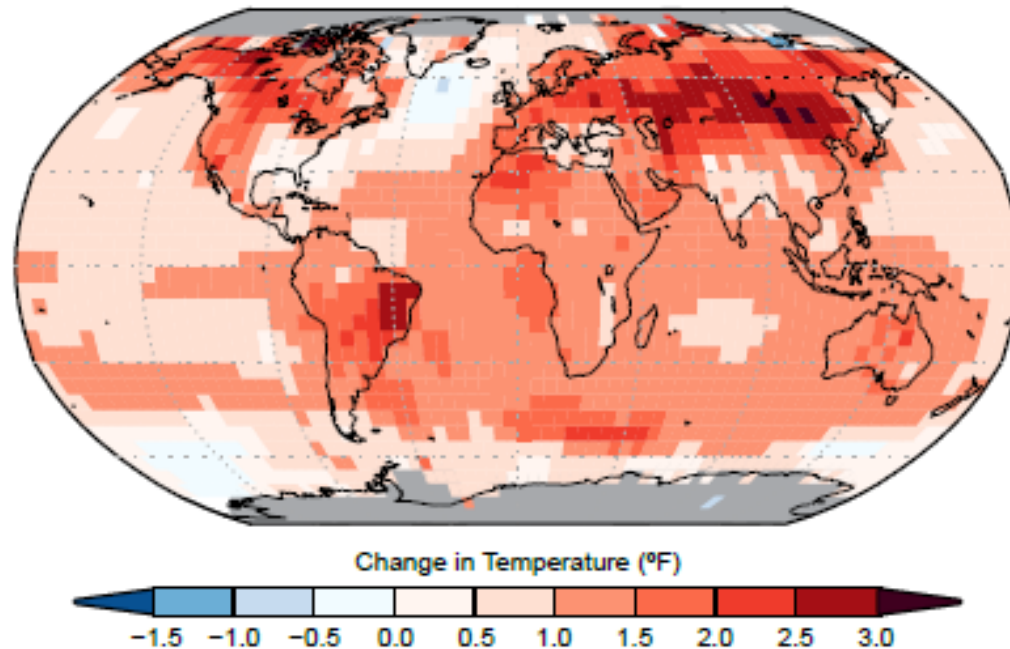
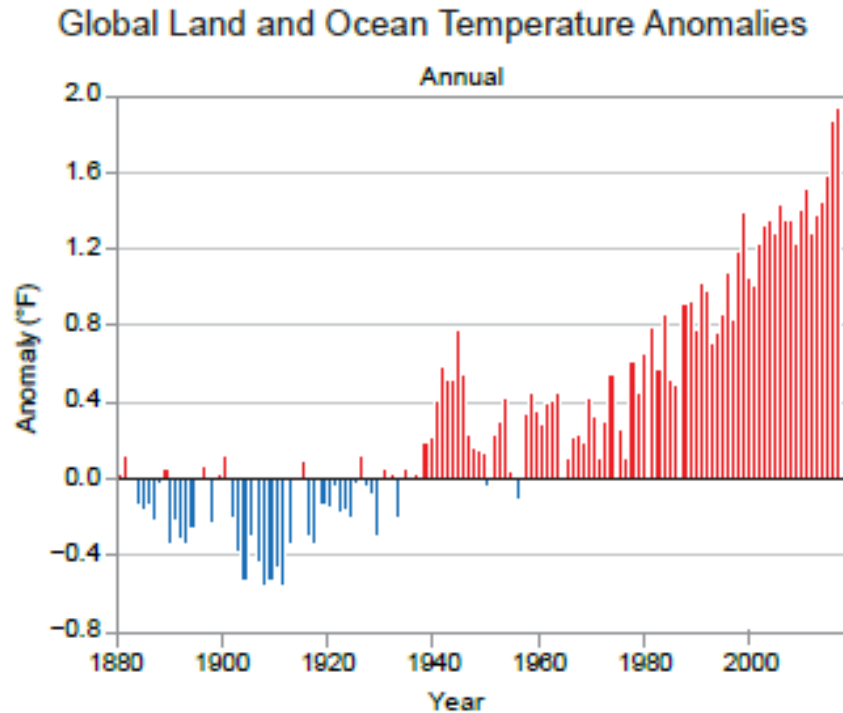
***This is a complex/nuanced subject
Completeness/detail suffer for brevity***

Detection: Unusual global warming in recent decades

Global Temperatures Continue to Rise

1986-2015 vs 1901-1960

Surface Temperature Change



Other indications

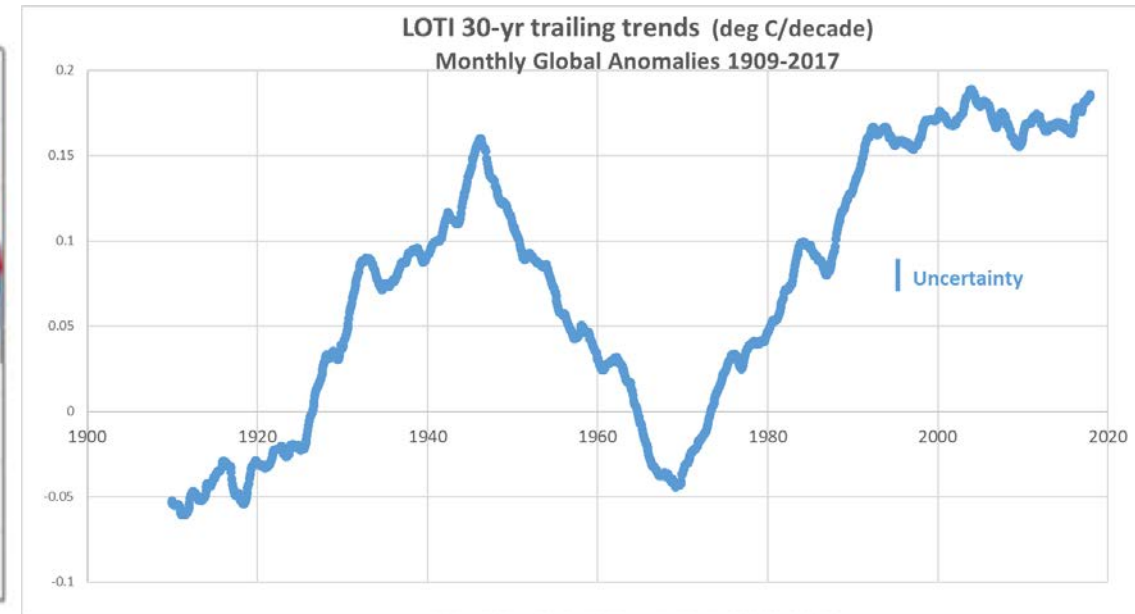
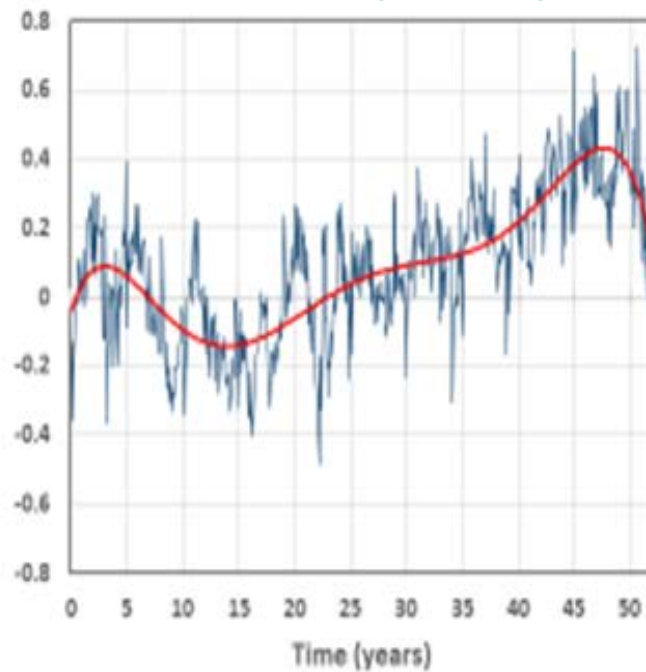
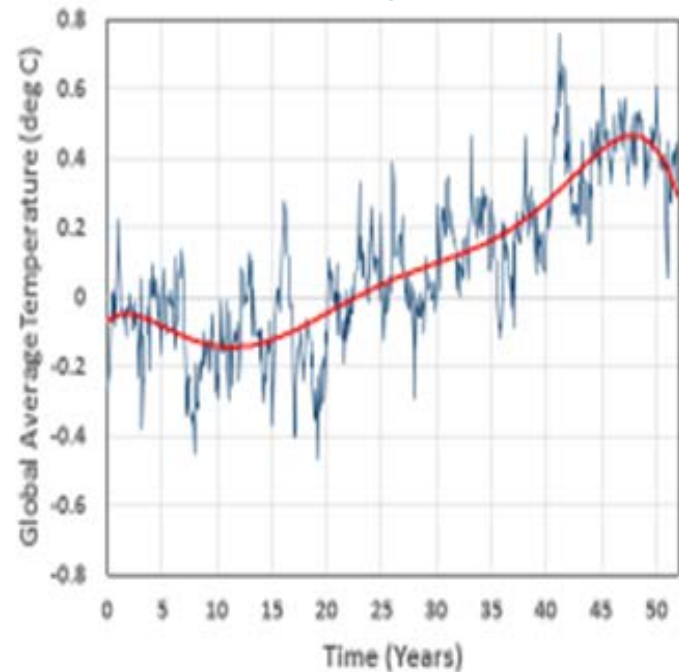
- Warming atmosphere
- Warming oceans
- Rising sea levels
- Shrinking Arctic ice
- Shrinking glaciers
- Growing humidity

Detection: “Unusual global warming in recent decades” ... But perhaps not so unusual?

HadCRUT3 Temperature Anomalies

1957-2008 (Human caused)

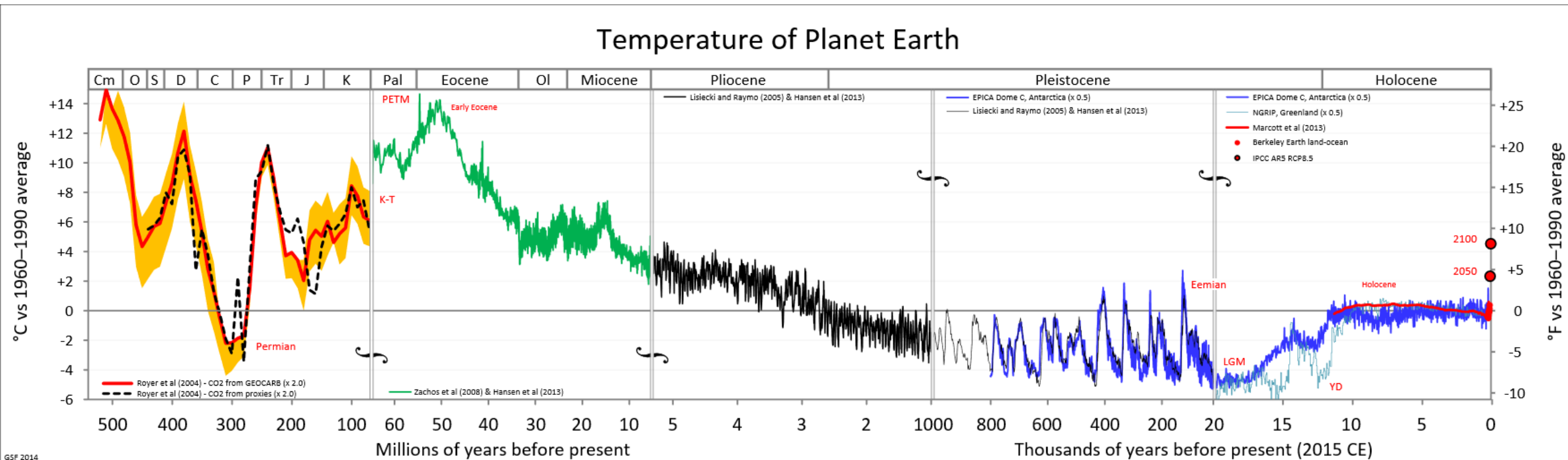
1895-1946 (Natural)



Temperature and time scales for the two time series are identical. One time series has been displaced vertically to give equal means over the 52-year warming period.

Detection: “Unusual global warming in recent decades” ... But temperature varies on its own

From https://en.wikipedia.org/wiki/File:All_palaeotemps.png#Summary



Attribution: “Humans have caused at least half of the warming since 1951”

- **Human influences on the climate include:**

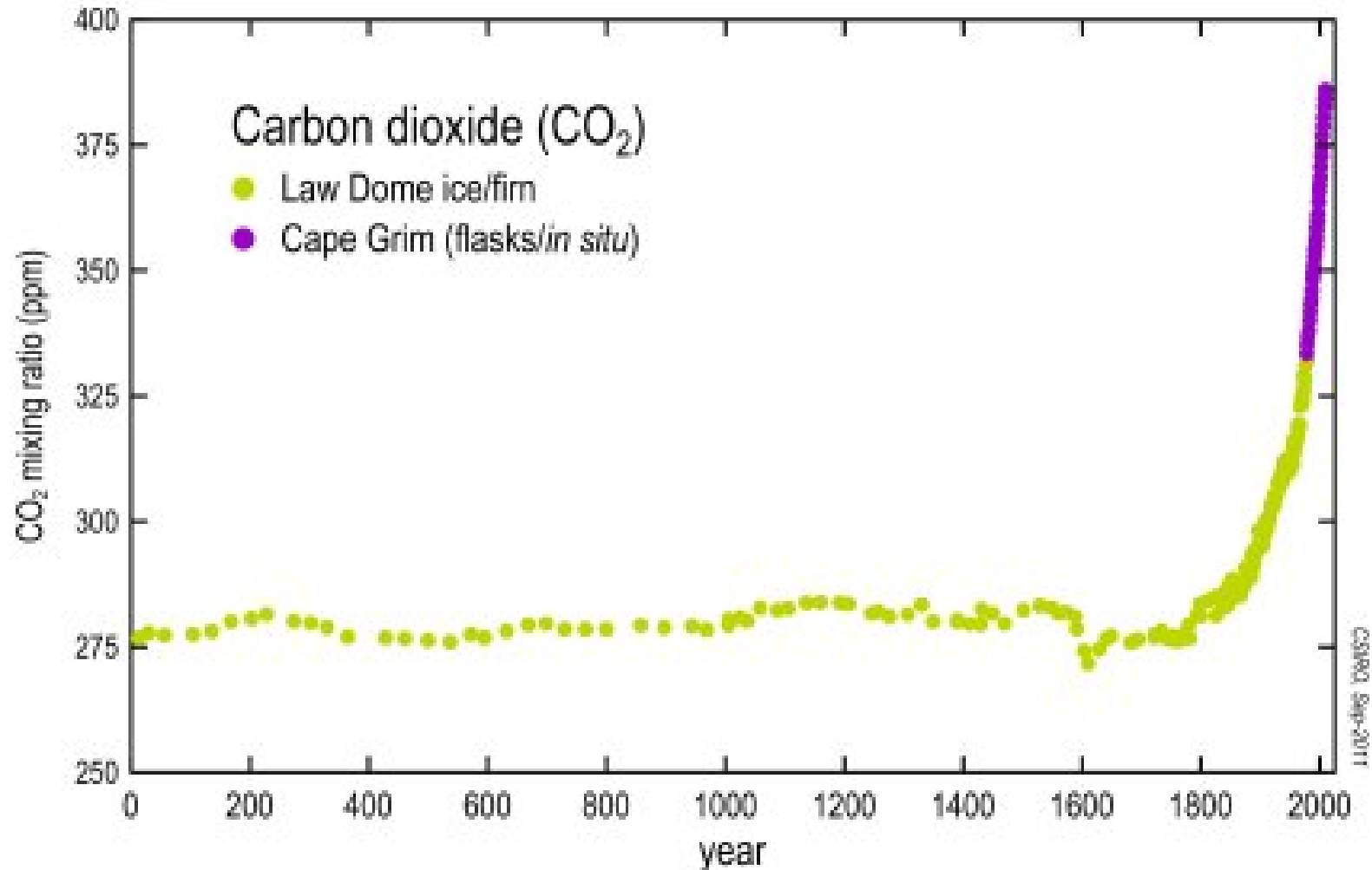
- Greenhouse gas emissions
- Aerosols
- Land use

- **Natural influences include:**

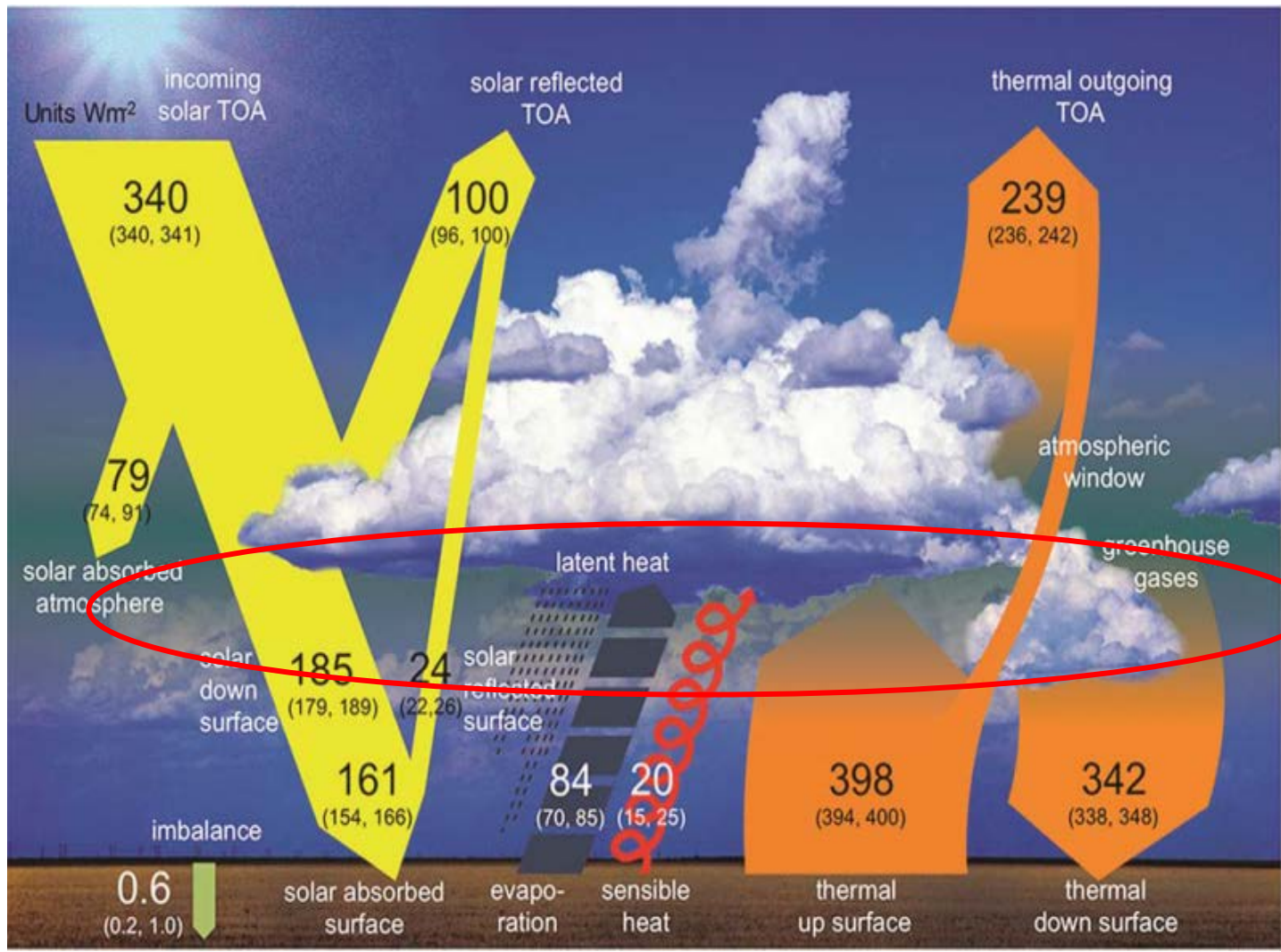
- Solar variability
- Volcanic and natural aerosols
- Changes in the carbon cycle

We find no convincing evidence that natural variability can account for the amount of global warming observed over the industrial era – CSSR, pg. 35

Attribution: “Humans are increasing the CO₂ concentration”



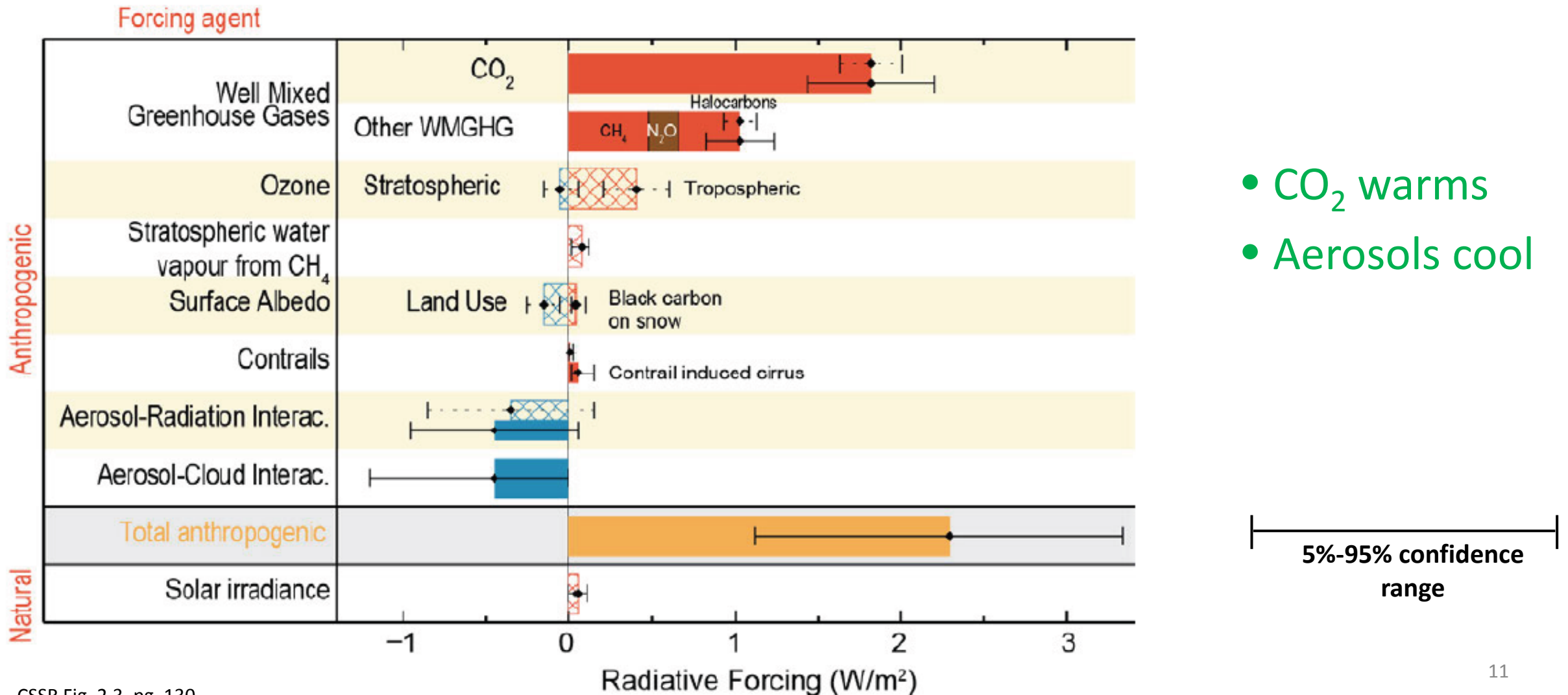
Attribution: “Humans exert small influences on a complex system”



Human influence growing with time; “Radiative Forcing” currently net +2.5, or <1%

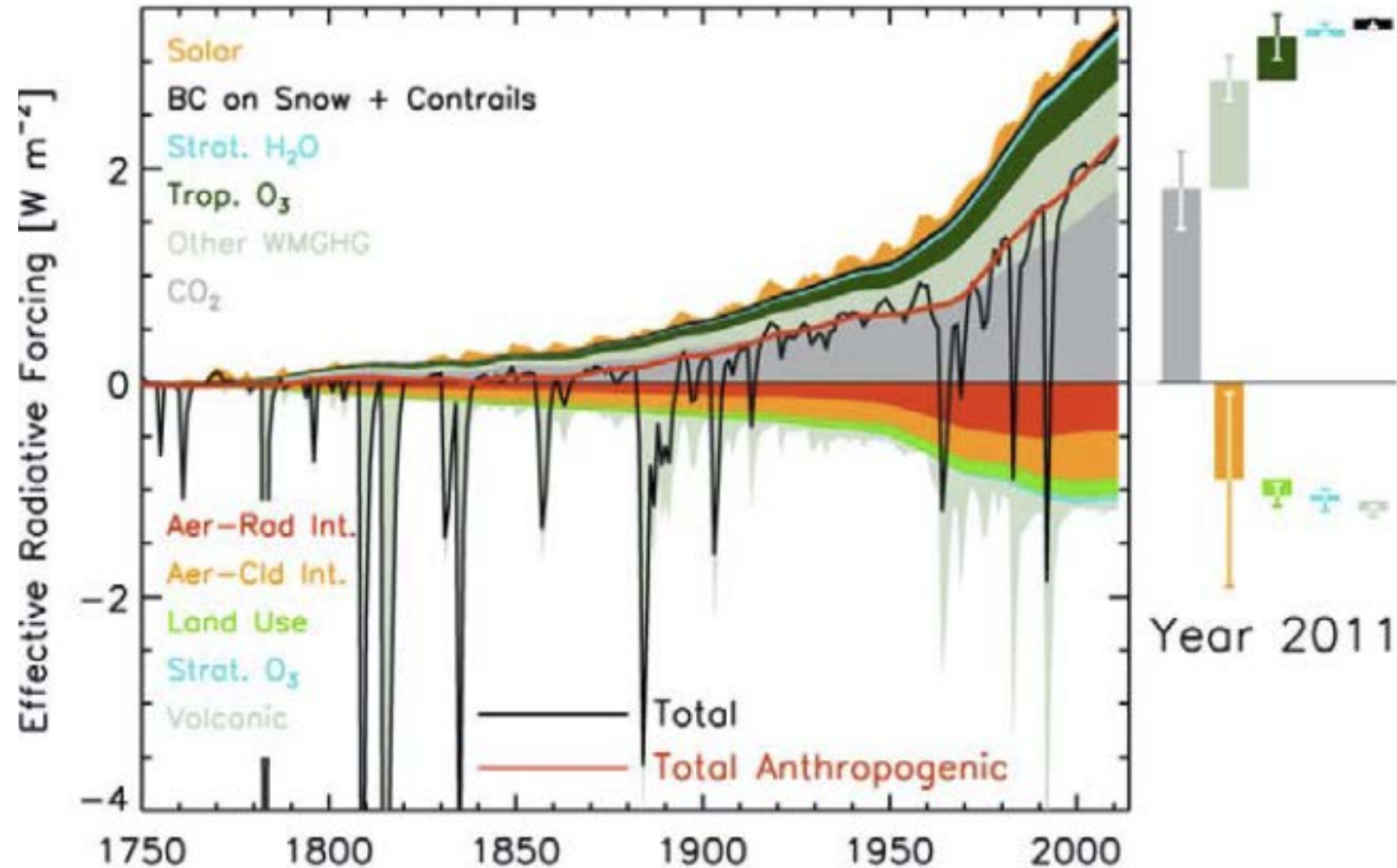
Attribution: “Human influences have grown since 1750”

Radiative Forcing of Climate Between 1750 and 2011

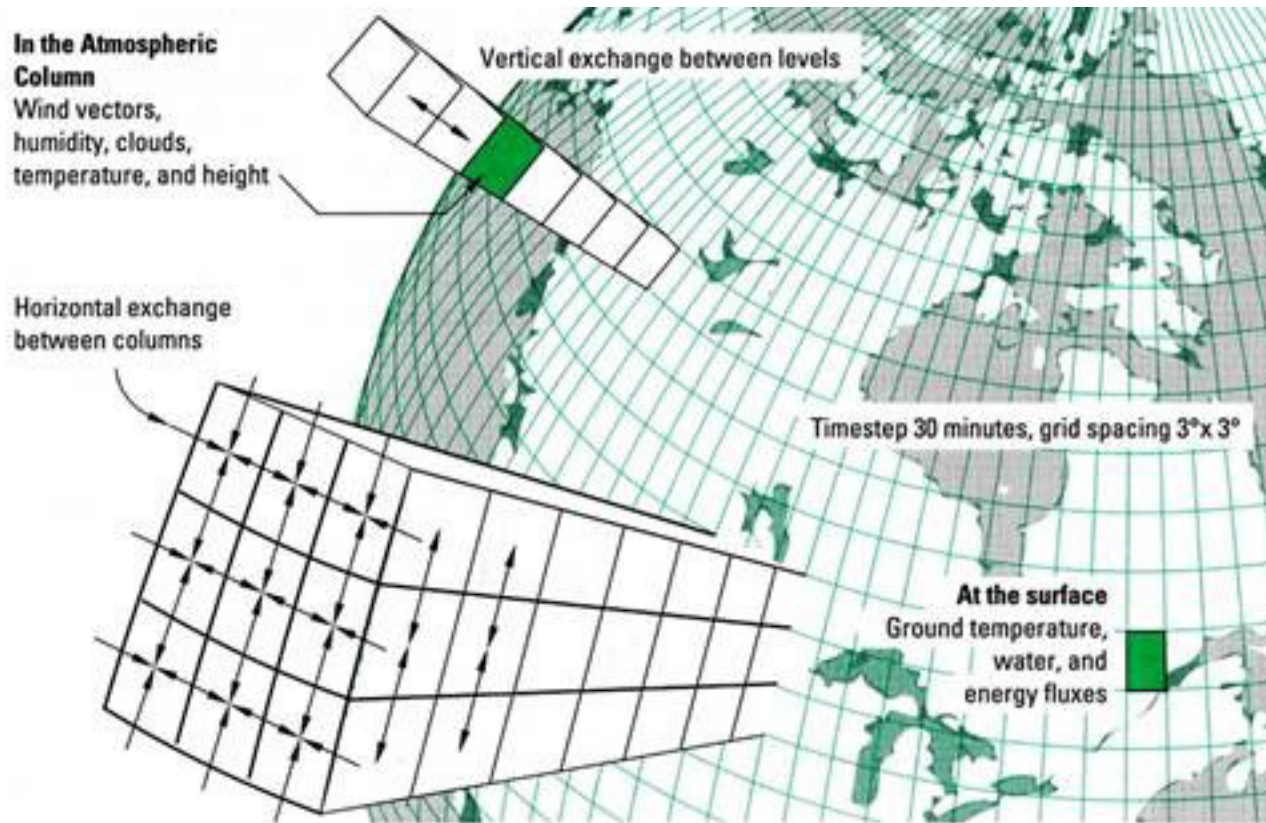


- CO₂ warms
- Aerosols cool

Attribution: ... But Human influences were much weaker before ~1950



Attribution: Climate models



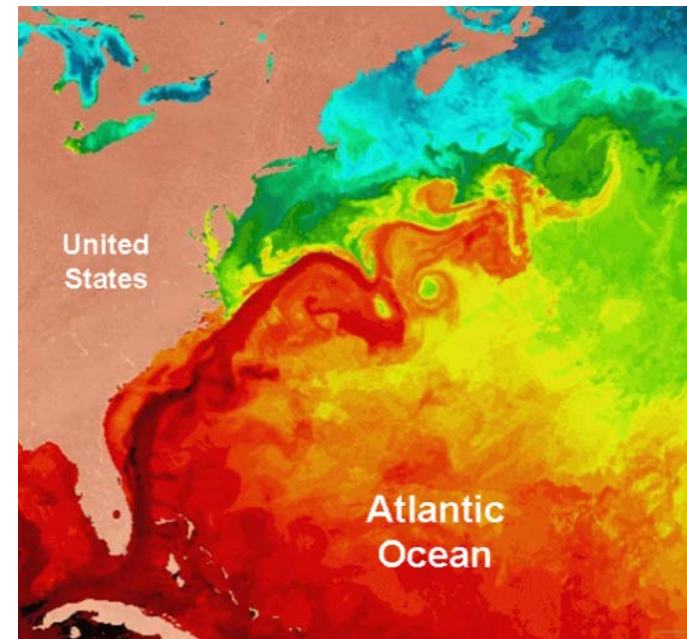
Model issues include:

- Subgrid scale parameterization of clouds, convection
- Ocean initial conditions
- Greenhouse-aerosol degeneracy
- Multidecadal modes of the climate system

- “Our models are useful, but imperfect”
- “They’re the best we’ve got and they’re improving”

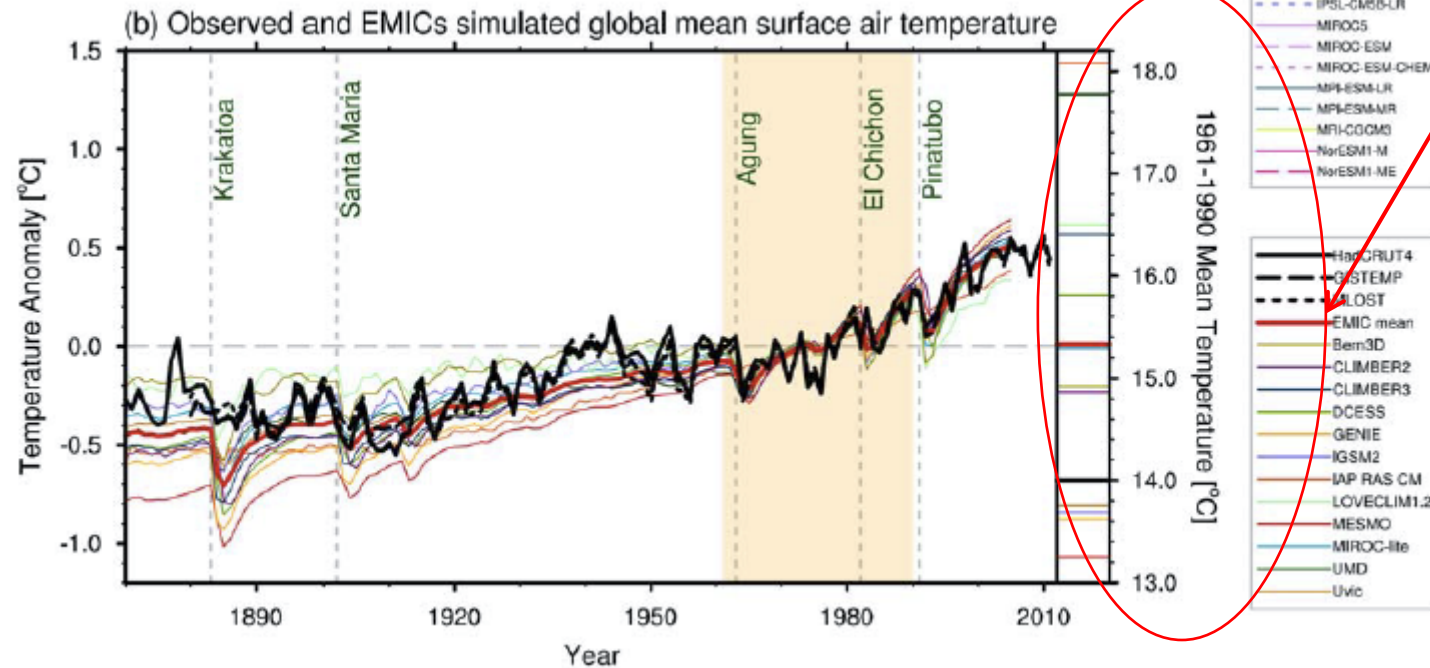
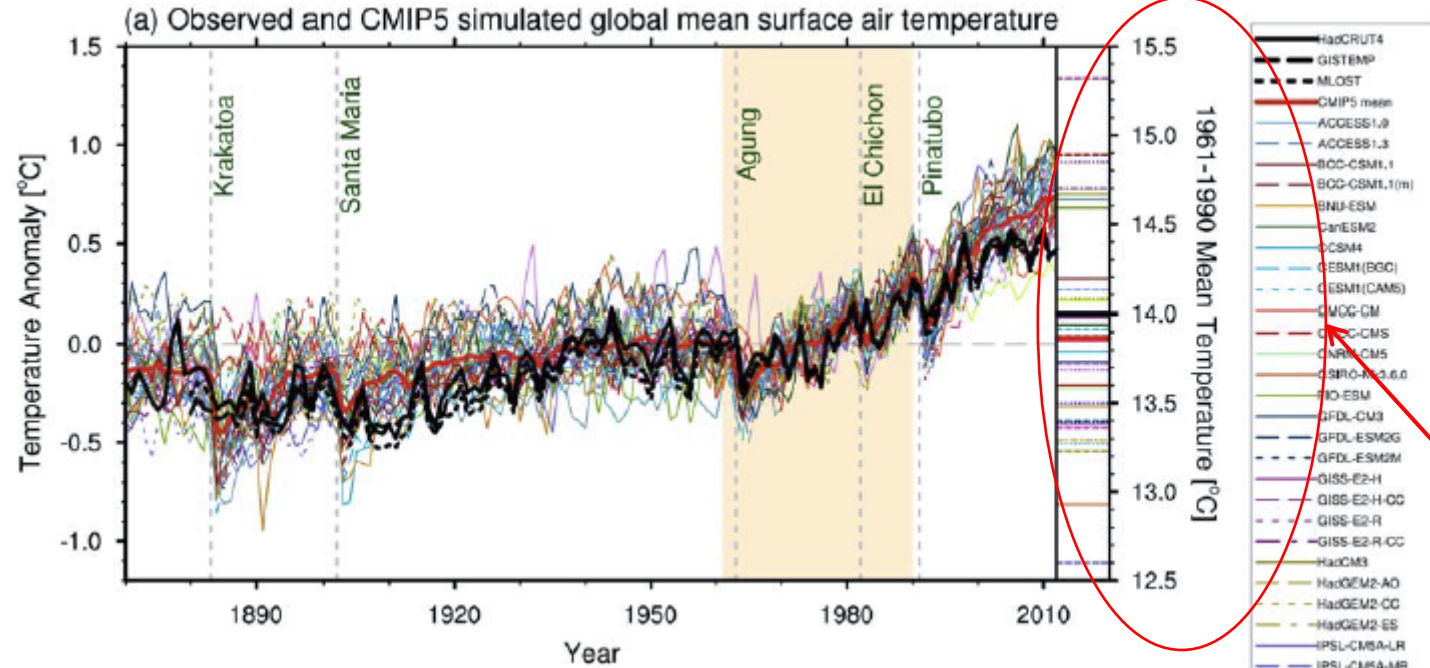
... But

- They’re not “just physics”- subjective judgements about small scale phenomena
- They fail to reproduce important aspects of the changing climate



Attribution:

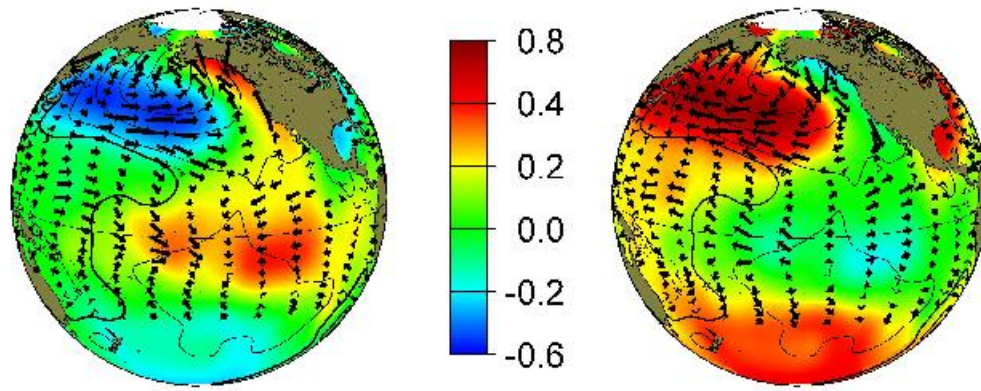
... But the models are unphysical



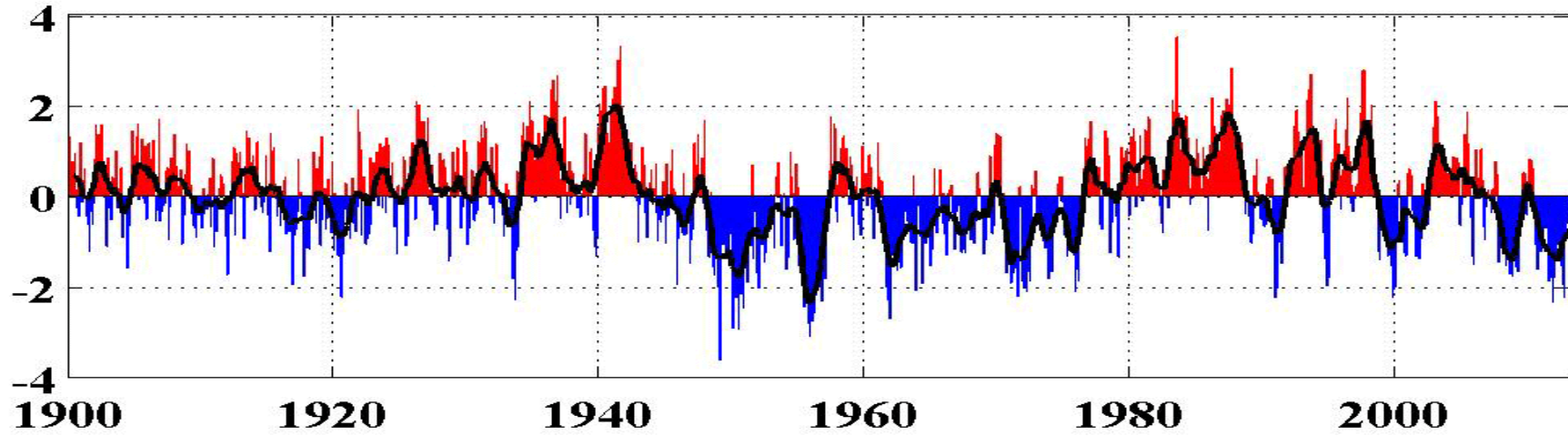
Note absolute temperatures on the RH scale

IPCC AR5 WGI Figure 9.8

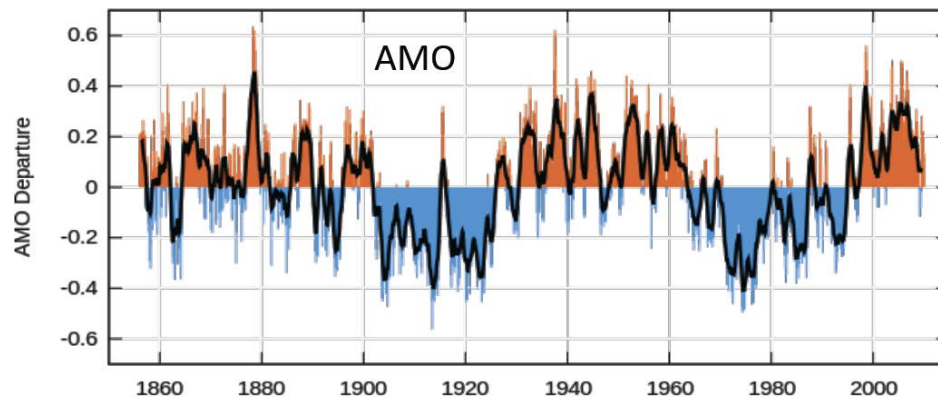
**Pacific
Decadal
Oscillation**
<http://jisao.washington.edu/pdo/>



monthly values for the PDO index: 1900-2013



**Atlantic
Multi-decadal
Oscillation**

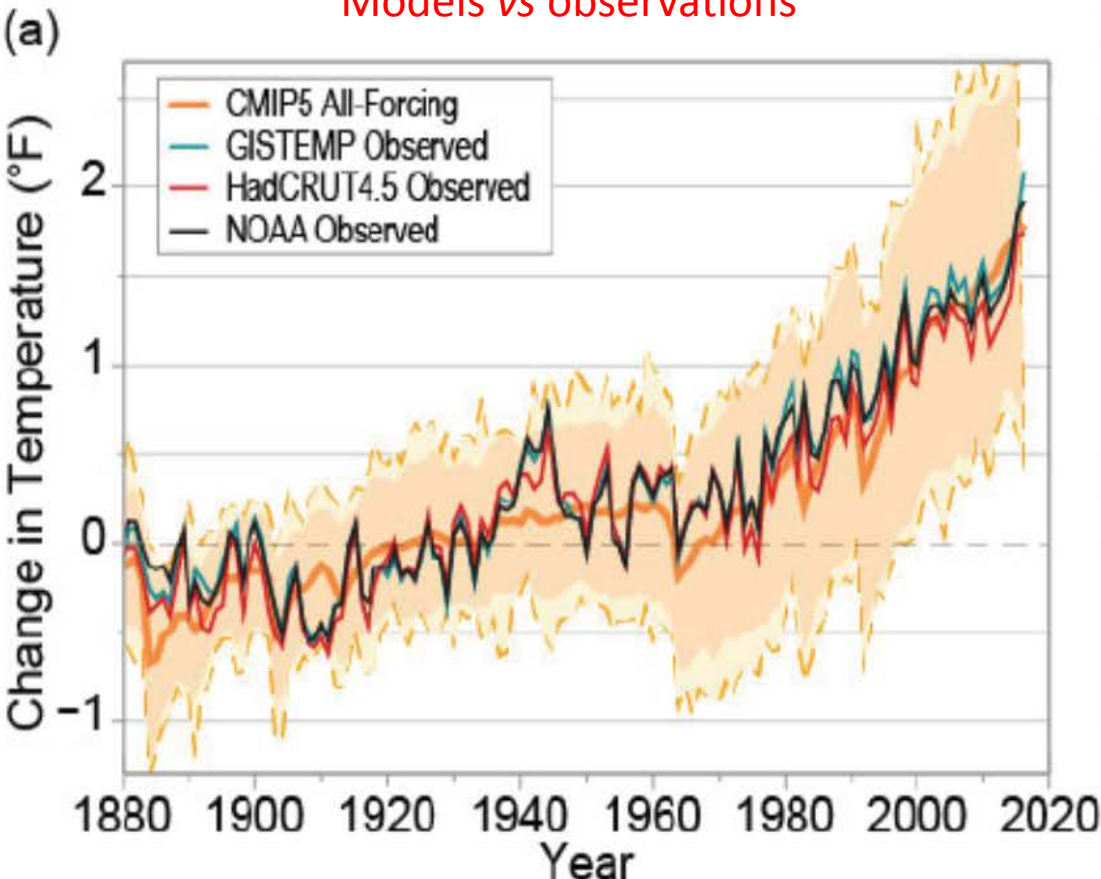


Attribution:
... **But** multidecadal
variability is not
present in the
models

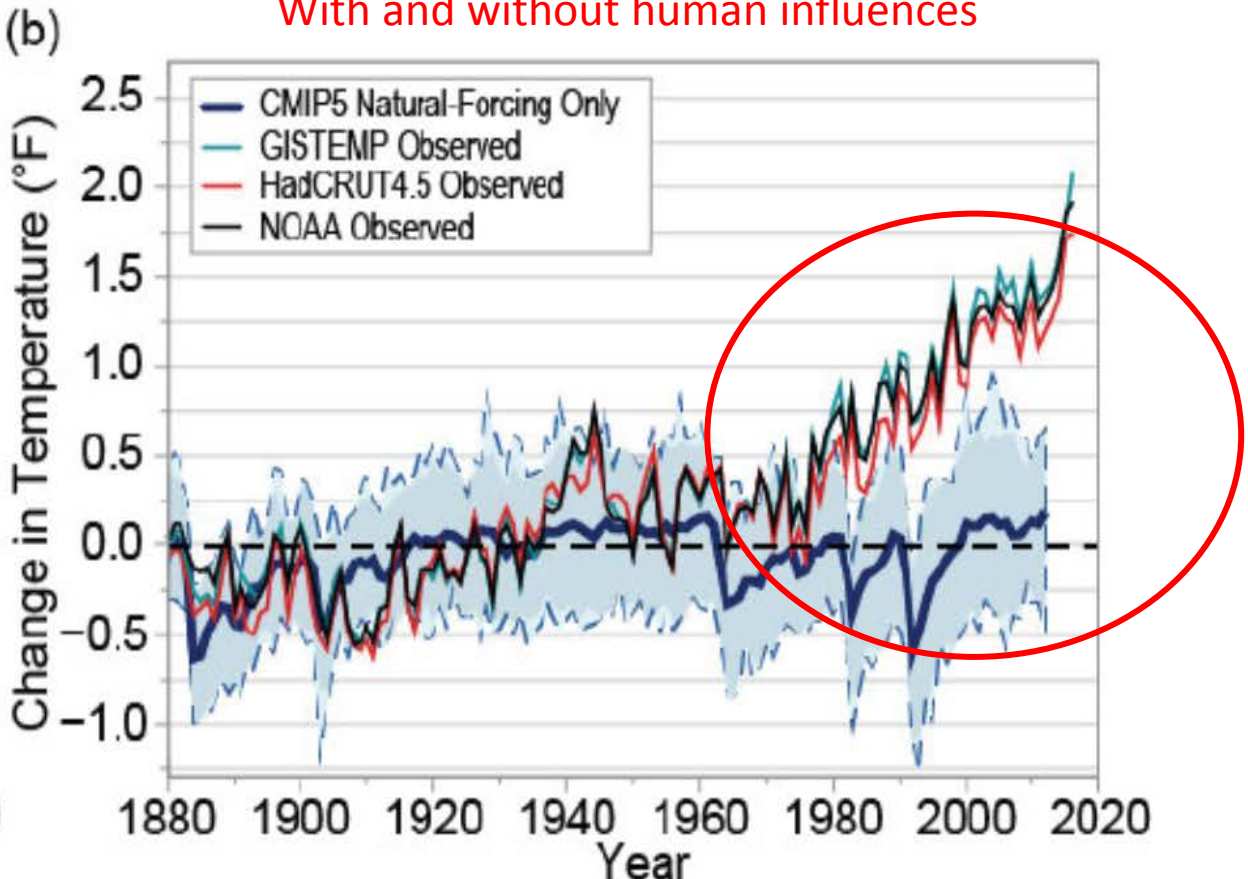
Attribution: “Models reproduce the historical record; human influences are significant”

Global Mean Temperature Change

Models vs observations

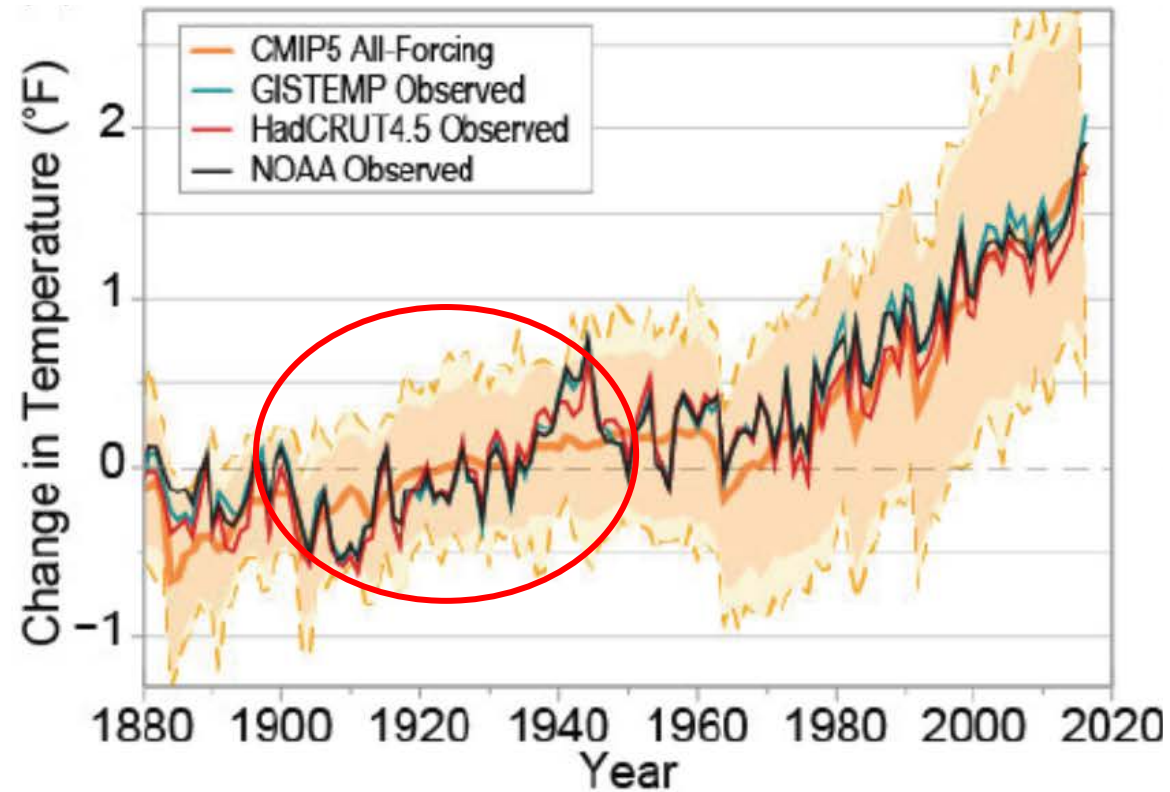


With and without human influences

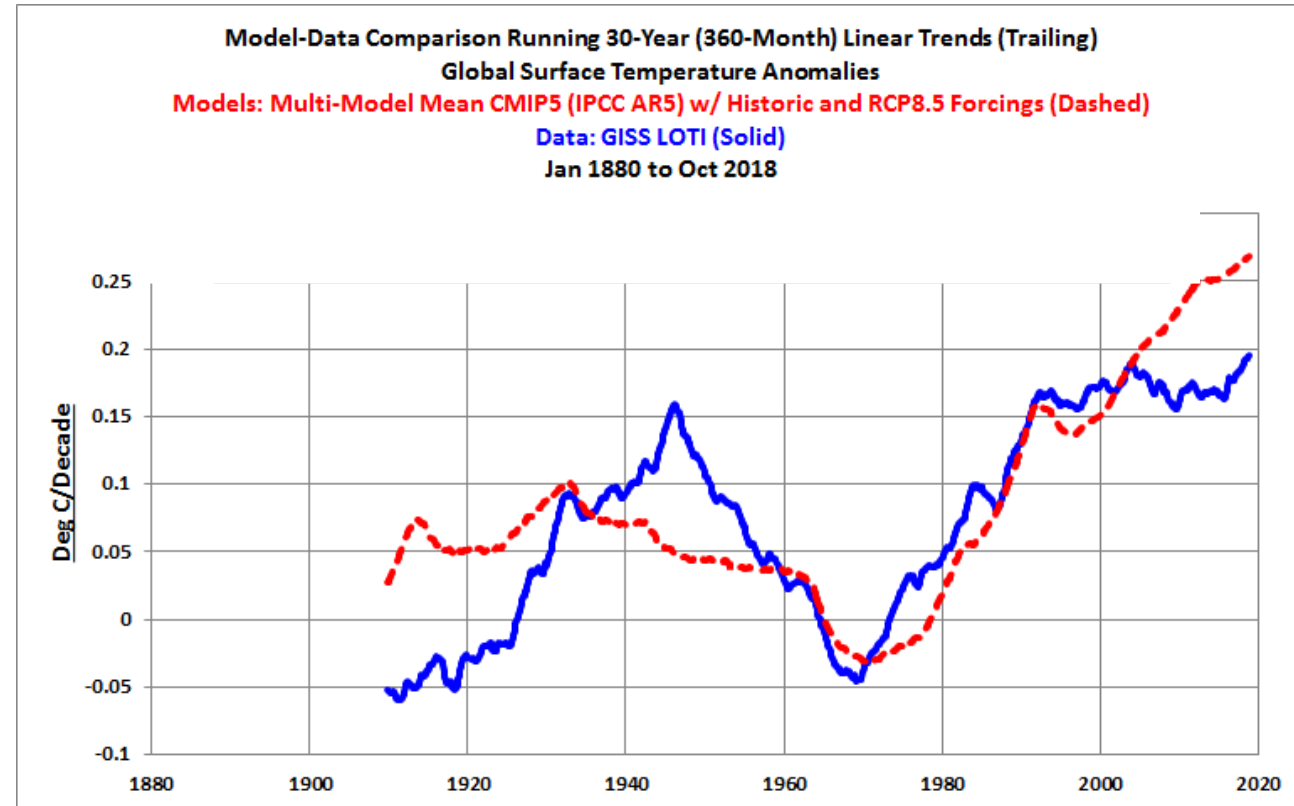


Attribution: “Models reproduce the historical record” ...But not very well and “run hot”

CMIP5 = Climate Model Intercomparison Project, 5th Ensemble

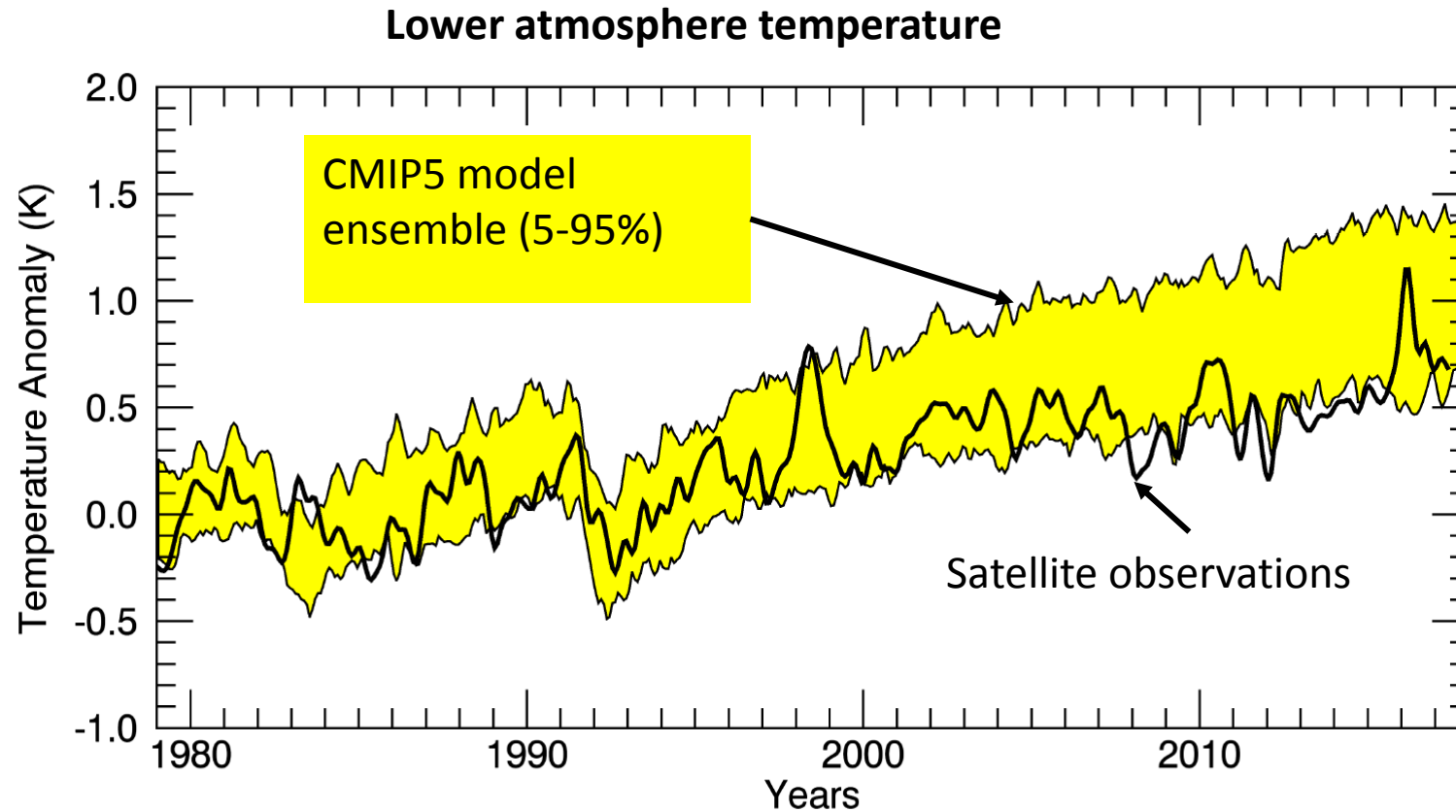


“It remains difficult to quantify the contribution to this warming from internal variability, natural forcing and anthropogenic forcing, due to forcing and response uncertainties and incomplete observational coverage.” – IPCC AR5 WGI, p. 887



<https://bobtisdale.wordpress.com/2018/11/15/october-2018-global-surface-landocean-and-lower-troposphere-temperature-anomaly-update/>

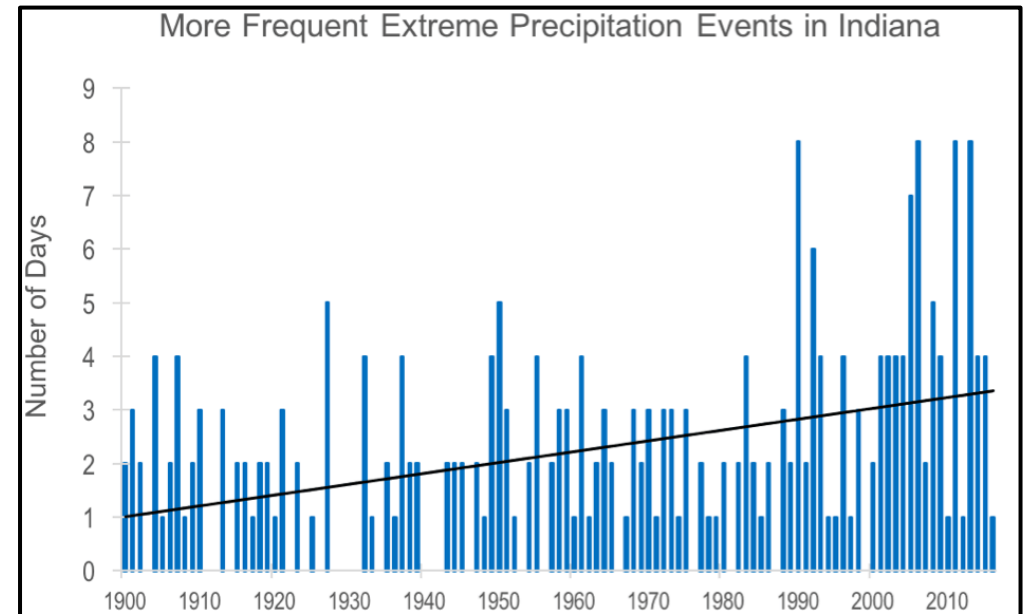
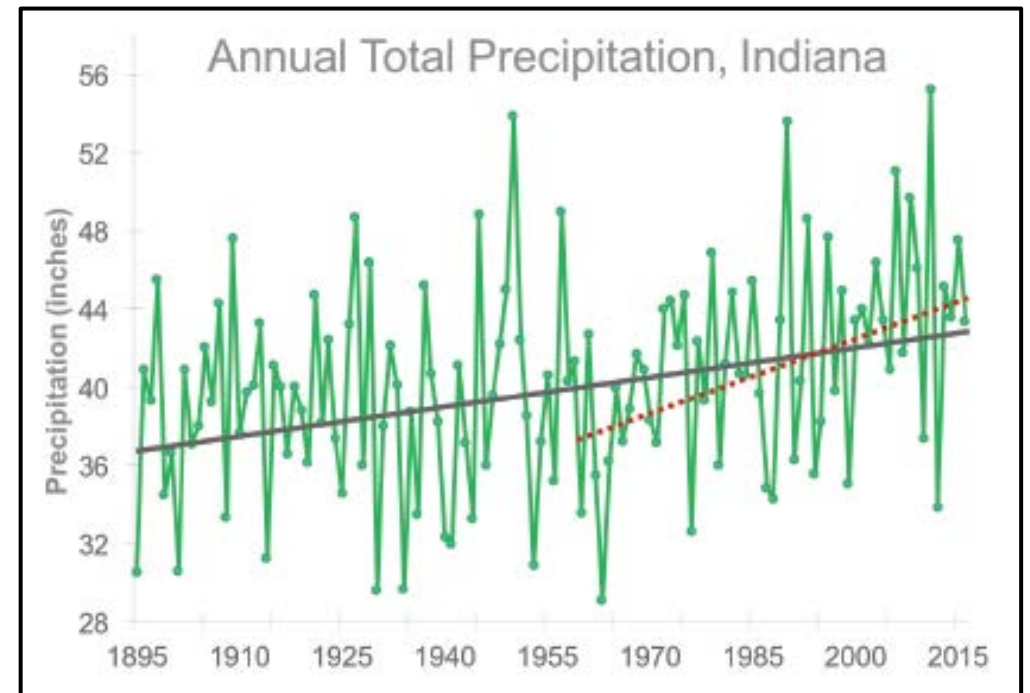
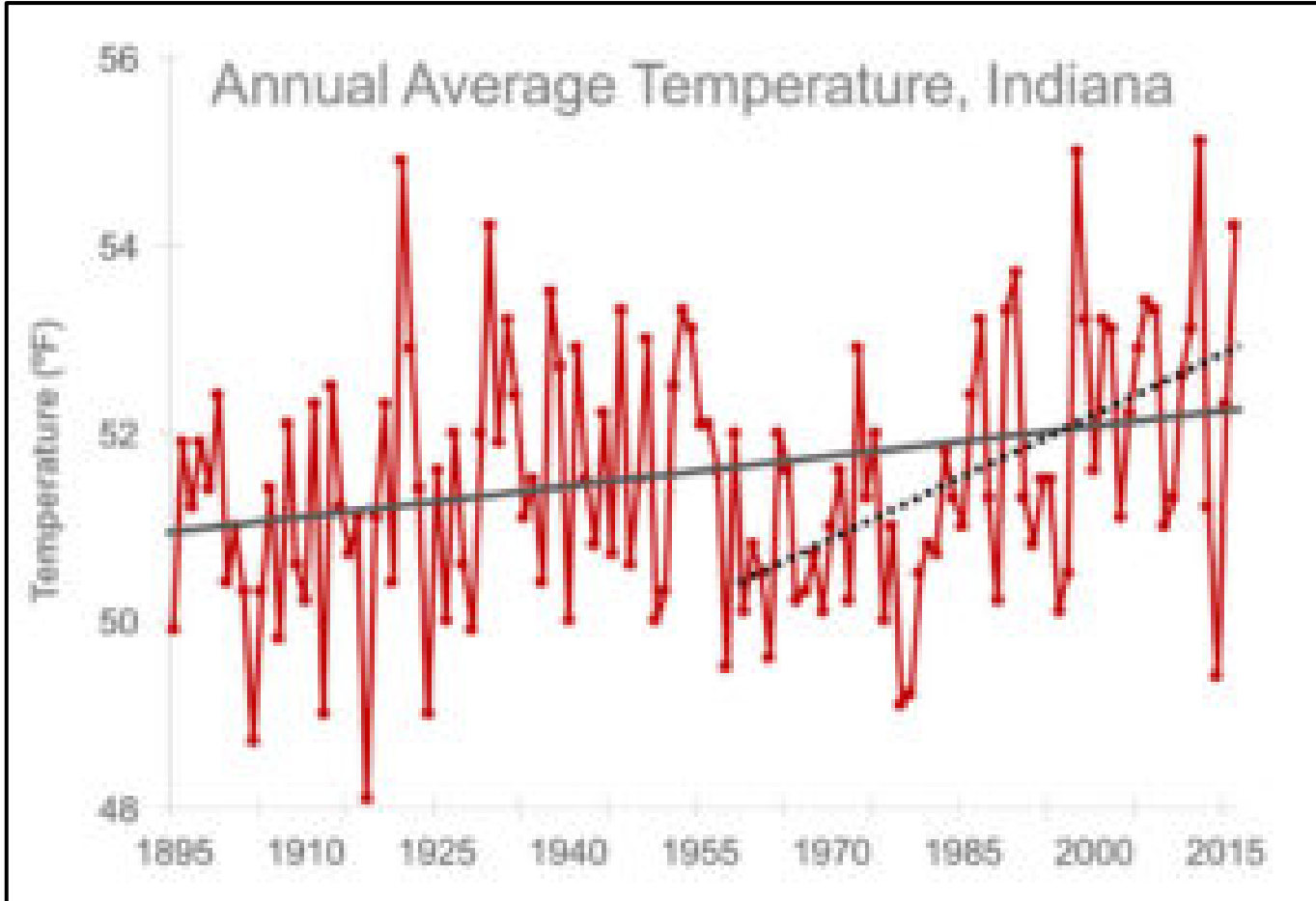
Attribution: “Models reproduce the historical record” ...But not very well and “run hot”



From <http://www.remss.com/research/climate>

Indiana climate data

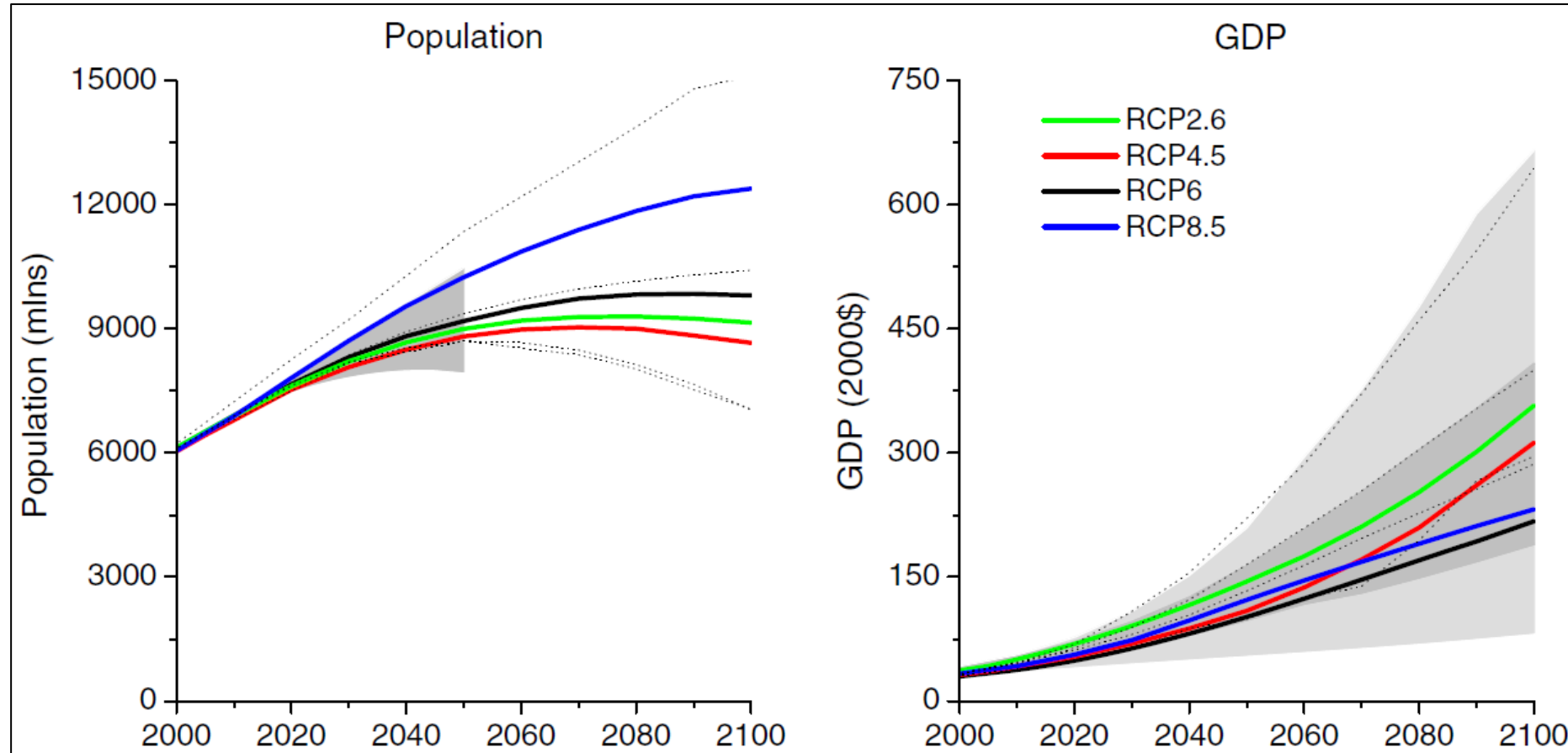
<https://ag.purdue.edu/indianaclimate/indiana-climate-report/>



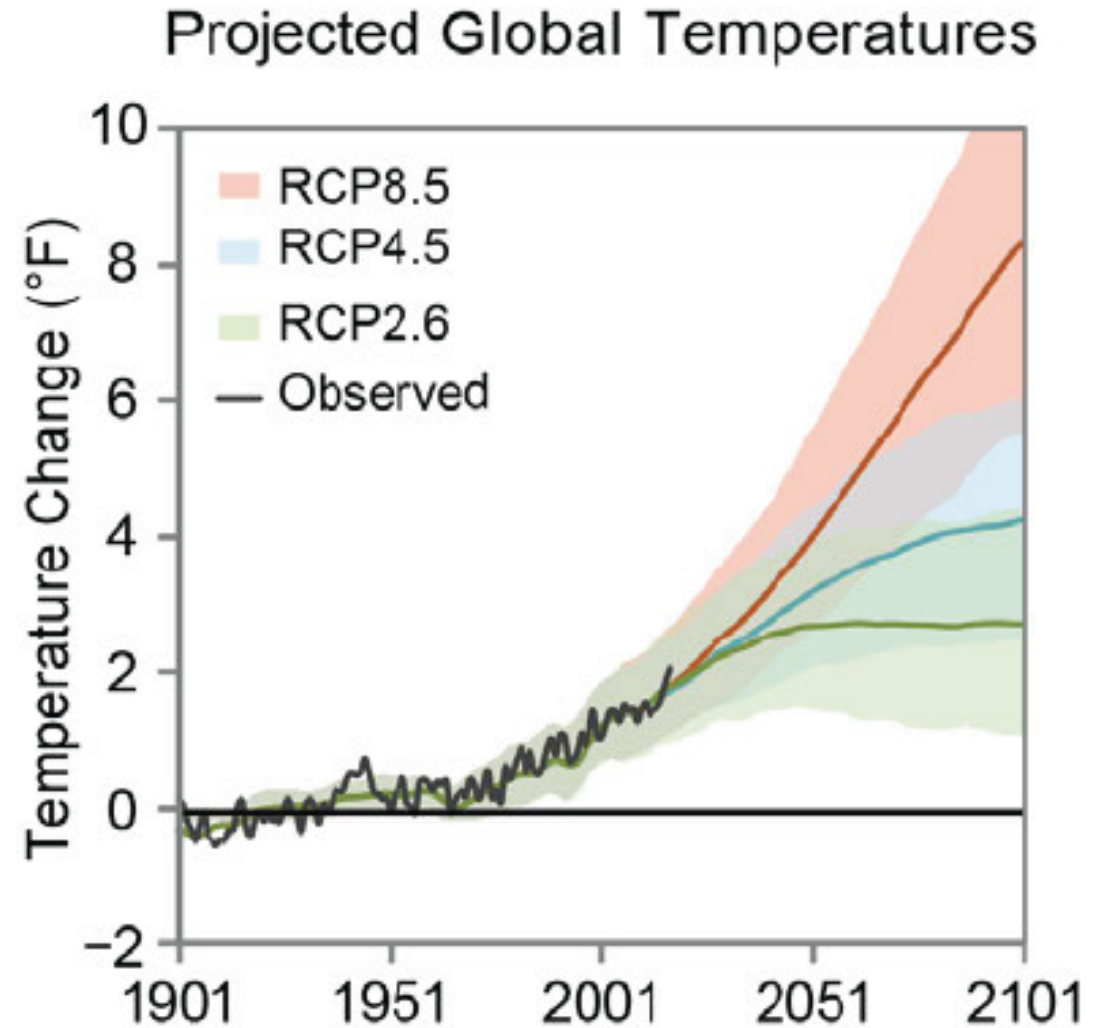
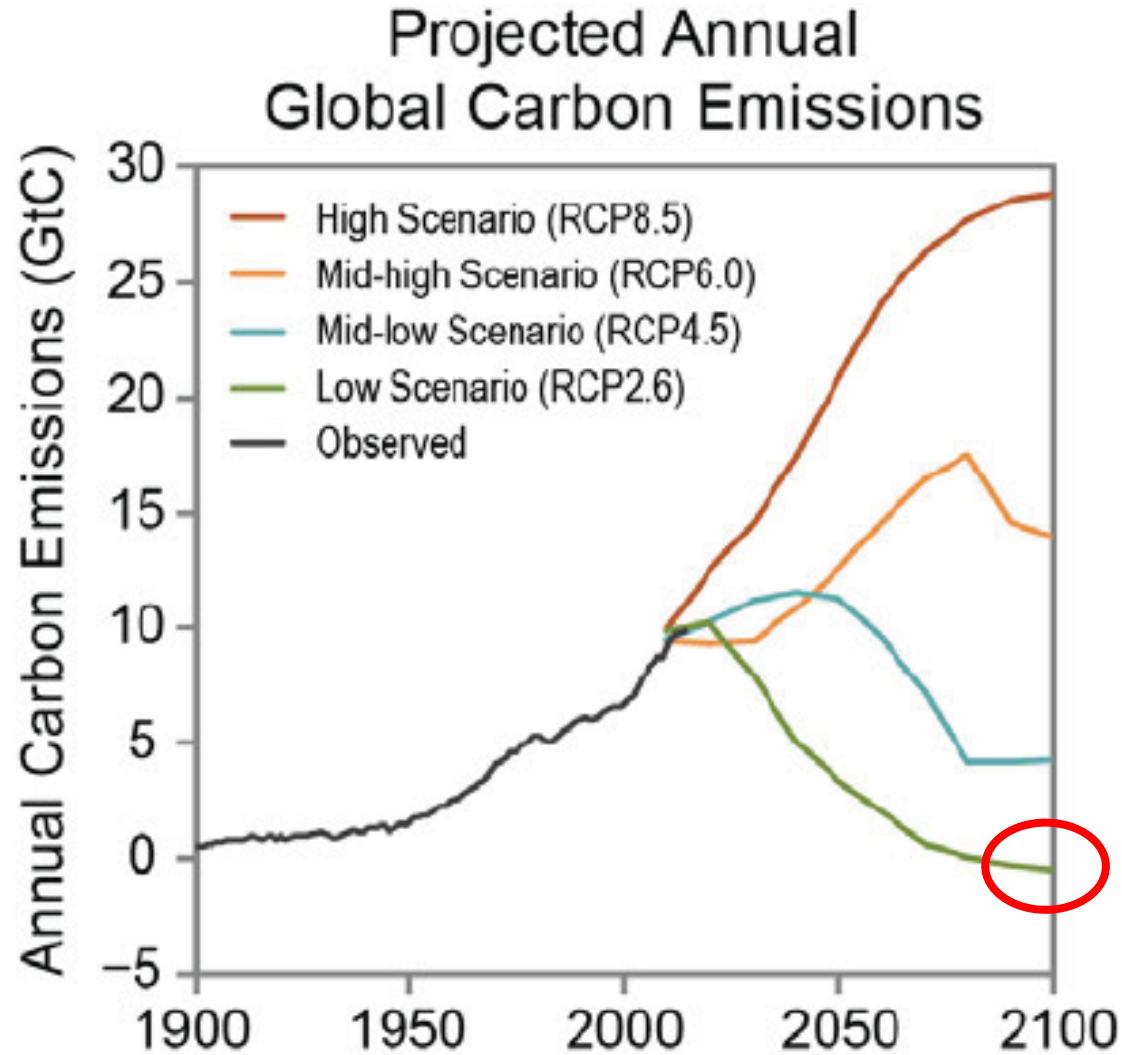
Projection: “We can usefully project future climates”

- Assume future trajectories for human influences
 - Demography, development, technology, economics, regulation, ...
 - GHG and aerosol concentrations, land use
 - Embodied in Representative Concentration Pathways (RCPs)
RCP n has forcing of n W/m² in 2100
- Run the models forward from today
- Average results over ensembles of models

Projection: “Alternative future population, GDP”



Projection: “Higher emissions mean higher temperatures sooner”



Projection: ...But uncertain response to human influences

“Key remaining uncertainties relate to the precise magnitude and nature of changes at global, and particularly regional, scales, and especially for extreme events and our ability to observe these changes at sufficient resolution and to simulate and attribute such changes using climate models.”

– CSSR, pg 58

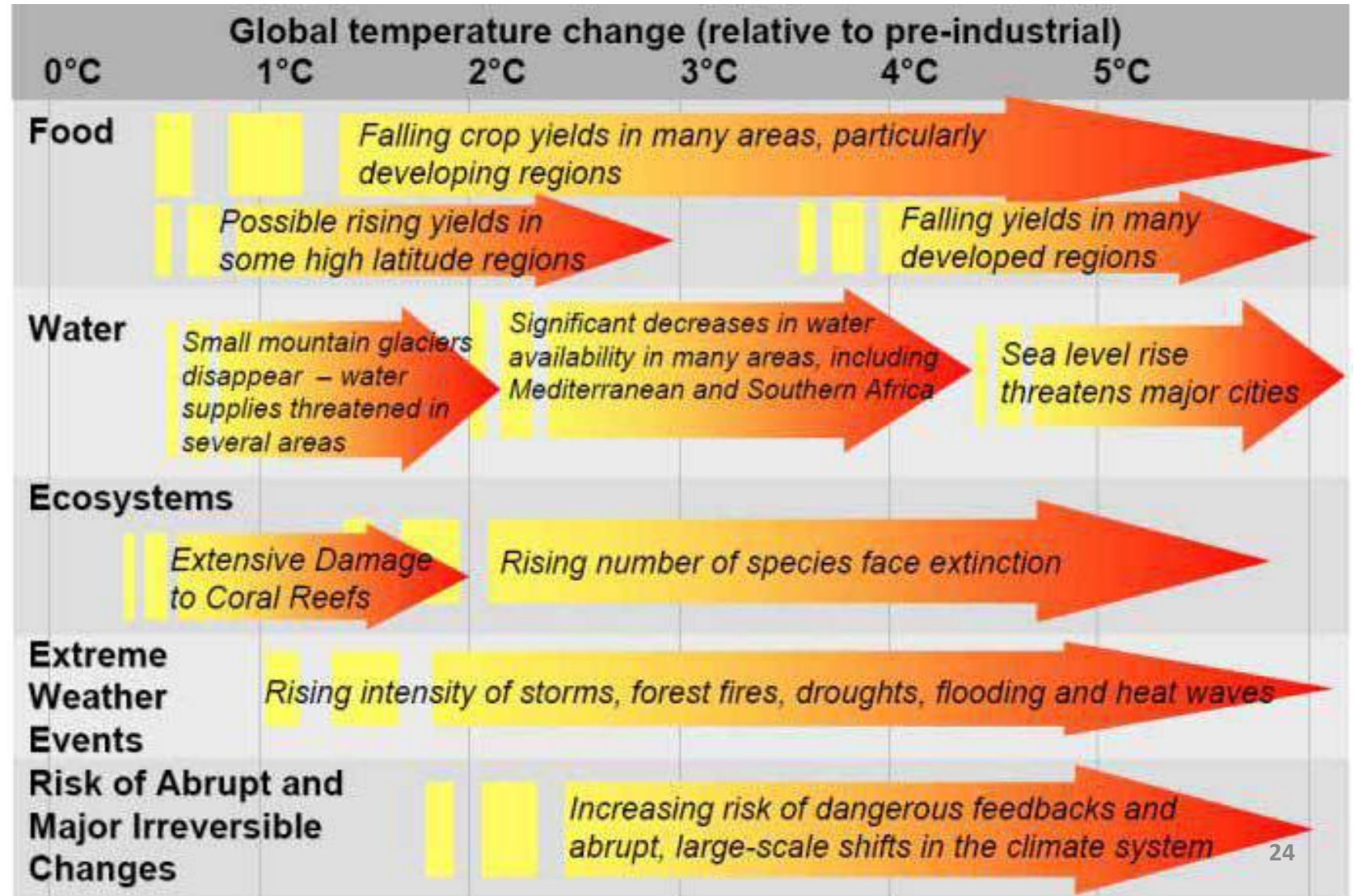
- “Estimated temperature response to increasing CO₂ is uncertain by a factor of 3”(!)
- Impacts beyond temperature largely not evident (“yet”?)

Impacts: “Already bad and will get worse”

Consensus Schematic



- “Global temperature change is a proxy for other impacts”
- “2C is the safe limit”,
... But is an ill-defined threshold



Impacts: “The Consensus refrain” ... But muddled

For some climate observable X :

e.g., storms, sea level, heat waves,

- X has changed in recent decades
- Humans have influenced X
- Understanding of X has improved (a relative statement)
- Human impact on X is uncertain (or yet undetected) because of:
 - Natural variability
 - Poor/short historical data
 - Confounding influences
 - Discordant models
- Human impacts on X will grow, but there are uncertainties in
 - character; magnitude; timing
- “It’s going to get worse”

Degree of confidence in each statement depends upon which X

Impacts: “IPCC on weather extremes”

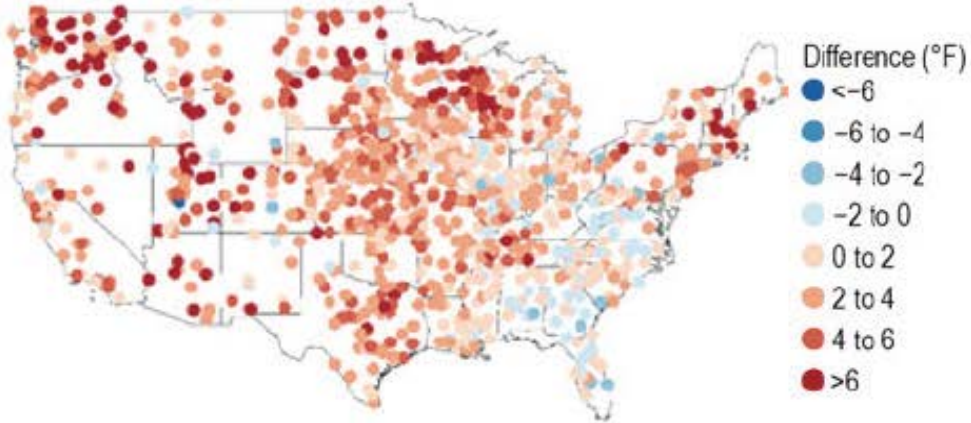
(modest paraphrases from AR5 WGI, Chapter 2)

- ...since about 1950 it is *very likely* that the numbers of cold days and nights have decreased and the numbers of warm days and nights have increased ... there is *medium confidence* that globally the length and frequency of warm spells, including heat waves, has increased since the middle of the 20th century
- ... *likely* that since 1951 increases in the number of heavy precipitation events in more regions than there have been decreases, but there are strong regional and subregional variations
- ... *low confidence* regarding the sign of trend in the magnitude and/or frequency of floods on a global scale.
- ... *low confidence* in a global-scale trend in drought or dryness since the middle of the 20th century,
- ...*low confidence* in trends in small-scale severe weather phenomena such as hail and thunderstorms
- ... *low confidence* in any longterm (centennial) increases in tropical cyclone activity, ... *virtually certain* increase in the frequency and intensity of the strongest tropical cyclones since the 1970s in the North Atlantic.
- ... *low confidence* in large scale changes in the intensity of extreme extratropical cyclones since 1900

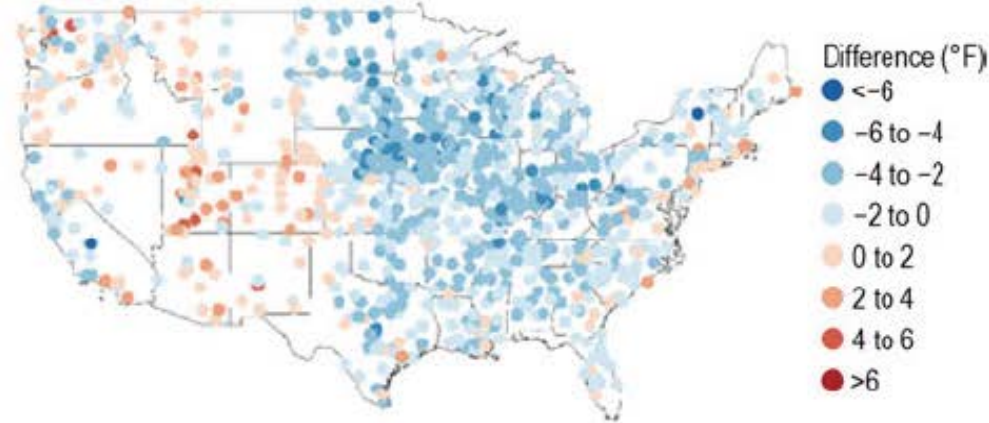
General statements about extremes are almost nowhere to be found in the literature but seem to abound in the popular media. It's this popular perception that global warming means all extremes have to increase all the time, even though if anyone thinks about that for 10 seconds they realize that's nonsense. – Gavin Schmidt, Director NASA GISS
(<https://www.eenews.net/stories/1059985592>)

Impact: “Temperature extremes becoming more common; certain to increase” ... **But** it isn't so simple

Change in Coldest Temperature of the Year
1986–2016 Average Minus 1901–1960 Average

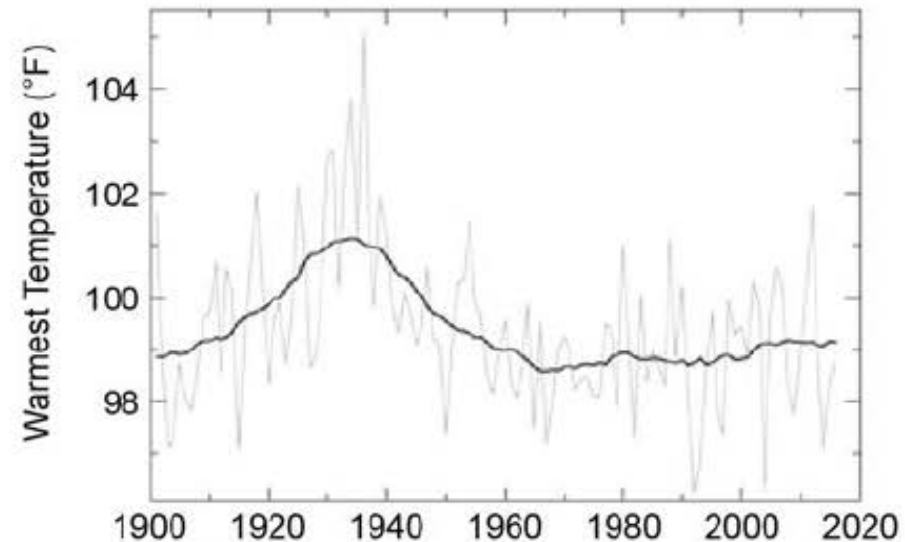
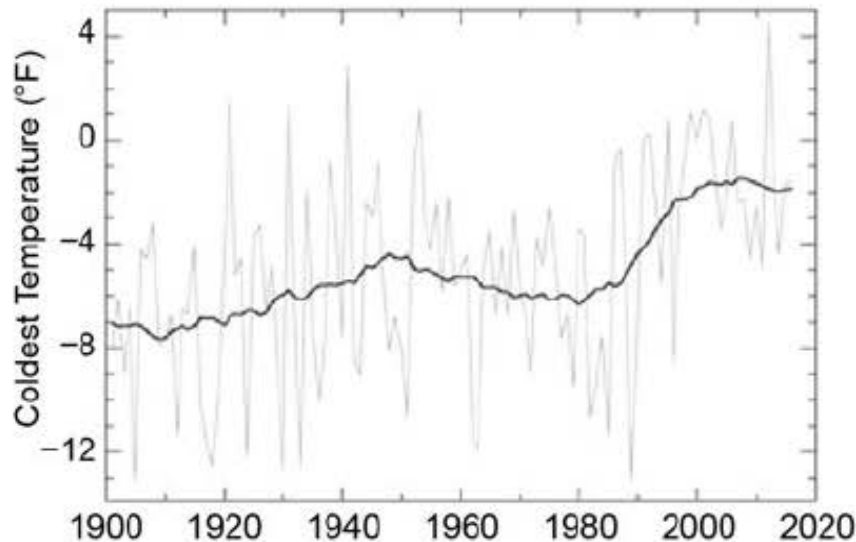


Change in Warmest Temperature of the Year
1986–2016 Average Minus 1901–1960 Average



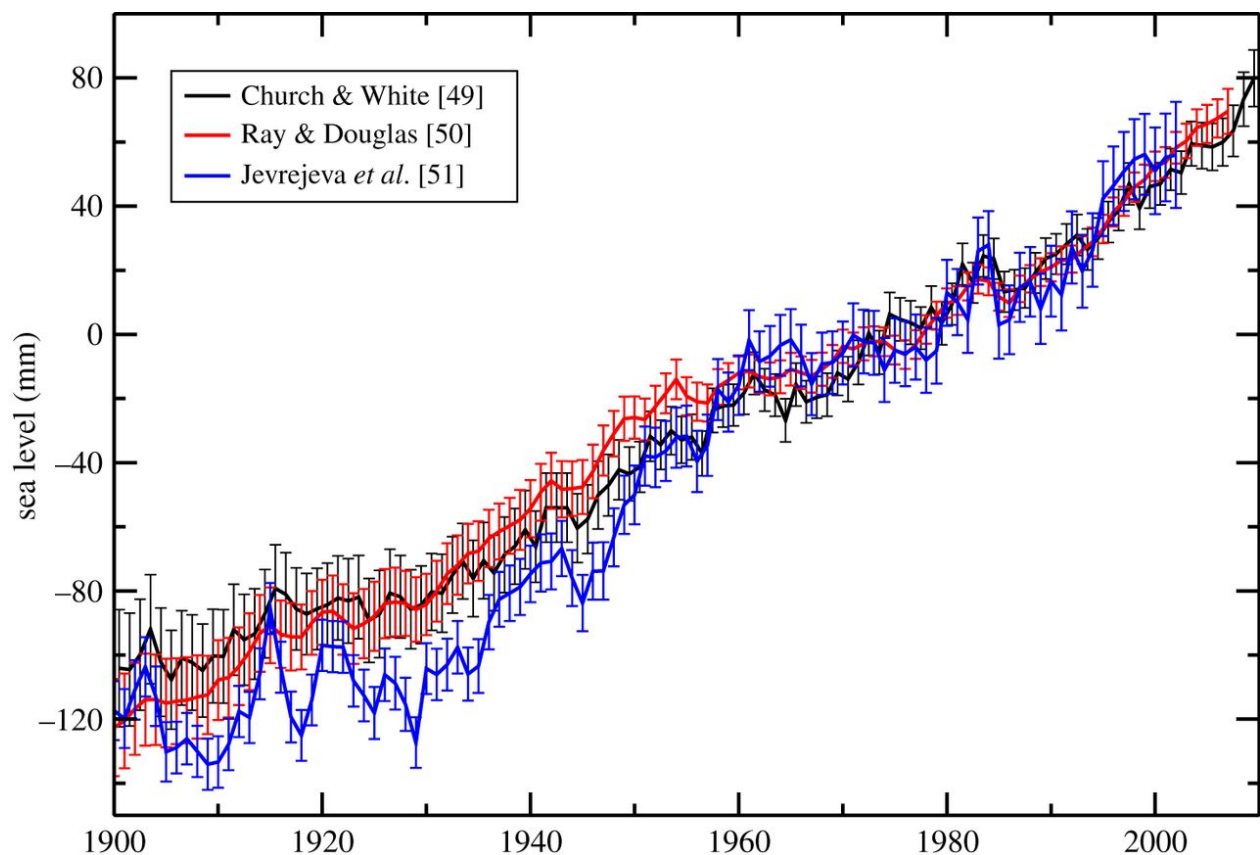
- Coldest temperatures increasing;
- Warmest temperatures unchanging
- Not “warming” but “milding”
- Agricultural intensification plays a role

US averages



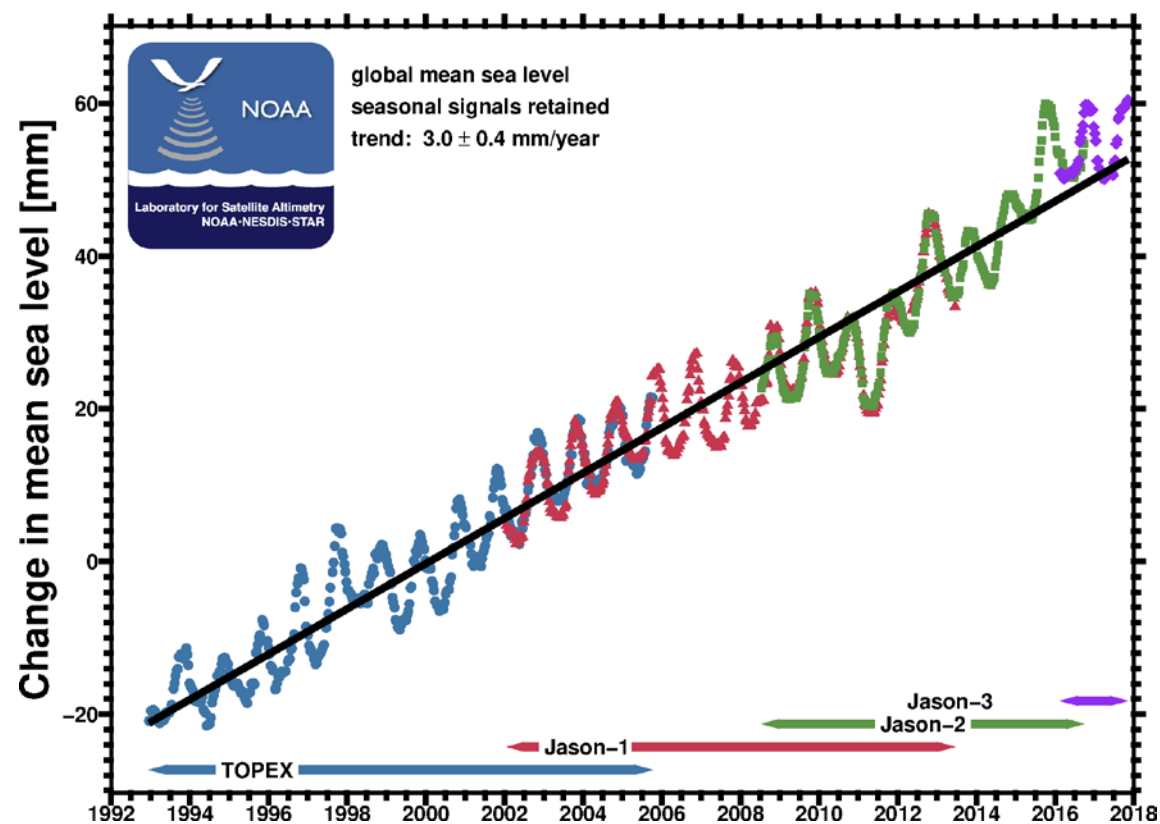
Impact: “Sea level is rising”

Tide gauges



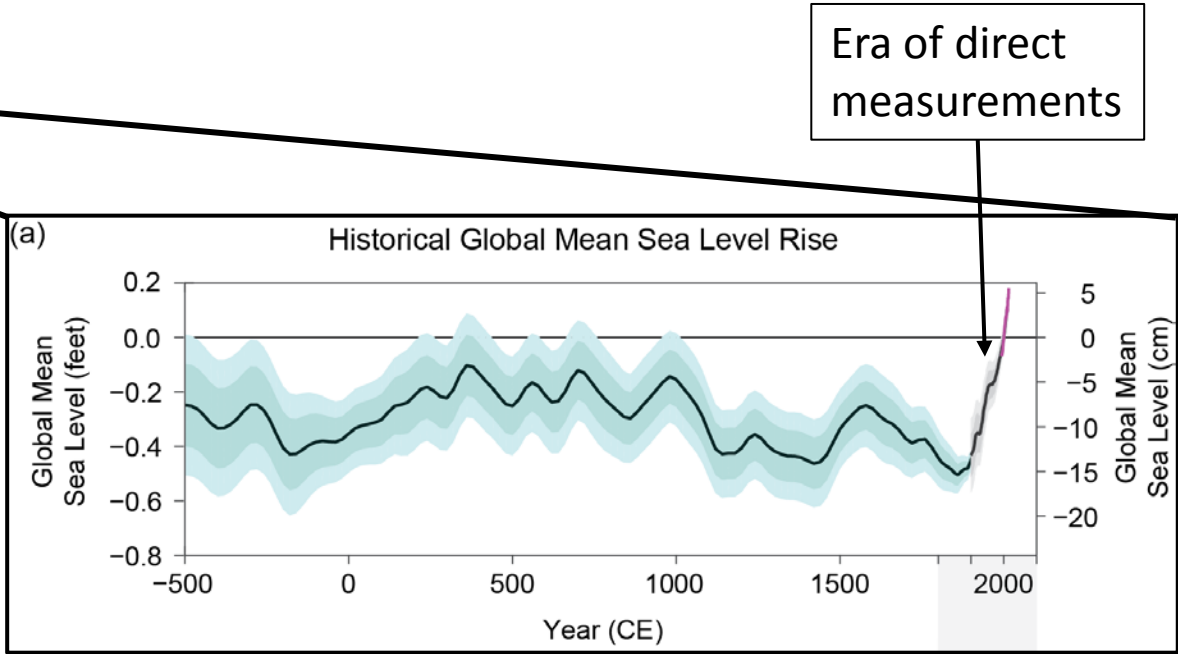
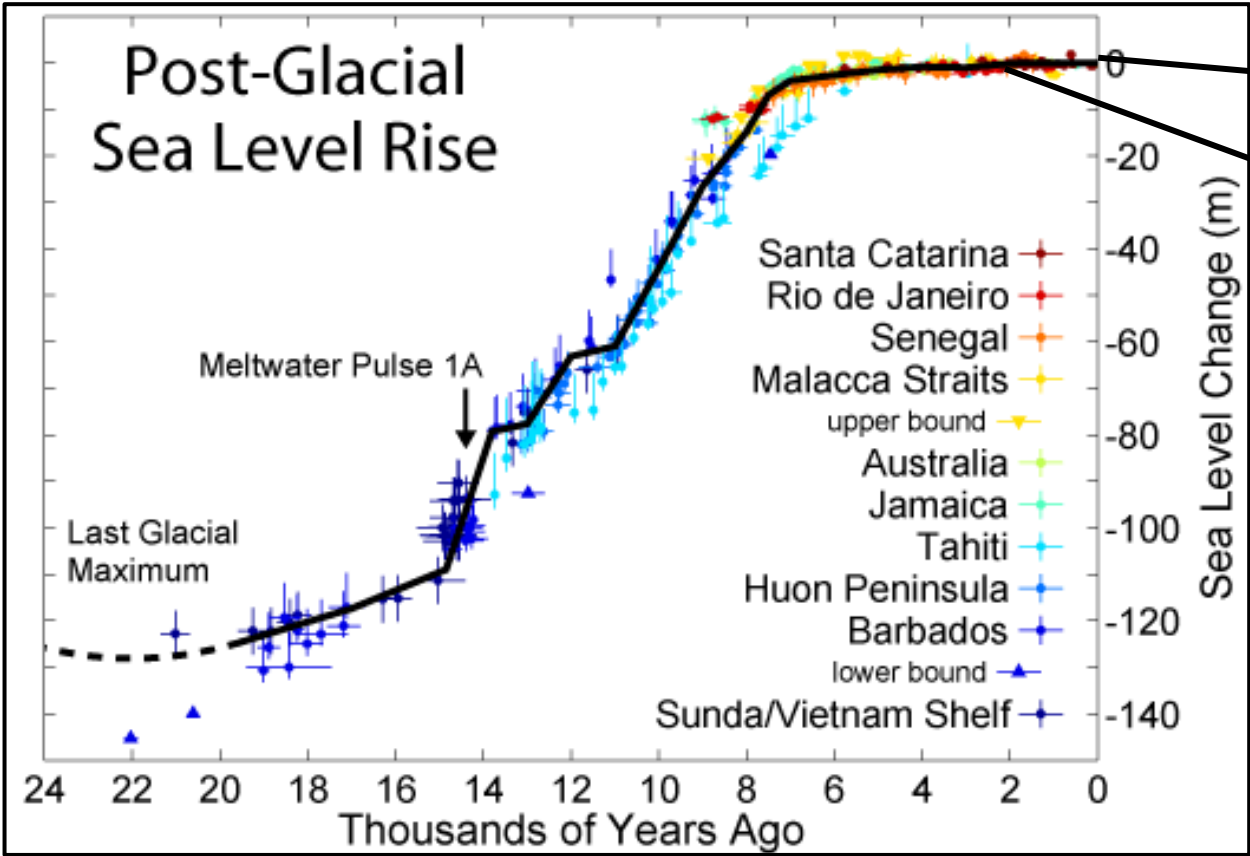
<http://rsta.royalsocietypublishing.org/content/372/2025/20130336>

Satellites



https://www.star.nesdis.noaa.gov/sod/lisa/SeaLevelRise/LSA_SLR_timeseries_global.php

Impact: “Sea level is rising”, ... But that’s not unusual

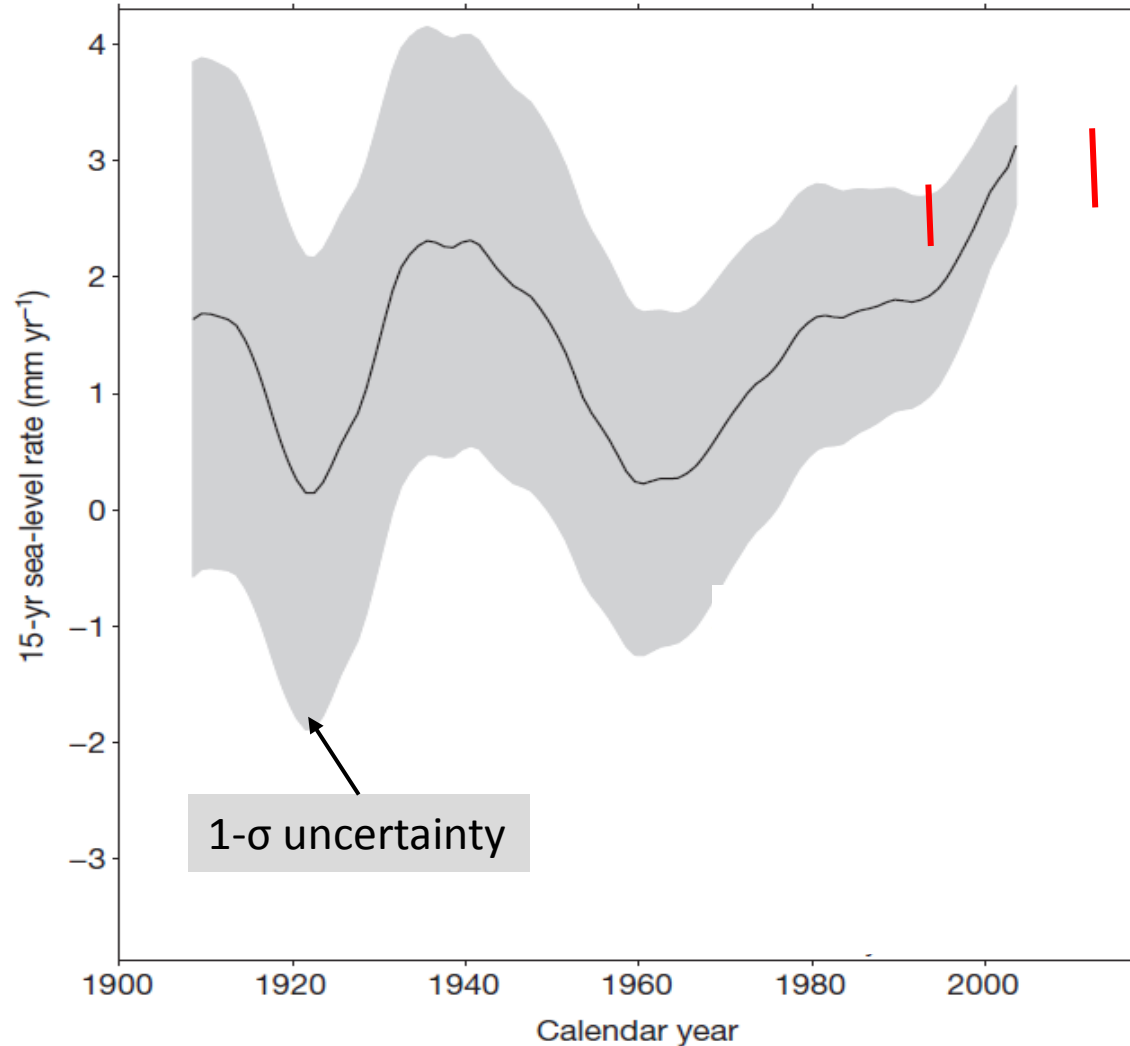


https://commons.wikimedia.org/wiki/File:Post-Glacial_Sea_Level.png

CSSR Figure ES.8, pg 26

Impact: “Sea level is accelerating”, ... But not obviously

Tide gauge analysis derived from Hay *et al.*, Nature Climate Change 7, 492–495 (2017) doi:10.1038/nature14093



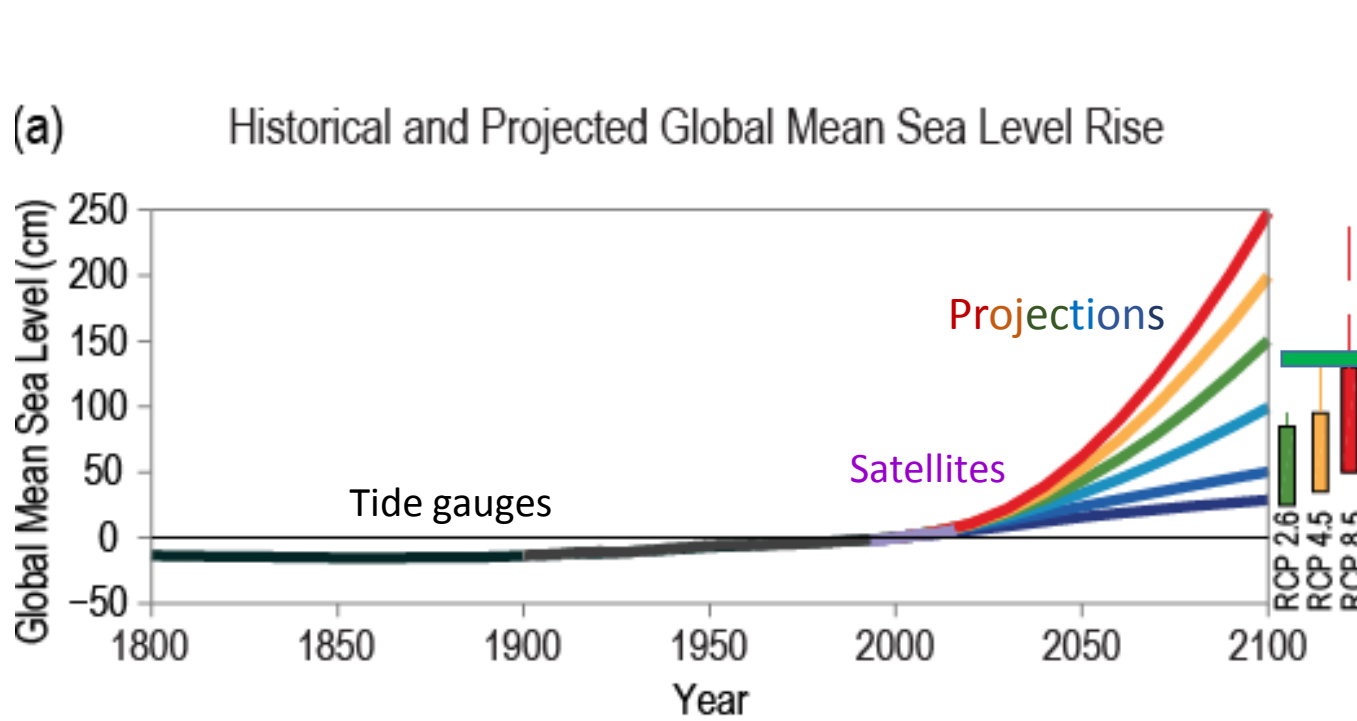
Satellite data from Chen *et al.*, <https://www.nature.com/nclimate/journal/v7/n7/full/nclimate3325.html>

- Global average precipitation is $\sim 1,000$ mm/yr
- Atmosphere holds 25 mm H₂O

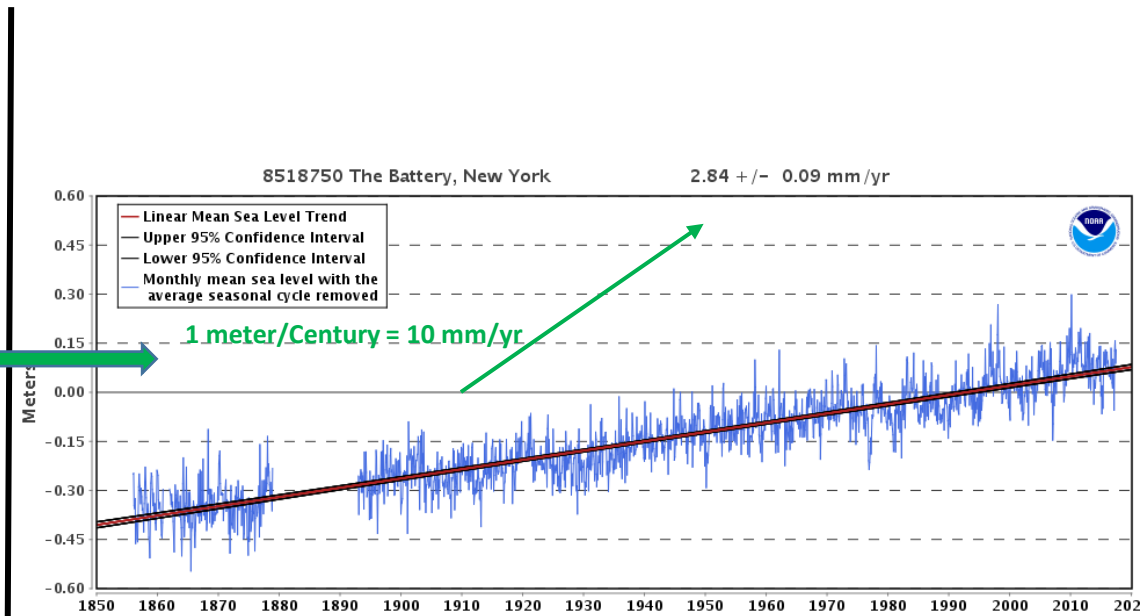
What would it take to convince Koonin:

- Good explanation of prior variability
- A several- σ signal

Impact: “Rapid sea level rise projected”, ...But discordant with observations



CSSR Figure 12.4 a), pg 342

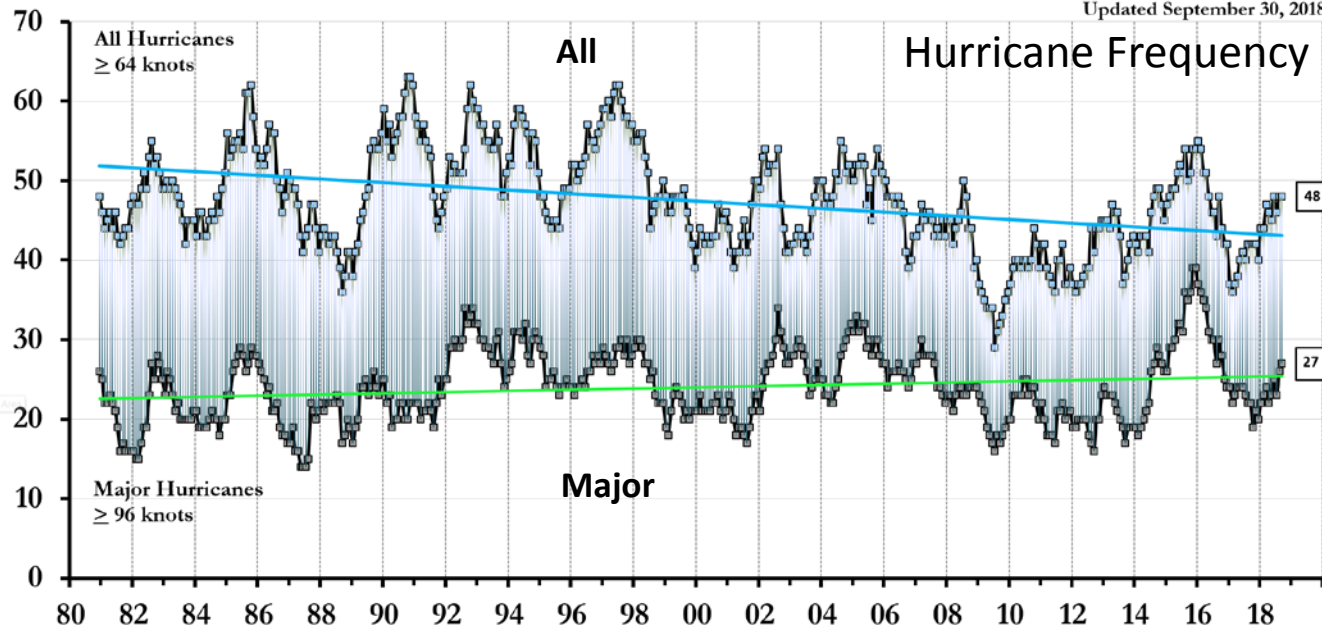


https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8518750

Sea level rises more rapidly with warmer temperatures

Global Major Hurricane Frequency -- 12 month running sums

Dr. Ryan N. Maue
Updated September 30, 2018



Impact: “Hurricanes” (1970-2017)

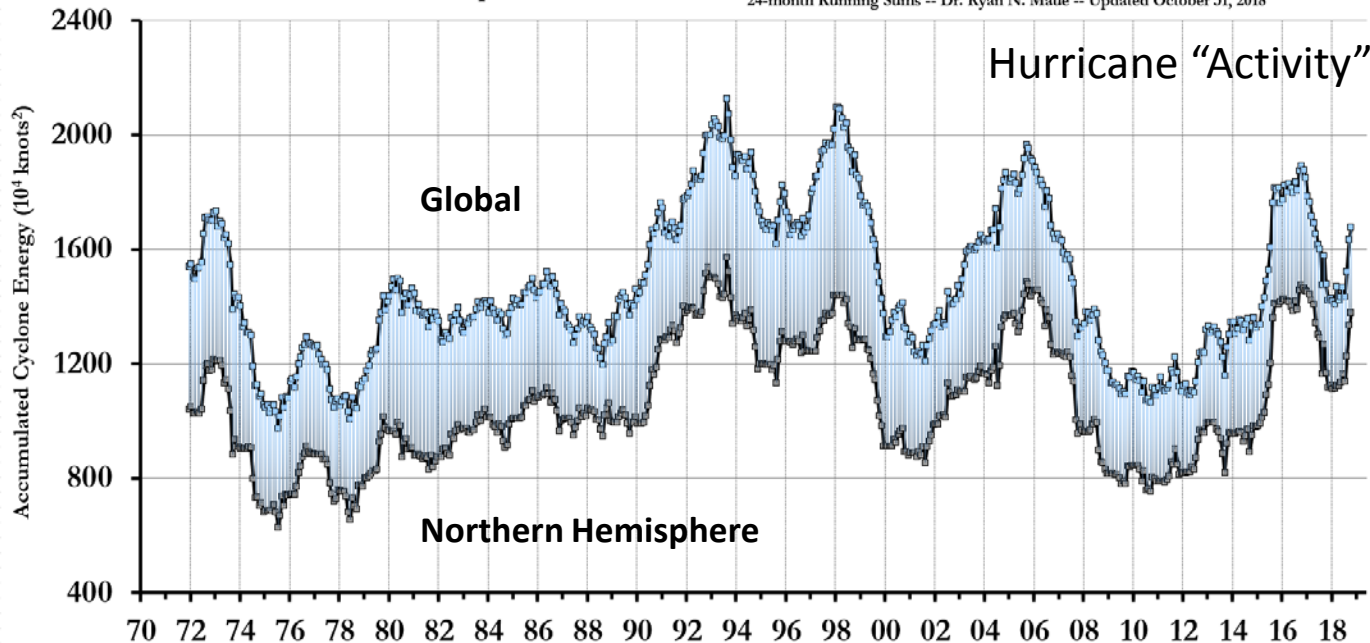
... there is still low confidence that any reported long-term (multidecadal to centennial) increases in TC activity are robust ... – CSSR, p 258

“It is premature to conclude that human activities—and particularly greenhouse gas emissions that cause global warming—have already had a detectable impact on Atlantic hurricane or global tropical cyclone activity. ...”

<https://www.gfdl.noaa.gov/global-warming-and-hurricanes/>

Posted Spring, 2016

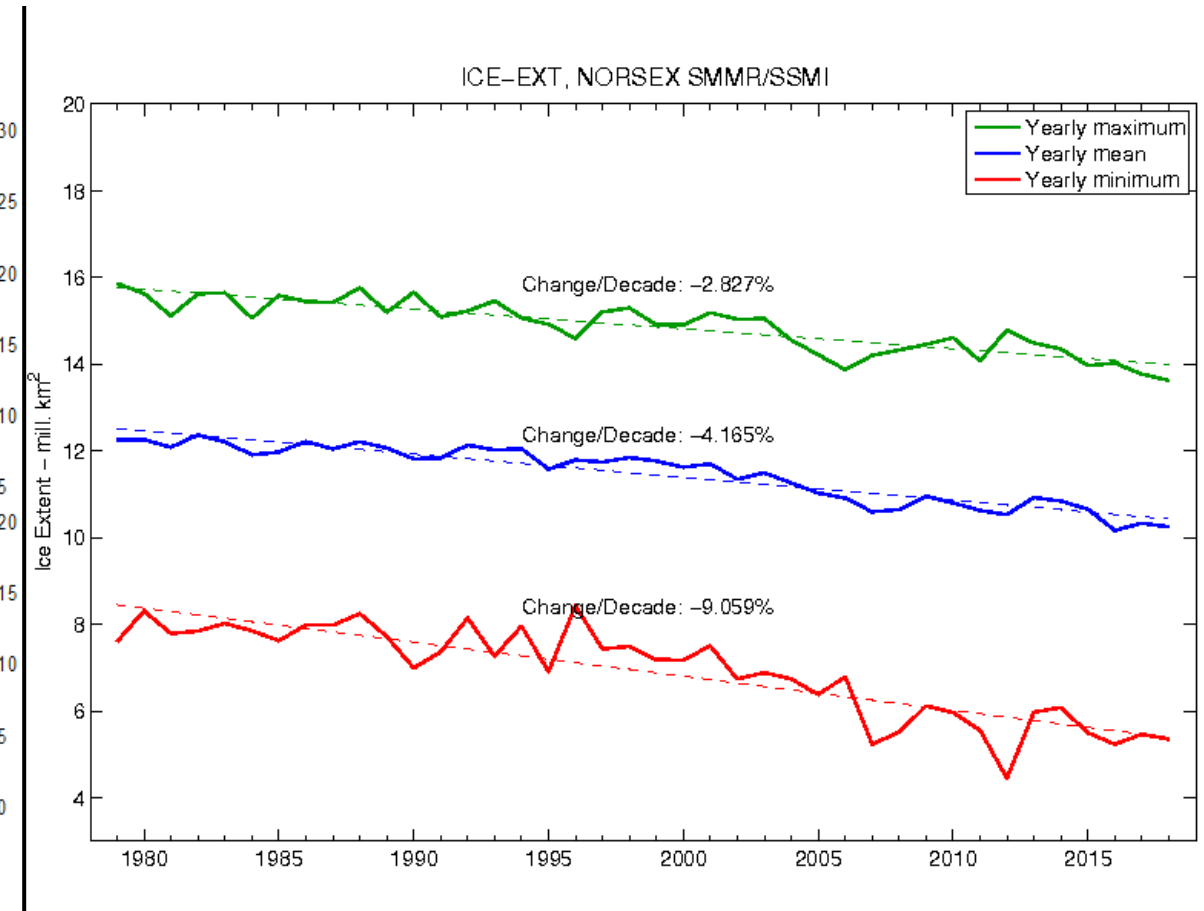
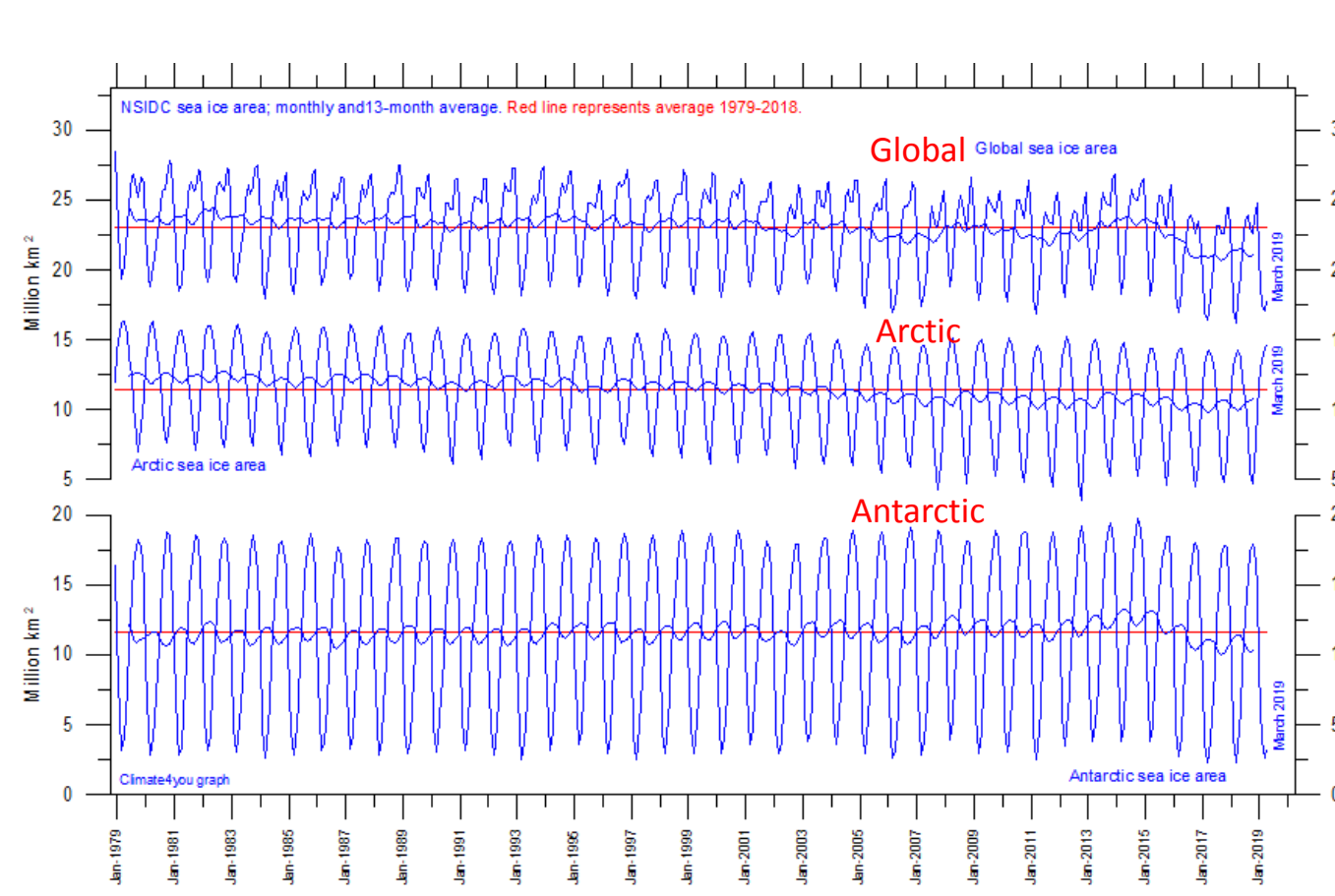
Global Tropical Cyclone Accumulated Cyclone Energy (ACE)
24-month Running Sums -- Dr. Ryan N. Maue -- Updated October 31, 2018



Impact: “Arctic sea ice is disappearing”

Sea Ice Area

Arctic Sea Ice Extent



Impact: “Arctic sea ice is disappearing”

...**But** it is highly variable

From a NYTimes report:

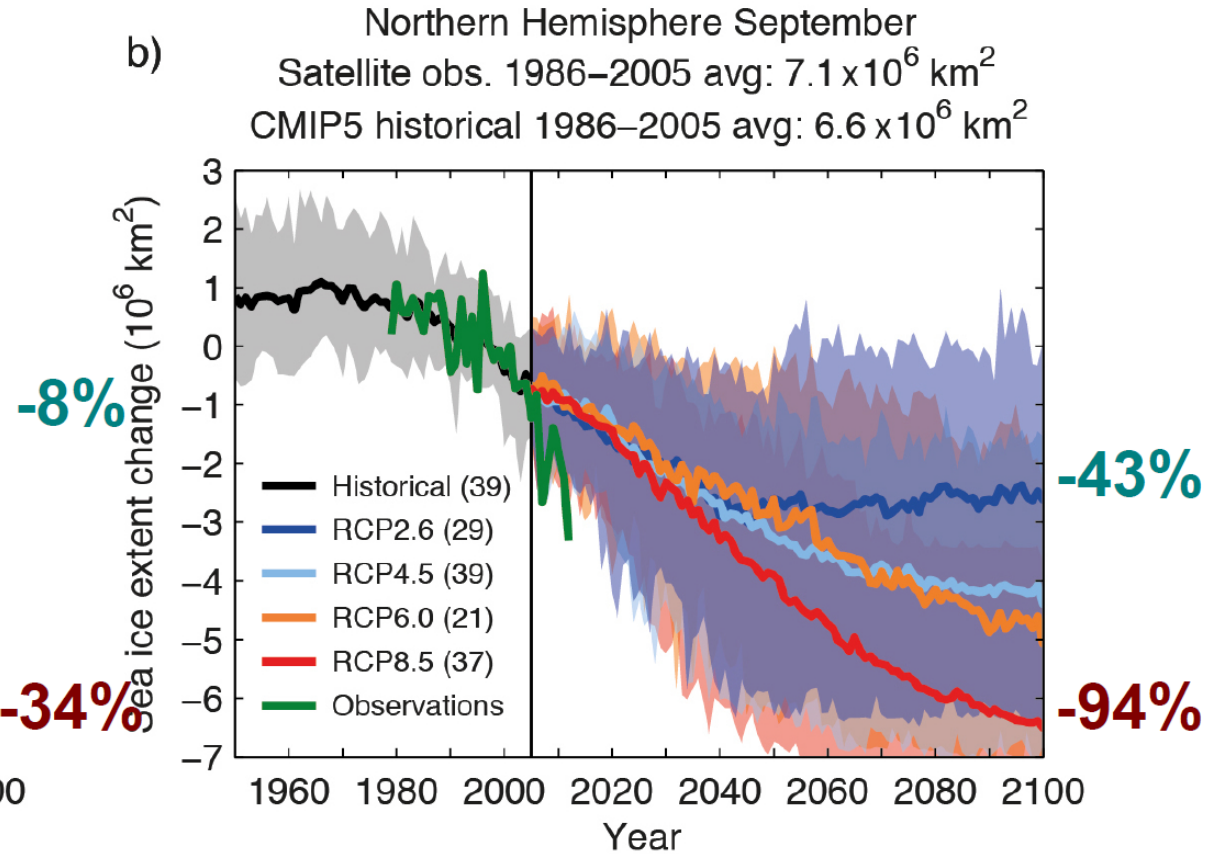
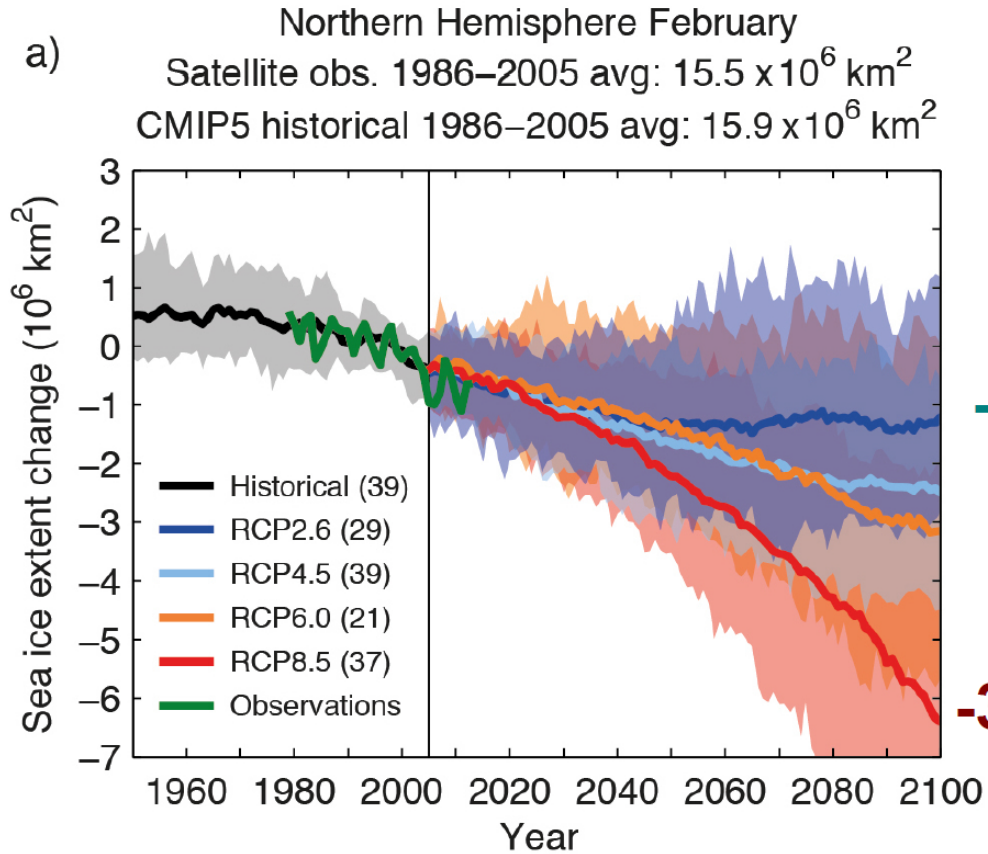
The Arctic seems to be warming up. Reports from fishermen, seal hunters, and explorers ... all point to a radical change in the climatic conditions, and hitherto unheard of temperatures in that part of the earth. Old glaciers have disappeared and land once covered with field ice is bare.

The [Eastern] Arctic is not recognizable as the same region fifty years ago.

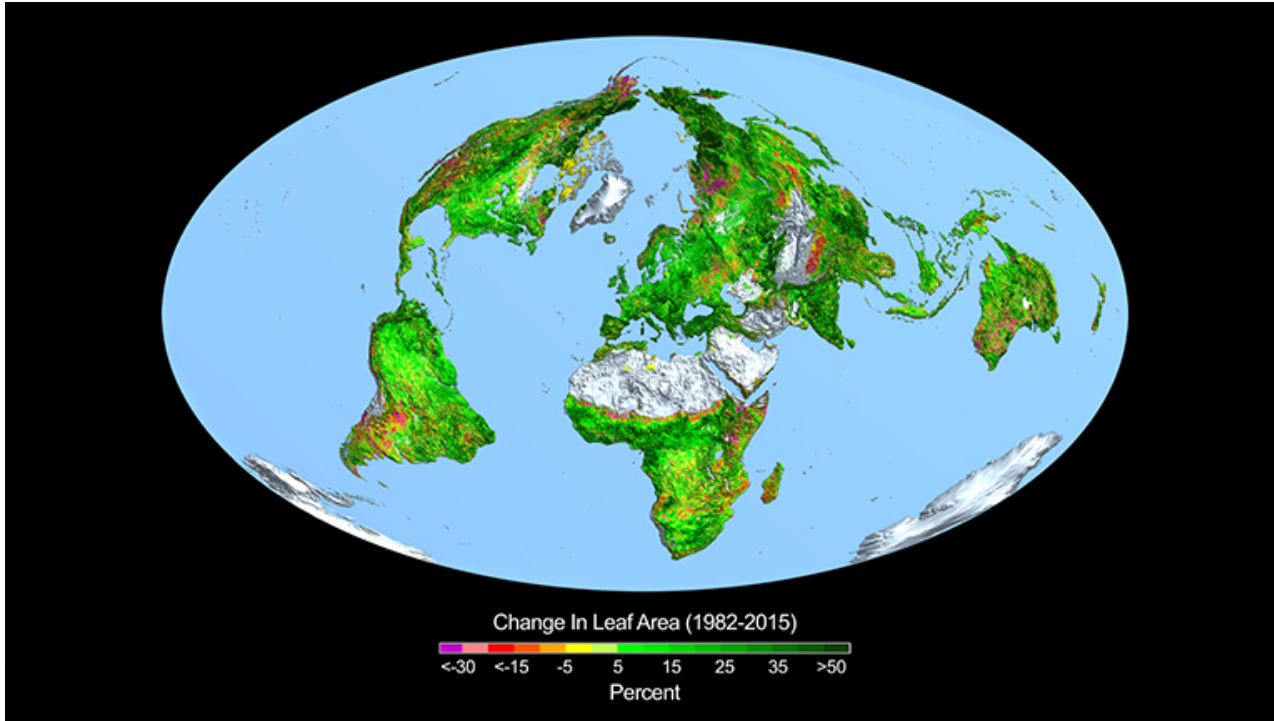
Formerly Spitzbergen held an even Summer temperature up to 3C; this year recorded temperatures up to 15 degrees and last Winter the ocean did not freeze over even on the north coast of Spitzbergen.

- Published February 23, 1923 (!)

Impact: Arctic sea ice projections



Impact: “Agriculture will be impacted”,...But plants love CO₂ and farmers aren't dumb

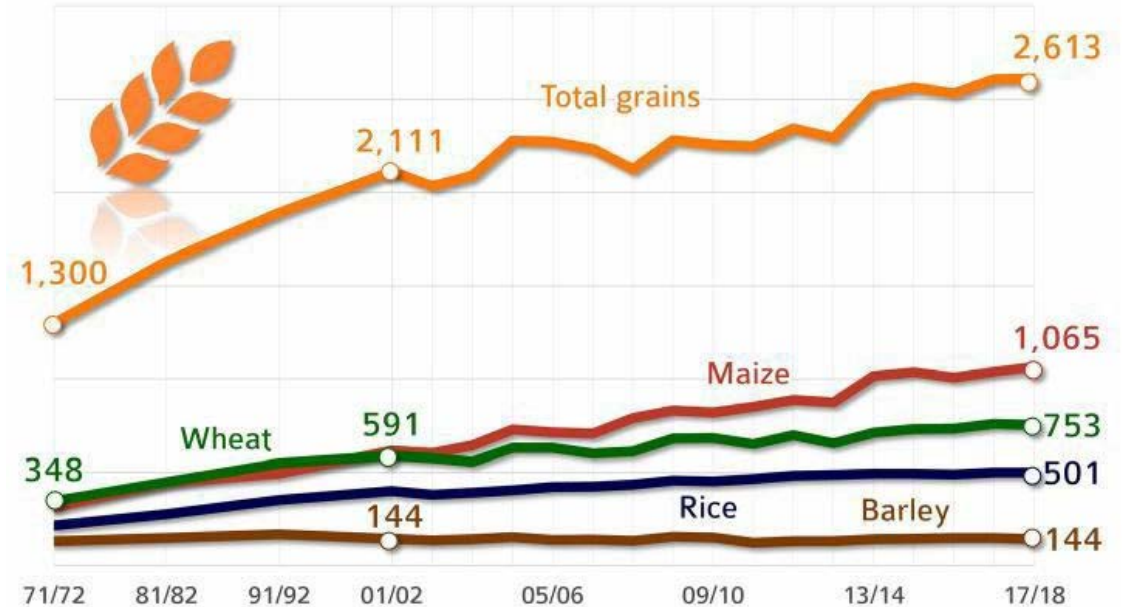


<https://climate.nasa.gov/news/2436/co2-is-making-earth-greener-for-now/>

Rising CO₂ concentration has made the earth greener (for now?)

Production of grains, total and by major crops, worldwide, 2017/18, estimated, in million tonnes

© AMI 2017 | Source: FAO

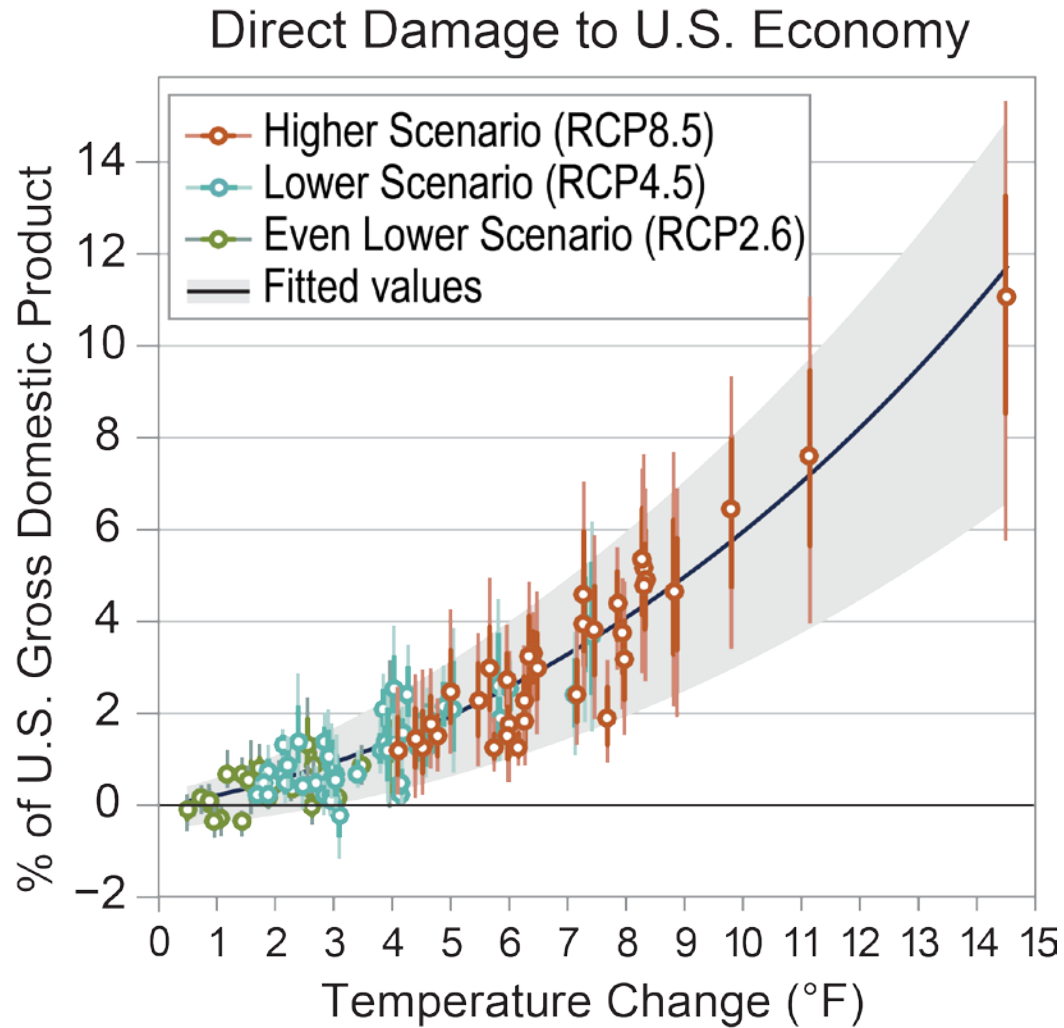


Total grains = maize, wheat, barley, rice, rye, oat, sorghum

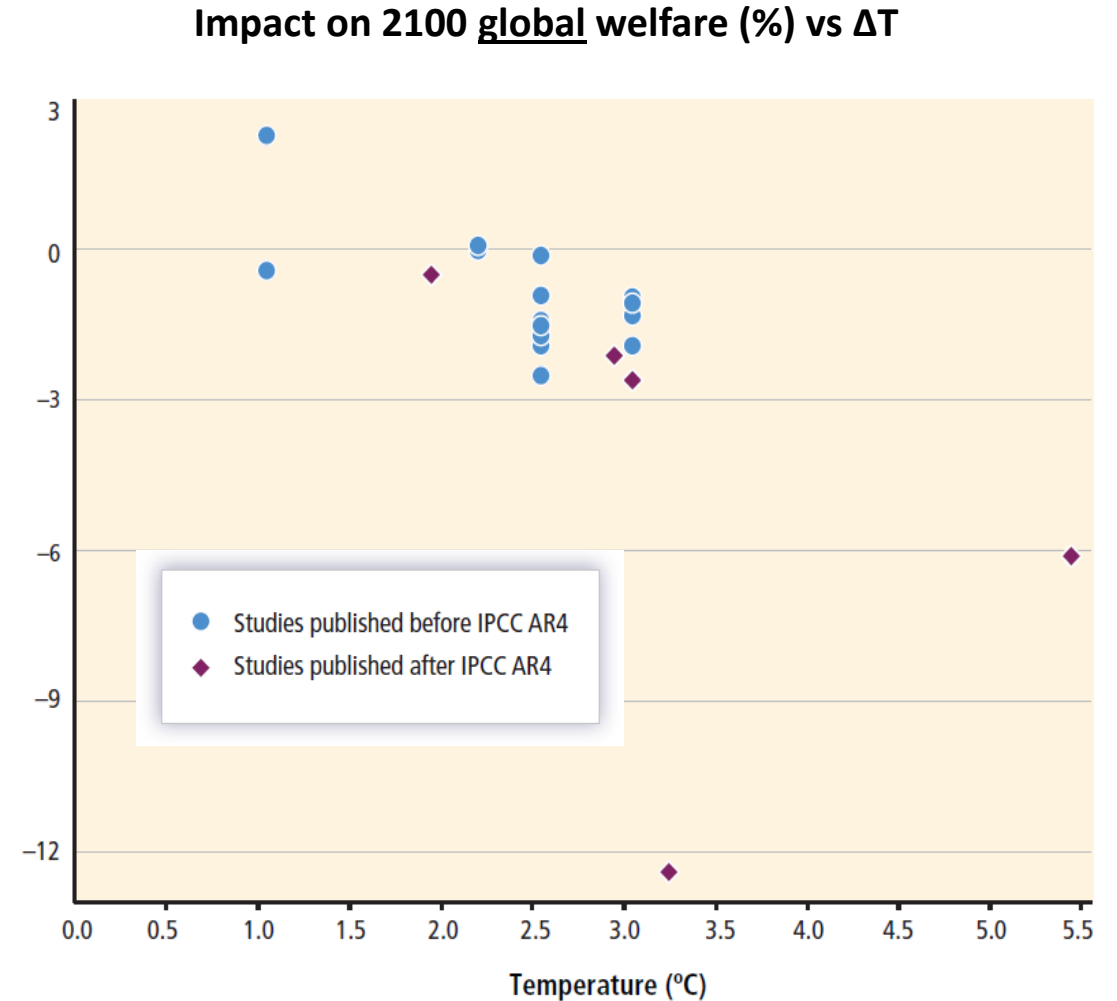
Agriculture has thrived despite climate change to date

Impact: Climate change will crash the economy

Ref: SEK WSJ 11/26/18

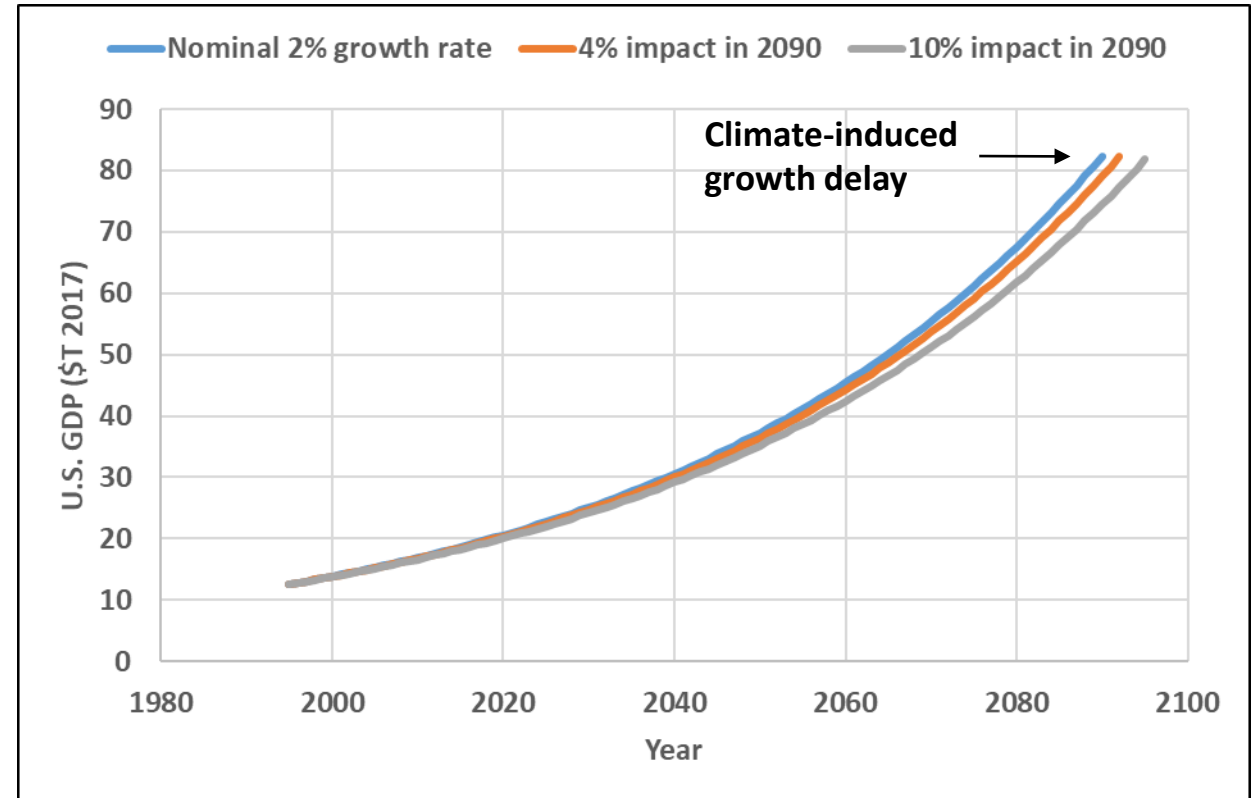
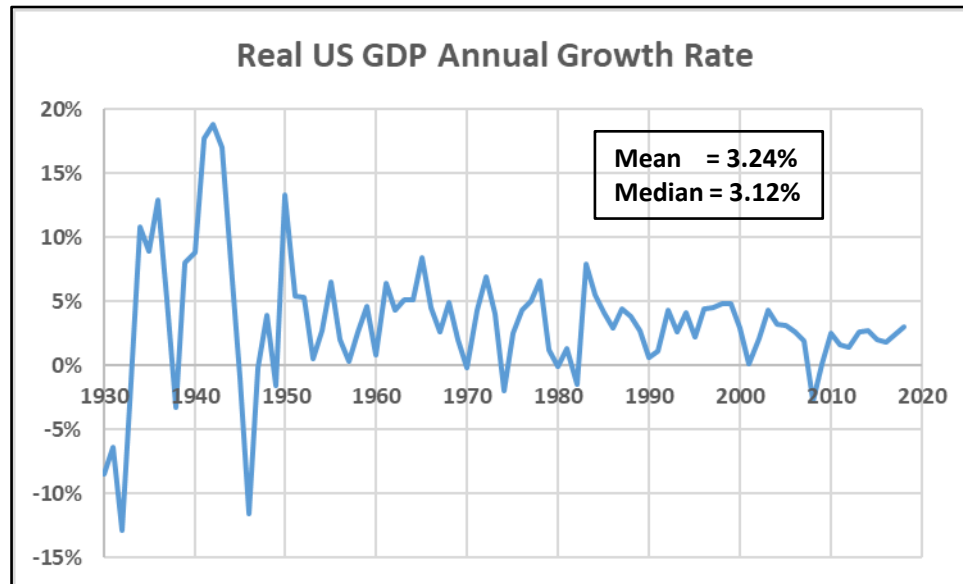
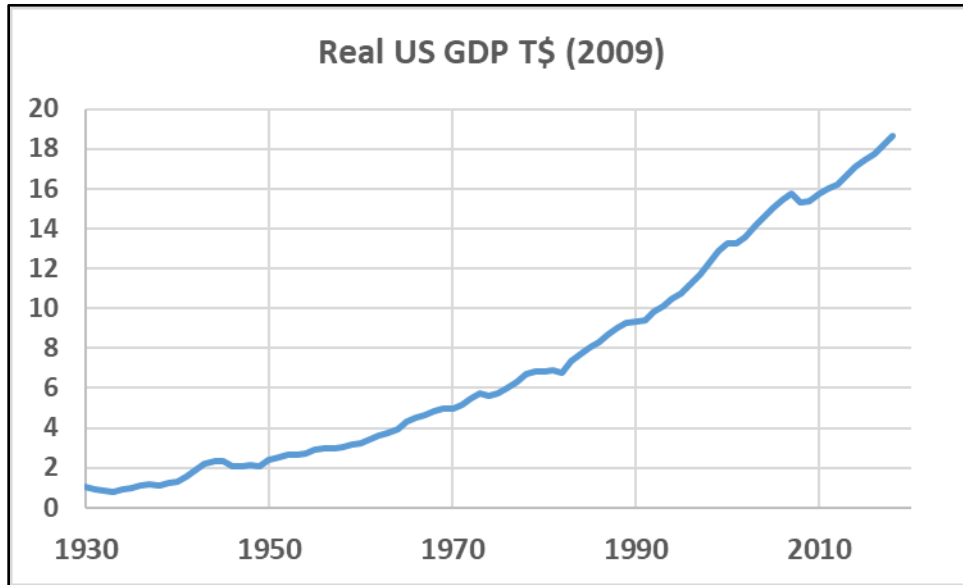


NCA4, vol II, Fig 29.3 (global T; 2080-2099 rel 1980-2010)



AR5 WGII Figure 10.1

... but at worst a bump in the road



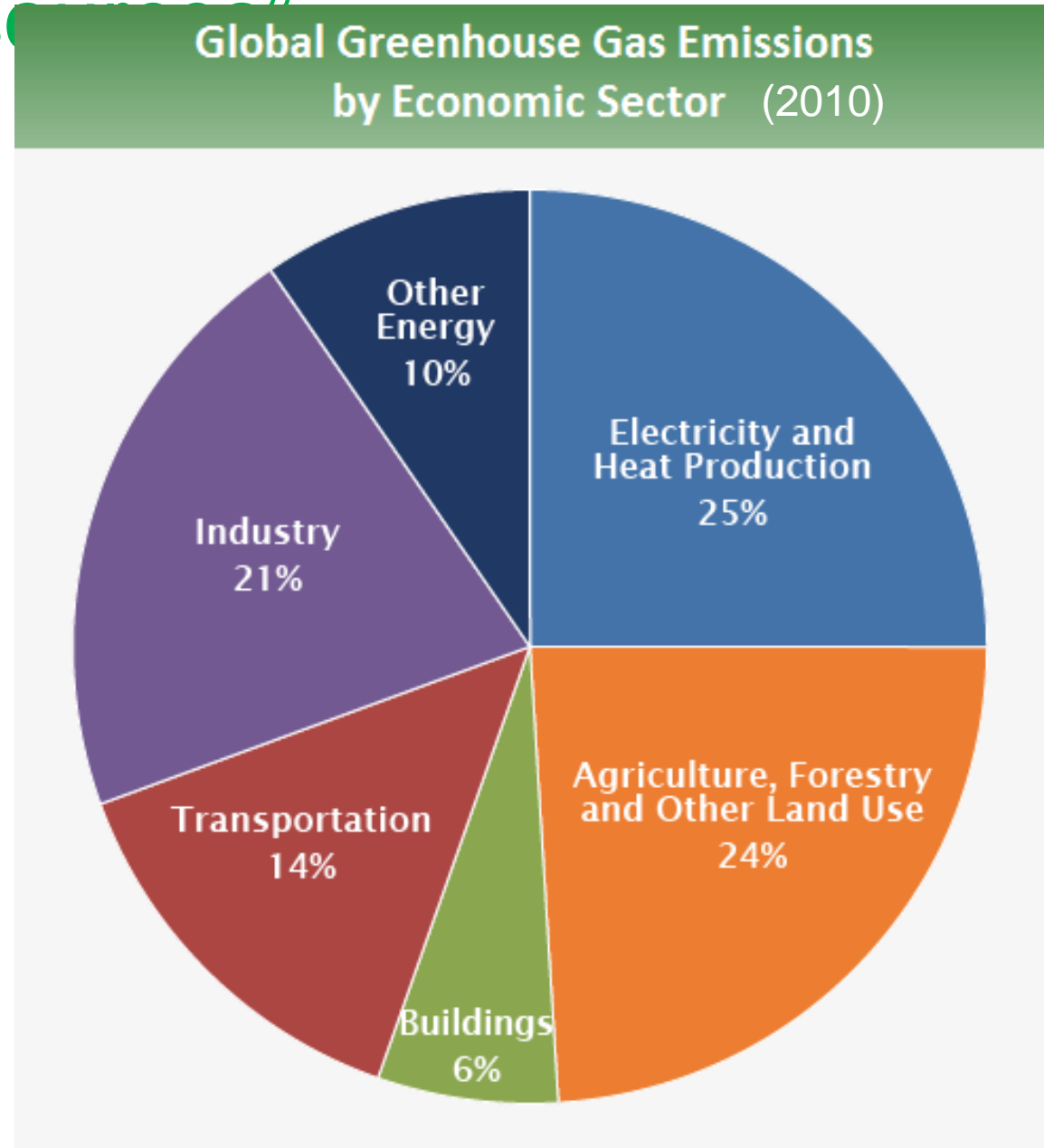
- At 2% CAGR,
10% decrement in 2090 = 5 years delay
- \$550B = 0.6% in 2090 = 4 months delay

Response: “We can (and must) reduce GHG emissions promptly to prevent the worst impacts” ... **But** that’s very hard

And it’s only one of three strategies

- **Mitigation** of human influences – reduce GHG emissions
 - GHG-lite energy sources (stationary, transport); energy efficiency
 - Aerosols; Land use; Agriculture
- **Adaptation**
 - Adapt infrastructure (e.g., sea walls); adapt processes (e.g., crops)
- **Geoengineering** – intentional intervention to counteract GHG influence
 - Carbon-dioxide removal? Solar radiation management?
- **For each:** Costs? Efficacy? Collateral effects (positive and negative)? Perception?

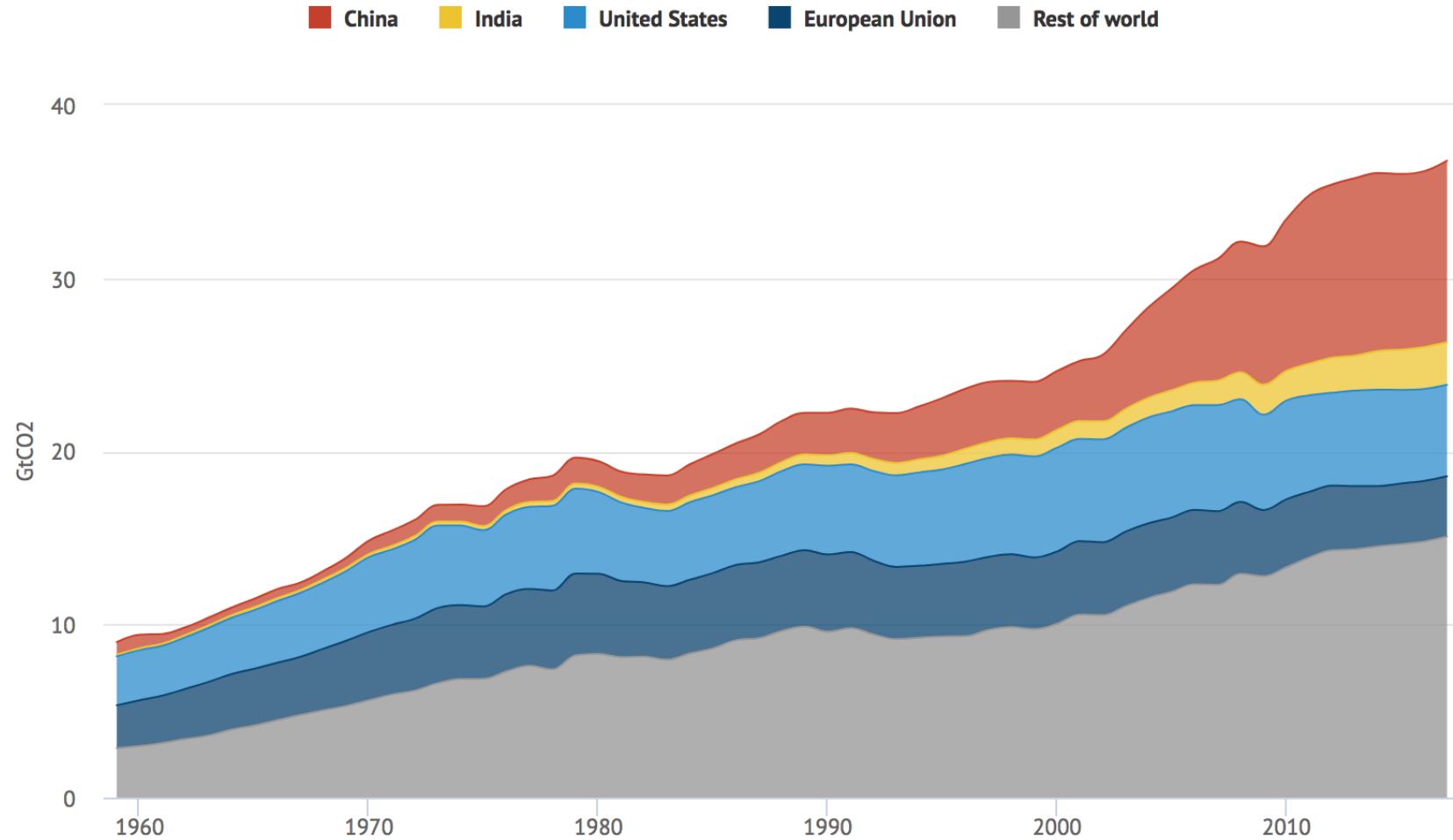
Response: “Diverse GHG Sources”



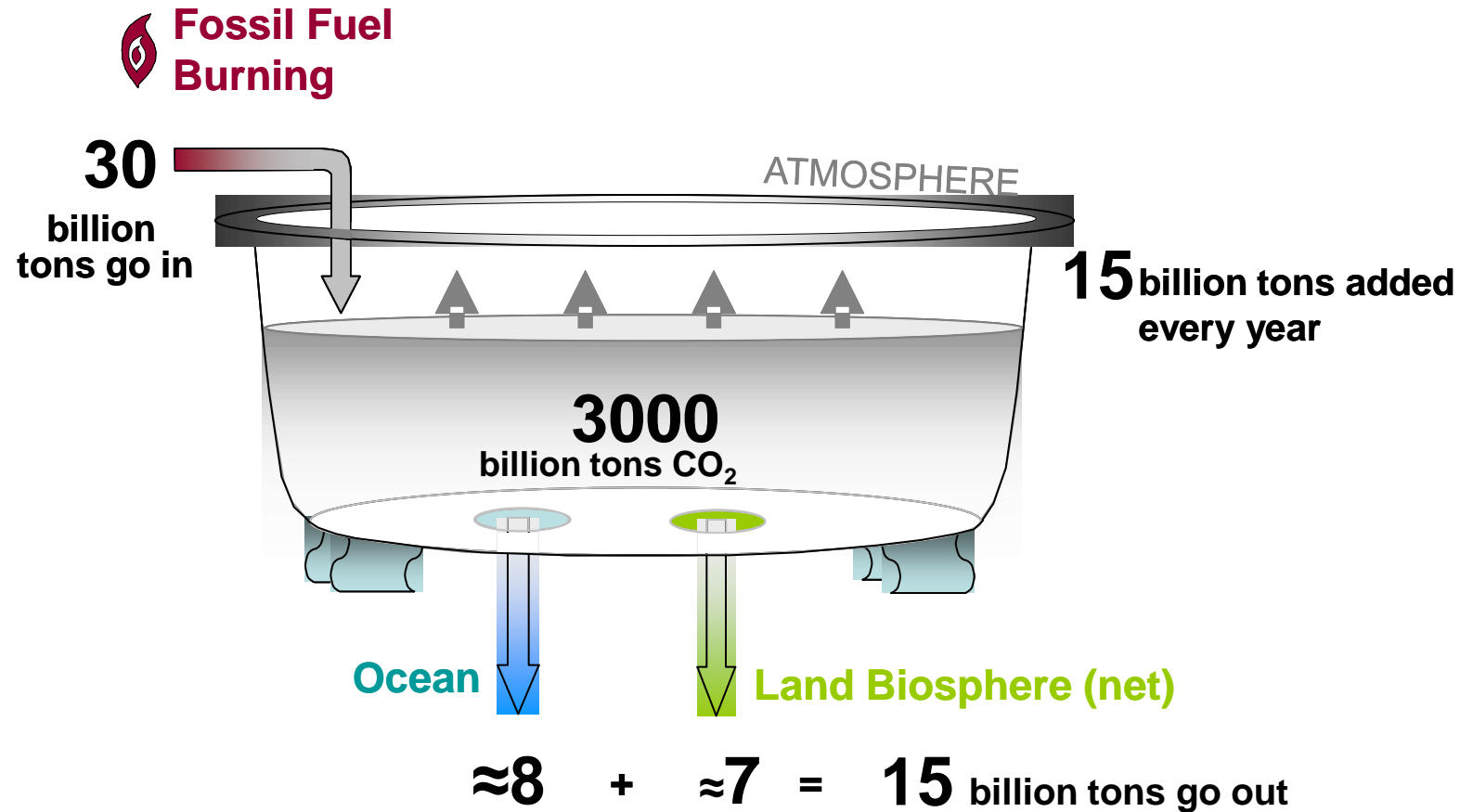
<https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data>

Response: Global CO₂ emissions

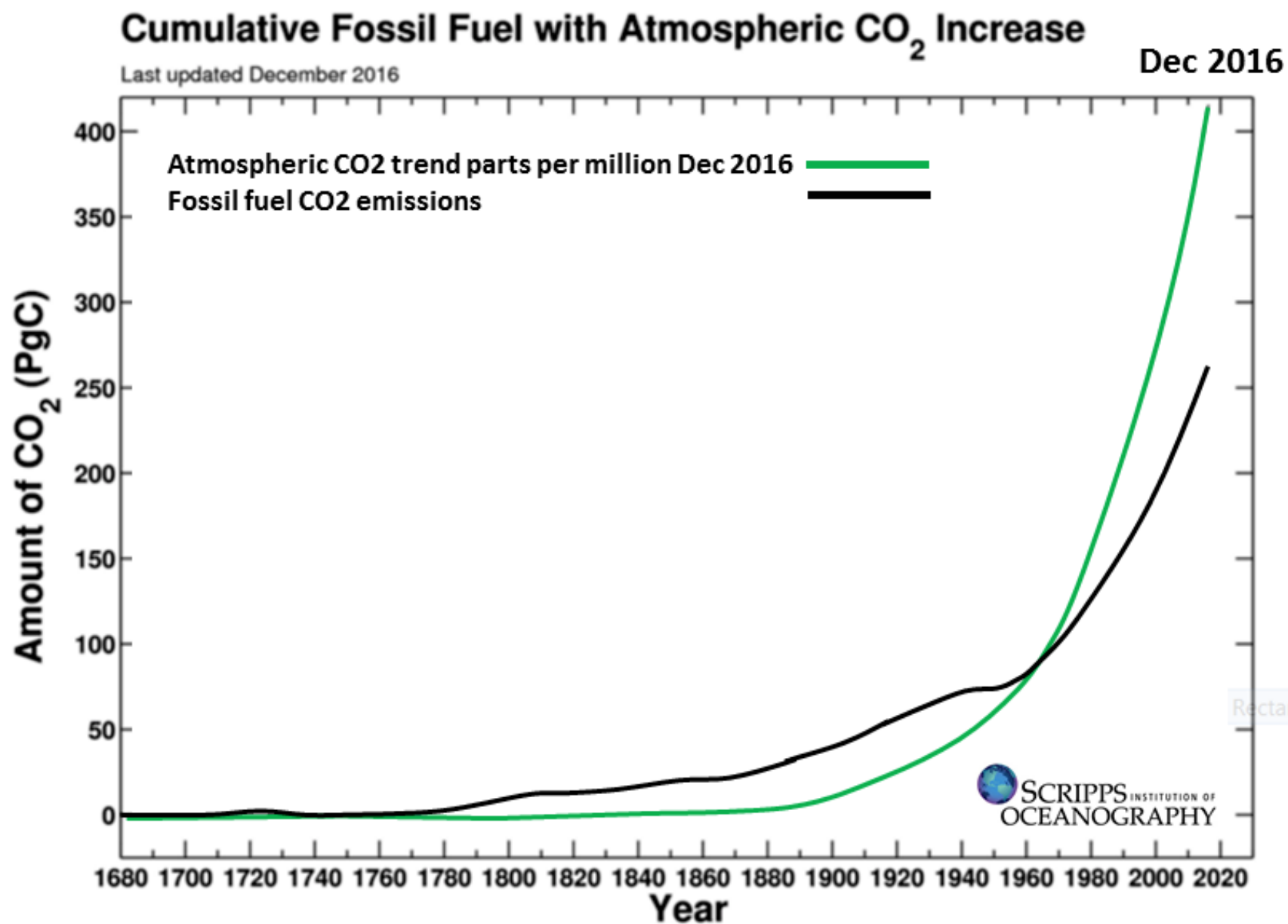
Annual CO₂ emissions from fossil fuels by country, 1959-2017



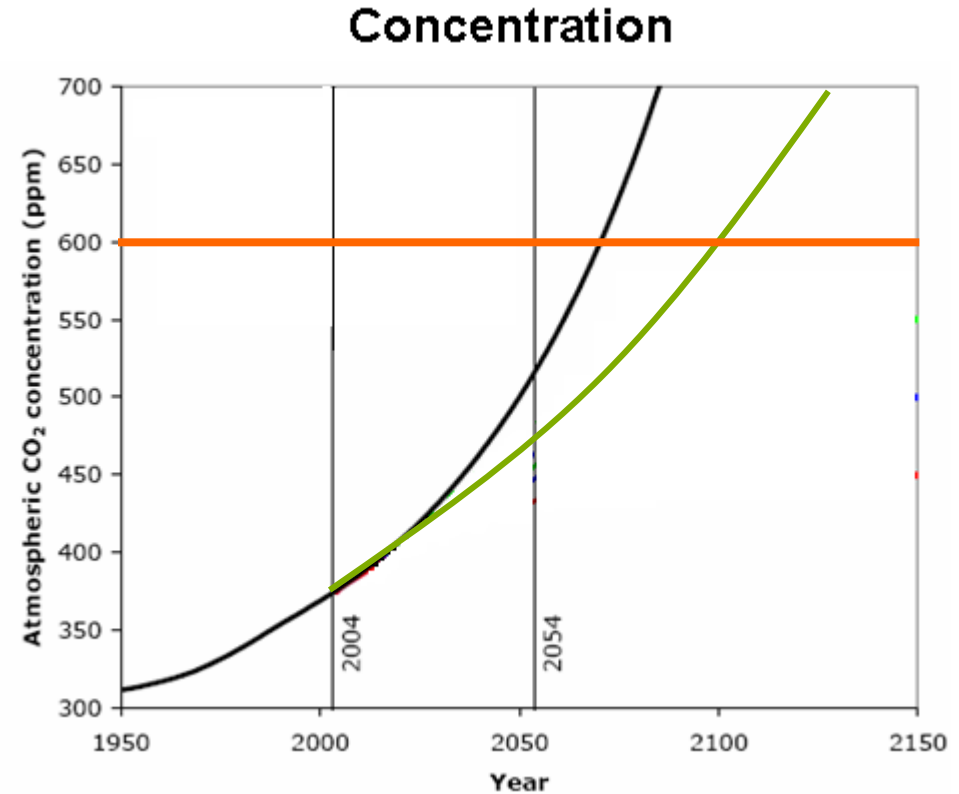
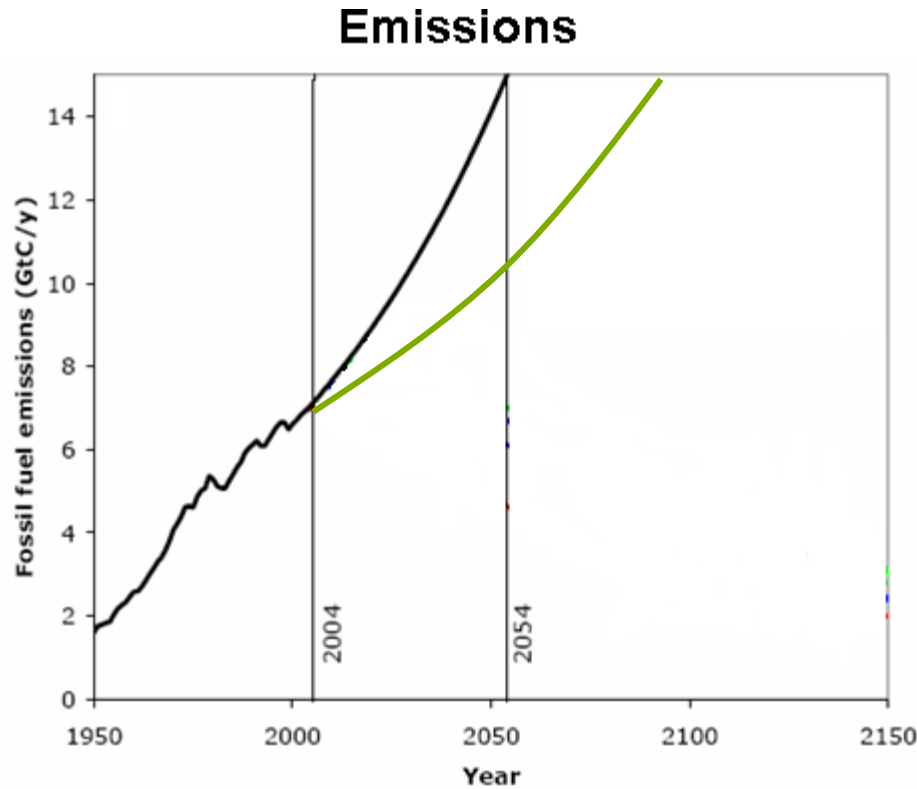
Response: “Half of the CO₂ emitted stays in the atmosphere for centuries”



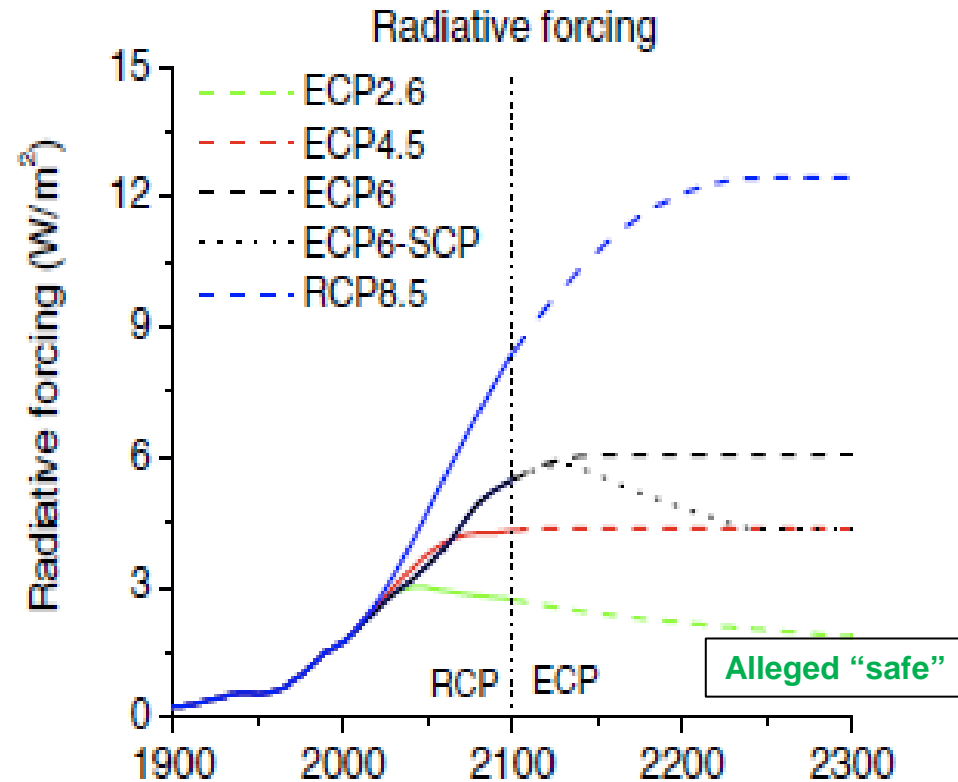
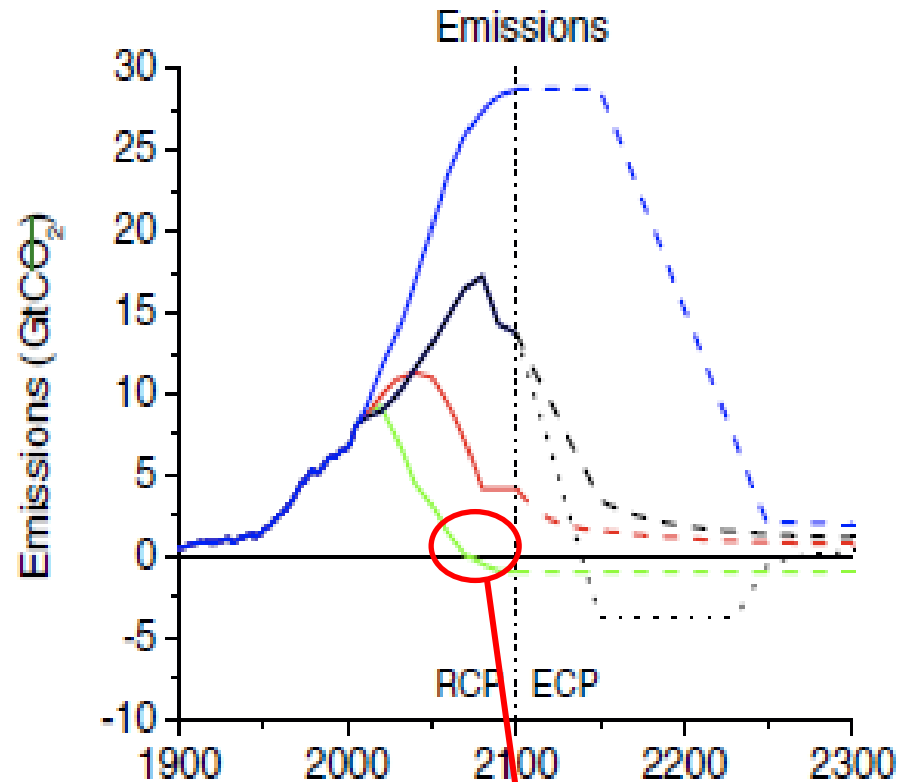
Cumulative Fossil Fuel with Atmos CO₂ Increase



Response: ... But the long CO₂ lifetime is highly problematic



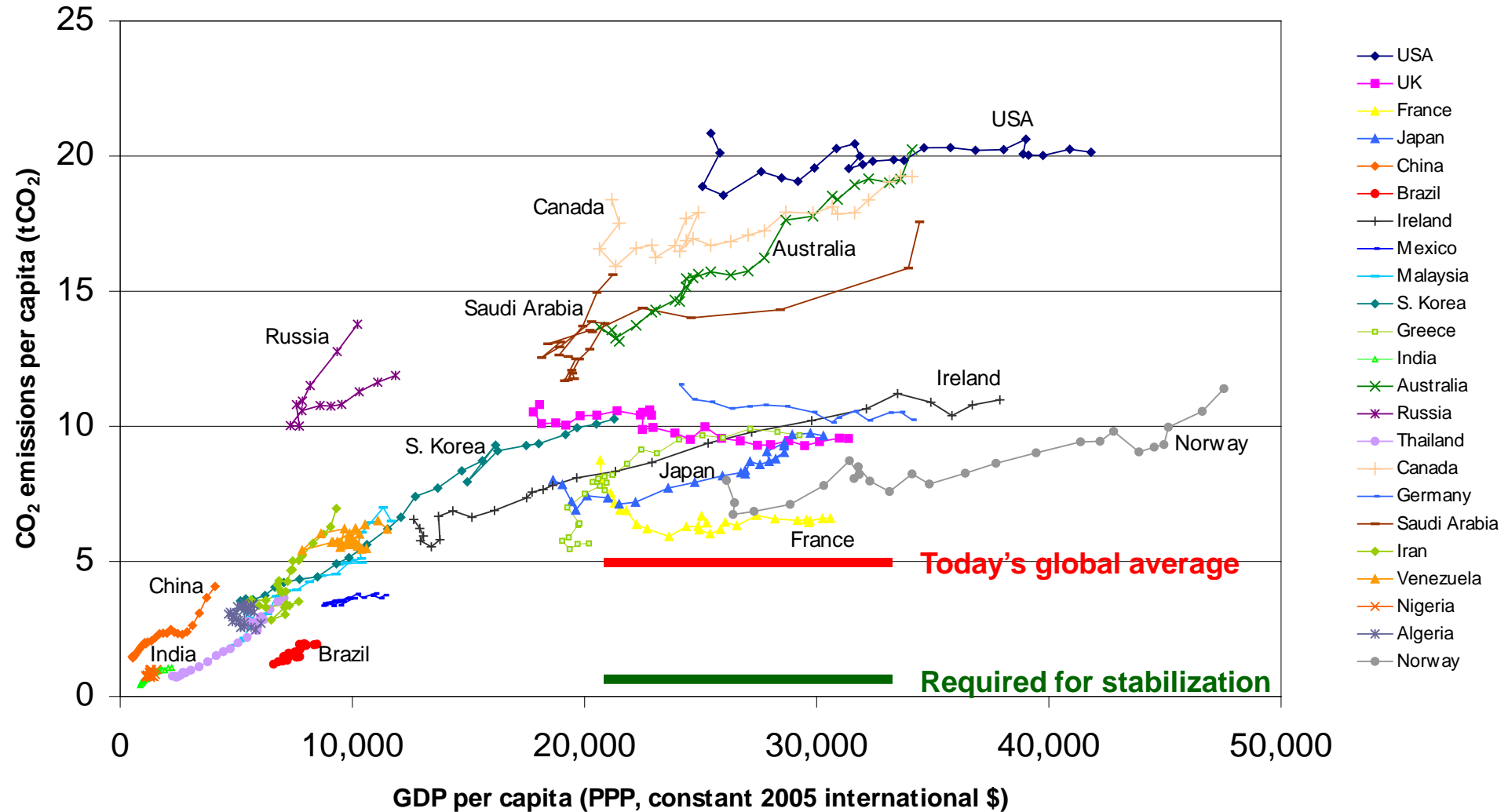
Response: IPCC says severe emission reductions just to stabilize human influences



ECP = Extended Concentration Pathway

Post-2075: NO oil, NO gas, NO coal, NO agricultural emissions
(absent sequestration or biological offsets)

Response: CO₂ emissions and GDP per capita (1980-2005)



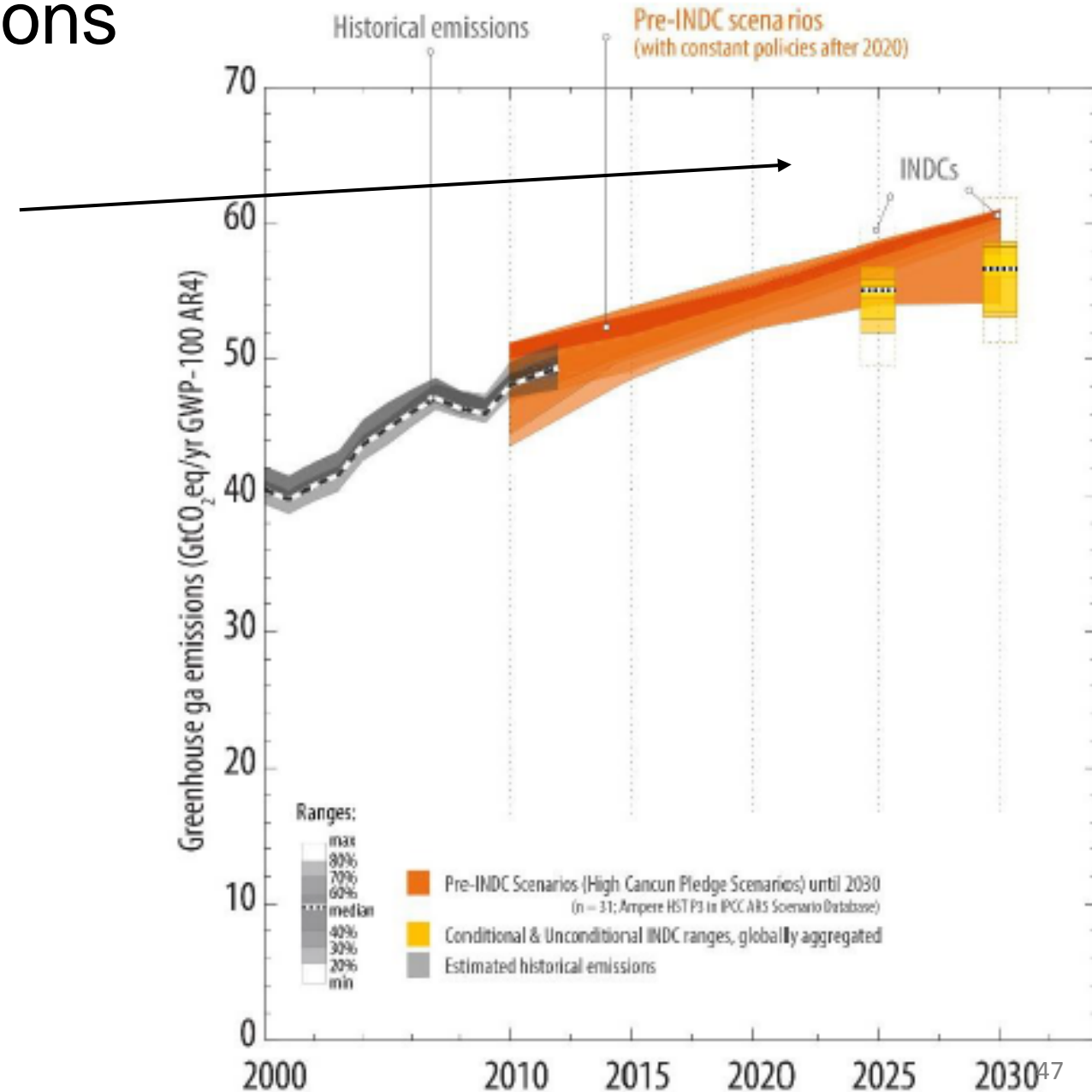
Response: “The Paris Agreement is important,”

...But won't much reduce emissions

INDC = “Intended Nationally Determined Contributions” (pledges)

Paris agreement:

- Has 5-year reviews with self-reporting
- Has no enforcement mechanism
- Is non-binding
- US, EU, Japan will not meet their 2030 commitments without further policy changes
- Chinese commitment to peak CO₂ emission by 2030 appears on track



Response: Adaptation is good for all seasons

- It is **agnostic**
 - indifferent to natural vs human-caused
- It is **proportional**
 - adapt more if the change is greater
- It is **local**
 - politically palatable as spending is “here and now”
 - does not require global consensus
- It is **autonomous**
 - It will happen on its own
- It is **effective**

But adaptation is much easier if you're richer

Koonin's takeaways (descriptive)

- **Climate continues to change** under natural and growing human influences
- The “**consensus**” is **not as solid** as popularly perceived
- Beyond rising temperature, most **projected impacts have not clearly emerged**
- We are **unlikely to even stabilize human influences** this century; **adaptation** will be the dominant response.

Response: “If I were in charge” (normative)

- **Clarify the policy discussion and the science that underpins it**
 - Sustain and bolster climate observations
 - Reframe the discussion to “values”; don’t use alleged certainty as a club
 - A scientific “red team” exercise to accurately portray “the science” (SEK, WSJ 4/20/17)
- **Pursue “easy” emissions reductions**
 - Non-CO₂ GHGs
 - Cost-effective efficiencies
 - Leverage credible side benefits (local environment, energy security)
 - RD&D for low-cost, emissions-free technologies
 - Fission, solar, storage/grid management, biofuels, CCS, fusion, ...
- **Reduce emissions further if/when**
 - the science becomes more certain (signal emerges from the noise) *or*
 - a values consensus emerges *or*
 - zero-emissions technologies become more feasible
- **Pursue adaptation vigorously**
 - Modes of adaptation (“wedges”)? What are we adapting to?
- **Investigate geoengineering as a last-resort option**
 - Research program? Feasibility tests? Governance?

Questions? Comments?