

Climate Change: Uncertainties and Time Scales

What we know and what we don't know

Geoffrey K. Vallis

Seattle, May 2013



Vancouver Sun

CULTURE May 09, 2011

Study: No Global Warming in North America

FIRE IT UP 15 67

Tweet 26

Recommend 7

SHARE +



AP Graphic

By Tom Spears, Ottawa Citizen

When your lawn scorches or the geraniums croak, it may be premature to blame global warming. One of the world's top science journals says climate hasn't changed in most of North America -yet.

In fact, says a study in *Science*, temperatures in most of North America have resisted the global trend. Elsewhere, the warming has already affected agriculture significantly, reducing yields and causing food inflation.

READ THE FULL STORY AT VANCOUVERSUN.COM



You think this is hot? Get used to it

Boiling summers could be norm, scientists say

By Doyle Rice
USA TODAY

This summer's stifling heat along the Eastern Seaboard and Deep South could be a preview of summers to come over the next few decades, a report by the National Wildlife Federation and the Asthma and Allergy Foundation of America says today.

In fact, federation climate scientist Amanda Staudt says, the summer of 2010 might actually be considered mild compared with the typical summers in the future. "We all think this summer is miserable, but it's nothing compared to what's in store for us," she says.



July in New York City: A boy plays in a Washington Square Park fountain as a heat wave with record temperatures rolled across the eastern USA.

Holiday Blizzard: More Signs of Global Warming

By Bryan Walsh | Tuesday, Dec. 28, 2010

Like 2.2k Tweet 293 0 Share 51

It's become as much a winter tradition as eggnog at Christmas and champagne on New Year's Eve — the first major snowstorm of the year bringing out the climate-change skeptics. And the bona fide blizzard that has frozen much of the Northeast just a few days after winter officially began definitely qualifies as major. But while piles of snow blocking your driveway hardly conjure images of a dangerously warming world, it doesn't mean that climate change is a myth. The World Meteorological Organization recently reported that 2010 is almost certainly going to be one of the three warmest years on record, while 2001 to 2010 is already the hottest decade in



People dig out along 72nd Street in New York City on Dec. 27,

THE INDEPENDENT

FREE MAGAZINE INSIDE TODAY

COMPLETE 7-DAY COURSE IMPROVE YOUR PHOTOGRAPHY

PART 1: HOW TO GET THE MOST FROM YOUR DIGITAL CAMERA

FINAL WARNING

According to yesterday's UN report, the world will be a much hotter place by 2100. This will be the impact...

+2.4°

COASTAL BEERS ALMOST LOST

By 2050, coastal cities like Miami and New York City could lose up to 2.4 degrees of beachfront property to rising sea levels.

+3.4°

MANHATTAN FLOODS TO DESERT

By 2050, Manhattan could lose up to 3.4 degrees of its area to rising sea levels.

+4.4°

WASHINGTON DC CAPS DISPLACE MILLIONS

By 2050, Washington DC could lose up to 4.4 degrees of its area to rising sea levels.

+5.4°

SEA LEVELS RISE BY FIVE METERS

By 2050, sea levels could rise by 5.4 meters, flooding coastal cities.

+6.4°

MOST OF LIFE IN EXTREME HEAT

By 2050, most of the world's population could live in extreme heat.

Snowstorm: East Coast Blizzard Tied to Climate Change

TIME

 Buzz up! 889 votes  Send  Share

By BRYAN WALSH — 2 hrs 18 mins ago

As the blizzard-bound residents of the mid-Atlantic region get ready to dig themselves out of the third major storm of the season, they may stop to wonder two things: Why haven't we bothered to invest in a snow blower, and what happened to climate change? After all, it stands to reason that if the world is getting warmer - and the past decade was the hottest on record - major snowstorms should be a thing of the past, like PalmPilots and majority rule in the Senate. Certainly that's what the Virginia state Republican Party thinks: the GOP aired an ad last weekend that attacked two Democratic members of Congress for supporting the 2009 carbon-cap-and-trade bill, using the recent storms to cast doubt on global warming. (See pictures



THE TIMES OF INDIA

Global Warming

[Home](#) [City](#) [India](#) [World](#) [Business](#) [Tech](#) [Sports](#) [Entertainment](#) [Life & Style](#) [Women](#) [Hotklix](#) [Spirituality](#) [NRI](#) [Real Estate](#)
[Opinion](#) [Blogs](#) [Auto](#) [Polls](#) [Speak Out](#) [Science](#) **Environment** [Education](#) [STOI](#) [Headlines](#) [Specials](#) [Crest](#) [Classifieds](#)
[Mocktale](#)

Global Warming [The Good Earth](#) [Developmental Issues](#) [Flora & Fauna](#) [Pollution](#) [Wild & Wacky](#)

You are here: [Home](#) » [Environment](#) » Global Warming

Soon, palm trees to dot Antarctica

Michael McCarthy | Aug 3, 2012, 03:21 AM IST

Massive Retirement Crisis

www.newsmax.com - 5 Ways Obama Policies Destroy Retirement (1 Big Way to Profit)

Ads by Google

READ MORE [Michael McCarthy](#)

For adults with type 2 diabetes

AdChoices 

[Palm trees](#) could grow in [the Antarctic](#) if climate

Three main themes

- Forcings vs feedbacks.

- What causes global warming? (a 'forcing')
- What amplifies (or diminishes) it? (a 'feedback')

- How certain are we?

- Is it really happening?
- Could it just be natural variability?

- When will it happen and how big will it be?

- Now or next year or next century or next millennia?
- How big will it be and how sure are we?

IS IT REAL?

JUST THE FACTS, MA'AM

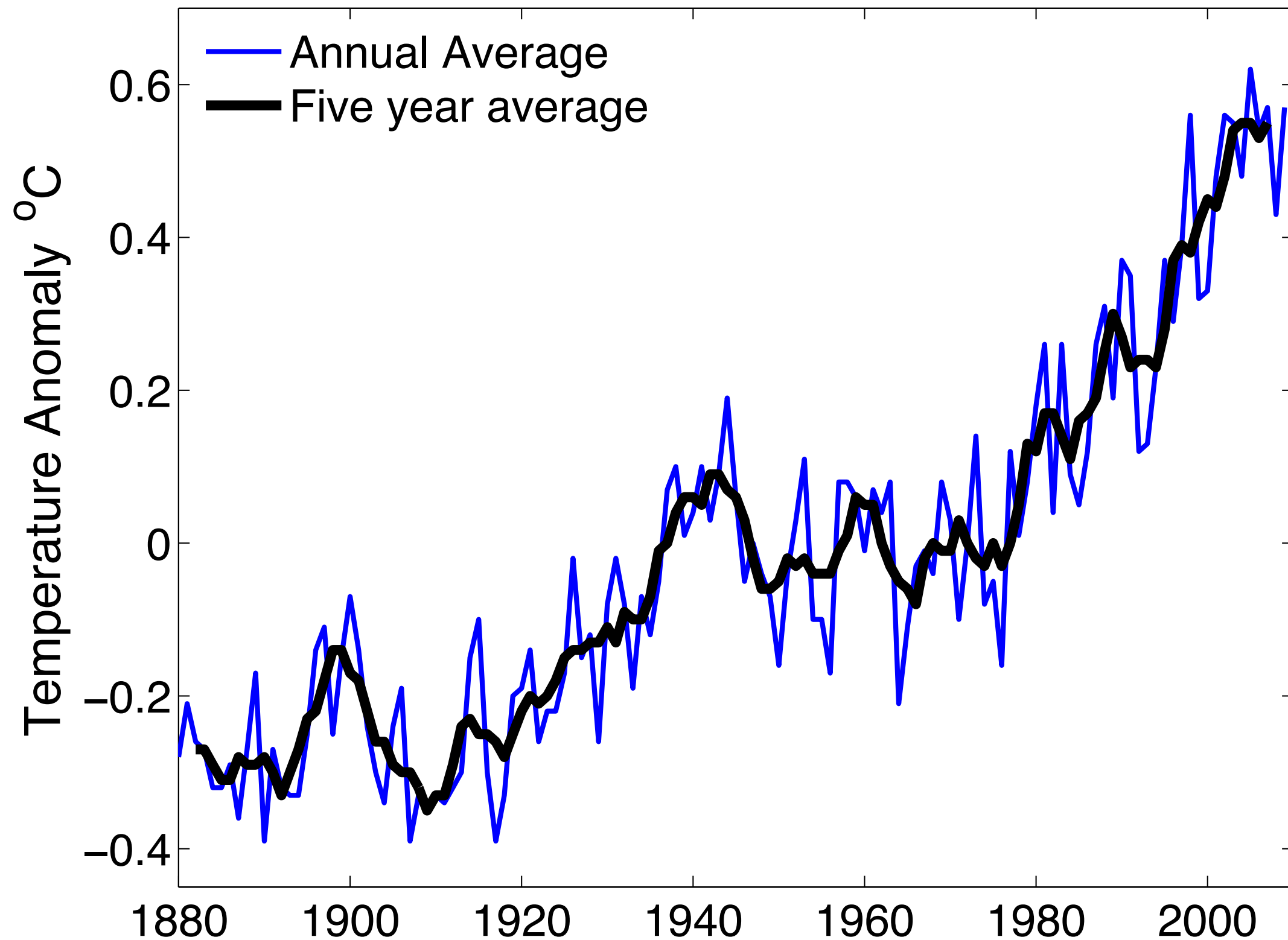


What we know

- Temperature has gone up, and will continue to go up.
 - It is not an artifact of urban measurement.
- It is almost certainly not natural variability.
 - We'll see the evidence!
- It is caused by increased greenhouse gases, mainly carbon dioxide.
 - That carbon dioxide is of anthropogenic origin (from fossil fuels)

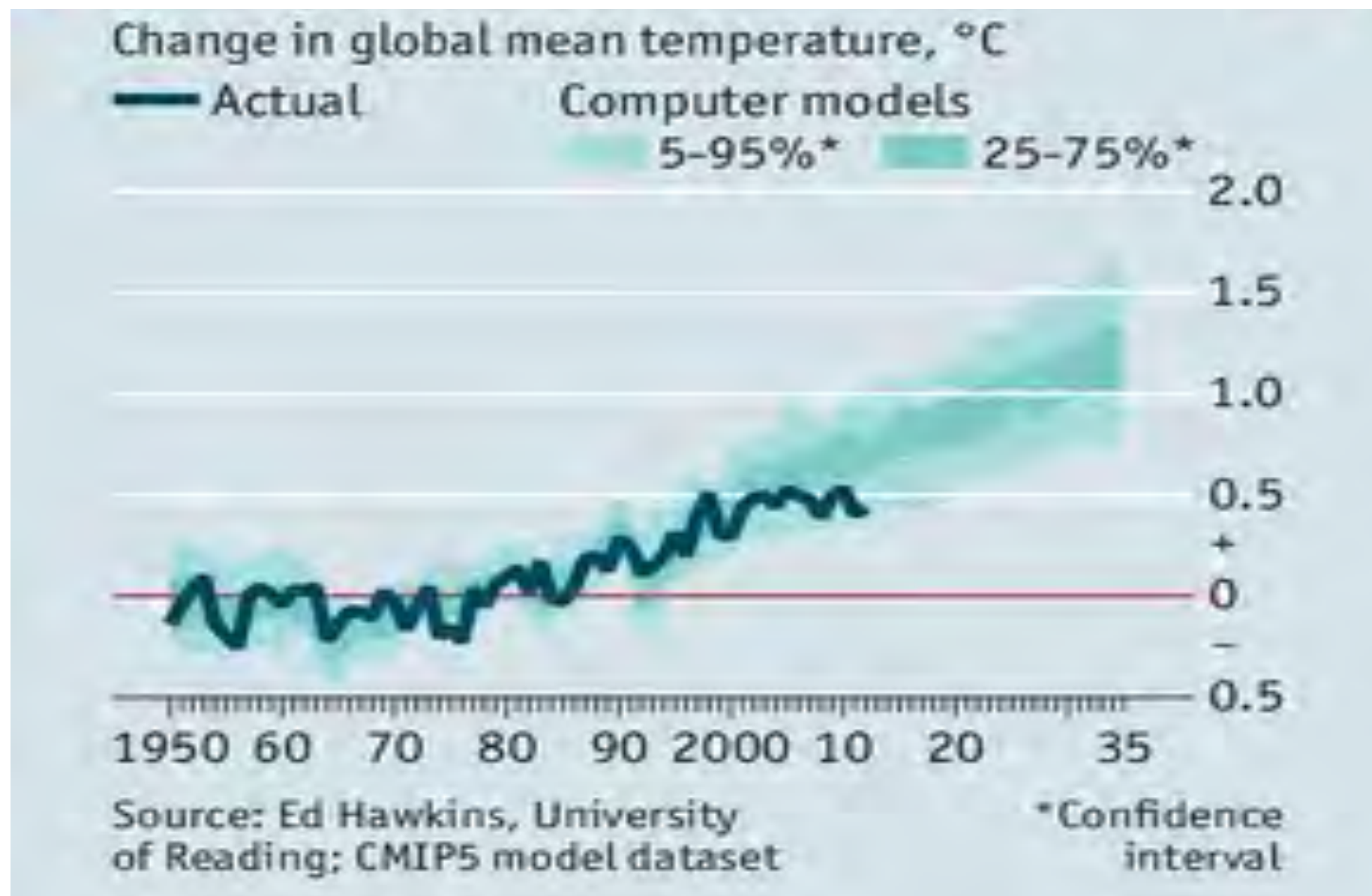
None of the above is controversial!

Global Warming - what is the fuss about?



Global average temperatures: not the whole story, but it is the basis for concern.

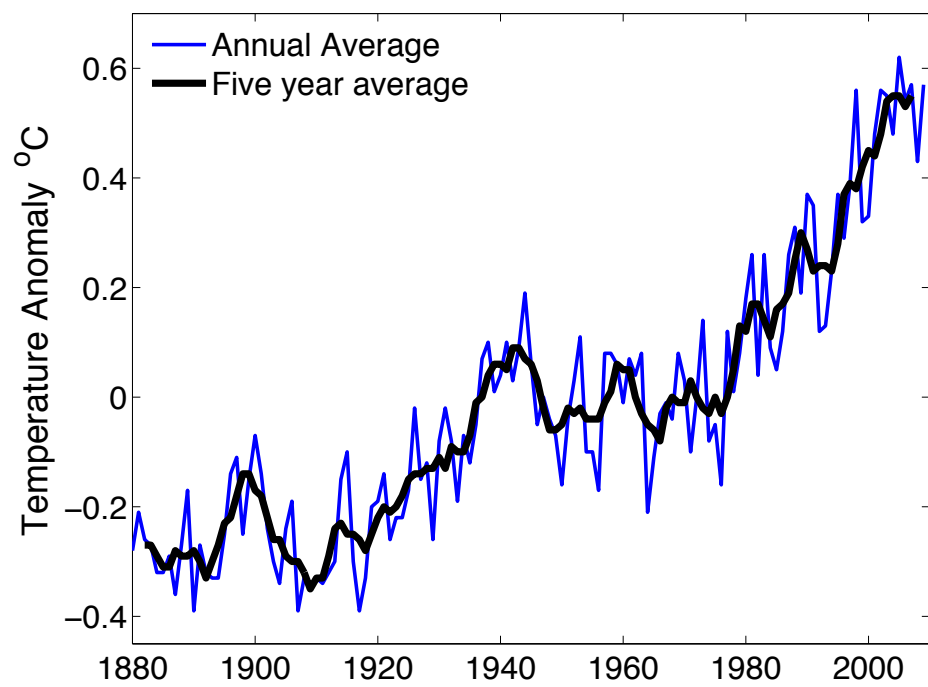
But there has been a largely unpredicted lack of warming in the last decade!



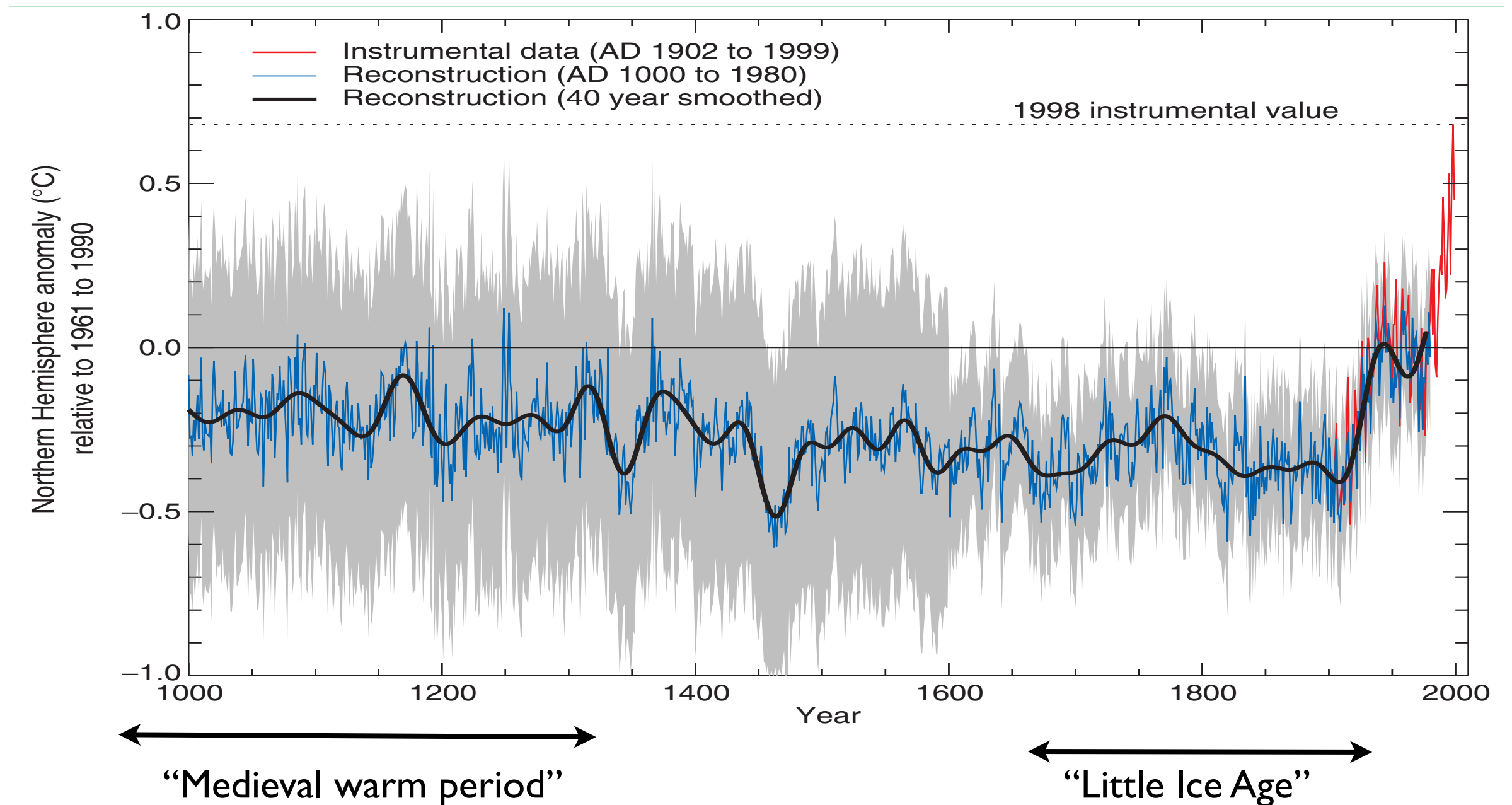
**Possible
Explanations:**

- **Natural
variability?**
- **Bad models and a
hyped science?**

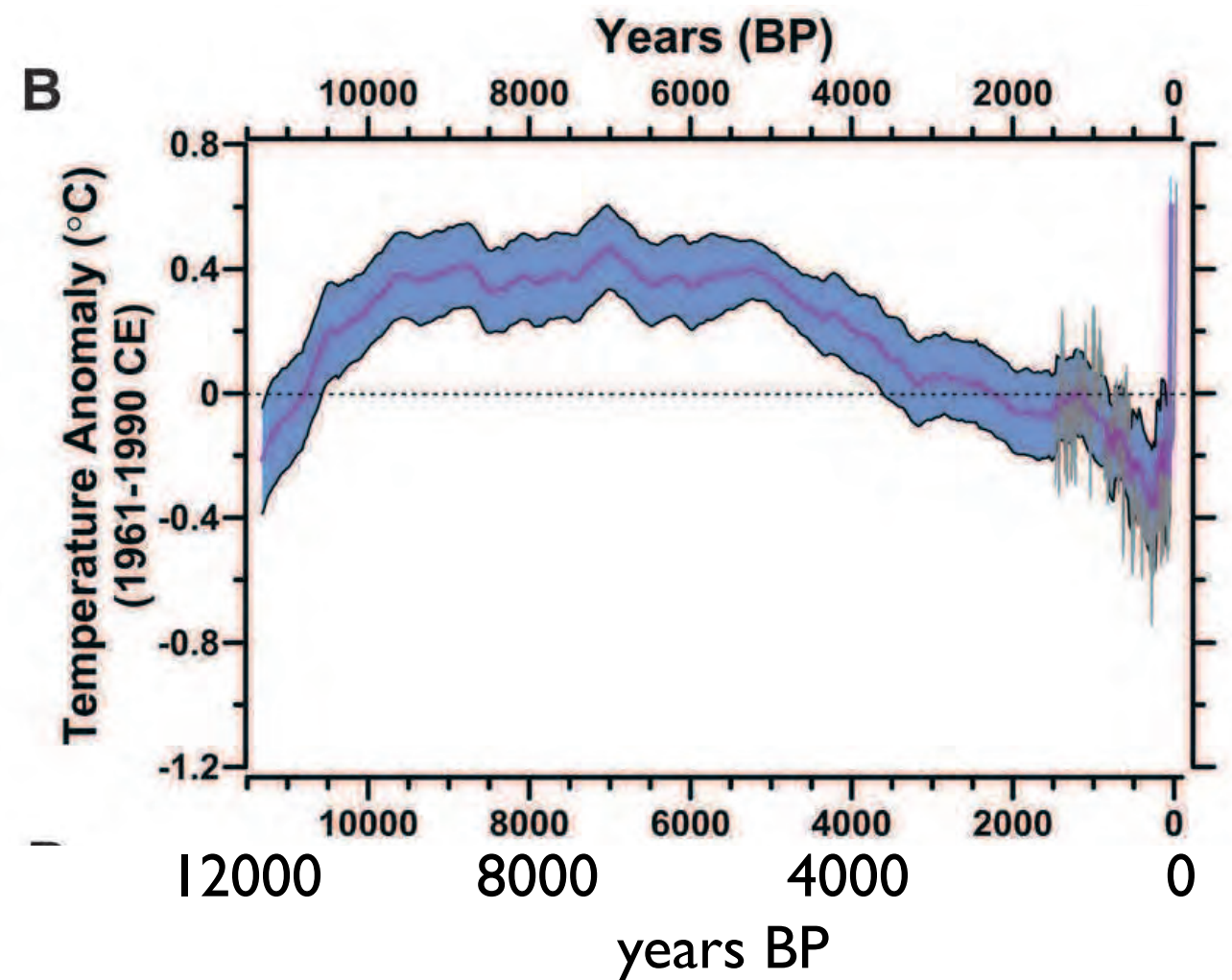
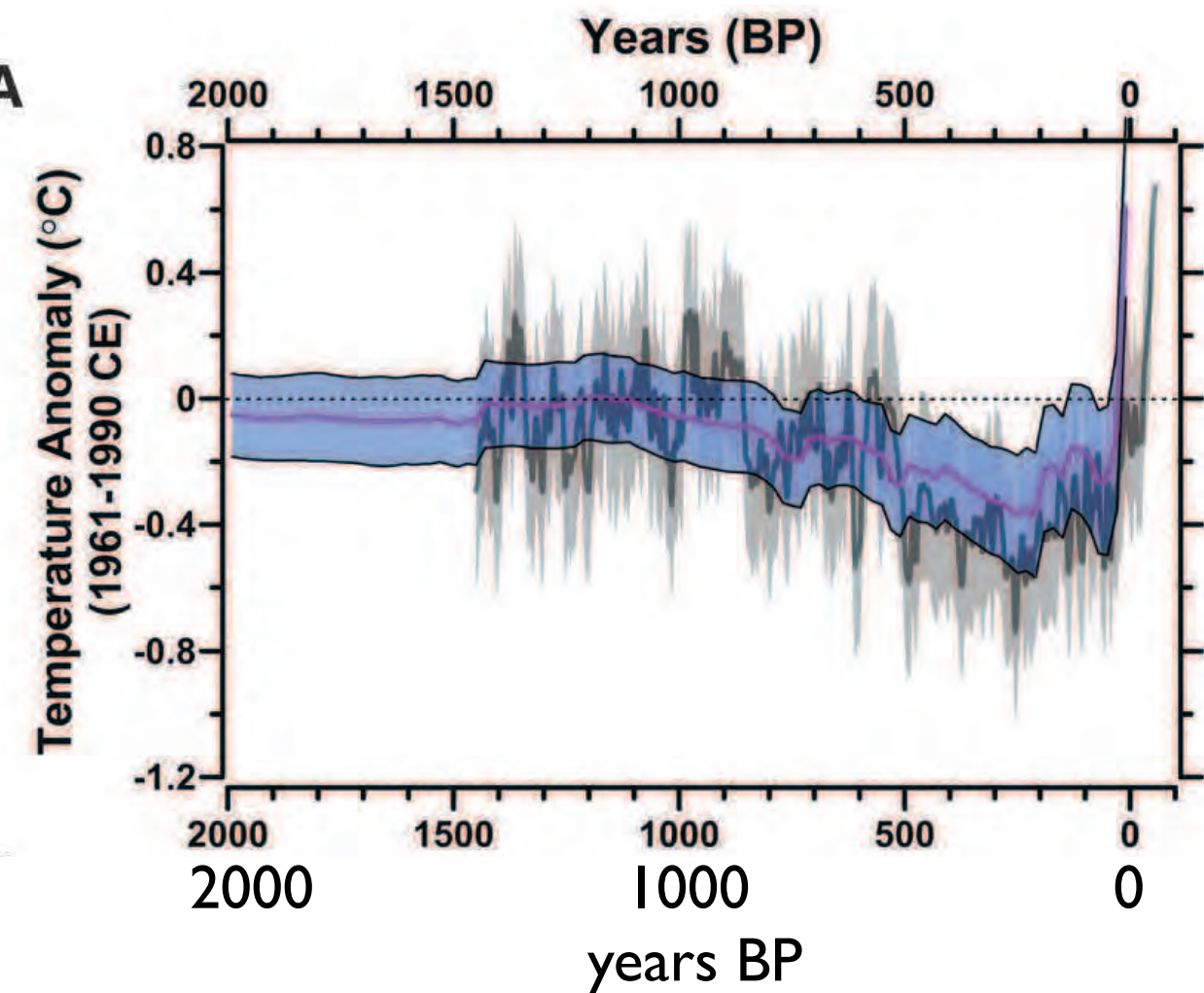
**We don't really
know!**



Warming in context: the millennial temperature record or 'hockey stick'

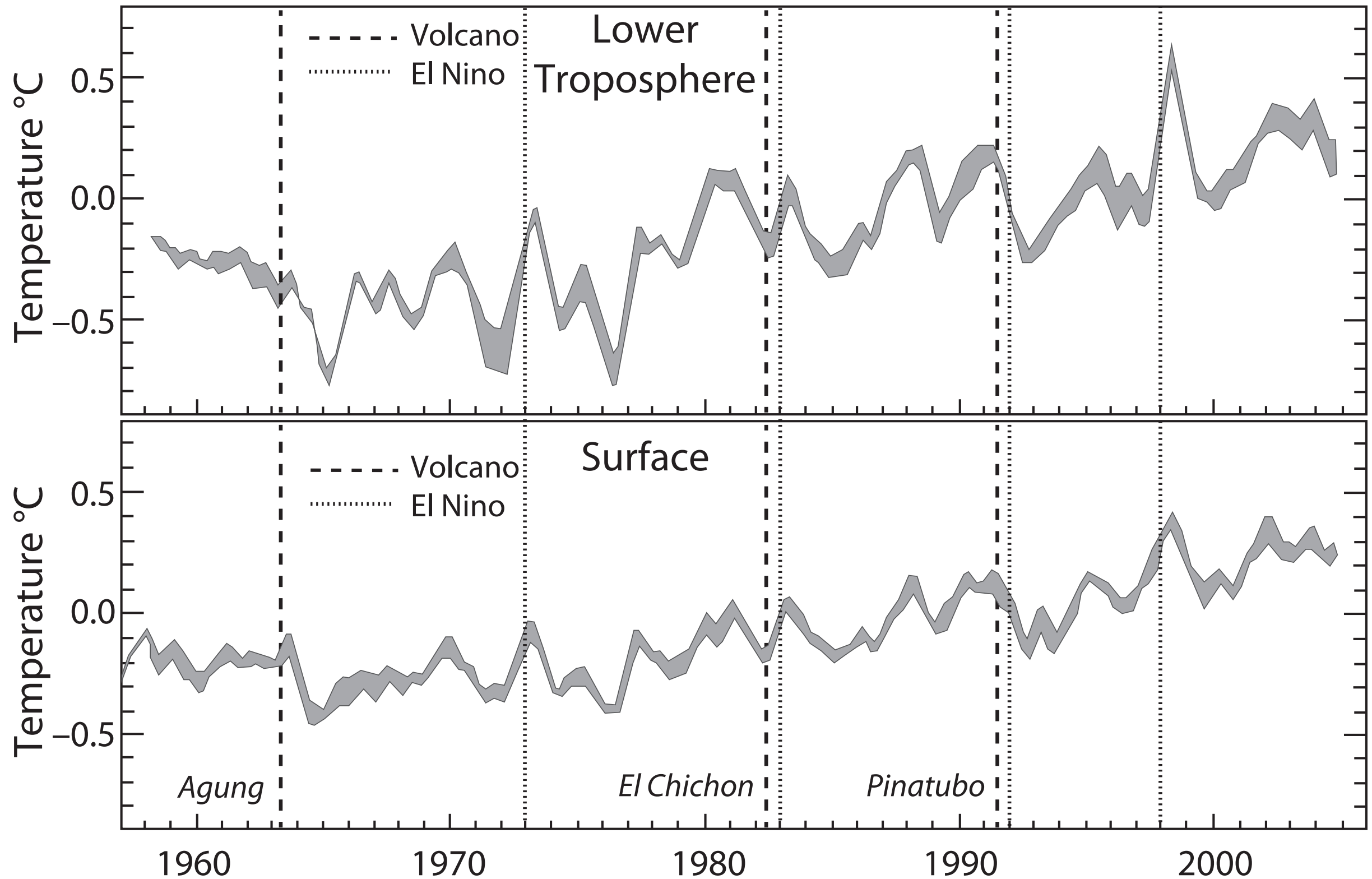


Temperature over the past 10,000 years.



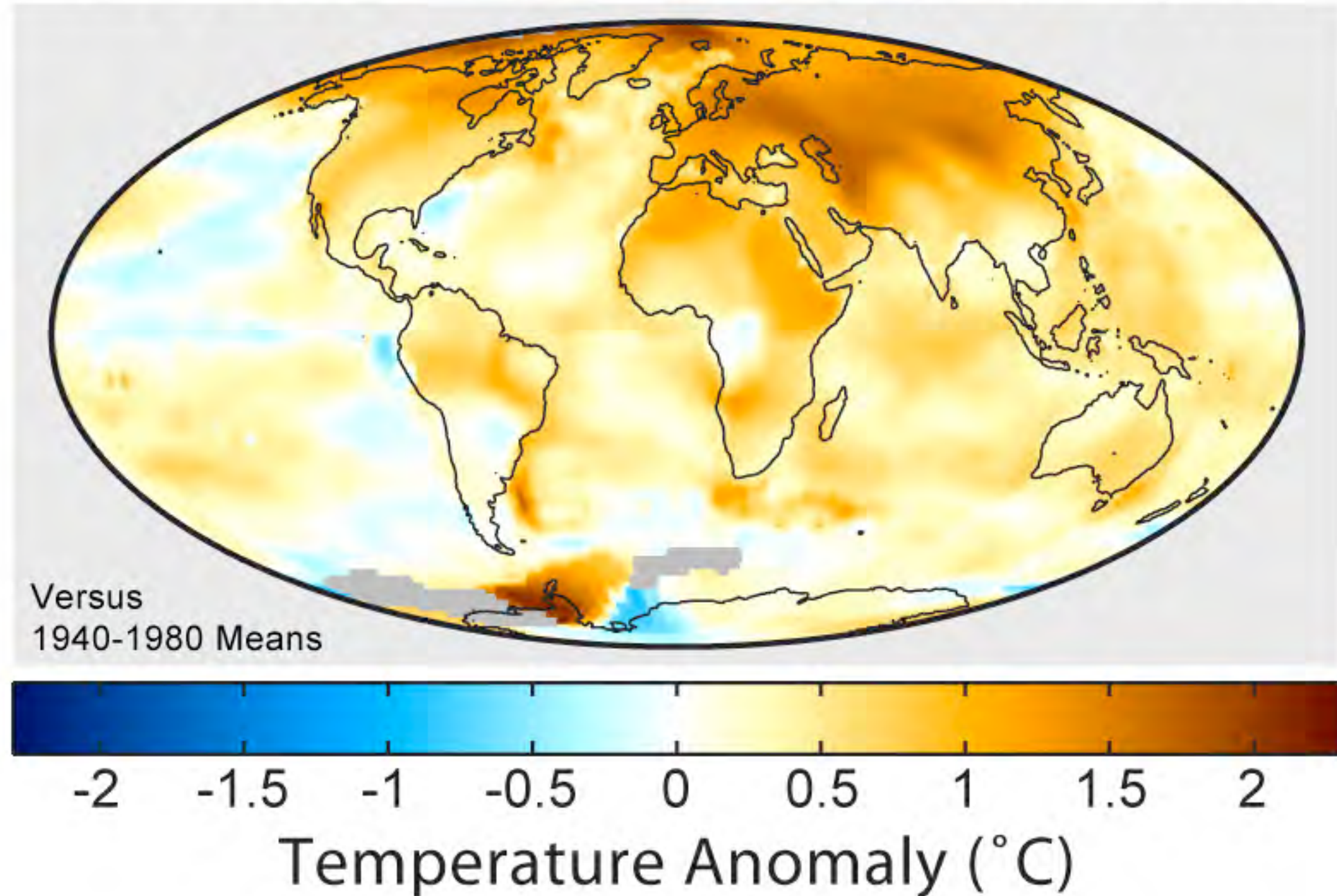
IS THE WARMING AN ARTIFACT OF URBAN GROWTH?

Temperature record using both satellites and thermometers



Patterns of temperature increase

1999-2008 Mean Temperatures



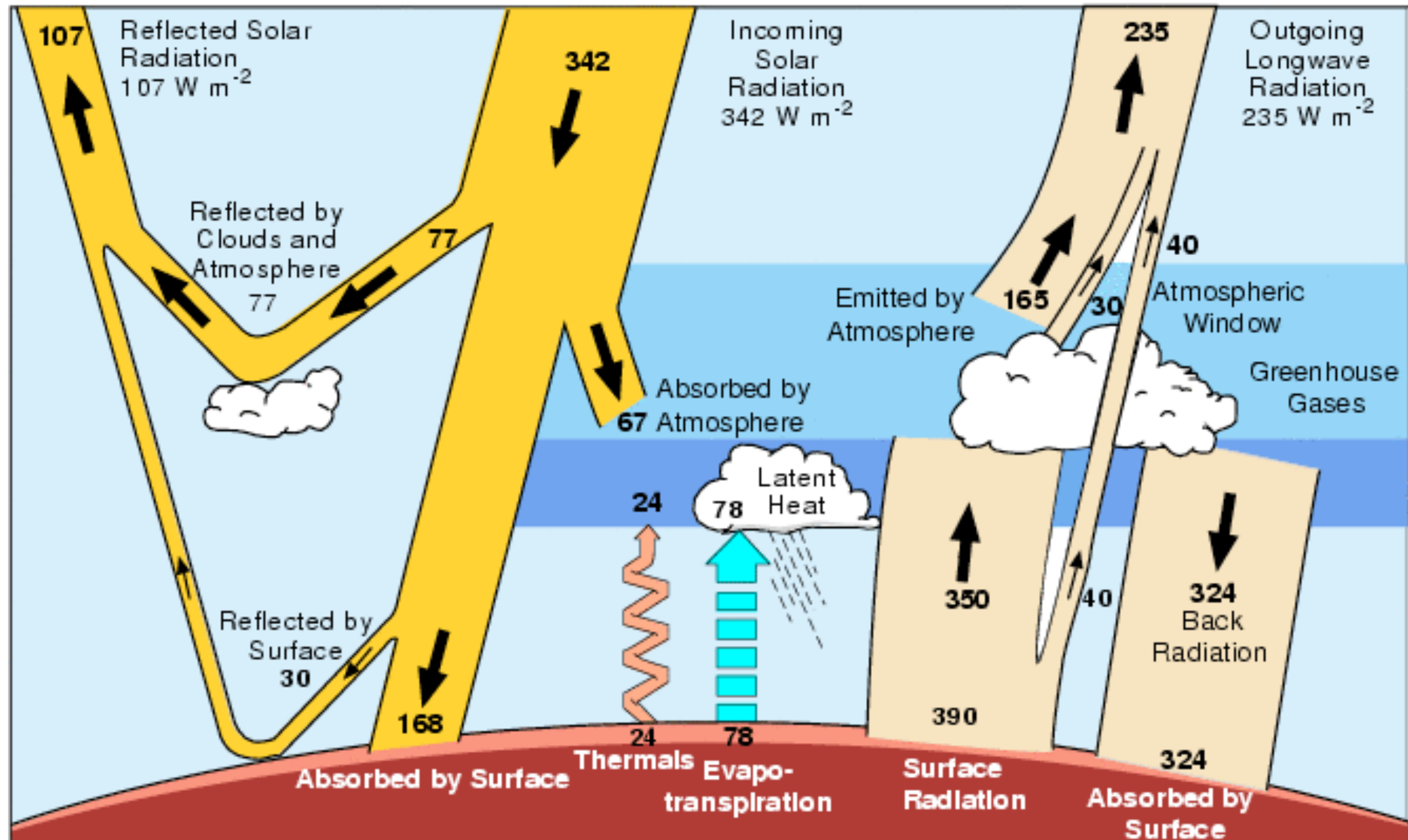
Amplification over land and at high
latitudes

WHAT CAUSES IT?

STILL STICKING WITH THE FACTS

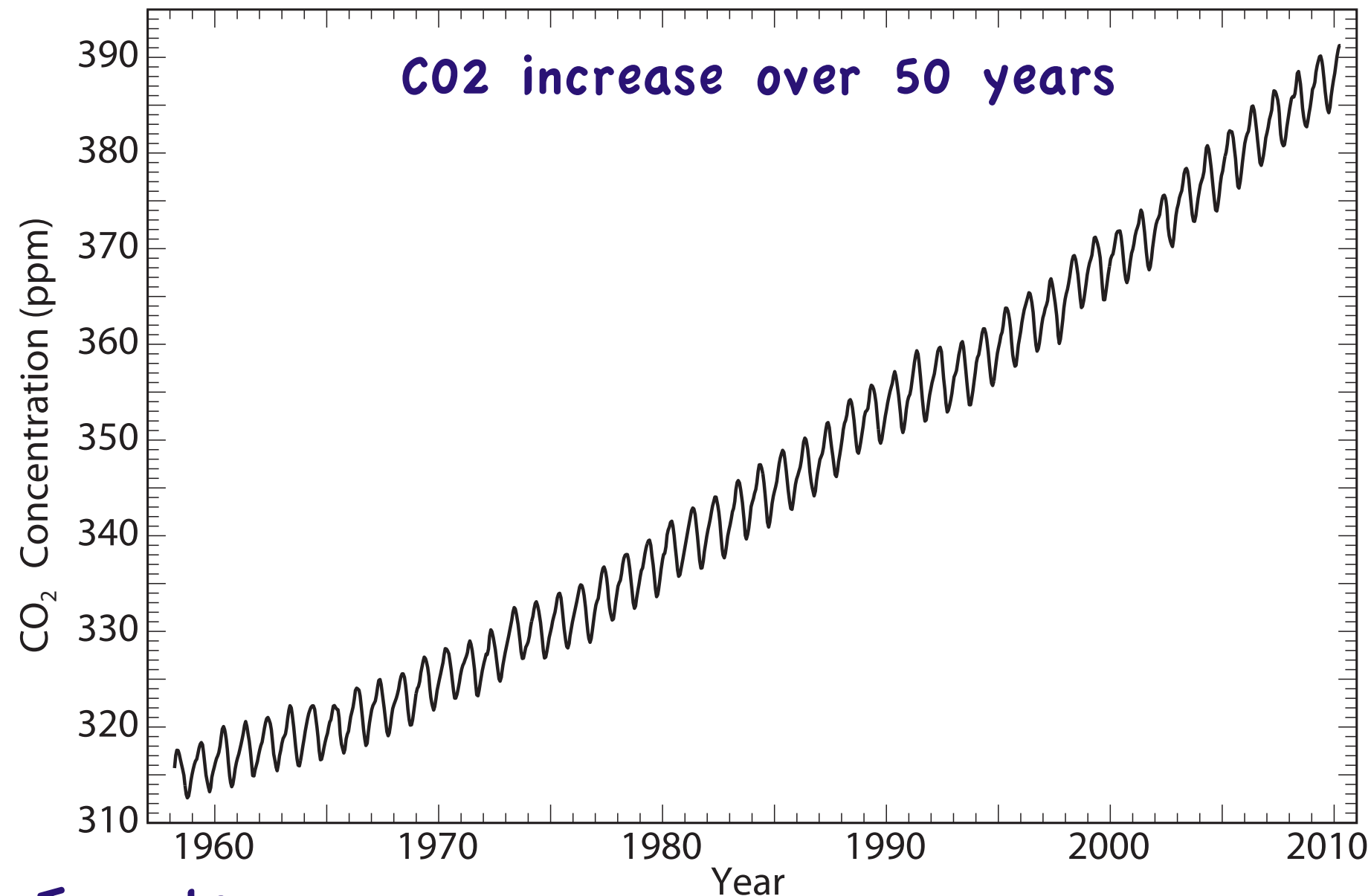


Global Heat Flows



Carbon dioxide and the Keeling curve

(one of the most famous curves in science)



To note:

- 1) The increase in CO₂ levels.
- 2) The 'breathing' of the planet.

CO₂ levels last week exceeded 400 ppm!

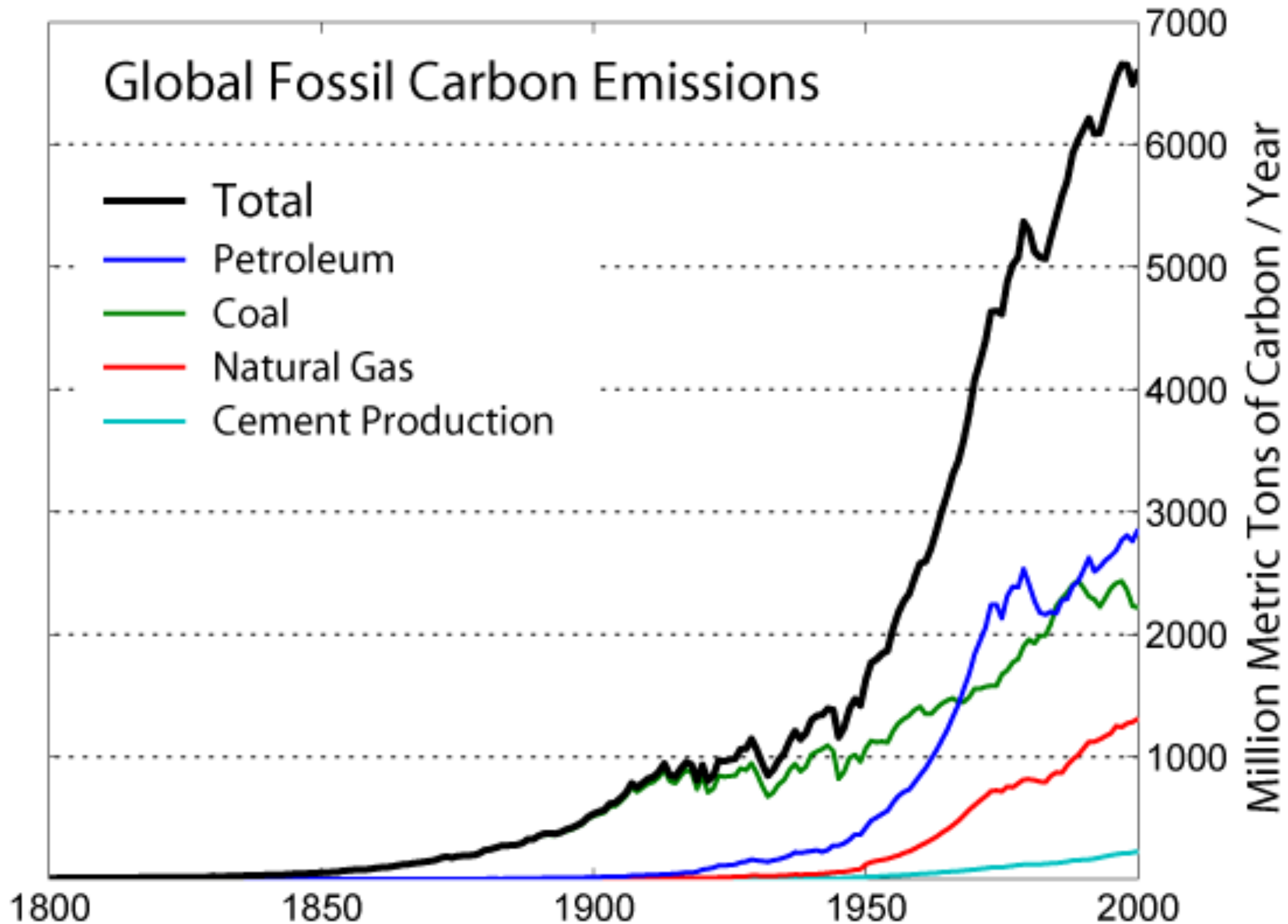


Burning of fossil fuels



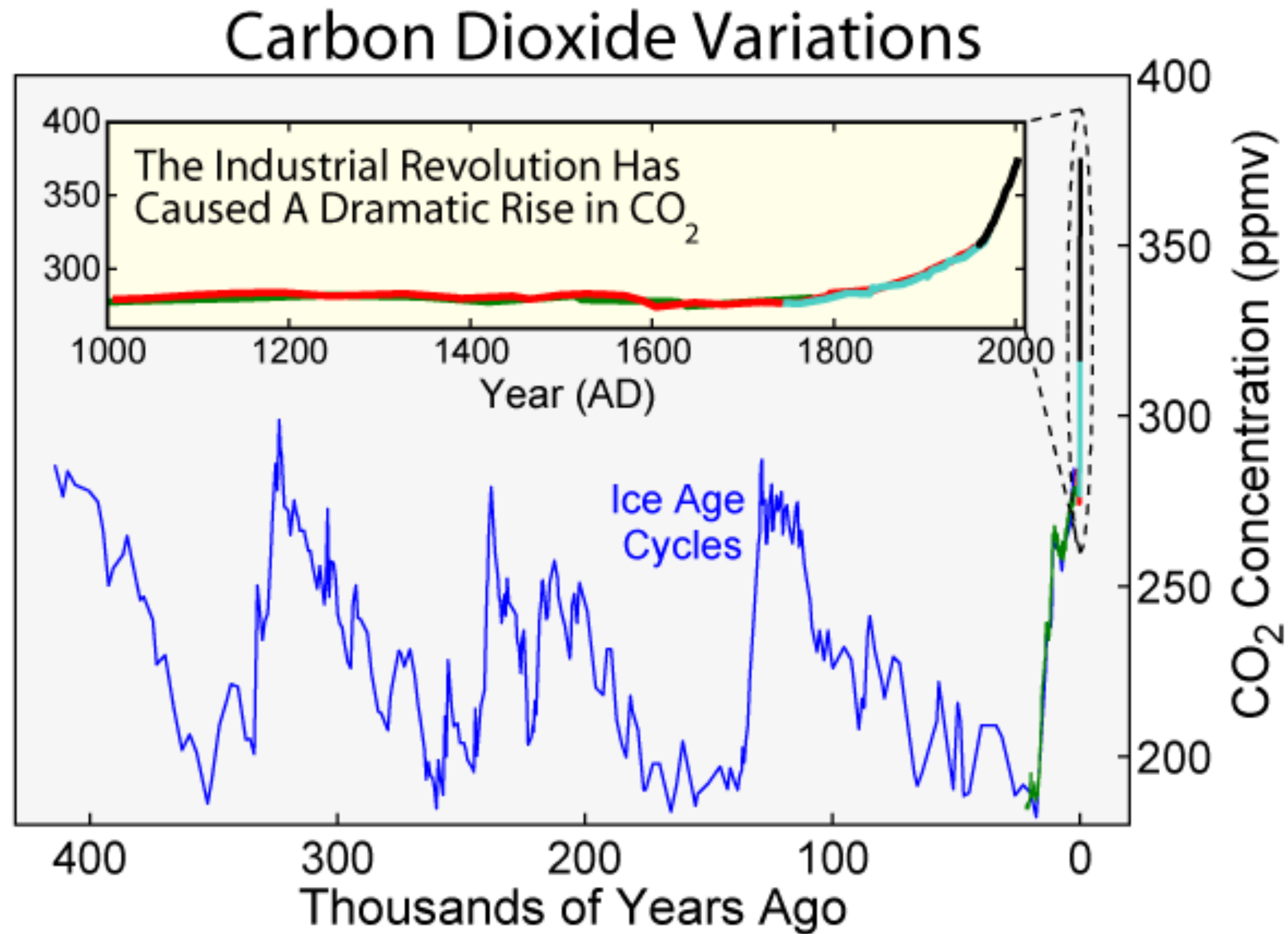
**and the respiration of
flora**

Carbon emissions from fossil fuels



Robert Rohde, Globalwarmingart.com and Marland, G., T.A. Boden, and R. J. Andres (2003). "Global, Regional, and National CO₂ Emissions" in *Trends: A Compendium of Data on Global Change*. Oak Ridge, Tenn., U.S.A.: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy.

CO₂ over the Last Half Million Years

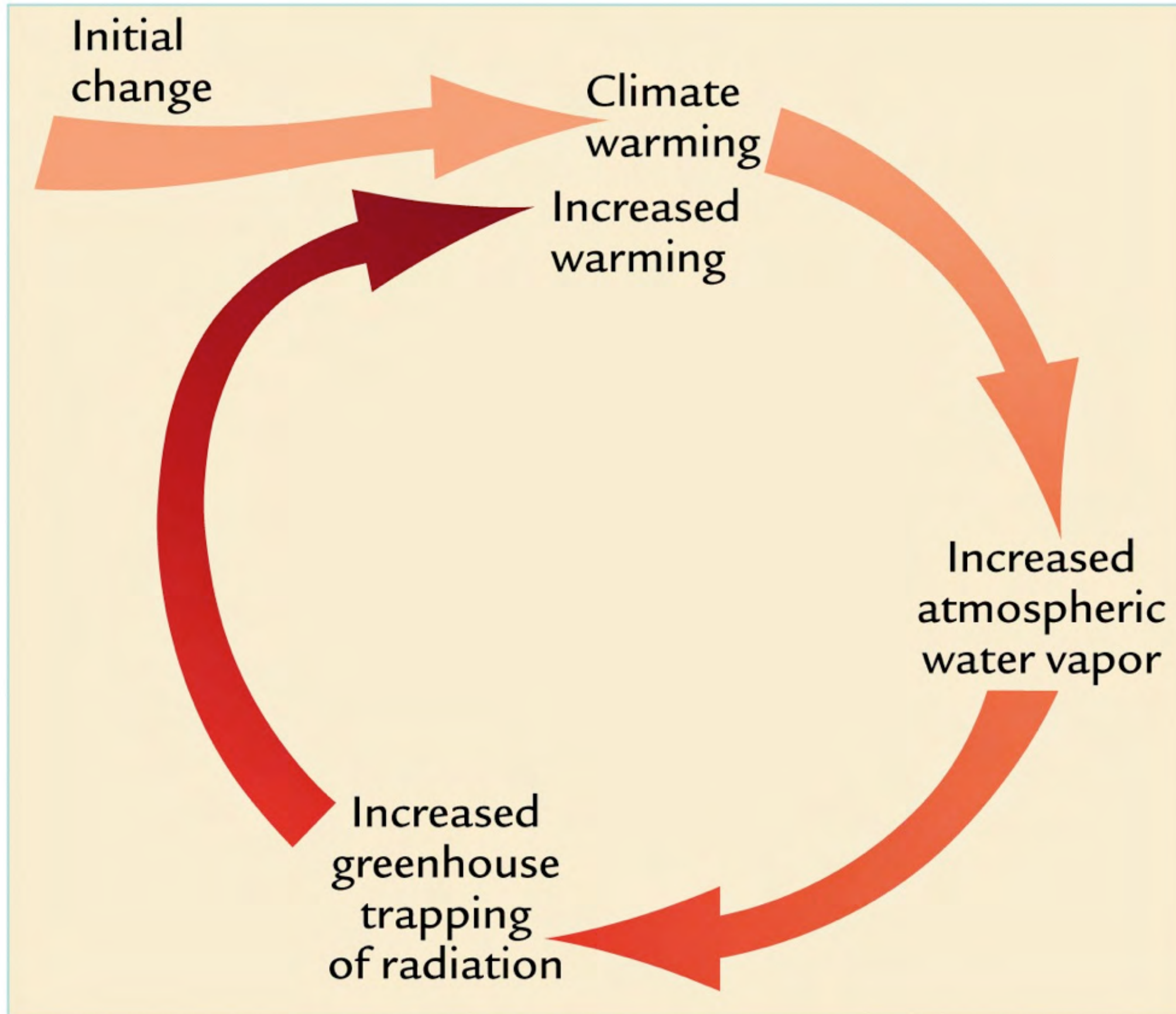


From air trapped in bubbles in ice in Antarctica.

Forcings and Feedbacks

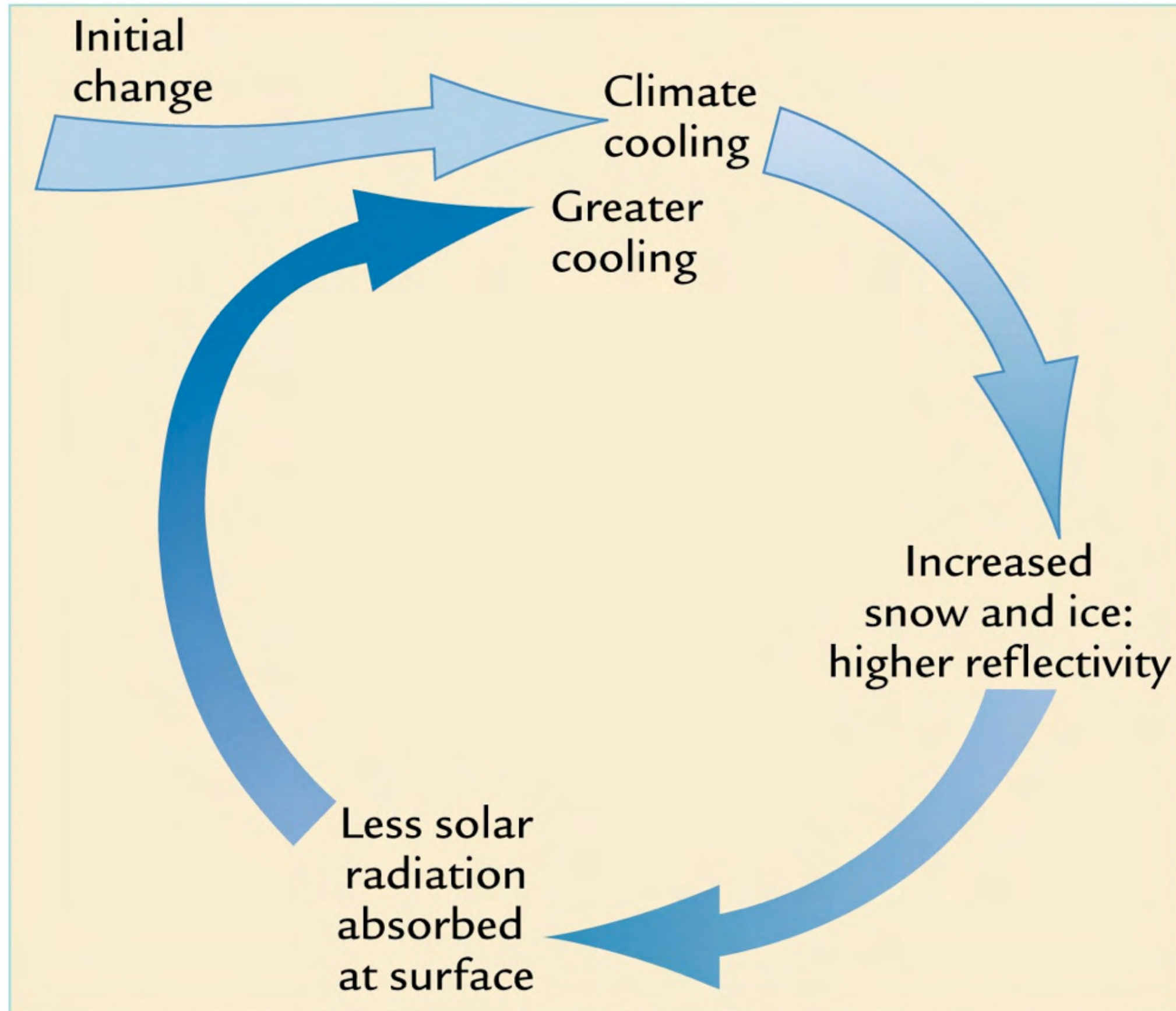
- Isn't water vapor the biggest greenhouse gas?
 - Yes! (by a good margin!)
- So carbon dioxide isn't really that important?
 - No!

Water vapor feedback

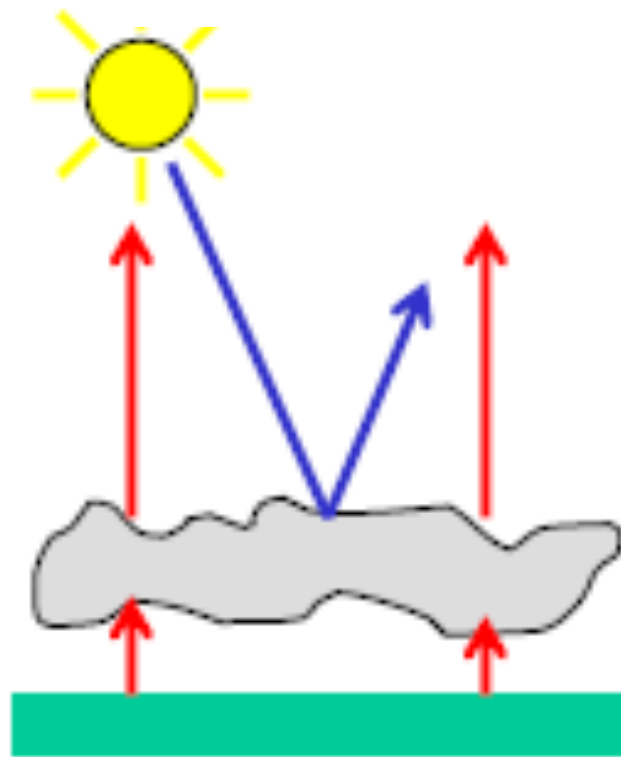


Take away all the CO_2 in the atmosphere - Earth freezes over!

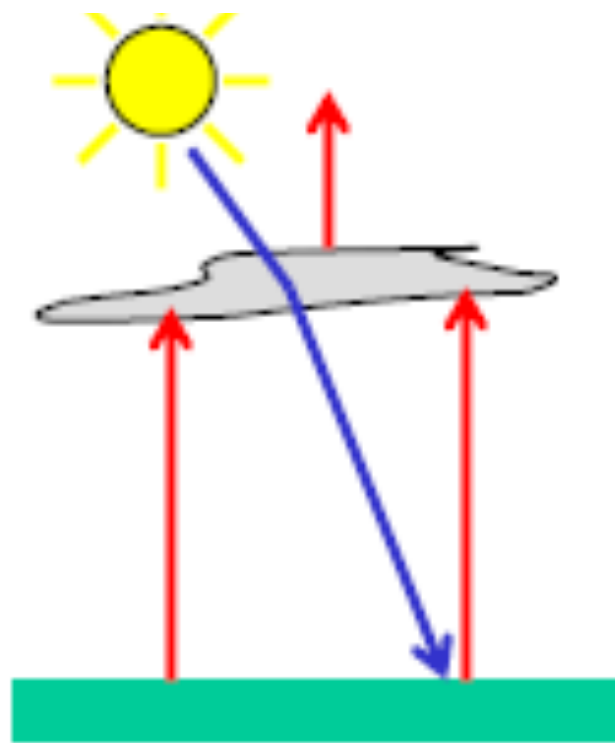
Another feedback: ice-albedo



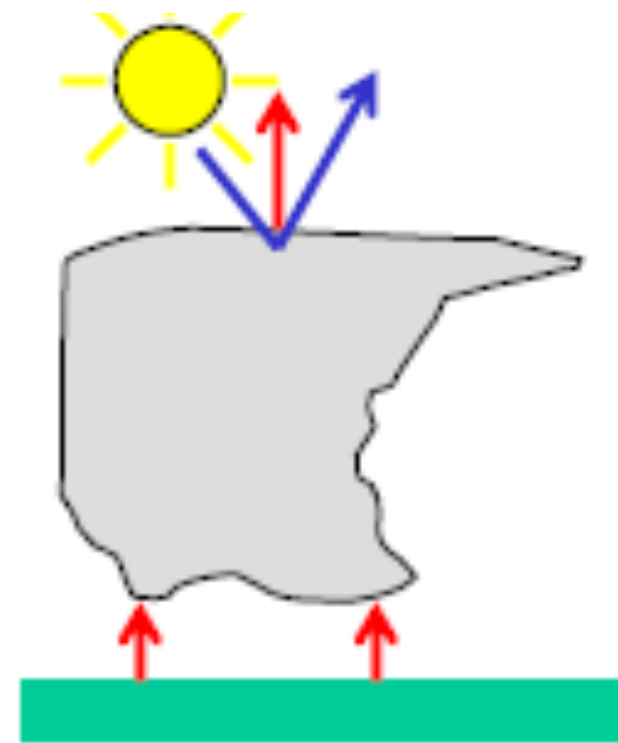
Cloud feedbacks – there is no nice loop!



low-level cloud
reflection $\gg 0$
greenhouse ~ 0
cools the earth



high-level cloud
reflection ~ 0
greenhouse $\ll 0$
warms the earth



thick cloud
reflection $\gg 0$
greenhouse $\ll 0$
(reflection +
greenhouse) ~ 0

Complicated – and therefore uncertain (in both magnitude and sign).
One of the biggest uncertainties in climate projections.

WITH ALL THESE COMPLICATED LOOPS,
MAYBE CLIMATE JUST VARIES
NATURALLY?



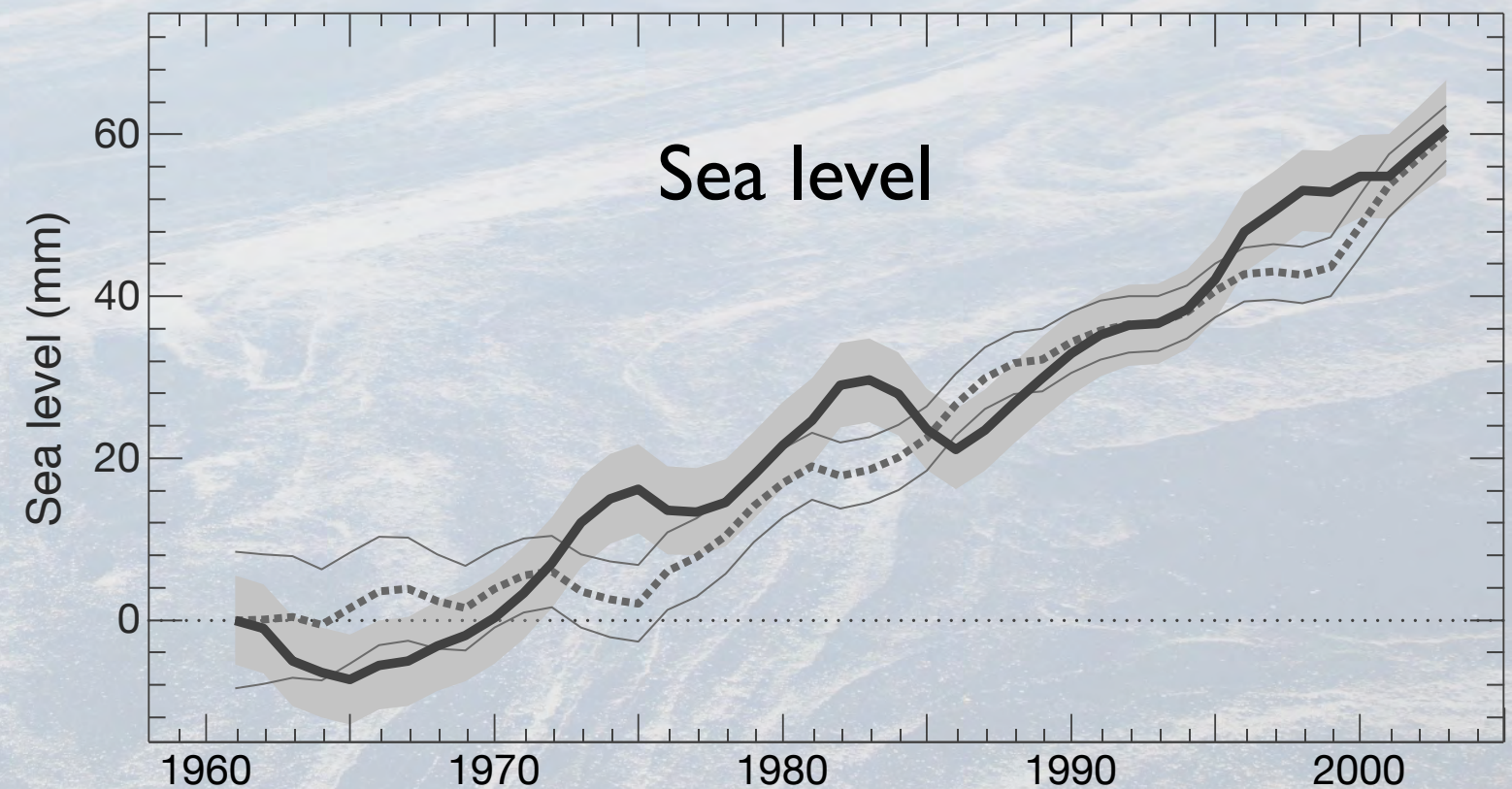
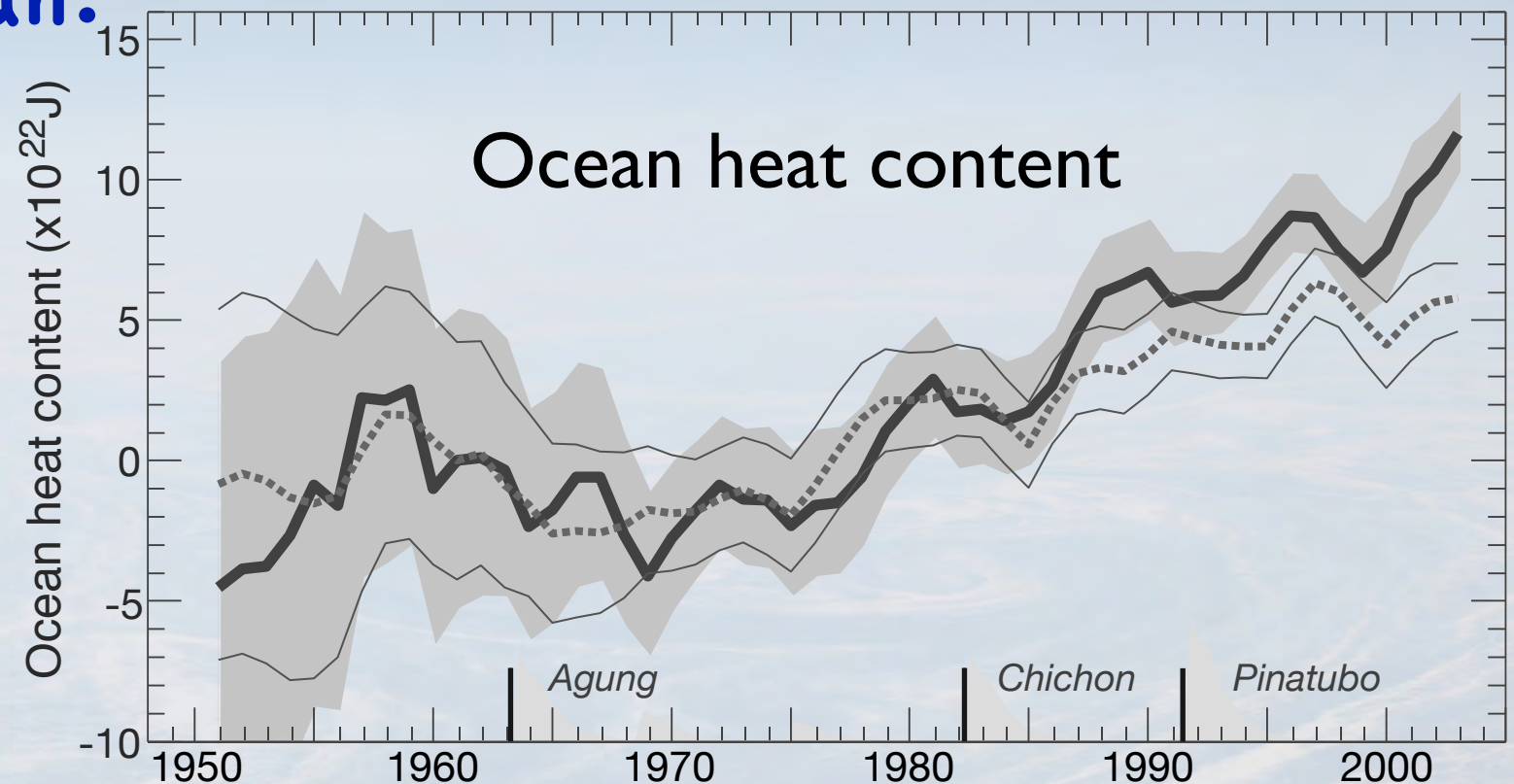
Natural Climate Variability

- The atmosphere is forgetful.
- The year-to-year memory of the climate system mostly resides in the ocean and land.
- The ocean can vary naturally on timescales of years, decades, centuries, millennia.
- But if the oceans were to cause global warming, they would do it by giving up heat to the atmosphere.

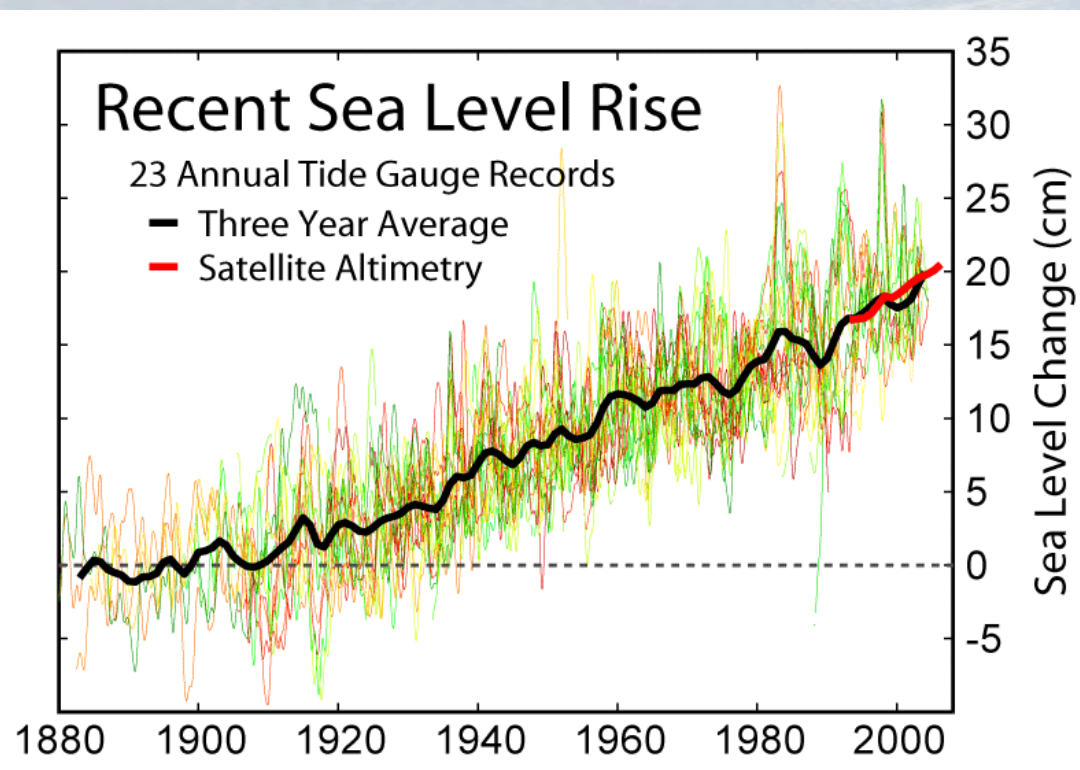
The warming of the ocean.

The ocean is warming
because of anthropogenic
radiative effects.

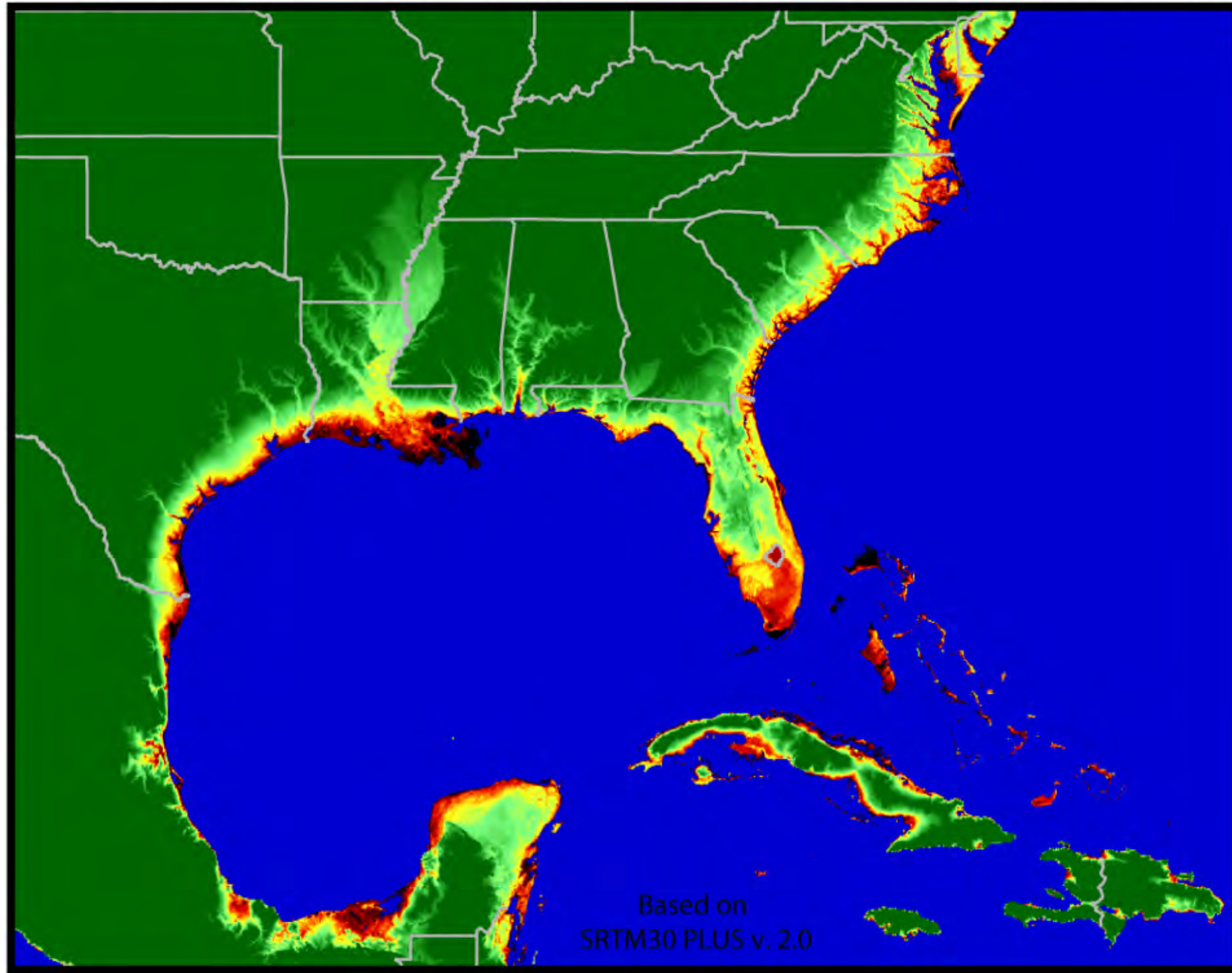
The ocean is not causing
the warming.



Time →



Sea Level Risks - US East Coast

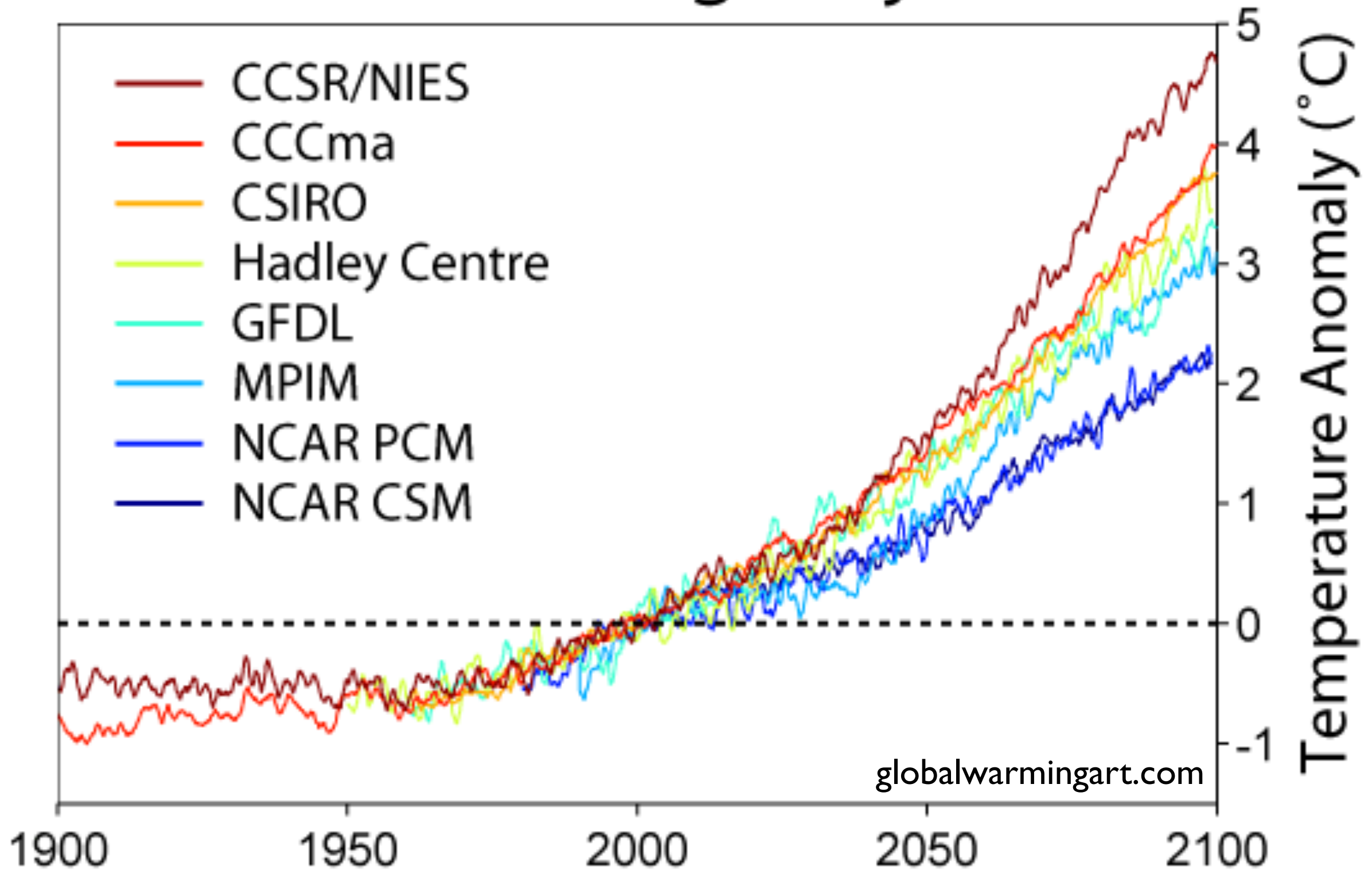


HOW MUCH WILL CLIMATE WARM?
HOW CERTAIN ARE WE?

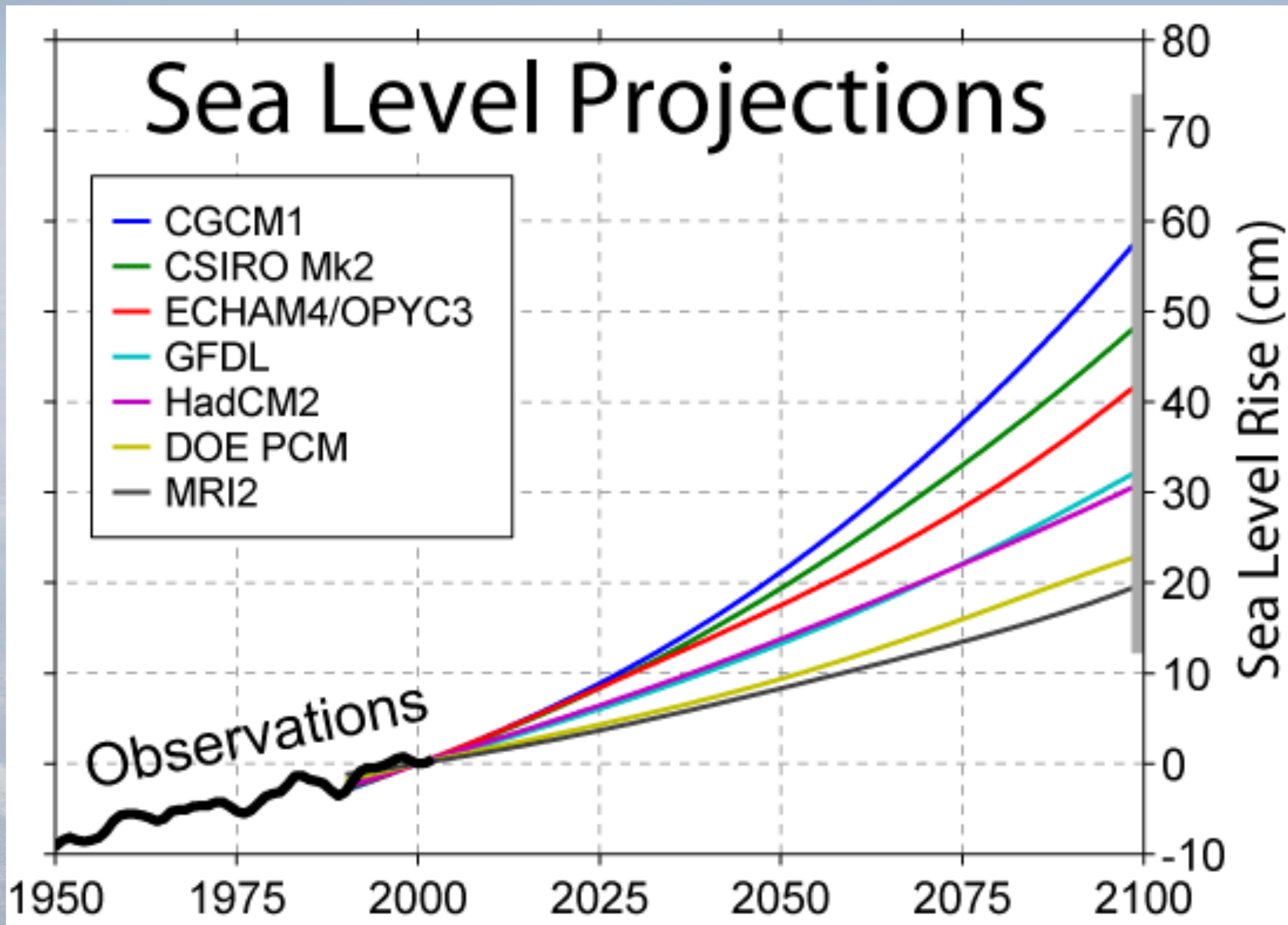
We have to move beyond the facts.



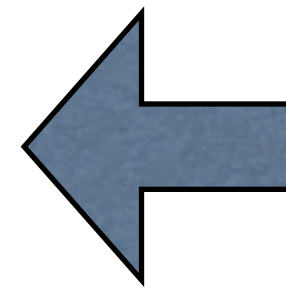
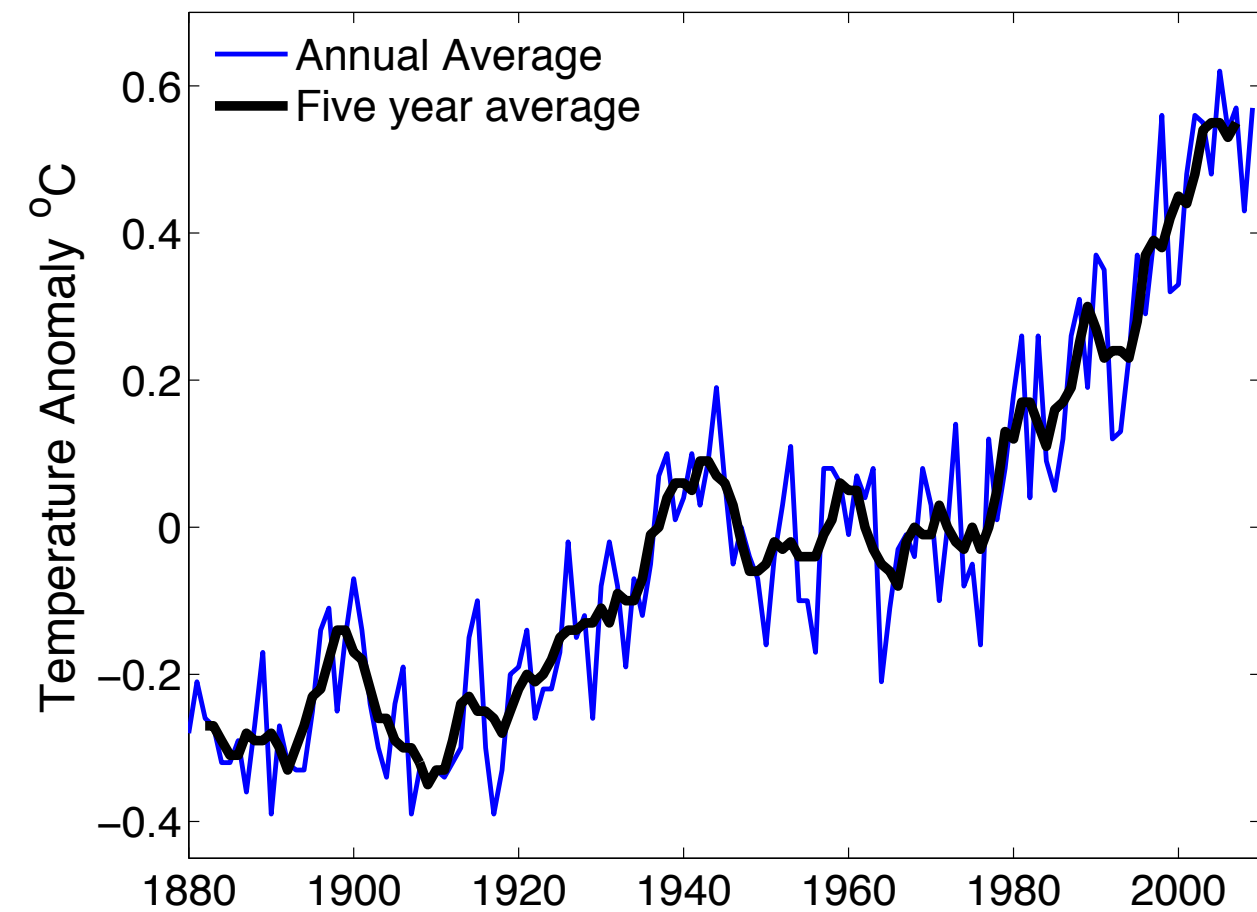
Global Warming Projections



Different models have different sensitivities....

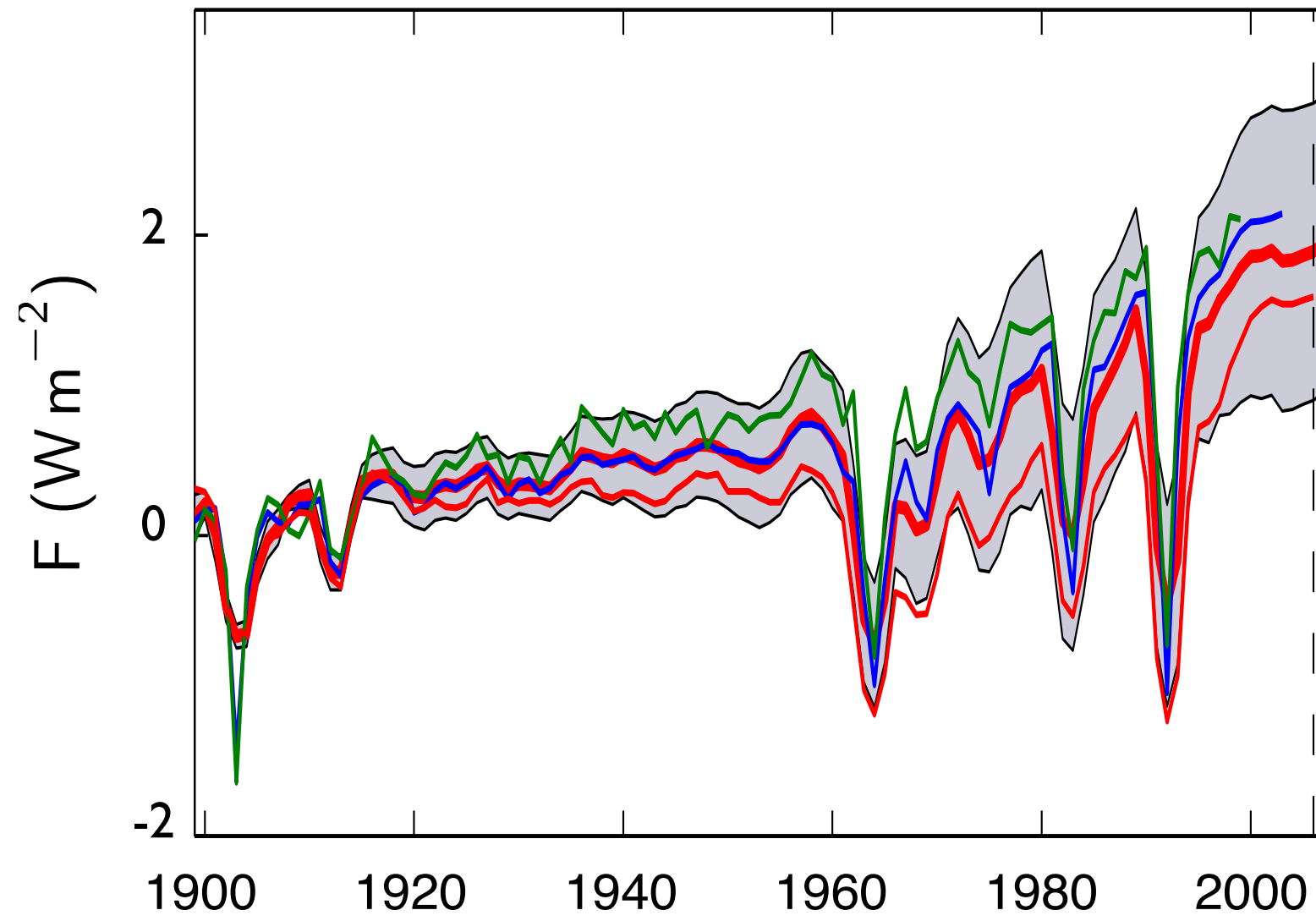
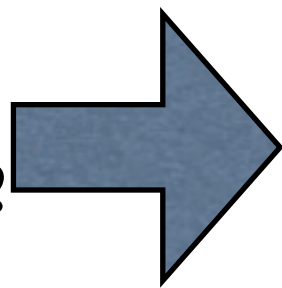


provided the great ice sheets don't
melt!

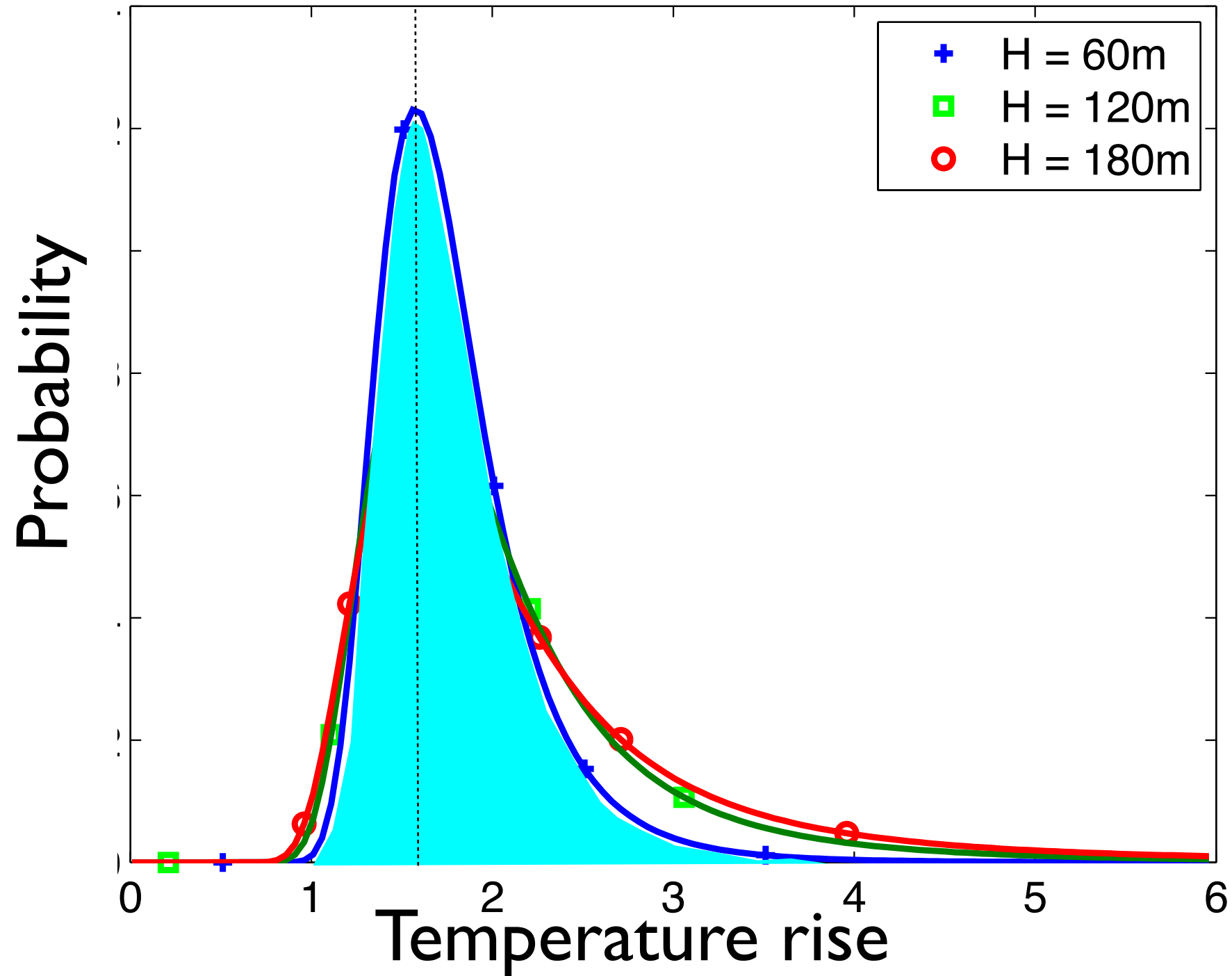


**The observed
temperature increase**

**The 'forcing':
the cause of
the temperature
increase (and its
uncertainty!)**



The Probability of Global Warming



We estimate global warming for a doubling of CO₂ at between 1.3 and 2.3° C with a most probable value of 1.6° C (3°F)

Weather and Warming

Effects that follow directly as a consequence of temperature increase are robust.

Indirect effects (e.g., wind patterns) are fraught with uncertainty (but may be larger!).

- Virtually certain

- Warming is greater at high latitudes, and over land (so likely less snowpack in USA).
- Sea-level rise is completely unavoidable. Could be very large (20 ft or more) if ice-sheets melt (but that is uncertain!)

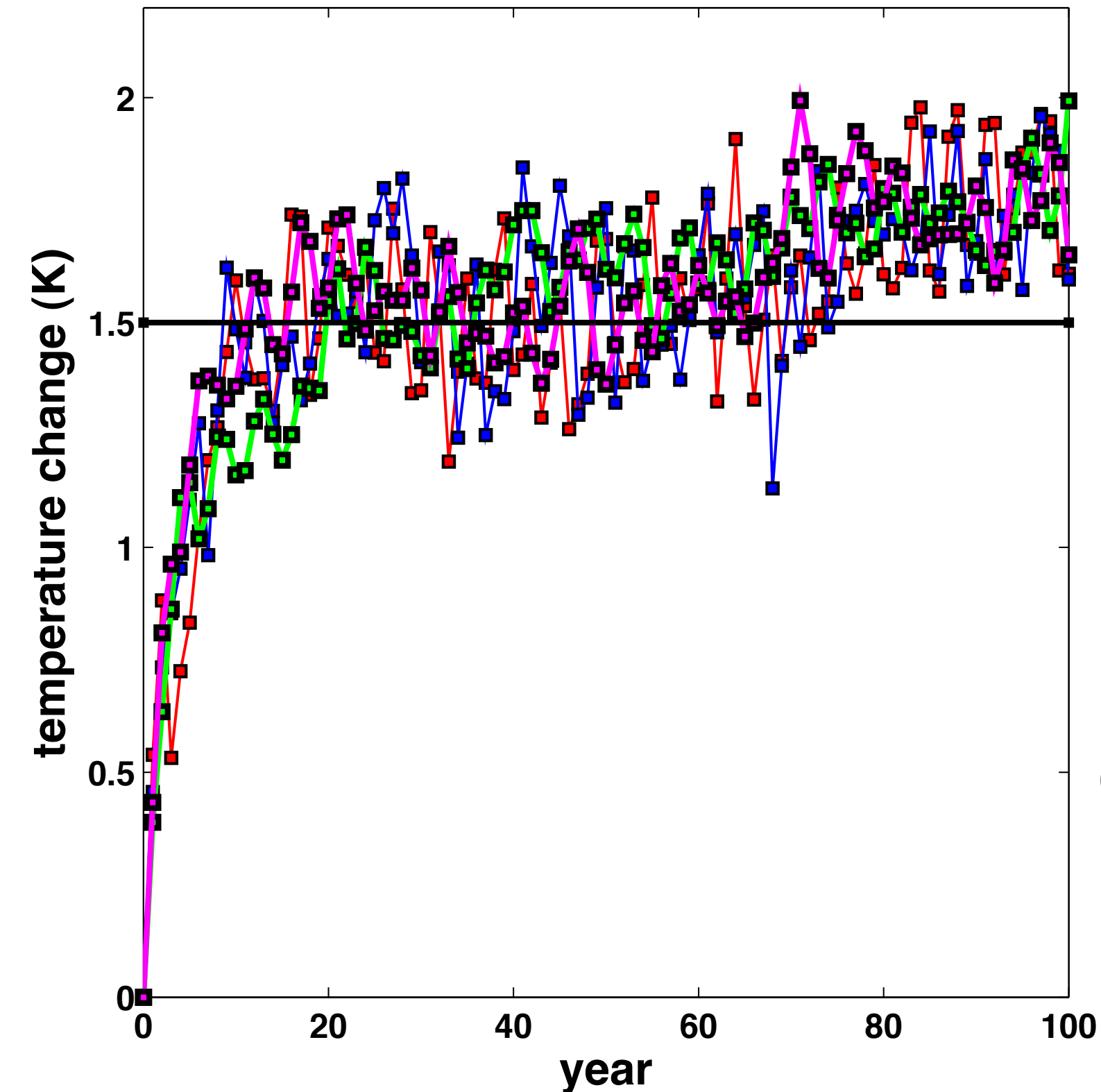
- Less certain.

- The wet gets wetter and the dry gets dryer – decent rule of thumb. But dynamical effects could overwhelm that.
- So more droughts and more floods, more extremes of weather.
- Effects on hurricanes: controversial. If anything, stronger but no more frequent.

HOW LONG WILL IT TAKE?

**AND WILL IT COOL DOWN AGAIN WHEN
WE RUN OUT OF FOSSIL FUELS?**

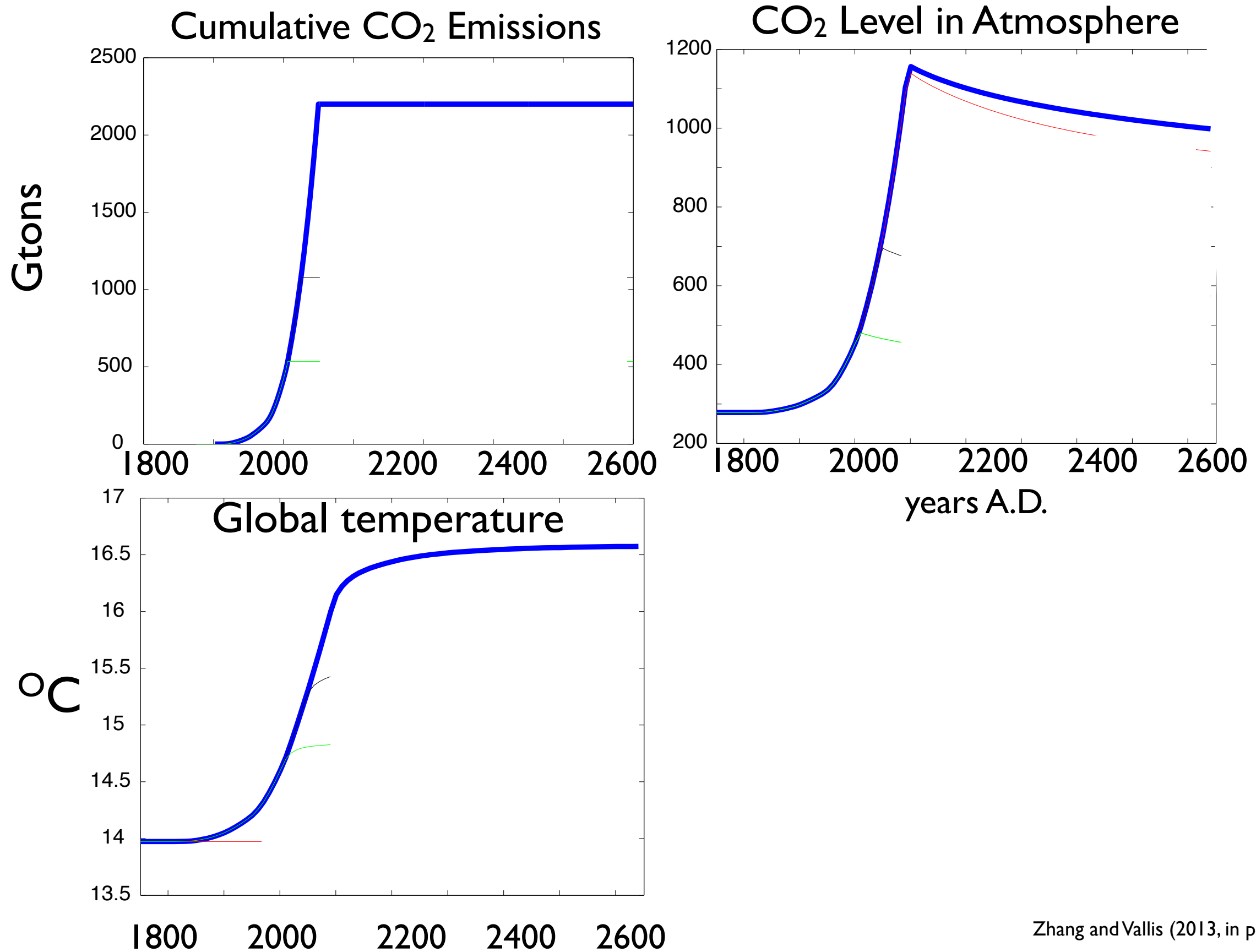
Temperature response to sudden increase of CO₂



Temperature increase is initially very quick (a decade) then a very slow (centuries or more) to the final equilibrium.

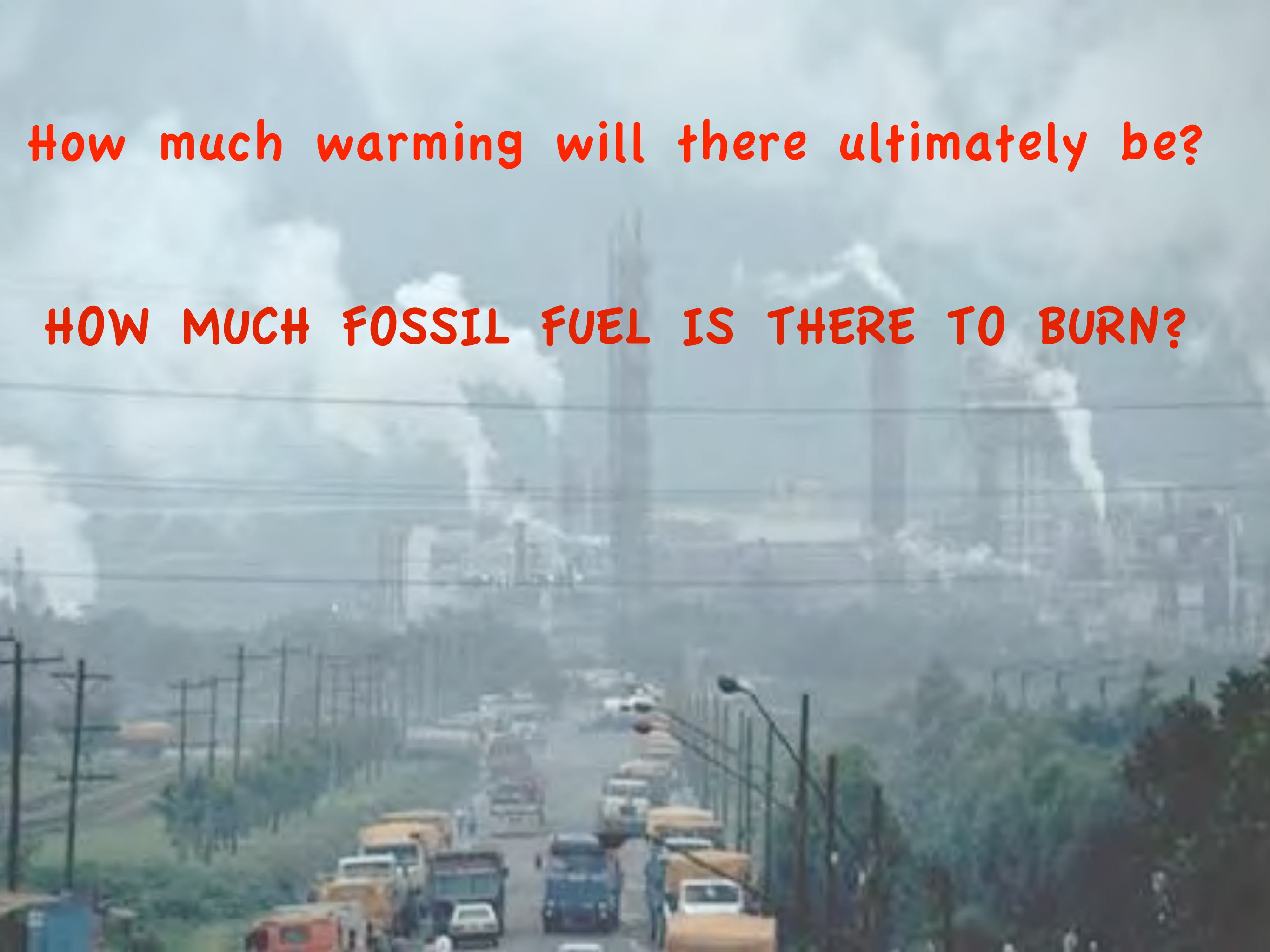
How long will the warming last for?

Possibly thousands of years!

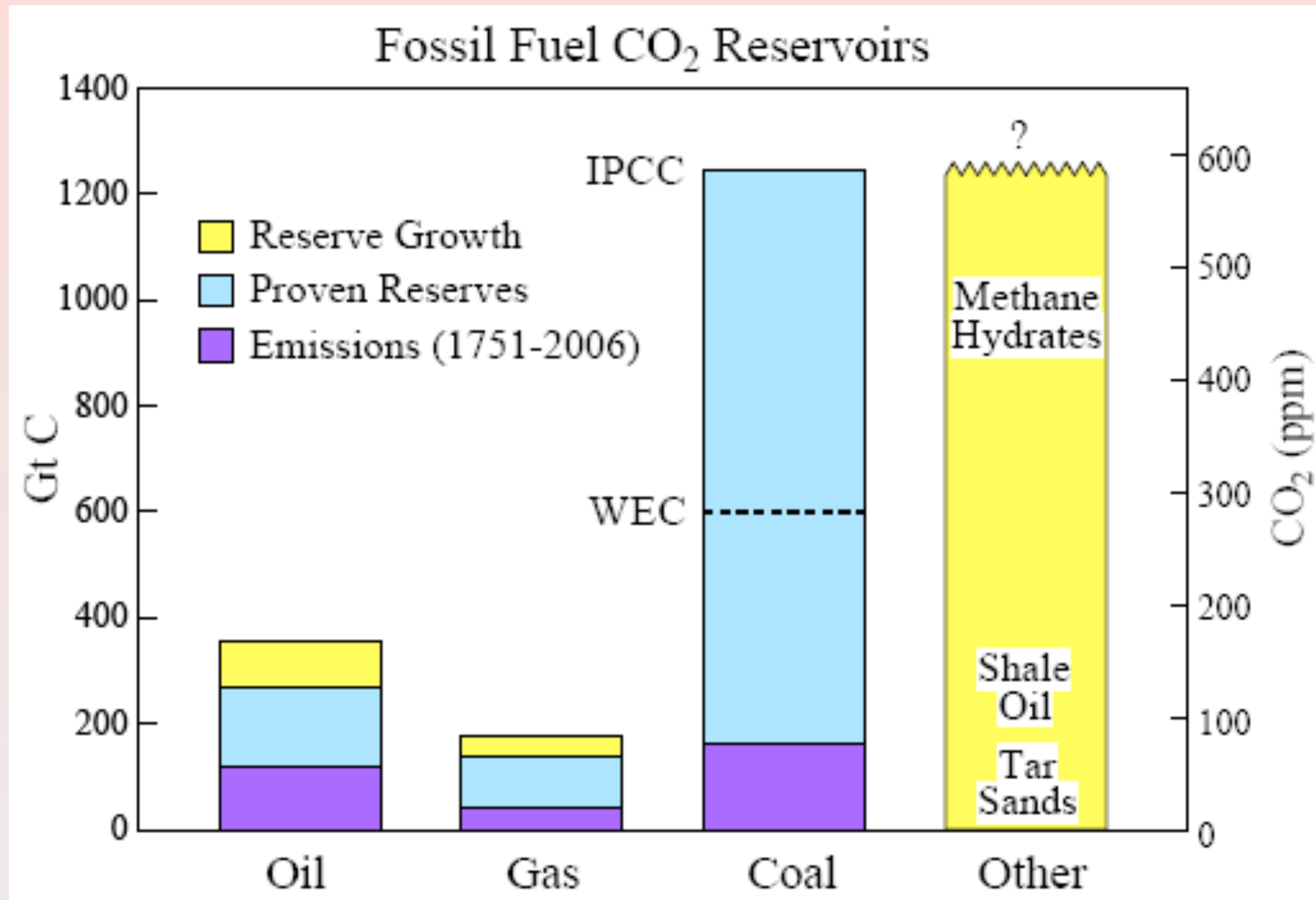


How much warming will there ultimately be?

HOW MUCH FOSSIL FUEL IS THERE TO BURN?



An estimate of fossil fuel reserves



WEC = World Energy Council,
IPCC = Intergovernmental panel on Climate Change

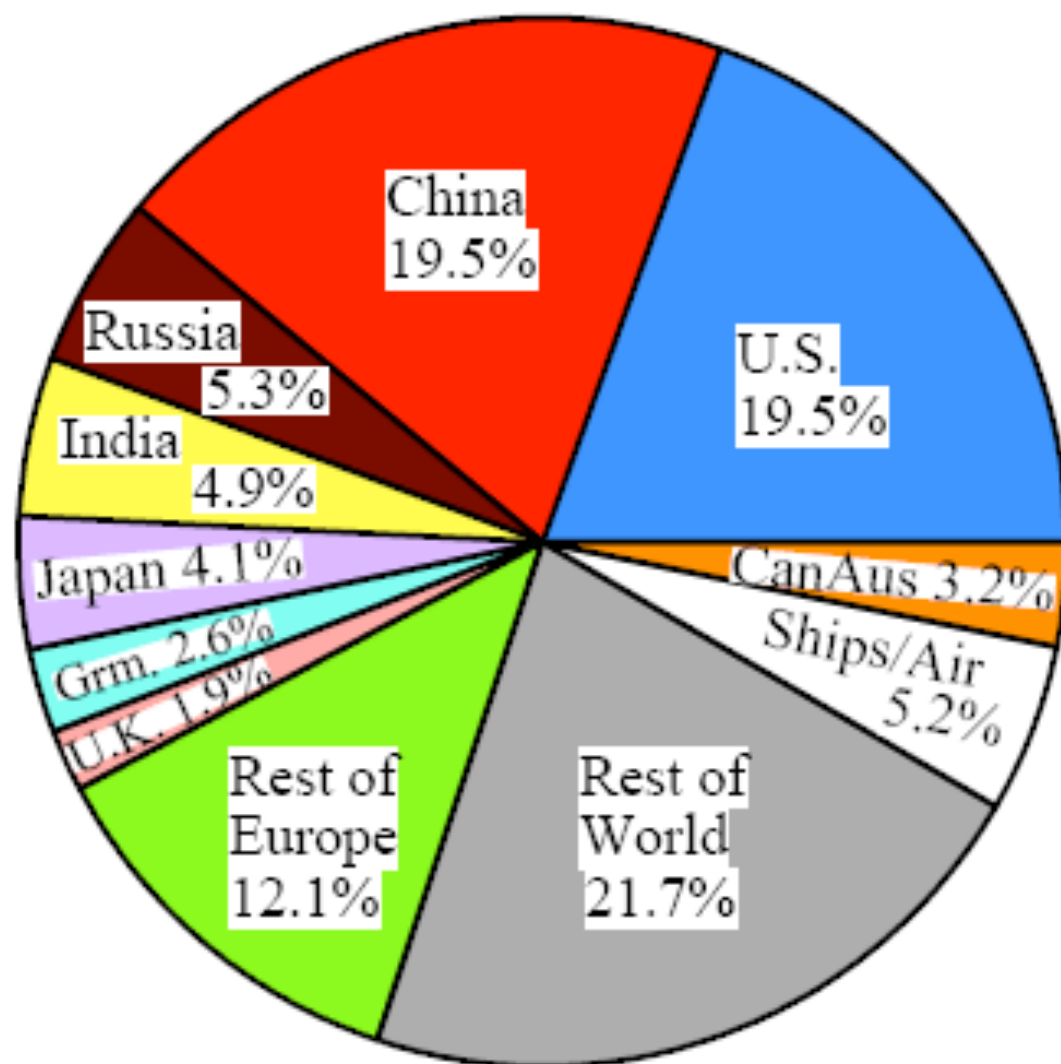
Fossil fuel budget (BP Statistical Review of World Energy, in round numbers)

- **Total known reserves (conservative estimates)**
 - **Coal: 860 Gtons. Oil: 230 Gtons. Natural Gas: 200 Gtons**
 - **Total: 1300 Gtons of fuel.**
- **Approx 1000 Gtons carbon in the ground.**
 - **N.B. We emitted about 200 Gtons in last 50 years**
- **Approx 500 ppm CO₂ addition, total of 800 ppm.**
- **Plus unknown reserves,**
 - **Possibly a quadrupling of CO₂ levels.**
- **Temperature to increase by 3°C (plus or minus 1.5°C, or more).**

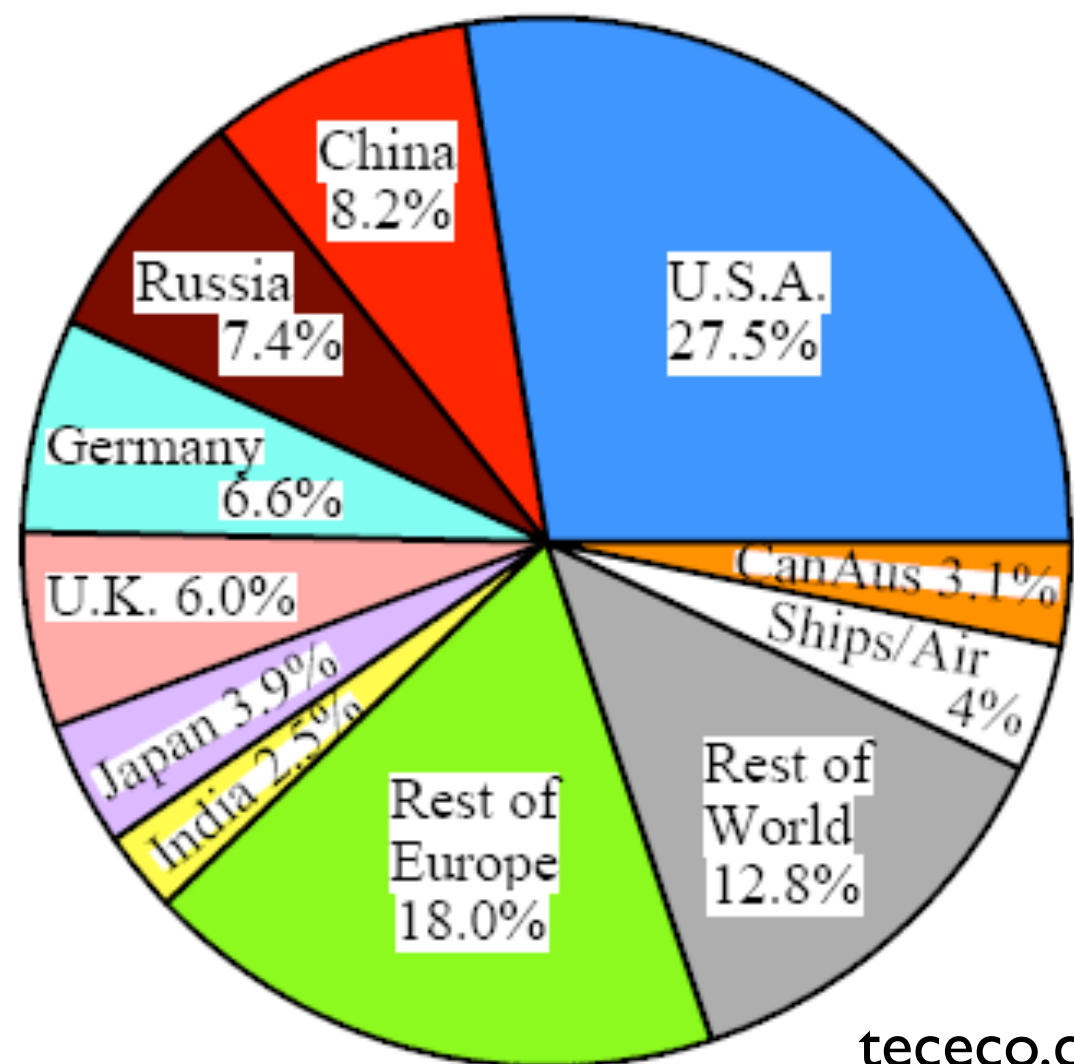
Who's to blame?

Fossil Fuel CO₂ Emissions

(a) 2006 Annual Emissions



(b) 1751-2006 Cumulative Emissions





- Should each country be 'allowed' to emit about the same amount of CO₂ per person?





- Should each country be 'allowed' to emit about the same amount of CO₂ per person?

- Suppose instead that one country decides to reduce its total fossil fuel emissions by, over time, reducing its population.

- Should it then not be allowed to emit more CO₂ per person than other countries that have no population policy?



The Good News

- Doubling of CO₂ likely gives us less than 2°C (3.5°F) average surface warming.
- Once CO₂ emissions halt, temperature no longer increases, because CO₂ levels slowly fall.

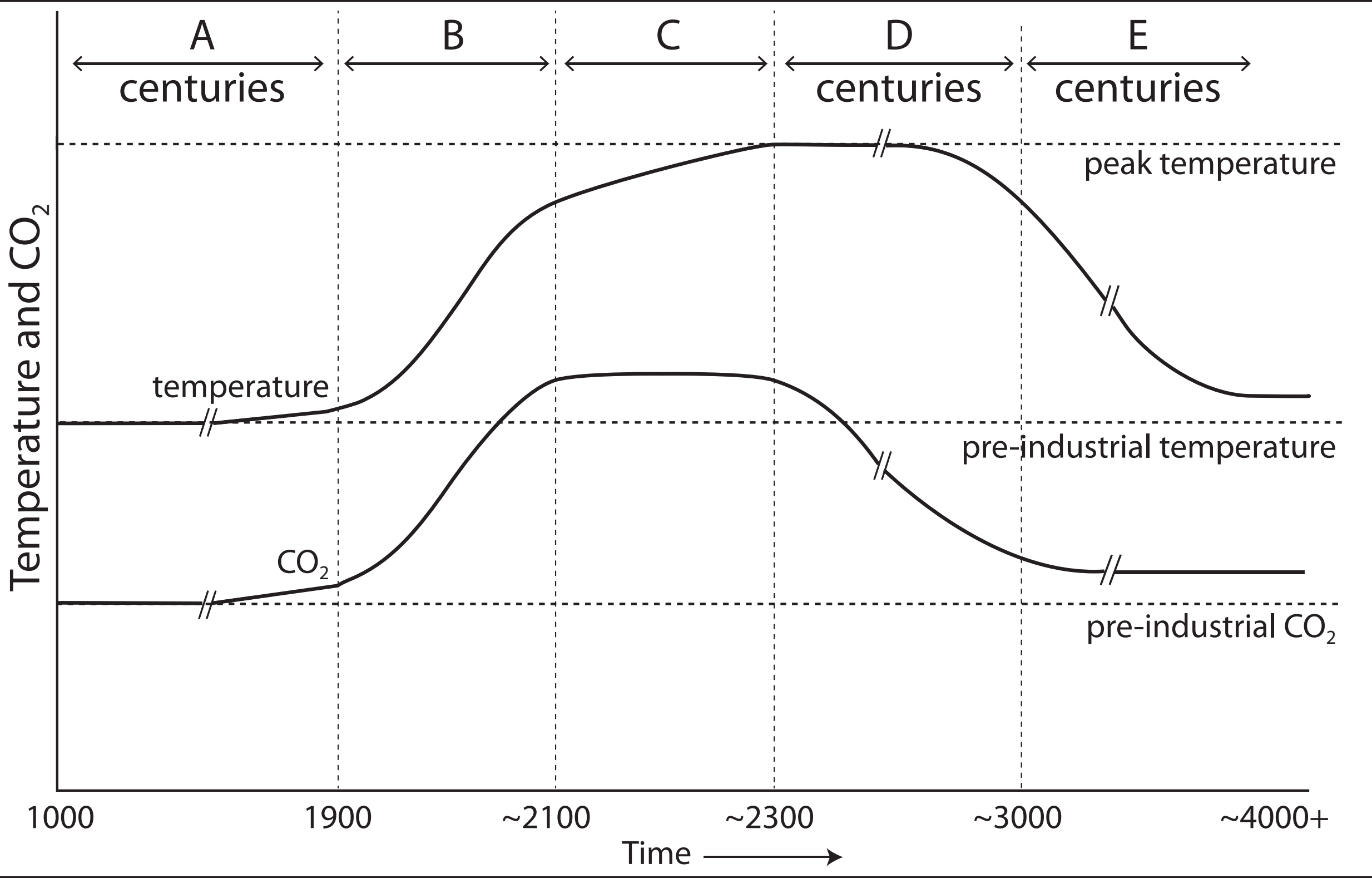
The Bad News

- Burning of all our oil and coal reserves could increase CO₂ levels by 4 or more.
- Produces a warming of 3°C (6°F), or more. (Uncertain!)
- Temperature does not fall after we have stopped emitting CO₂.
 - It will take centuries to revert to normal once emissions cease.
 - Ice sheets could then melt, with catastrophic sea-level rise

A Personal Opinion

- In the short term (years to a few decades) global warming will be a smaller problem than is sometimes opined.
- In the long term (centuries and beyond) global warming will be a larger problem than is sometimes imagined.
- Melting of the Greenland ice sheets is a distinct possibility, with sea-level rise of more than 6 m (20 ft).

A temperature - carbon dioxide scenario



The Fast Mixed Layer and the Slow Deep Ocean

