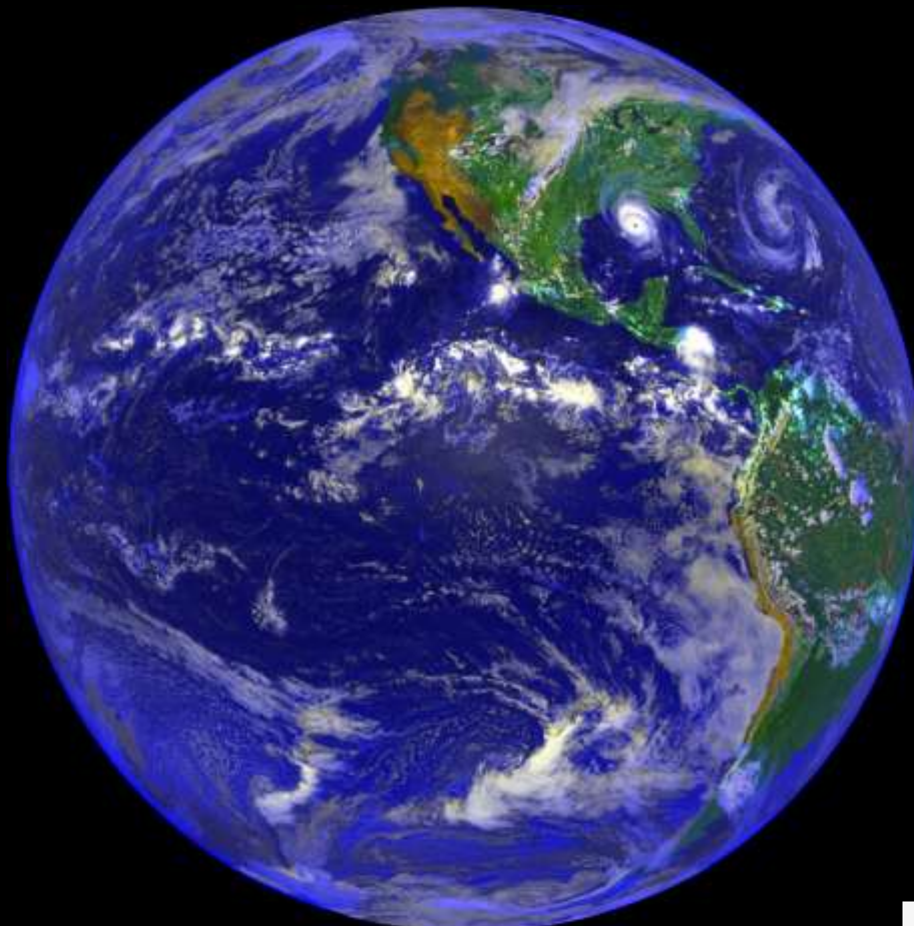
The Science of Climate Change



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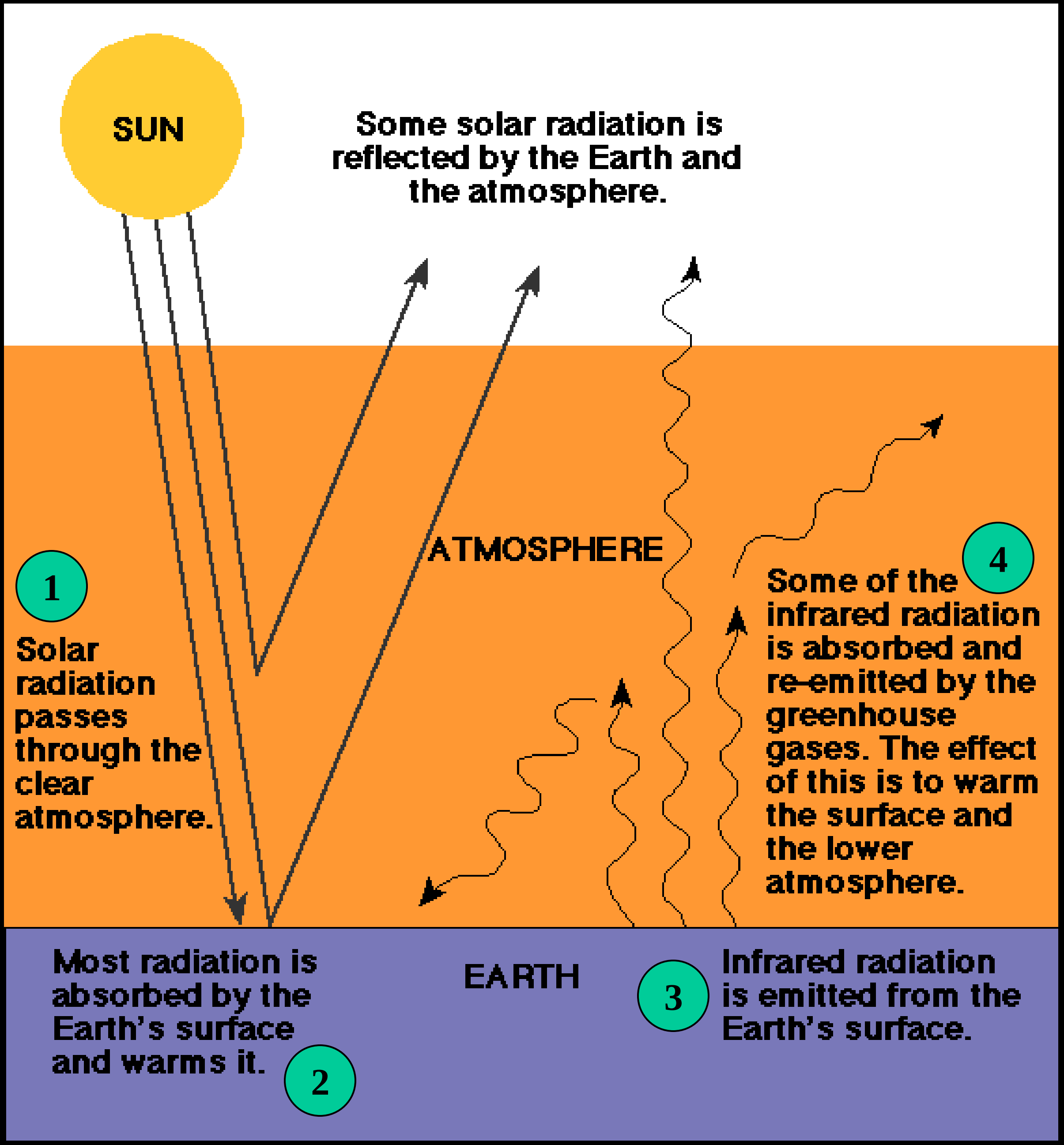
greenhouse gases in the atmosphere trap heat at the Earth's surface and prevent it from escaping.

These gases include:

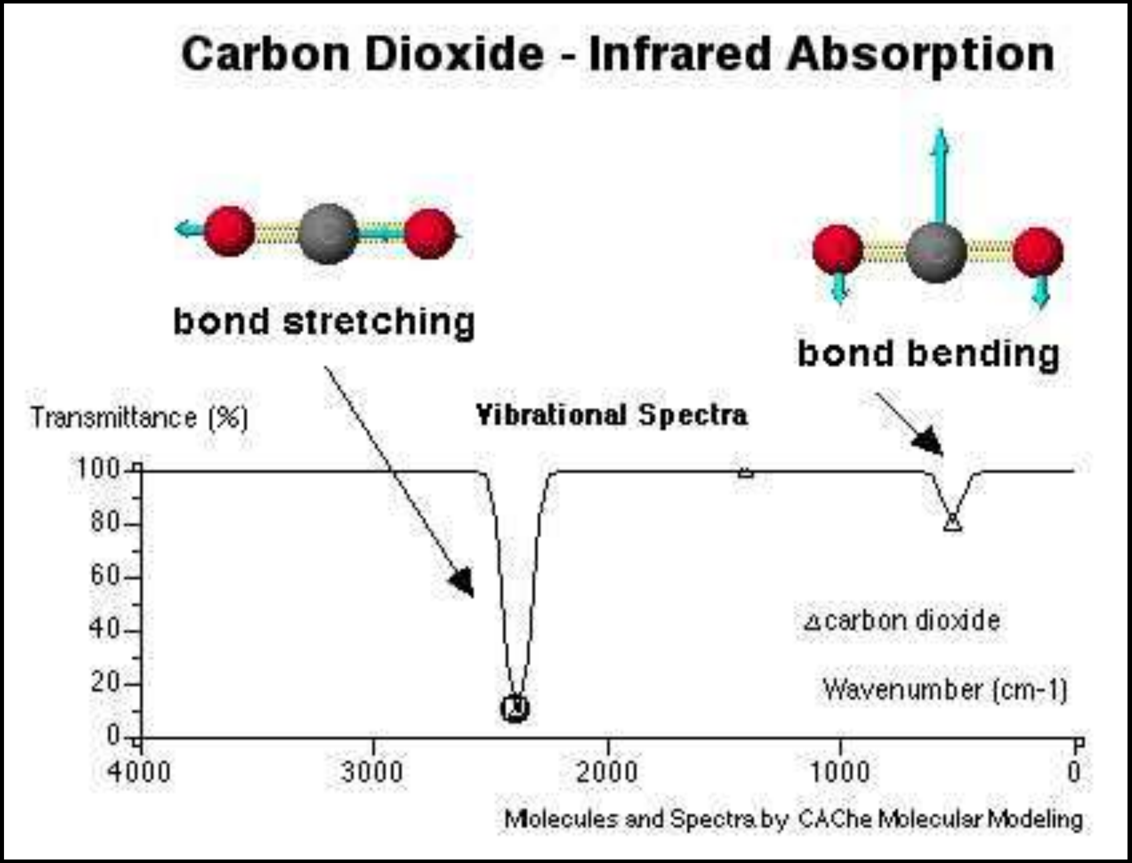
- Carbon dioxide CO_2
- Methane CH_4
- Nitrous oxide N_2O
- Chlorofluorocarbons
- *Water vapor H_2O*

(this is the most important one, by far!)

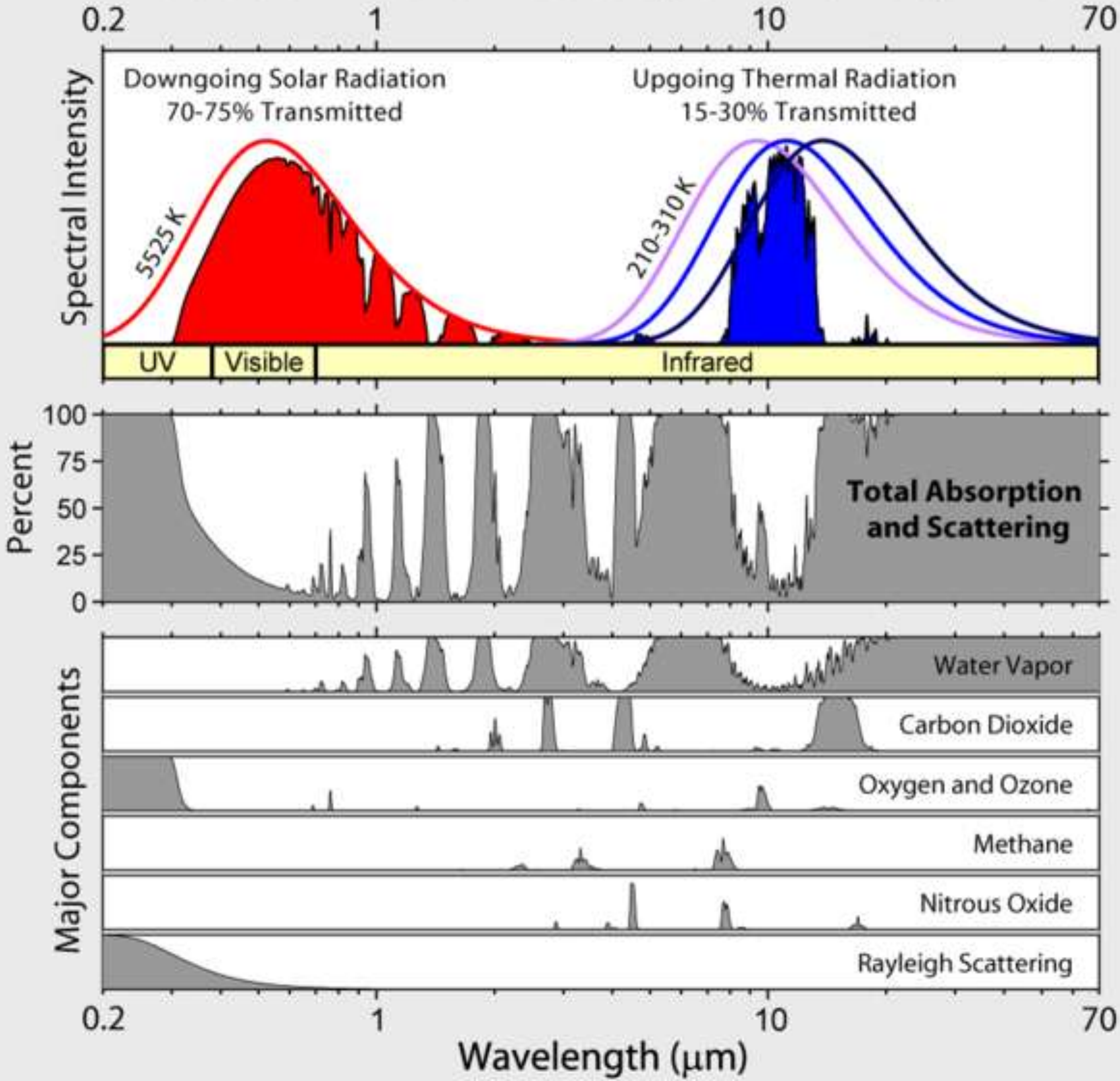


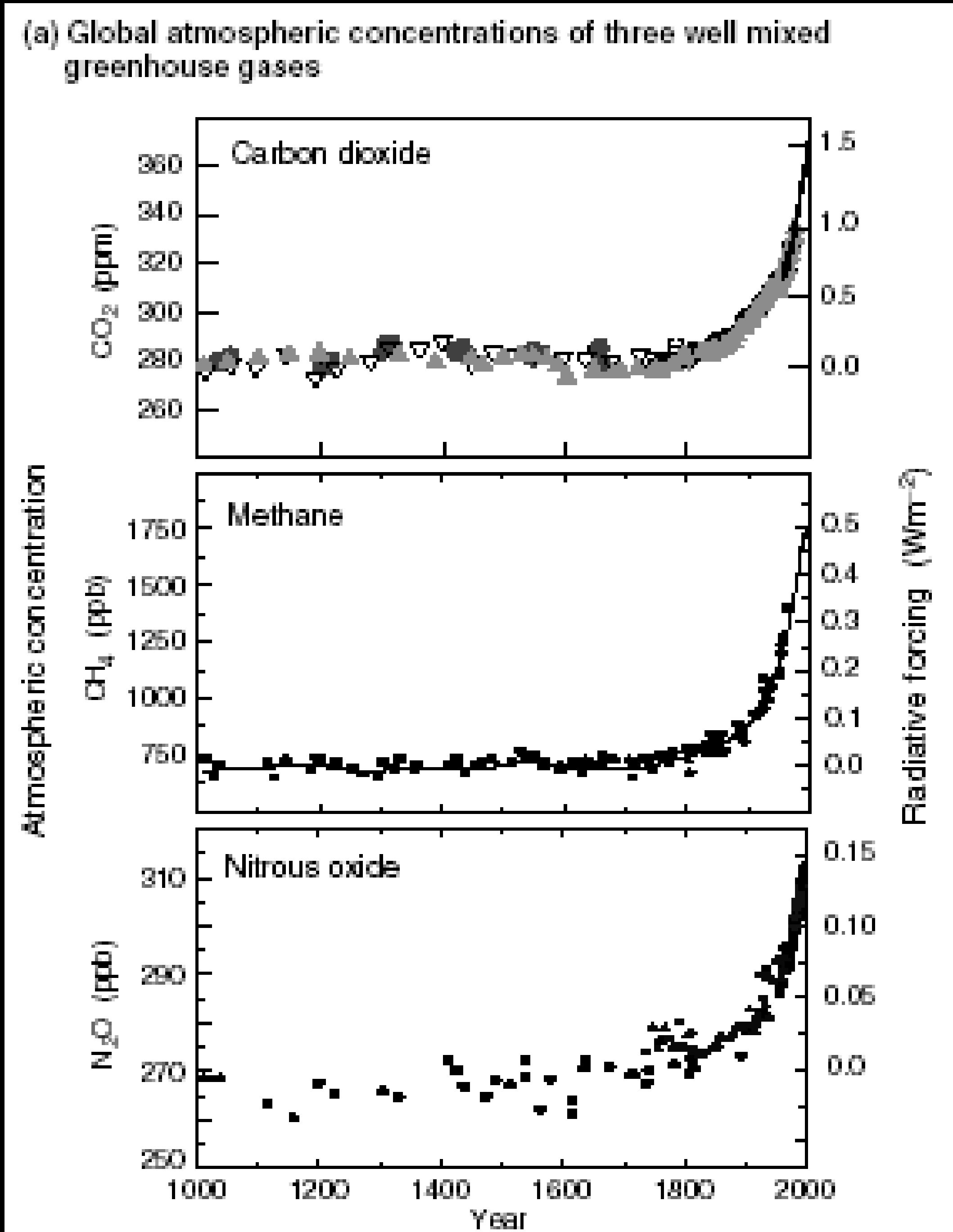
without greenhouse gases average temp of Earth would be -18ºC instead of 15ºC

greenhouse gases trap heat because they absorb radiation in the infrared range, according to specific bond geometries and vibrational modes (ex CO_2 below)



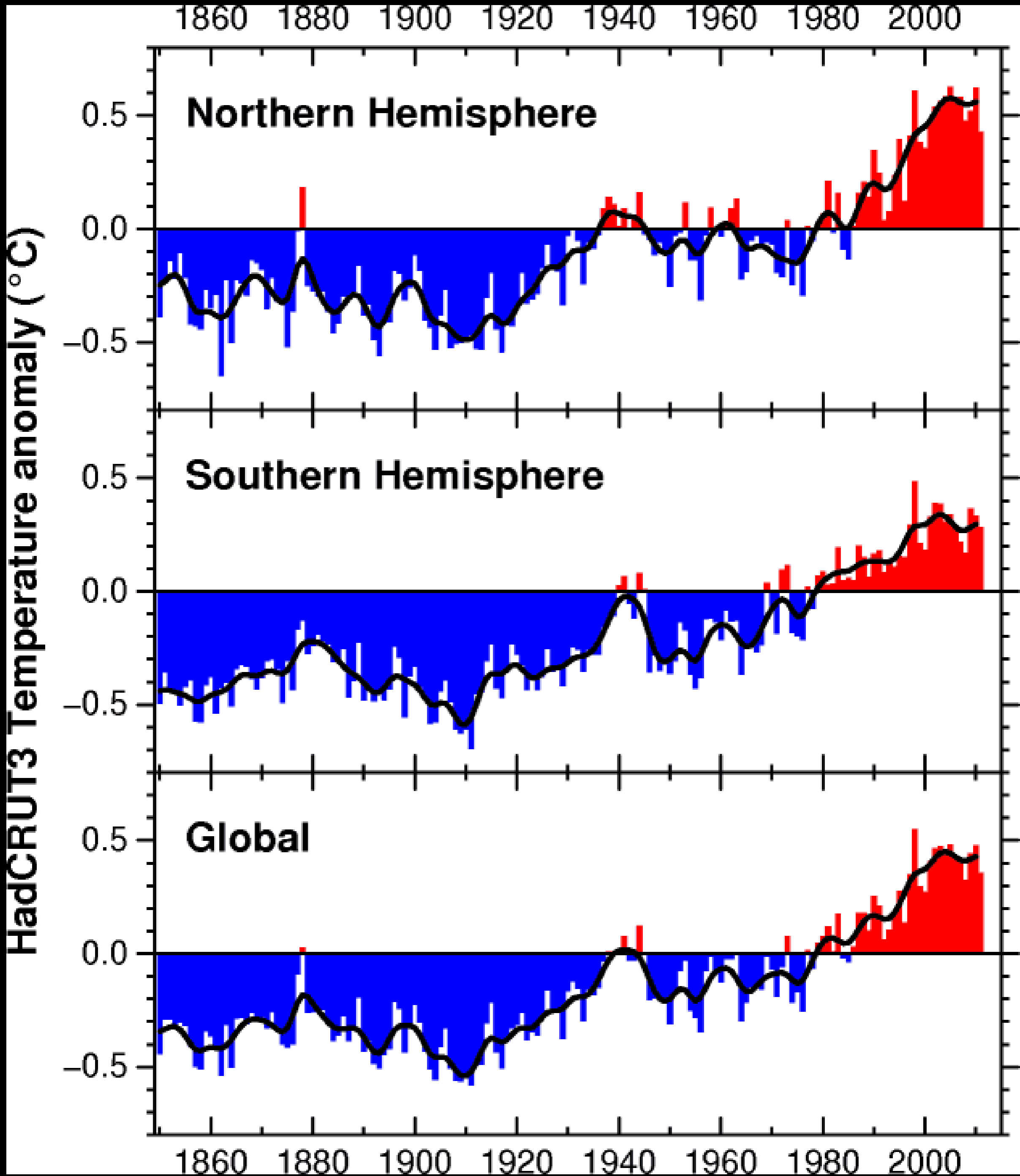
Radiation Transmitted by the Atmosphere





ice core CO2 records confirm that the CO2 trend began in the 1800’s

The ‘instrumental’ record of climate shows a ~1ºC warming over the last century



Source: Hadley Center UK Met Office Jones et al., 1999

A paleo perspective: glacial-interglacial cycles

CO_2

range = 200 to 280ppm

Temperature

range = 5ºC

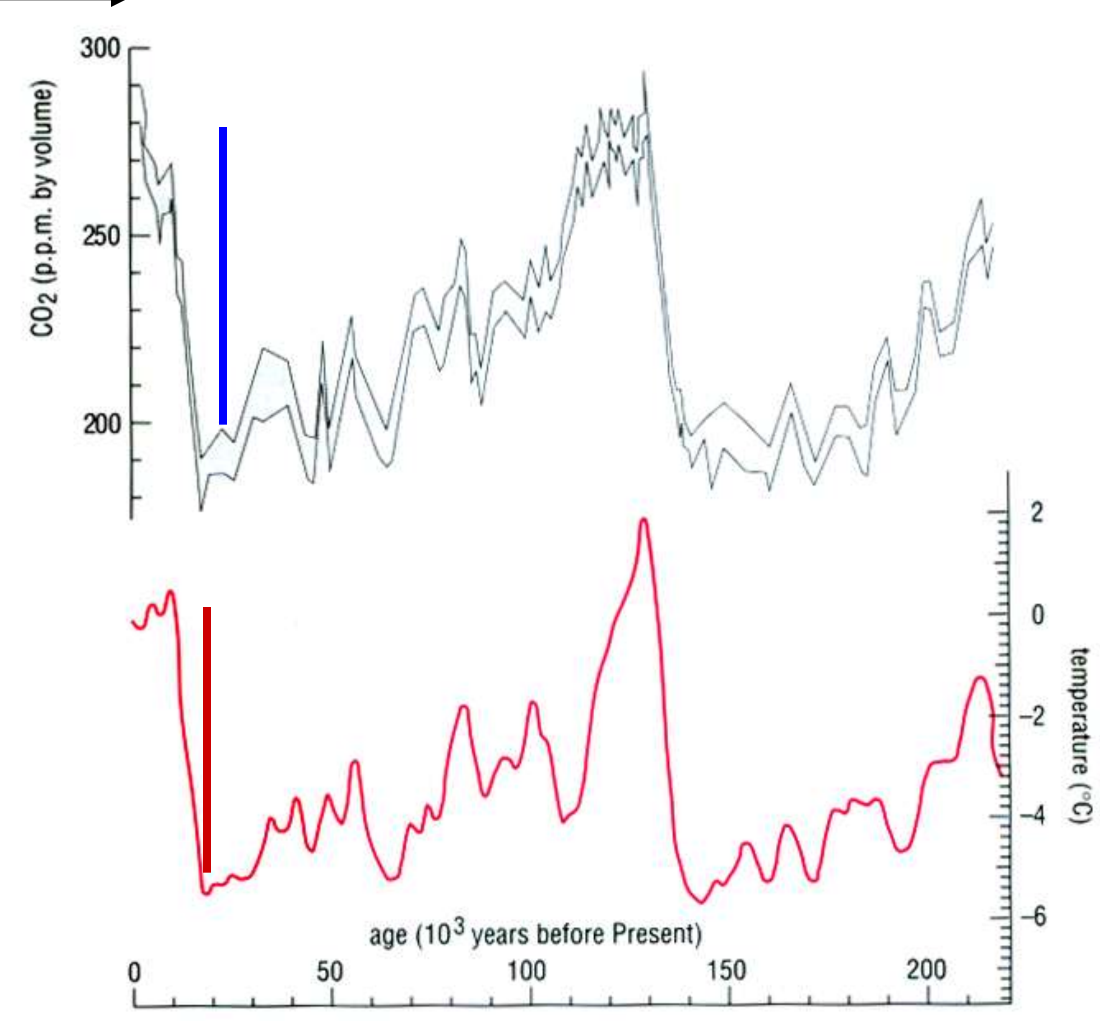
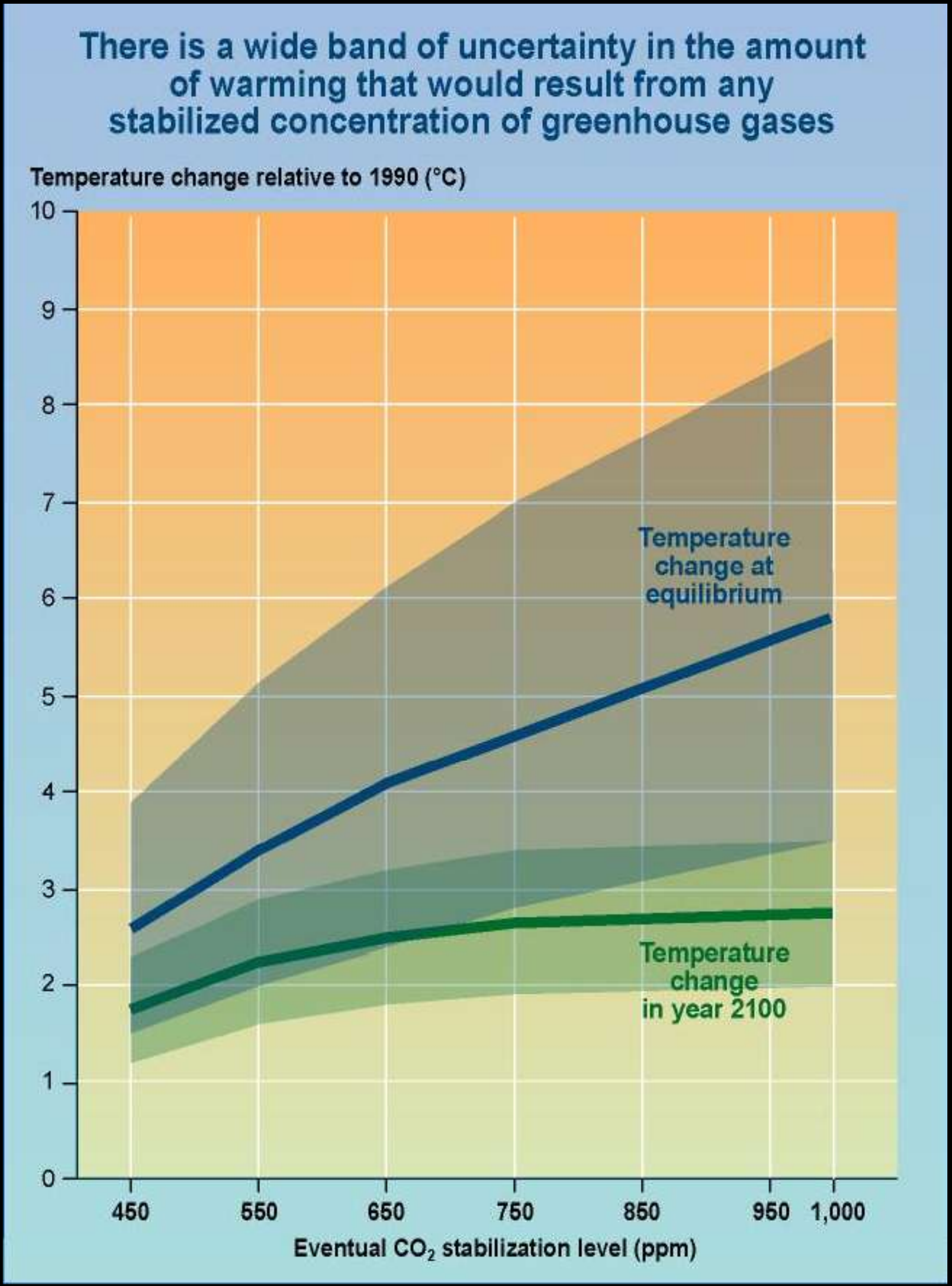


Figure 7.2 Variation with time in atmospheric CO_2 concentrations, determined from air bubbles trapped in an ice core from Vostok in eastern Antarctica (grey curve – width of shade area corresponds to measurement error); along with the atmospheric temperature at the surface, inferred from measurements of the deuterium/hydrogen isotopic ratio in H_2O (red curve).

But **why doesn't an 80 ppm change in CO_2 correspond to a 5 C change?**

The climate system does not reach equilibrium instantaneously

Other processes can change the equilibrium temperature.



Why do 99.999% of climate scientists believe that CO_2 is warming the planet?

1. Theory predicts that increasing atmospheric CO2 should warm the planet.

2. Geologic evidence links CO2 and temperature in the past.

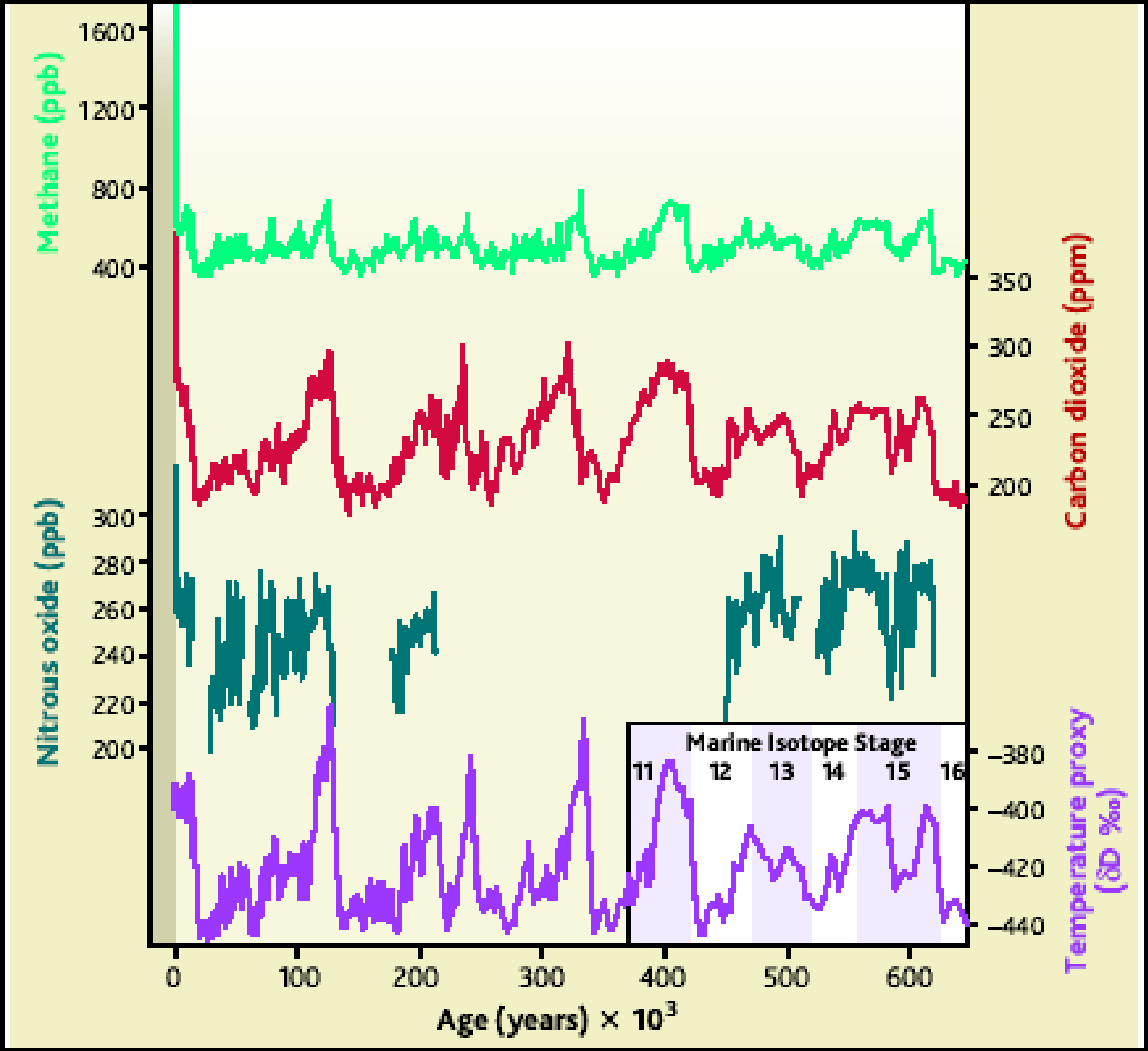
3. The warming is unprecedented in the most recent centuries (dwarfs natural variability).

4. Climate models show that rising CO2 is necessary to simulate 20^{th} century temperature trends (solar and volcanic minor players).

Ice core climate and CO_2 records

tiny gas bubbles
in the ice trap
ancient air samples

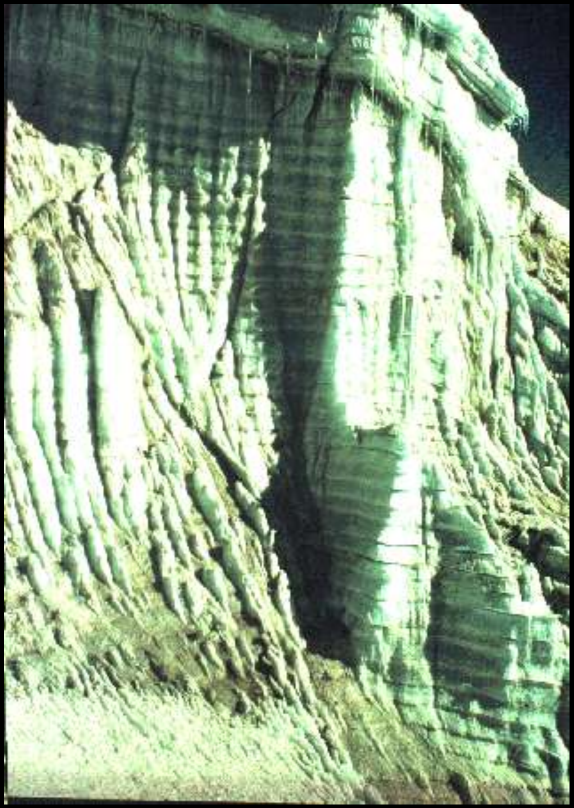
#2 Atmospheric CO_2 and temperature over the past 650 thousand years

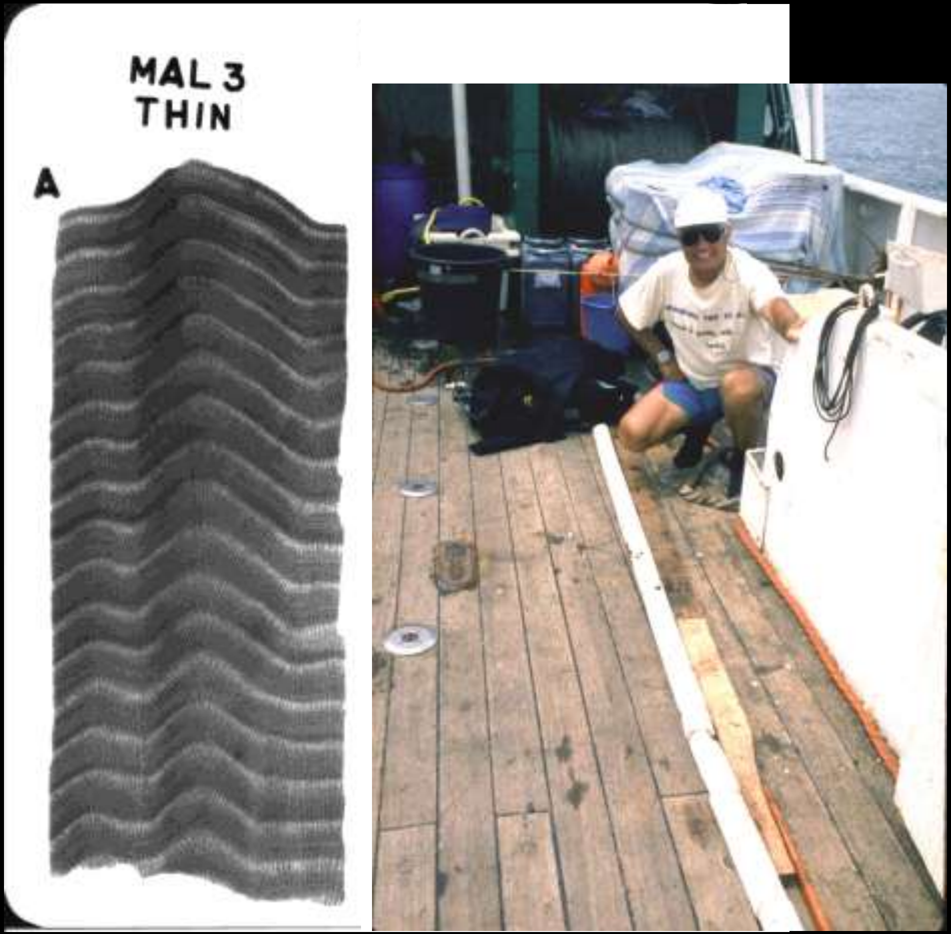


CO_2 and temperature are closely linked on geologic timescales

To understand how climate has changed in the past, we need to use records of climate preserved in ice cores, ancient tree rings, coral bands, and other “**paleoclimatic**” sources:

key is to CALIBRATE to temperature records





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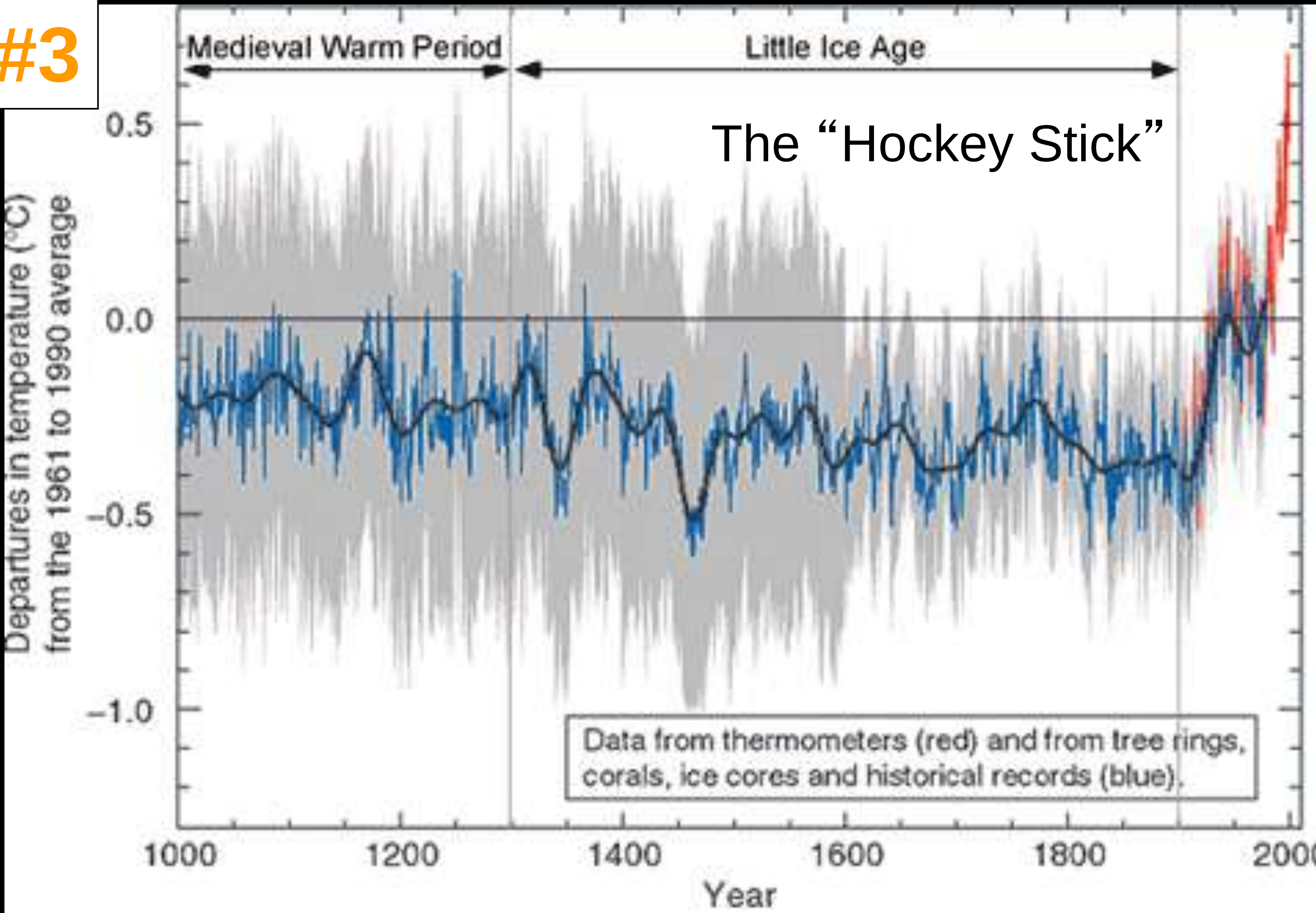


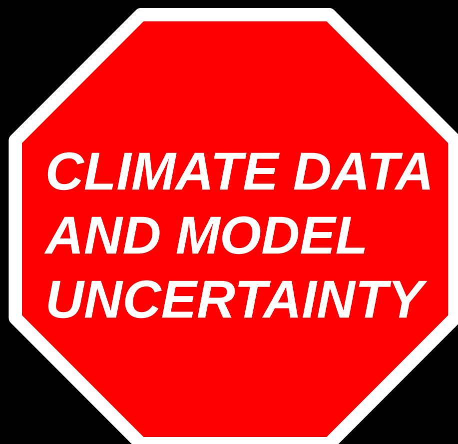
<u>Key Points</u>:

error bars increase as you go back in time

natural variability accounts for <0.5ºC over the last millennium

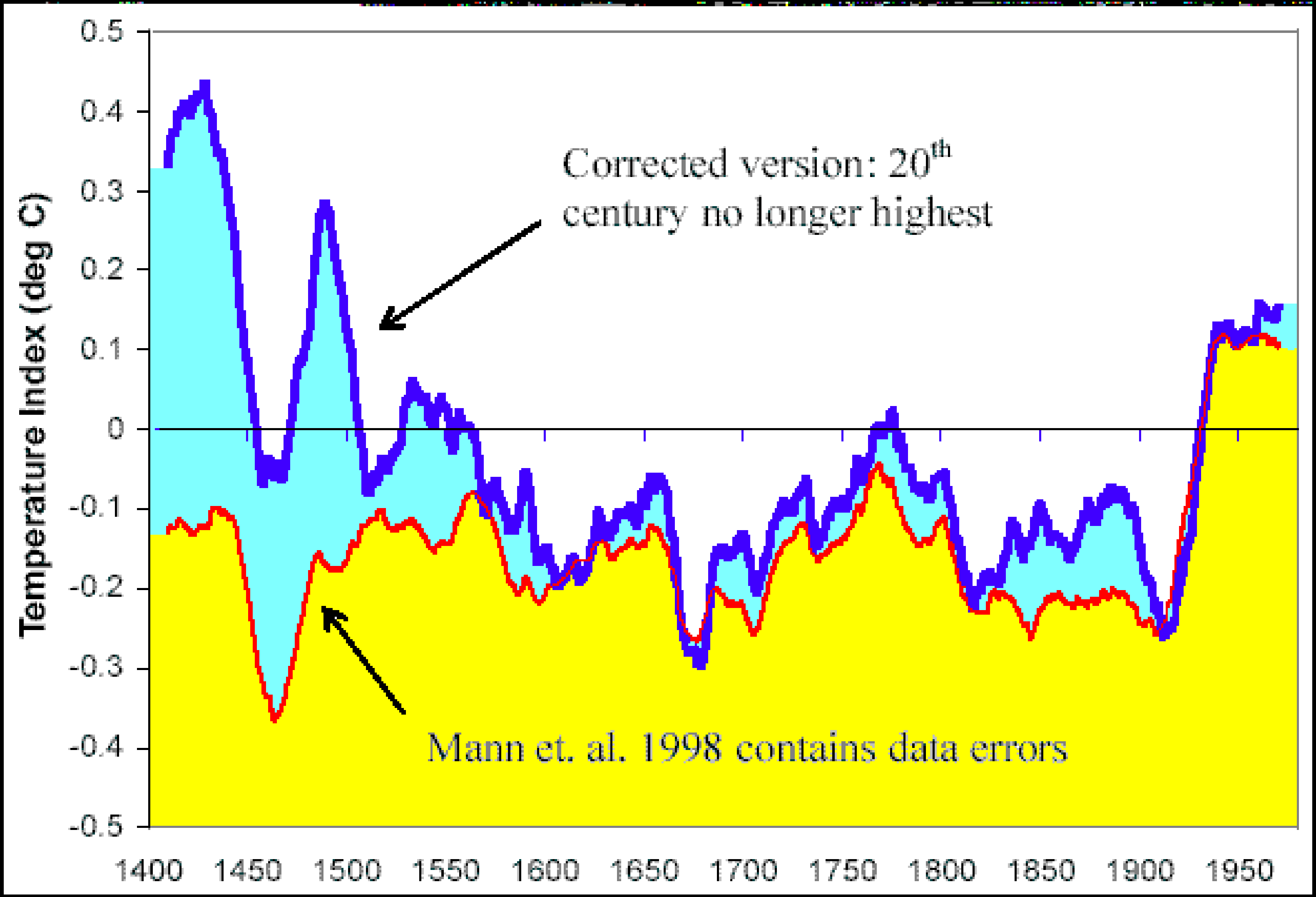
late 20th century temperature trend is unprecedented

Climate science under seige: live from the trenches

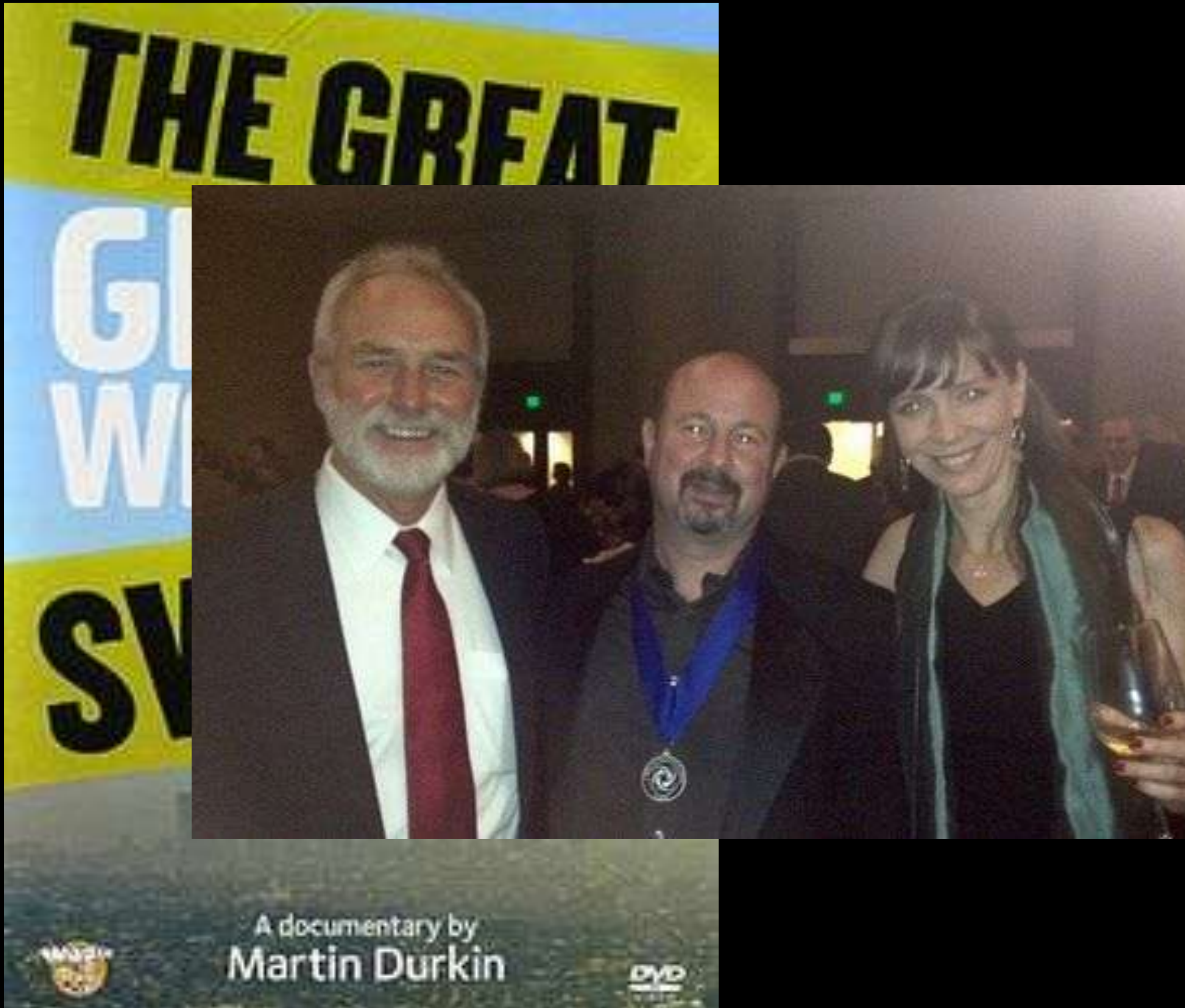


"Much of the debate over global warming is predicated on fear, not on science."
-- Sen. Inhofe, R-Okl

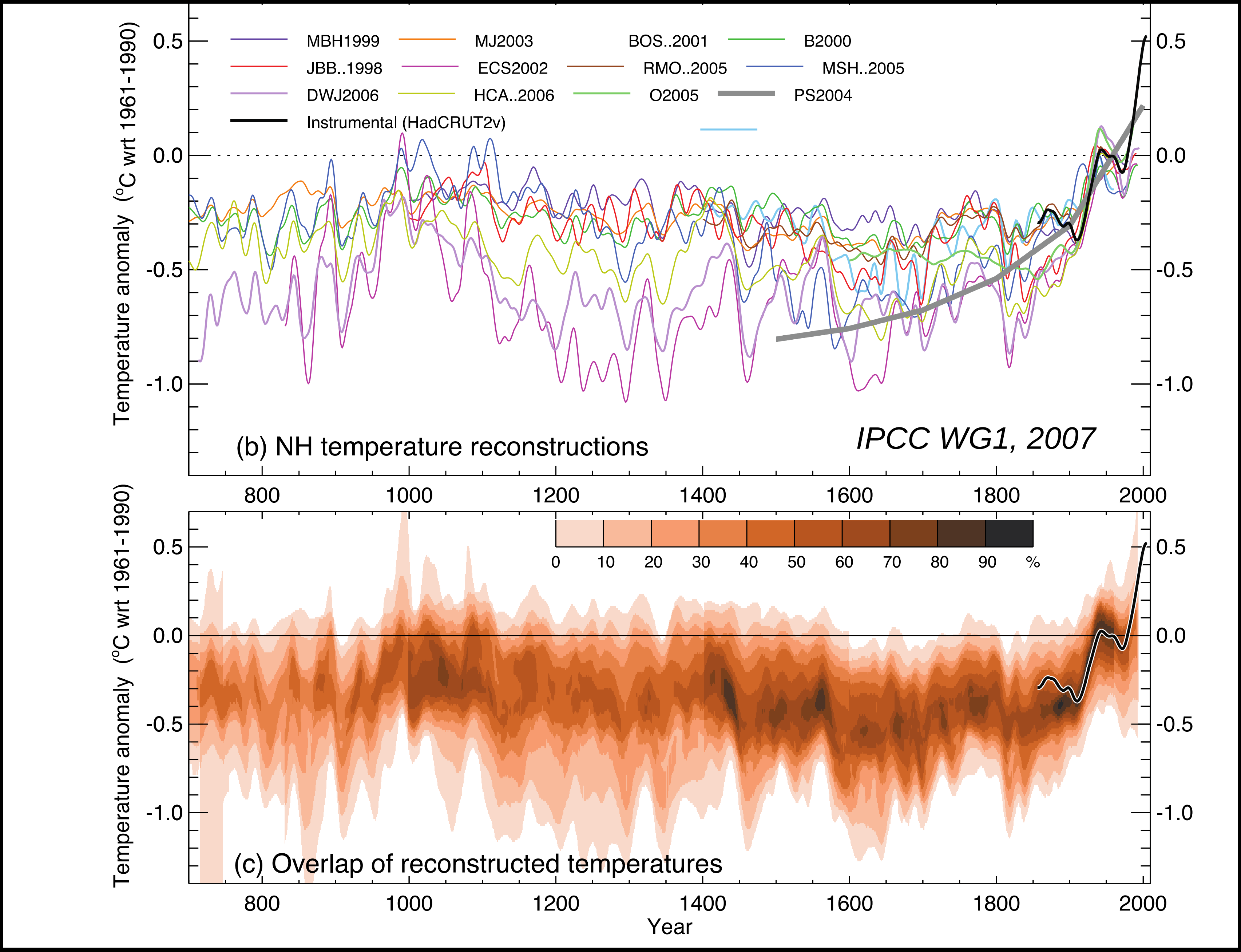
A broken "hockey stick"?



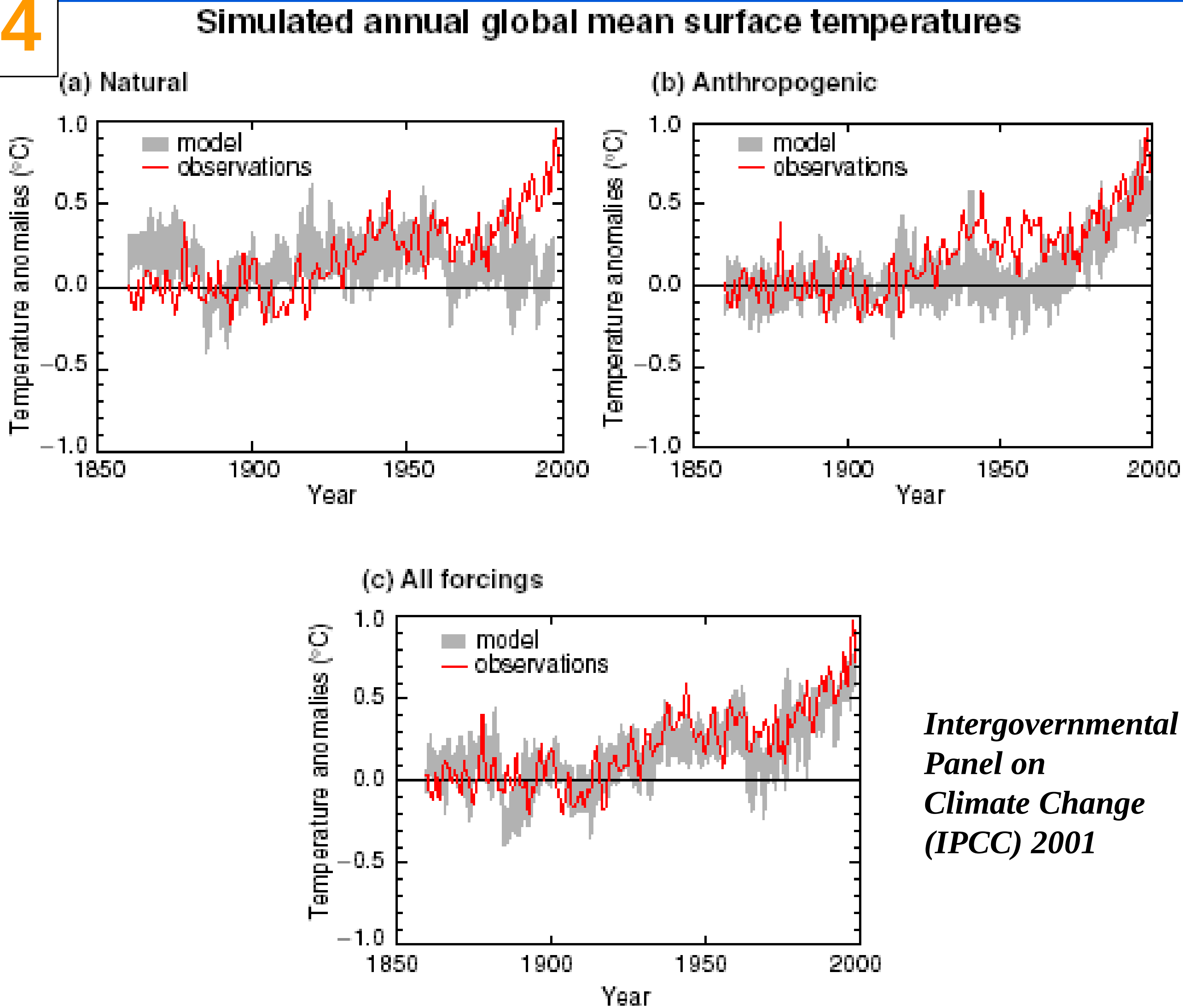
http://www.freerepublic.com/focus/f-news/1010630/posts


THE GREAT
A documentary by
Martin Durkin
DVD

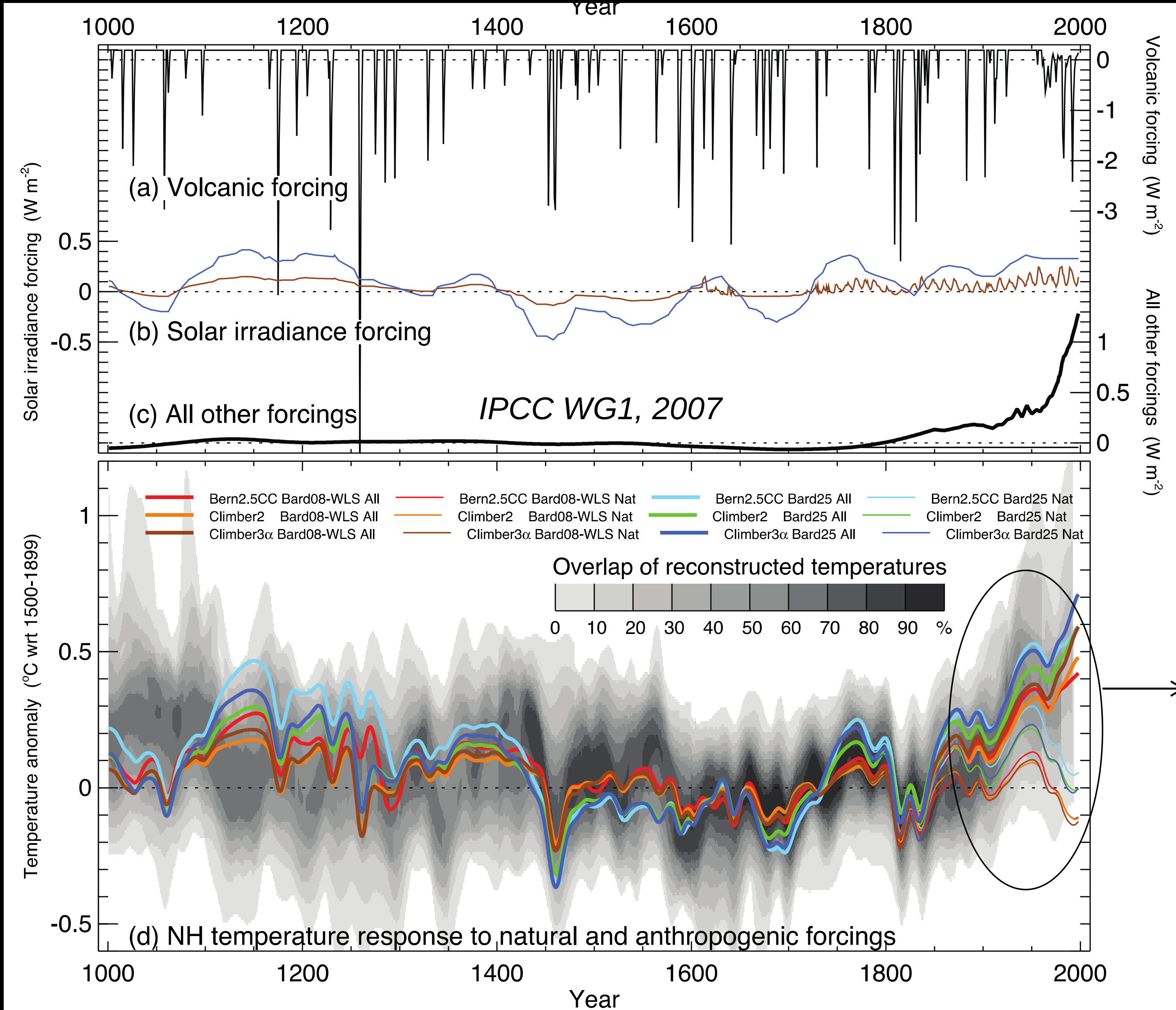
The “hockey stick” has been reproduced many times



#4



Intergovernmental Panel on Climate Change (IPCC) 2001


Year
1000
1200
1400
1600
1800
2000
Volcanic forcing (W m-2)
0
-1
-2
-3
(a) Volcanic forcing
Solar irradiance forcing (W m-2)
0.5
0
-0.5
(b) Solar irradiance forcing
(c) All other forcings
IPCC WG1, 2007
All other forcings (W m-2)
1
0.5
0
Bern2.5CC Bard08-WLS All
Climber2 Bard08-WLS All
Climber3α Bard08-WLS All
Bern2.5CC Bard08-WLS Nat
Climber2 Bard08-WLS Nat
Climber3α Bard08-WLS Nat
Bern2.5CC Bard25 All
Climber2 Bard25 All
Climber3α Bard25 All
Bern2.5CC Bard25 Nat
Climber2 Bard25 Nat
Climber3α Bard25 Nat
Overlap of reconstructed temperatures
0 10 20 30 40 50 60 70 80 90 %
Temperature anomaly (°C wrt 1500-1899)
1
0.5
0
-0.5
(d) NH temperature response to natural and anthropogenic forcings
1000
1200
1400
1600
1800
2000
Year

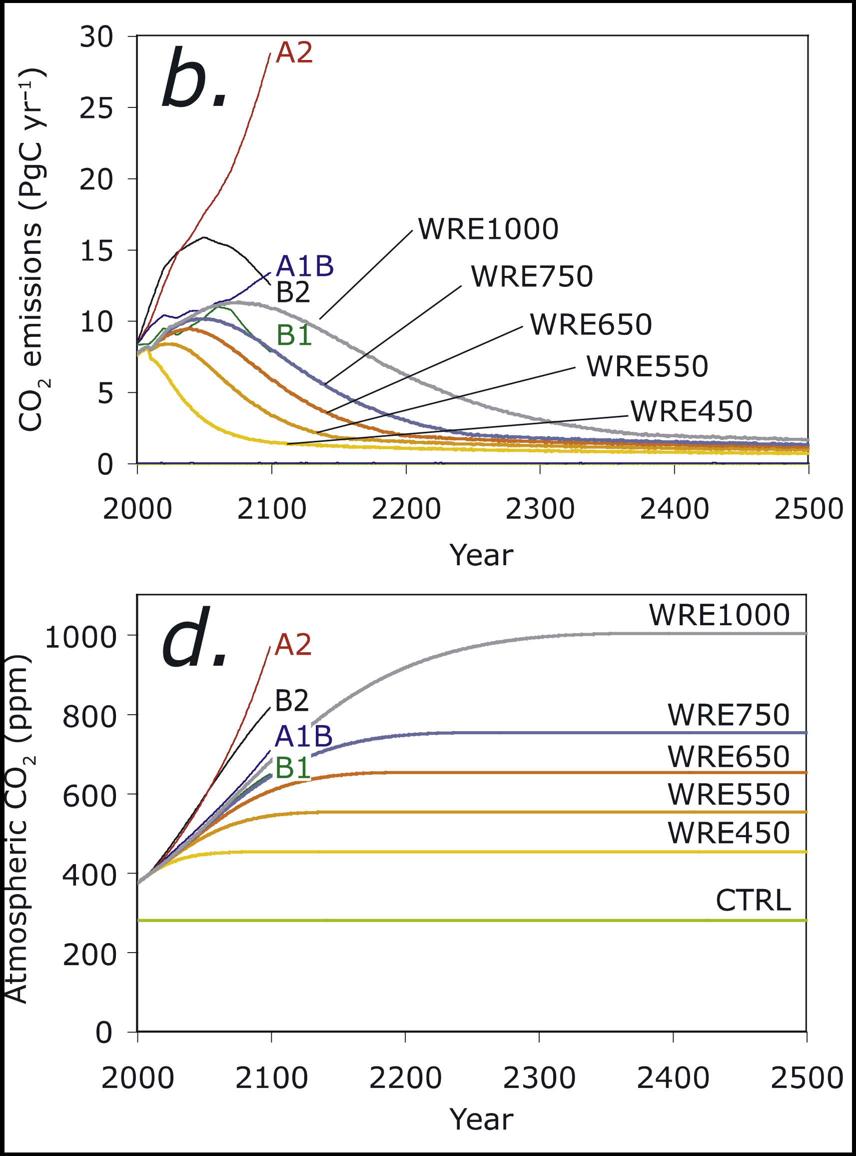
You need CO_2

Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations[12]. This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in greenhouse gas concentrations". Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns (see Figure SPM-4 and Table SPM-2). {9.4, 9.5}

Consequences of Global Warming (IPCC SPM-AR4)

1) Reduced uptake of CO_2 by land and ocean in warmer climate
2) Rising sea levels (0.3 to 0.6m by 2100)…. at a minimum
3) Ocean pH will decrease by 0.14 to 0.35 (already down 0.1)
4) Snow cover will decrease, permafrost melt, sea ice melt
5) Extreme events (temperature and precipitation) will become more frequent
6) Tropical cyclones will become more intense
7) Storm tracks will move poleward
8) Rainfall will increase in the high latitudes, decrease in the subtropics
9) Meridional overturning of Atlantic ocean will decrease

The uncertain CO_2 future



Caldeira and Wickett, 2005

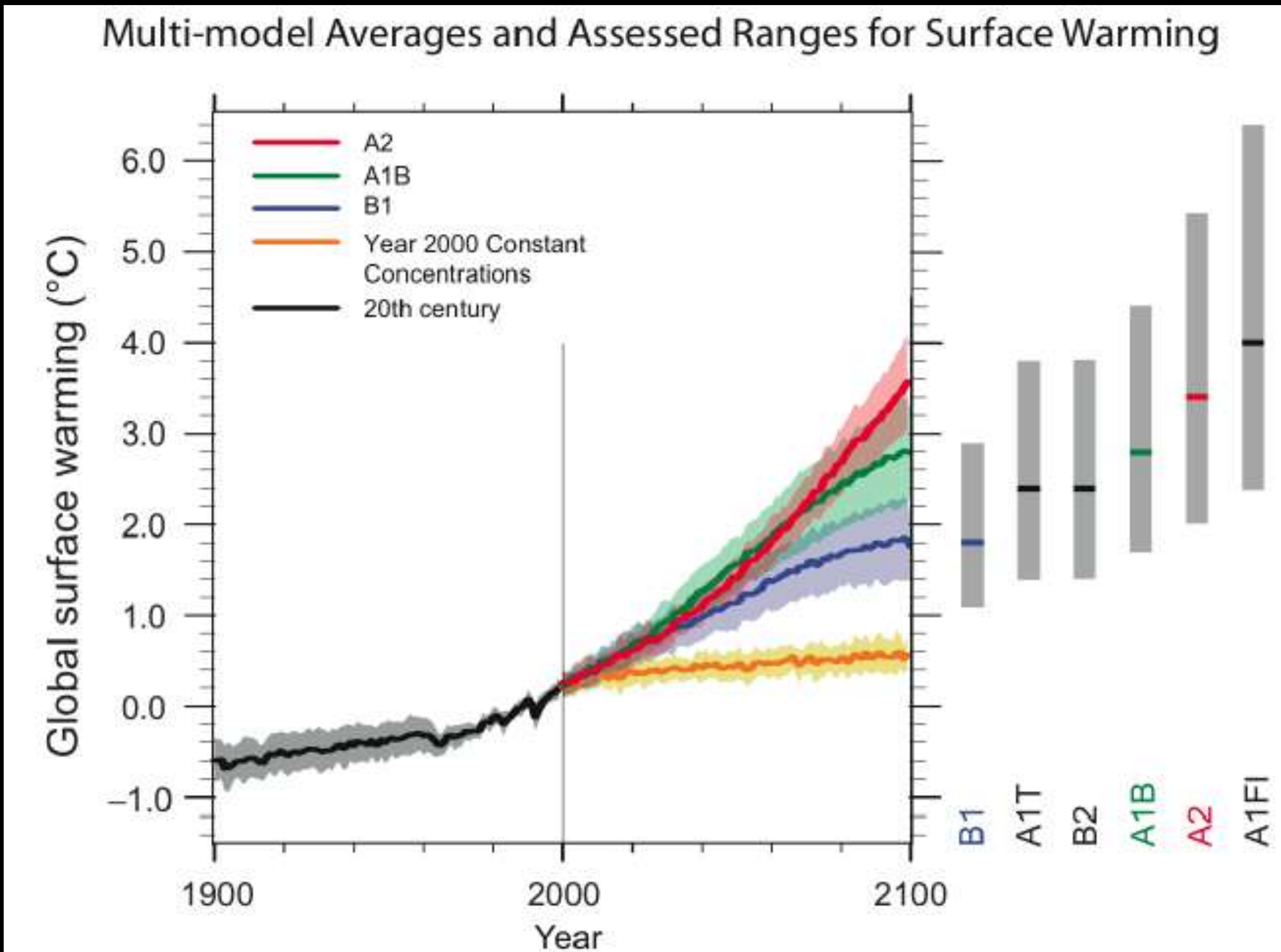
<u>Range of CO2 emissions scenarios</u>:

Strict international agreements → CO2 at 650ppm by 2100

Mid-ground → 850ppm by 2100

Business as usual → 1370ppm by 2100

The uncertain climate future



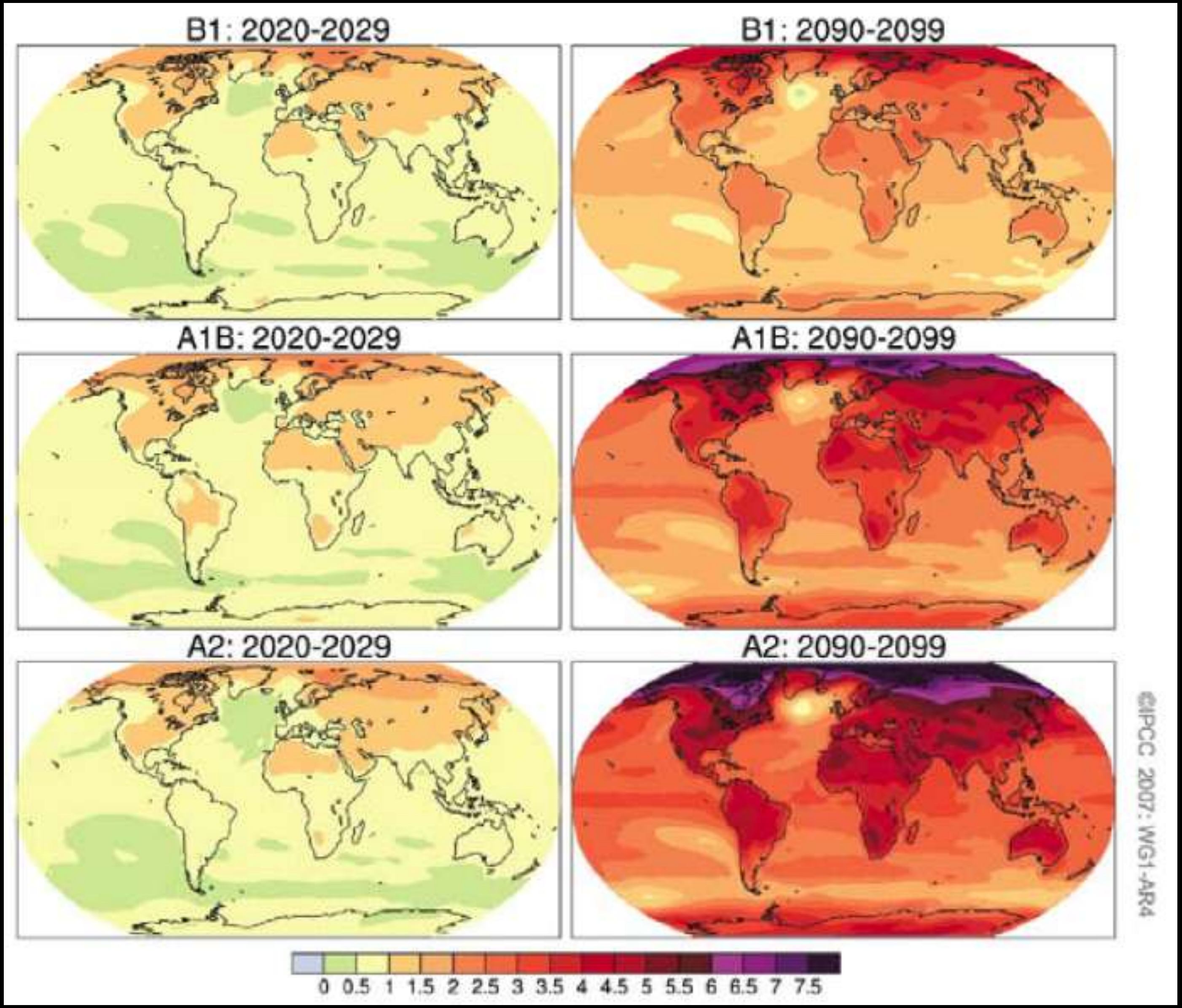
COLORS= different CO_2 paths

grey bars= different model responses to different CO_2 concentrations

Take-homes:
Lower limit: 1˚ C by 2100

Upper limit: 6.5˚ C by 2100

Projected temperature change: global view

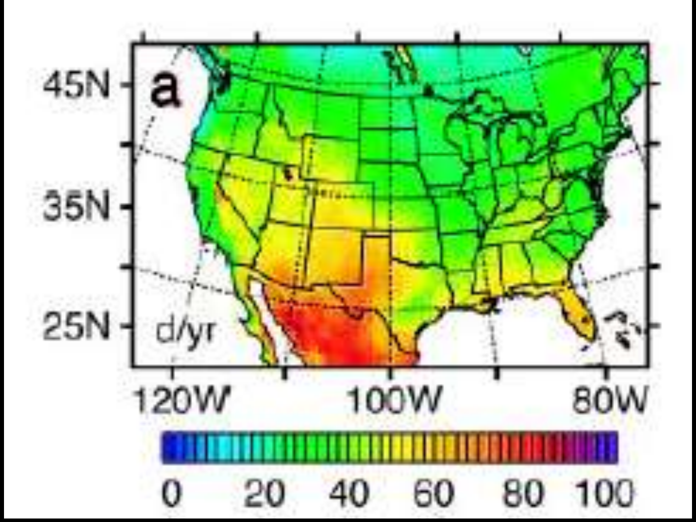


<u>Take-homes</u>:
-poles warm more

-land warms more

-ocean warming
 patchy and complex

uneven warming will shift rainfall patterns

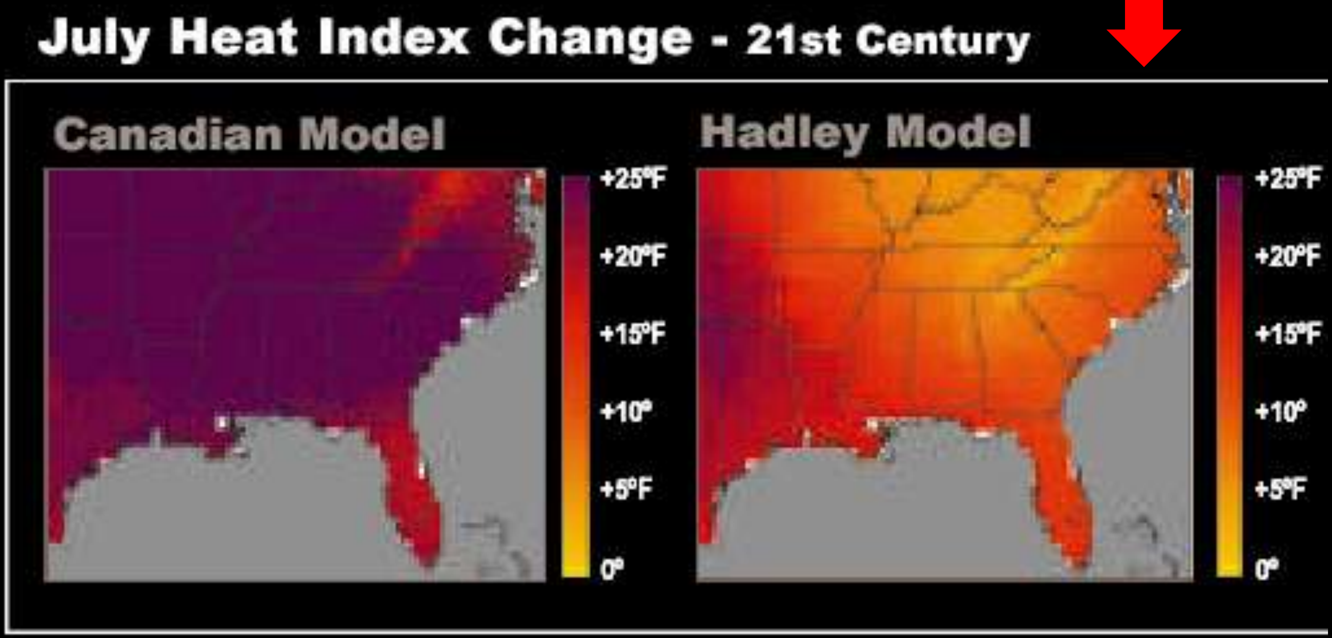


Diffenbaugh et al, 2005

Regional models use global model output, run at high-resolution (5km) grid

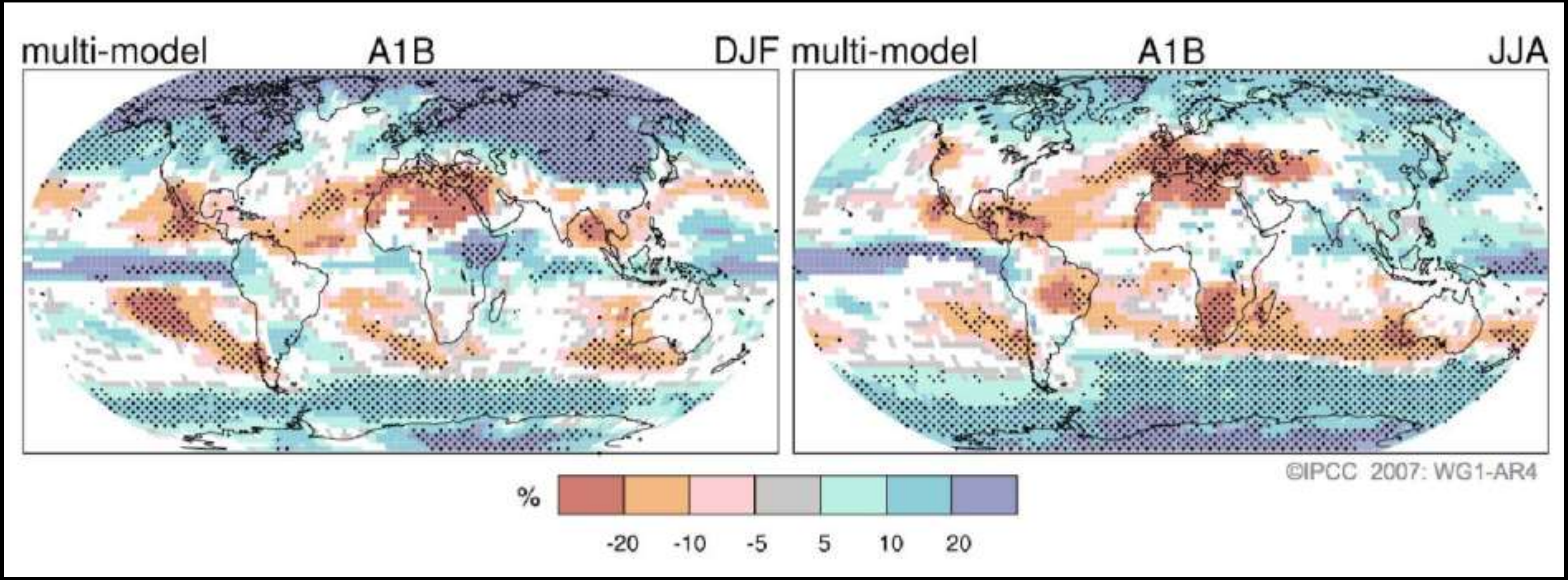
Length of heat waves increase (# days/event)

Peak temperatures increase



US http://www.usgcrp.gov/usgcrp/nacc/se-mega-region.htm

Projected precipitation change: global view

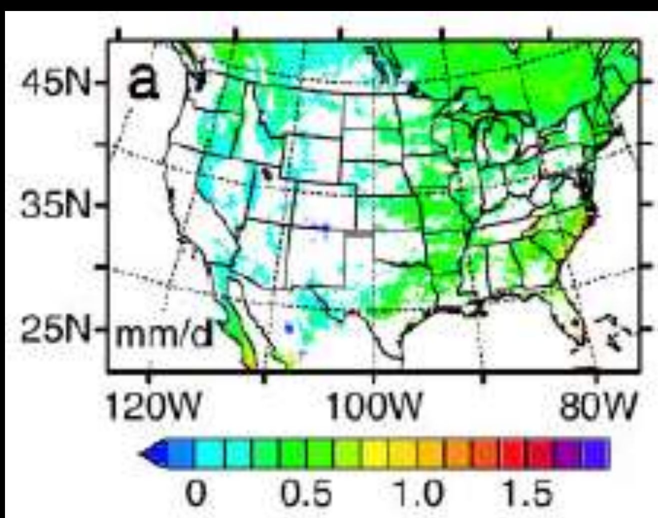


white = models disagree
color = models mostly agree
stippled = models agree

Projecting precipitation is VERY uncertain business,
yet extremely critical to human impacts.

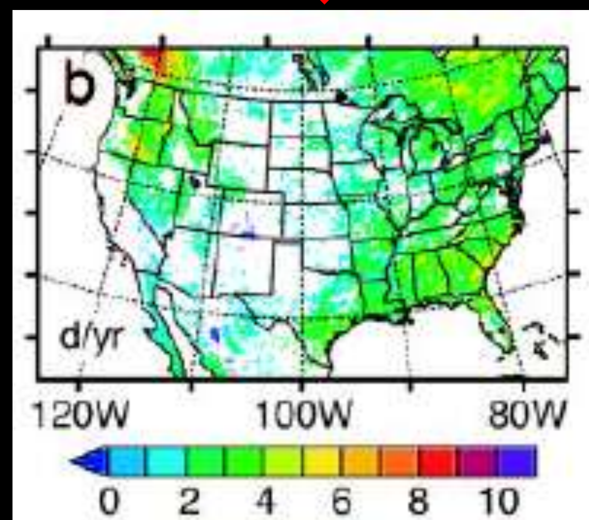
Projected precipitation change: regional view

change in yearly
average precipitation



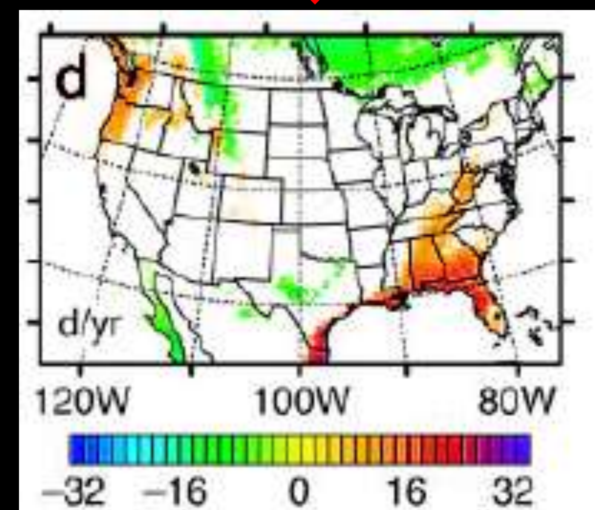
mm/day

heavy rain days



days/yr

dry days



days/yr

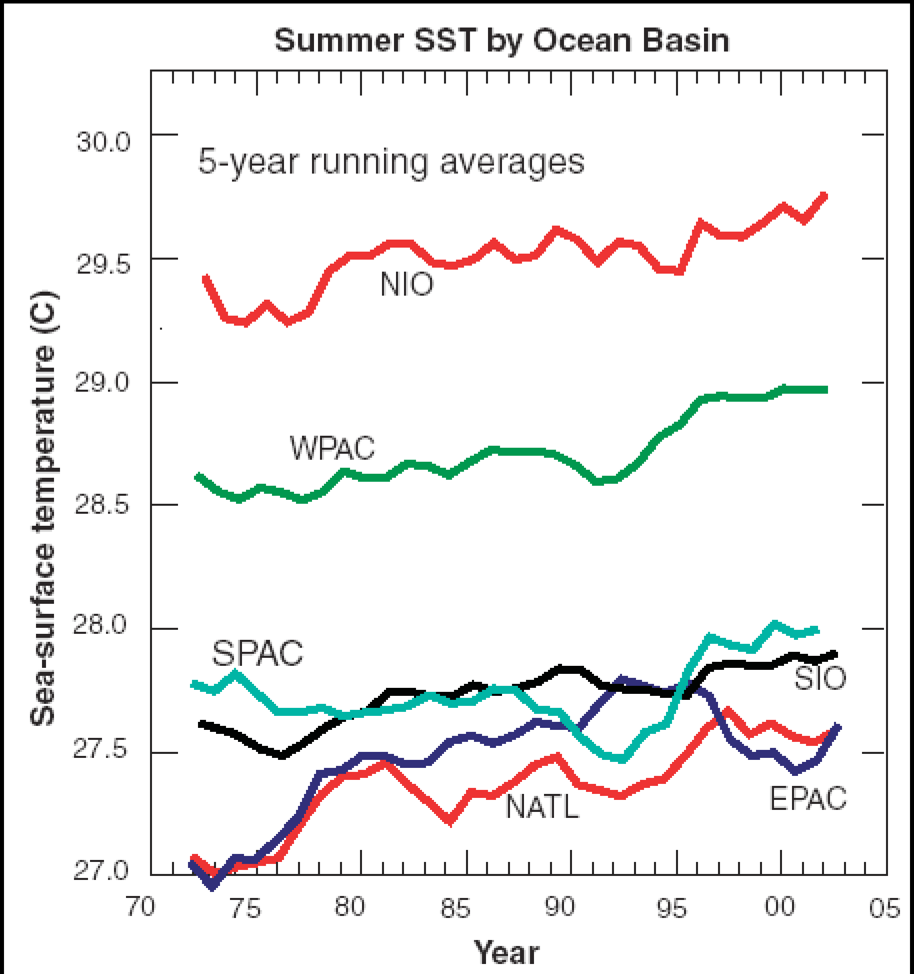
Diffenbaugh et al, 2005

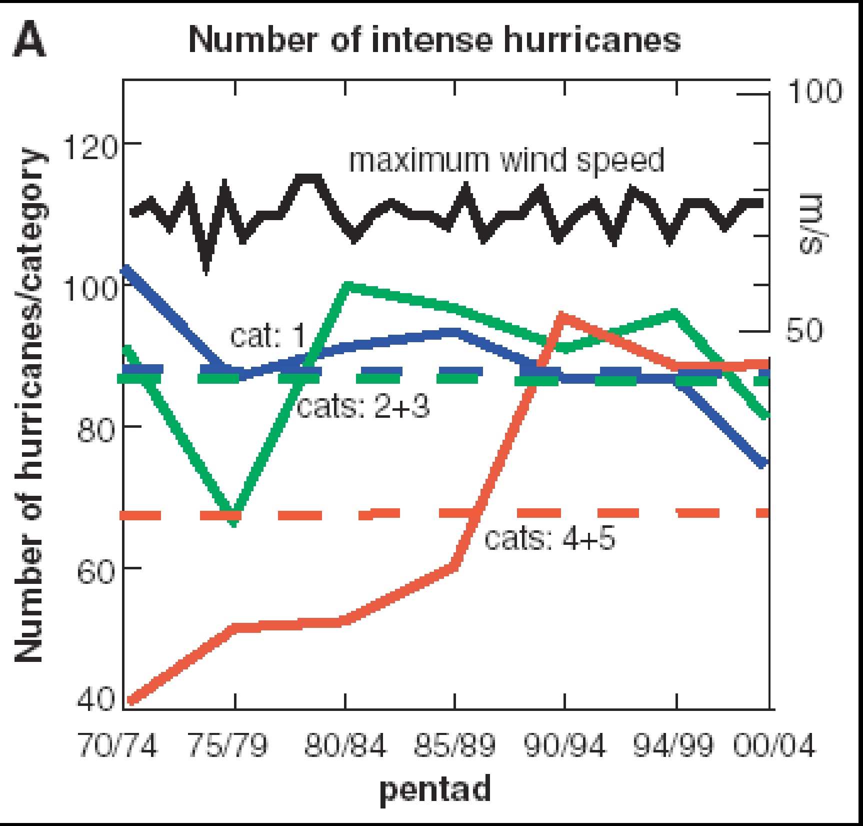
Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment

P. J. Webster,[1] G. J. Holland,[2] J. A. Curry,[1] H.-R. Chang[1]

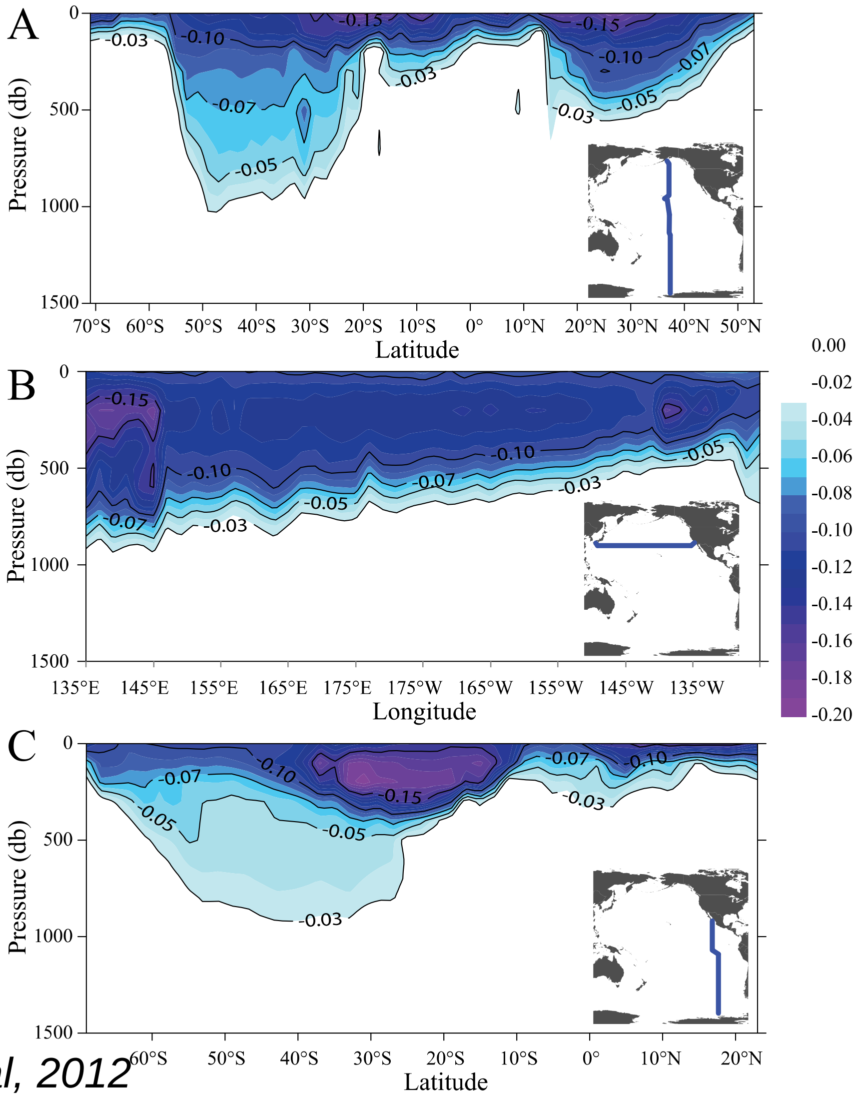
IPCC says increase in hurricane intensity "likely" (66%)

16 SEPTEMBER 2005 VOL 309 SCIENCE





Increasing CO_2 decreases ocean pH

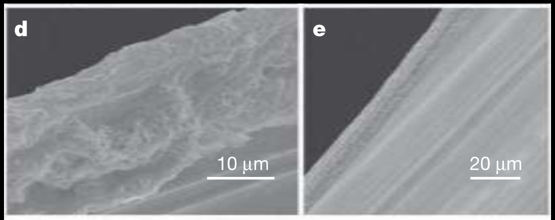


Feely et al, 2012

Figure 10. Change in aragonite saturation state (Ωarag) along the (a) P16, (b) PO2, and (c) P18 sections based on the anthropogenic CO_2 differences from *Sabine et al.* [2008].

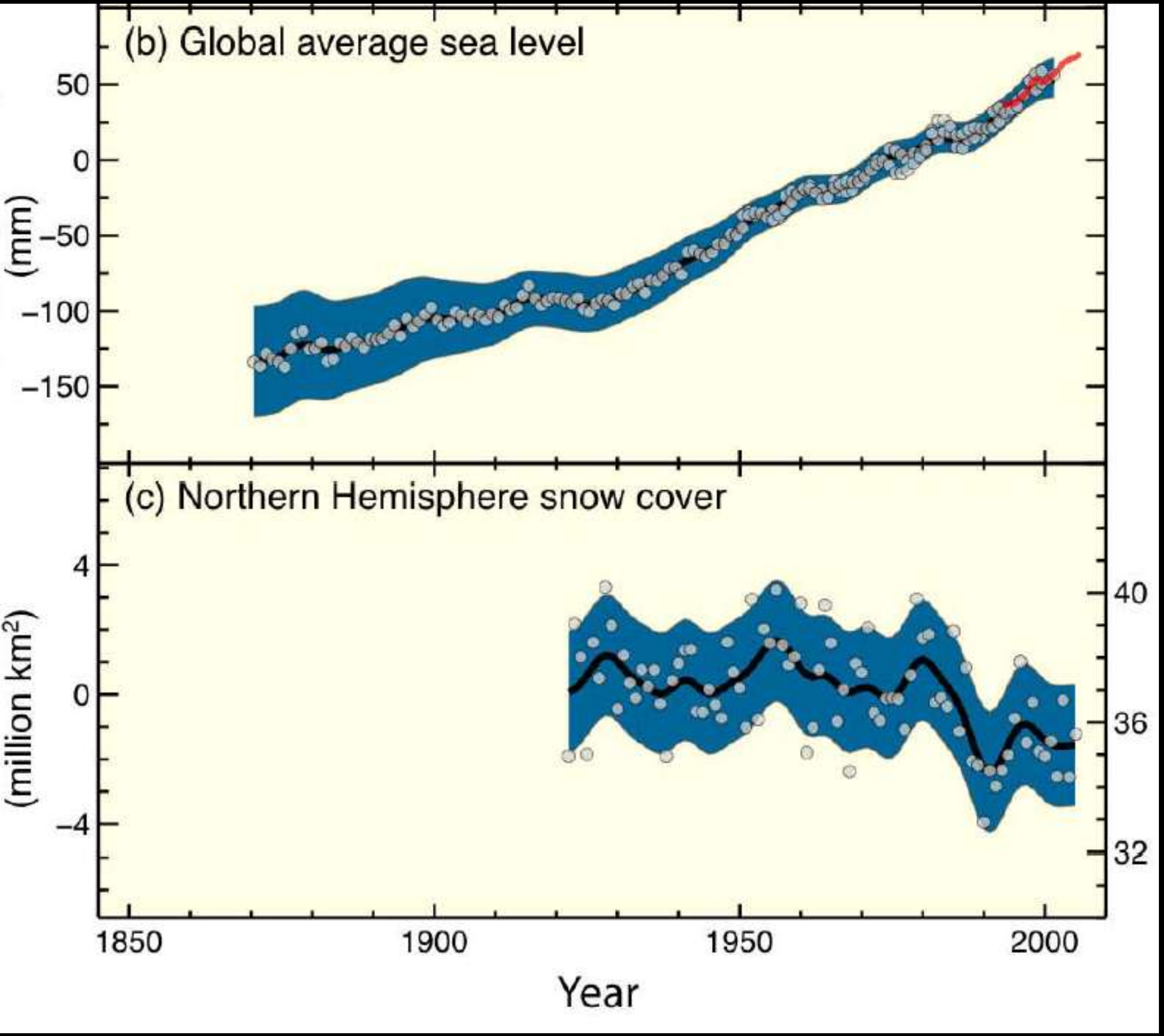
- already measureable as -0.1 pH unit in 30yrs
- will continue as atmospheric CO_2 increases
- effect on marine calcifiers (corals) can't be good

(ex = pteropod exposed



Orr et al, 2005

Ice and sea level: wild cards



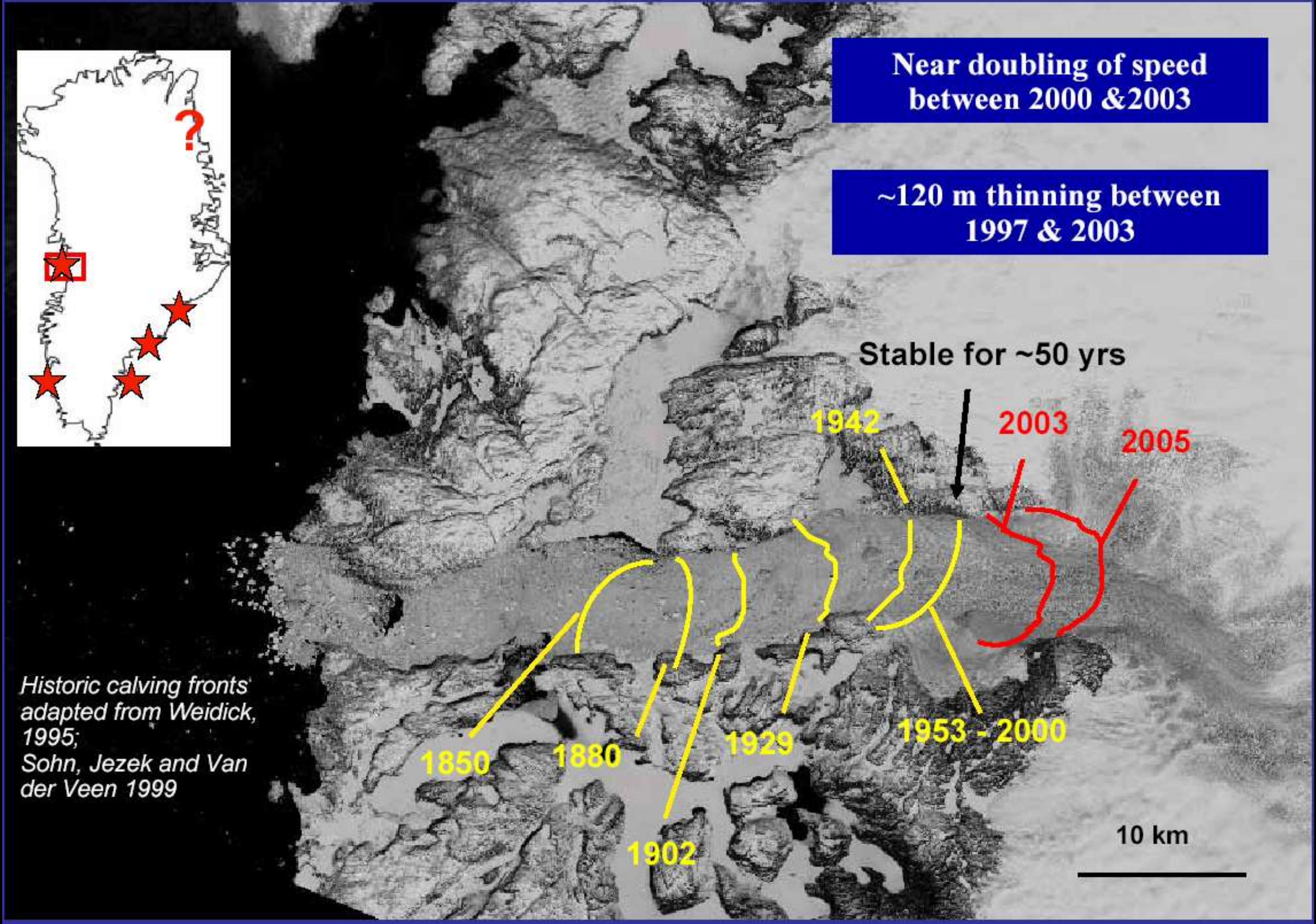
The Earth's ice is melting, sea level has increased
~3 inches since 1960
~1 inch since 1993

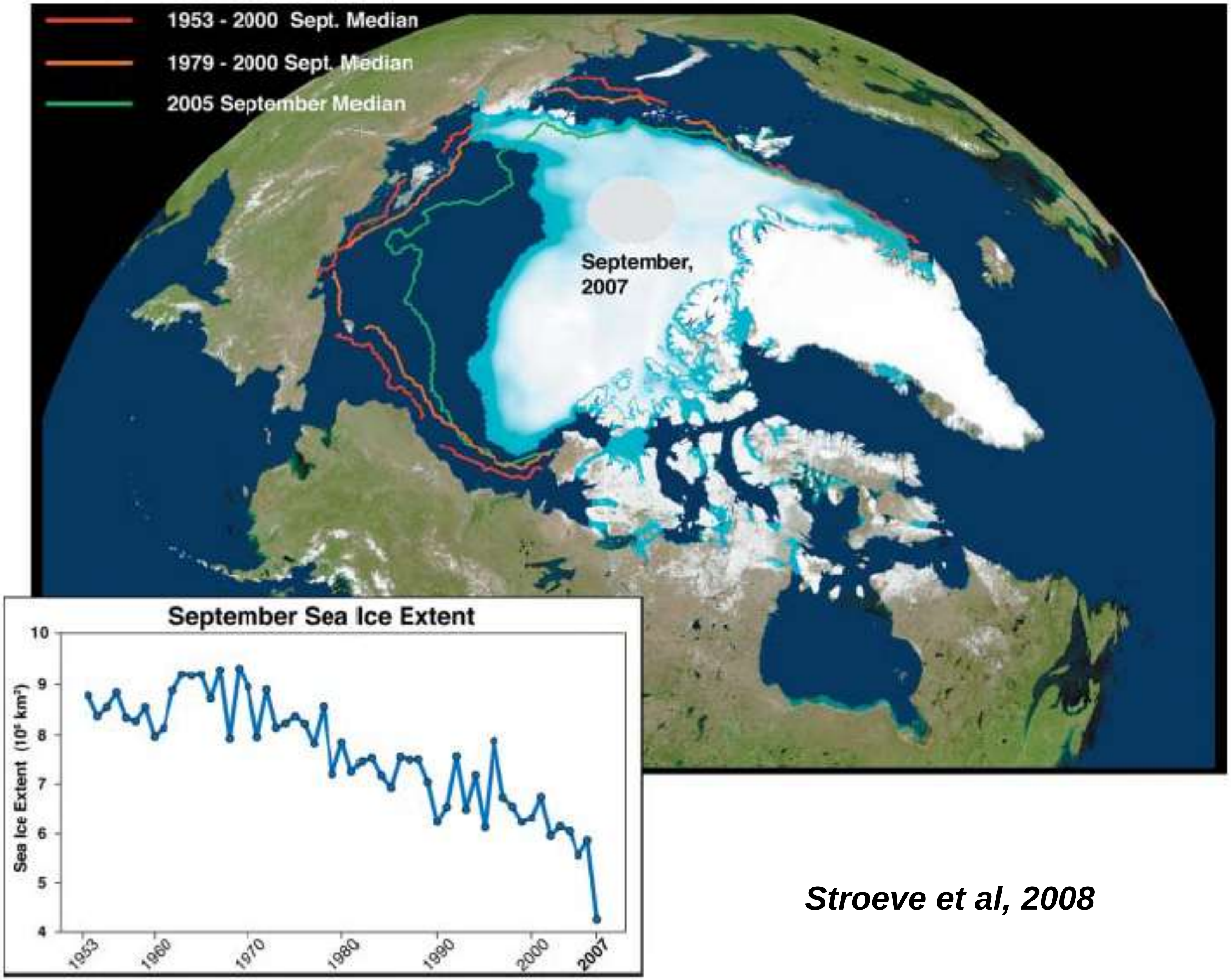
-signs of accelerating melting are now clear

-land ice particularly striking, poles more complicated

-IPCC estimates project current trends forward i.e. LOWER estimate using no acceleration

Retreat of the Jakobshavn Ice Stream

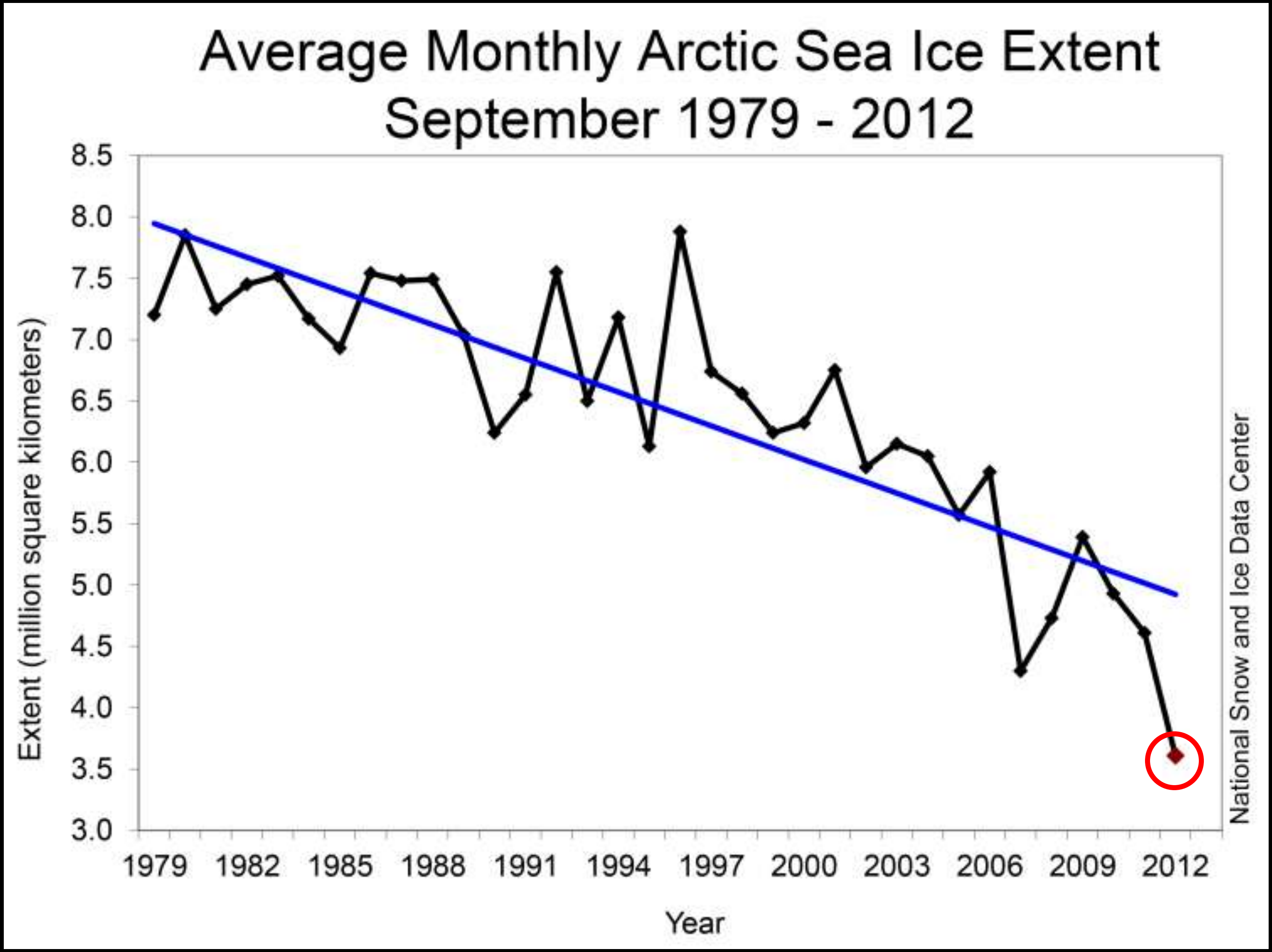




Stroeve et al, 2008

Arctic Summer Sea Ice reducing over 30 years of satellite record

2012 a record low



Mass balance estimates
(blue/black = traditional;
Red = satellite gravity)
For

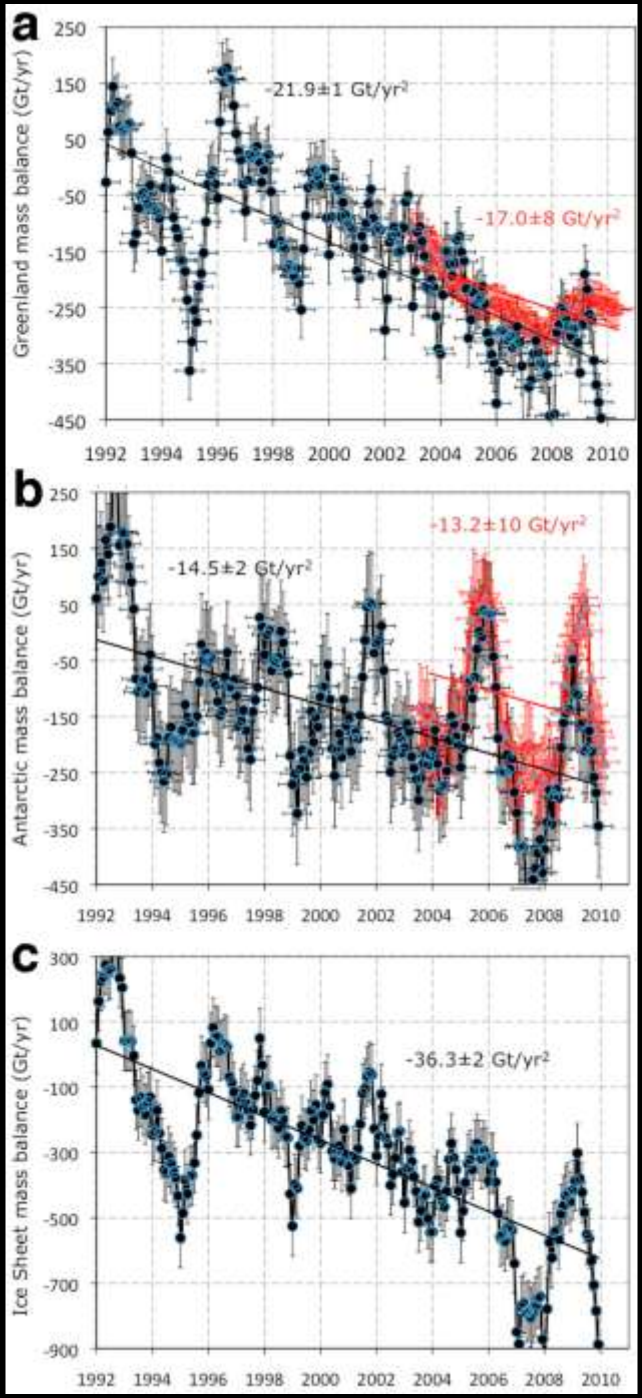
Can we detect melting of the polar ice sheets?

GREENLAND

YES,
especially in Greenland.

ANTARCTICA

BOTH



Rignot et al., GRL 2011

New Radar Data Show ice streams That penetrate Deep into Antarctica

Rignot et al., Science 2011

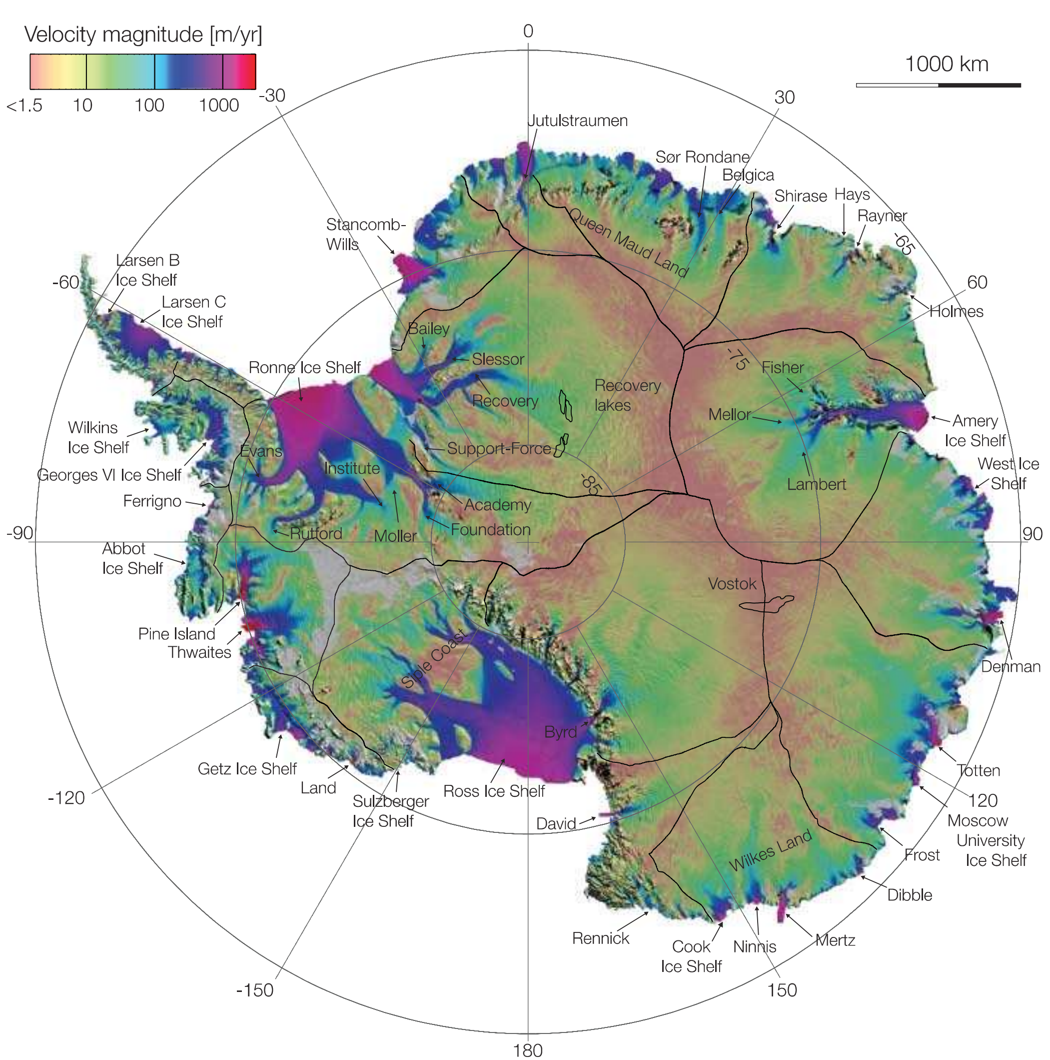
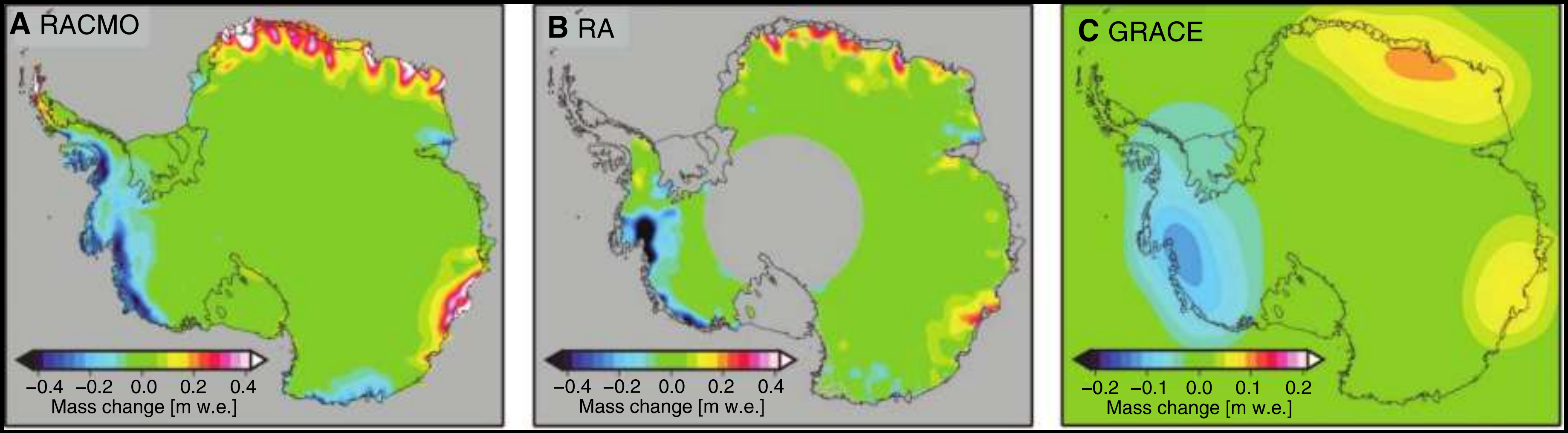
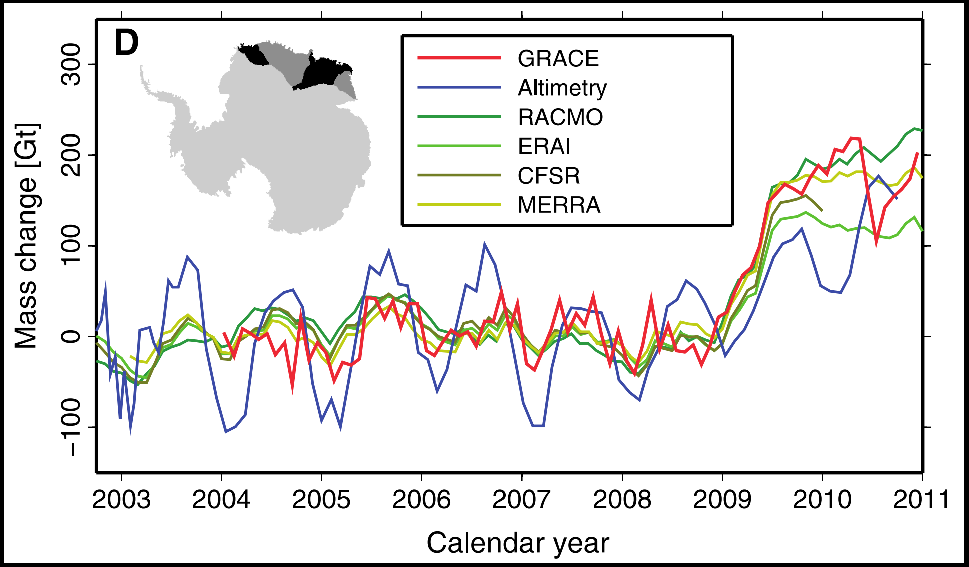


Fig. 1. Antarctic ice velocity derived from ALOS PALSAR, Envisat ASAR, RADARSAT-2, and ERS-1/2 satellite radar interferometry, color-coded on a logarithmic scale, and overlaid on a MODIS mosaic of Antarctica (*22*), with geographic names discussed in the text. Pixel spacing is 300 m. Projection is polar stereographic at 71°S secant plane. Thick black lines delineate major ice divides (*2*). Thin black lines outline subglacial lakes discussed in the text. Thick black lines along the coast are interferometrically derived ice sheet grounding lines (*23*).

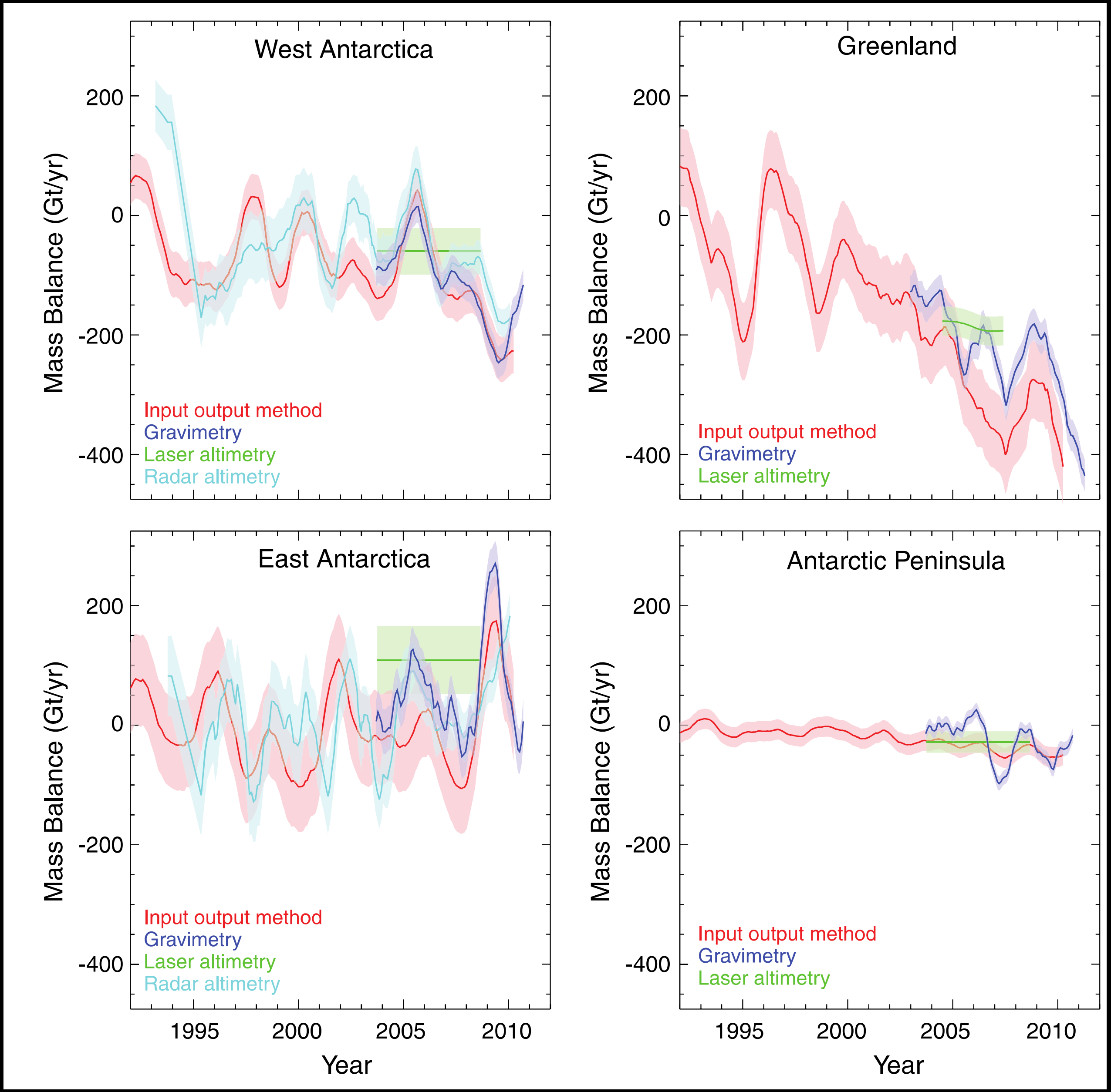
Mass balance of Antarctica is critical…





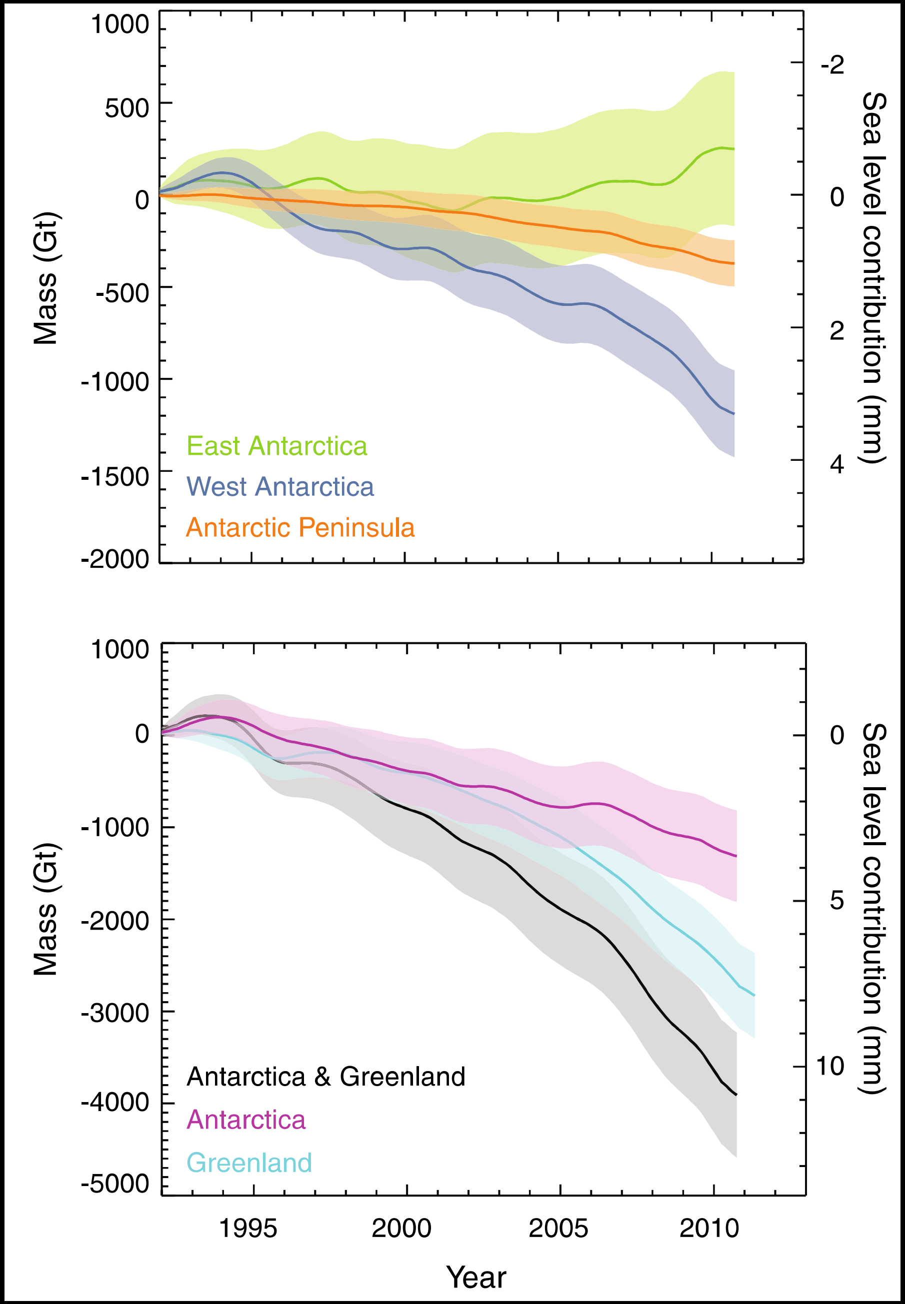
Some parts are growing

Shepherd et al., Science 2012



But most parts are melting

Shepherd et al., Science 2012



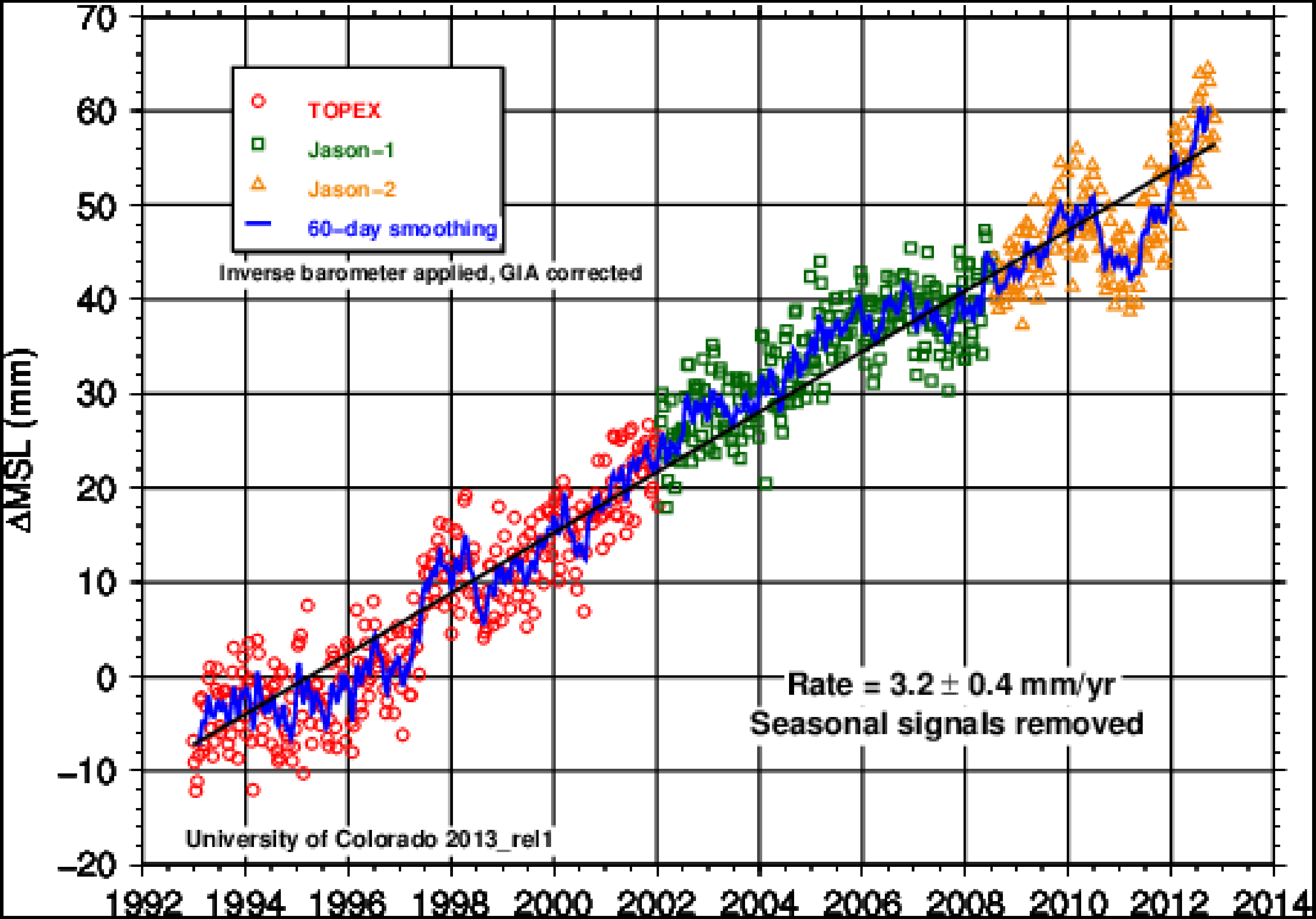
Cumulative mass balance is negative.

Translation: data support melting polar ice caps.

Implies that sea level has risen by 11±4mm since 1990.

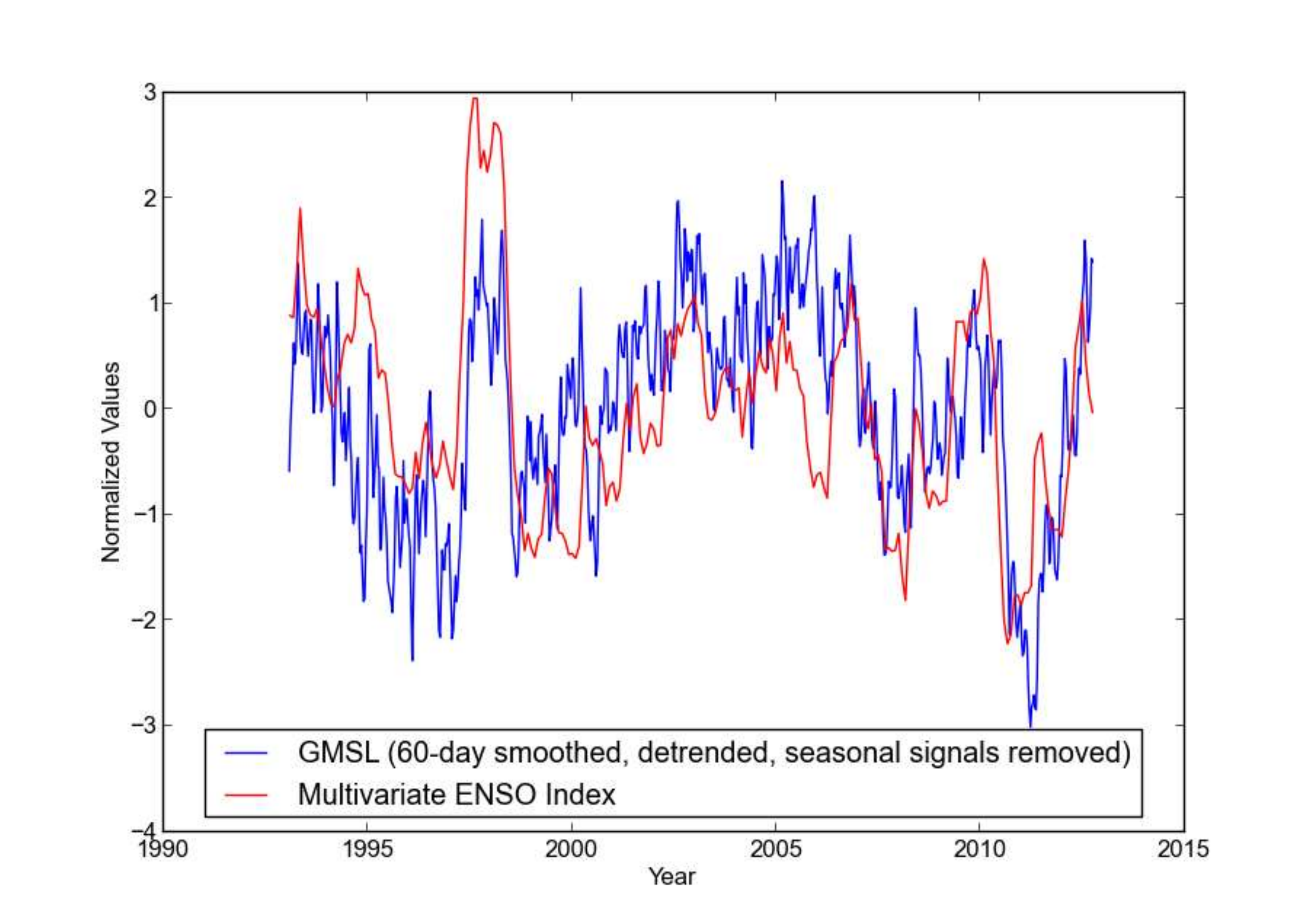
Shepherd et al., Science 2012

20 years of satellite-based sea level estimates



Nerem et al., 2010

Sea level changes with phase of the El Nino-Southern Oscillation



Nerem et al., 2010

Sea level rise:

IPCC says +7” to +22” by 2100,
recent trends are 3mm/yr → +12” by 2100

much more if rapid ice sheet collapse occurs (positive feedback from “bed lubrication”)

most scientists (including me!) would go on record for 1m rise (30 inches)

http://www.geo.arizona.edu/dgesl/index.html

CERTAIN

Warming of 1-6° C by 2100.
Sea levels will rise by 6 to 30 inches by 2100.
Oceans will continue to acidify.

Precipitation patterns will change. More irregular precipitation.

Extreme events will increase, hurricanes more intense.

Prospect of abrupt climate change.

UNCERTAIN

We have already committed to centuries of climate change