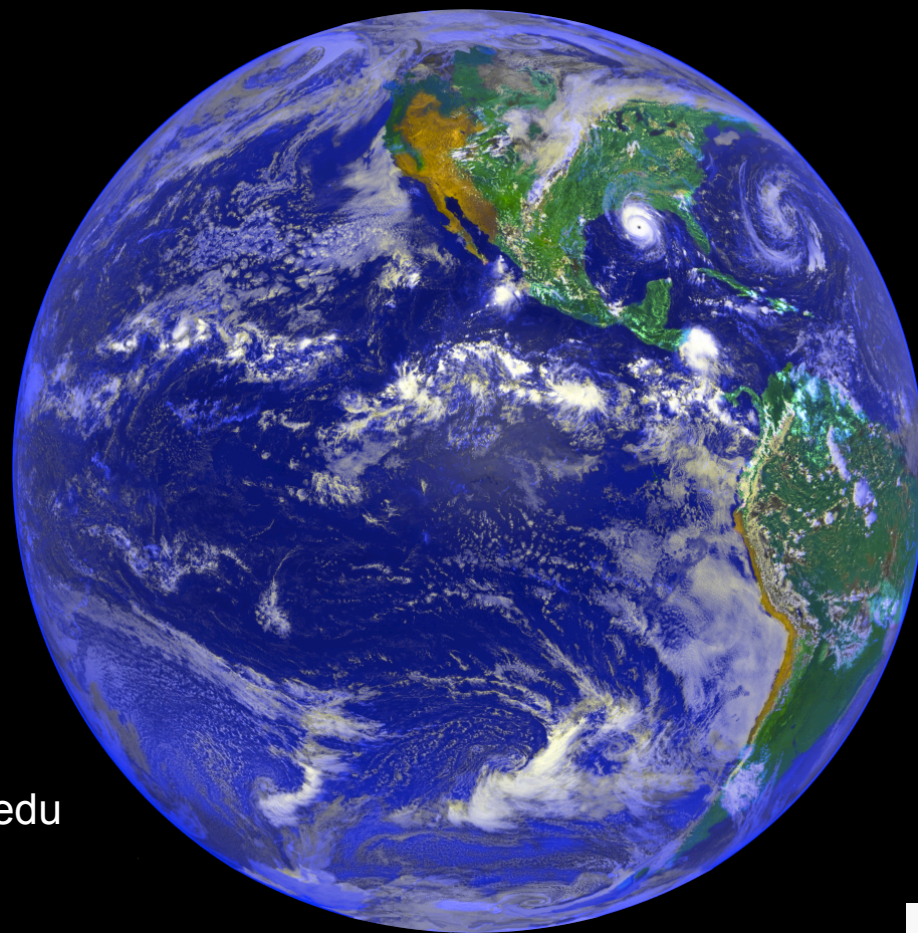


A Paleoclimate Perspective on Global Warming



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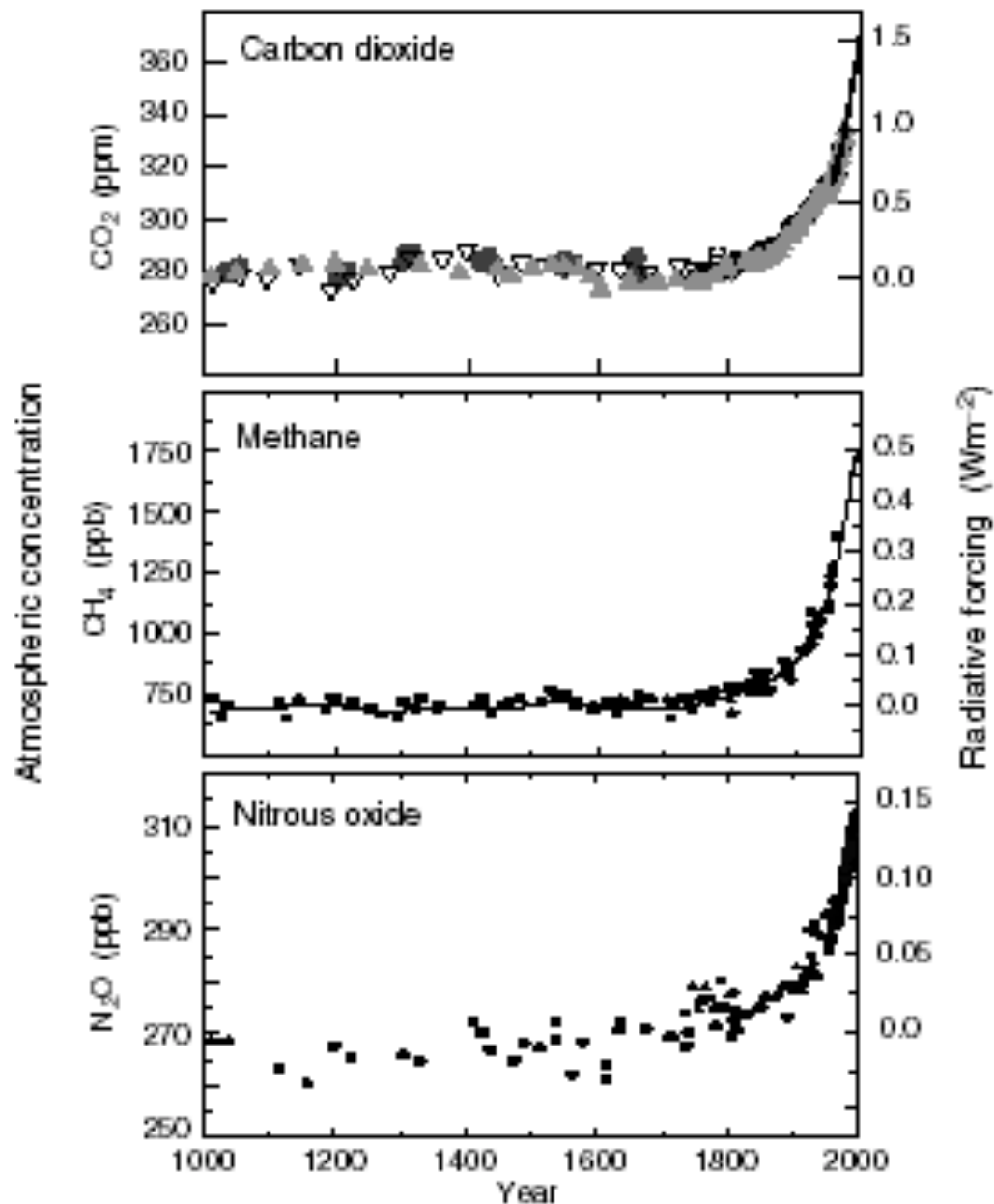
CO2 Forum
March 5, 2009



Paleoclimate data can be used to investigate the following:

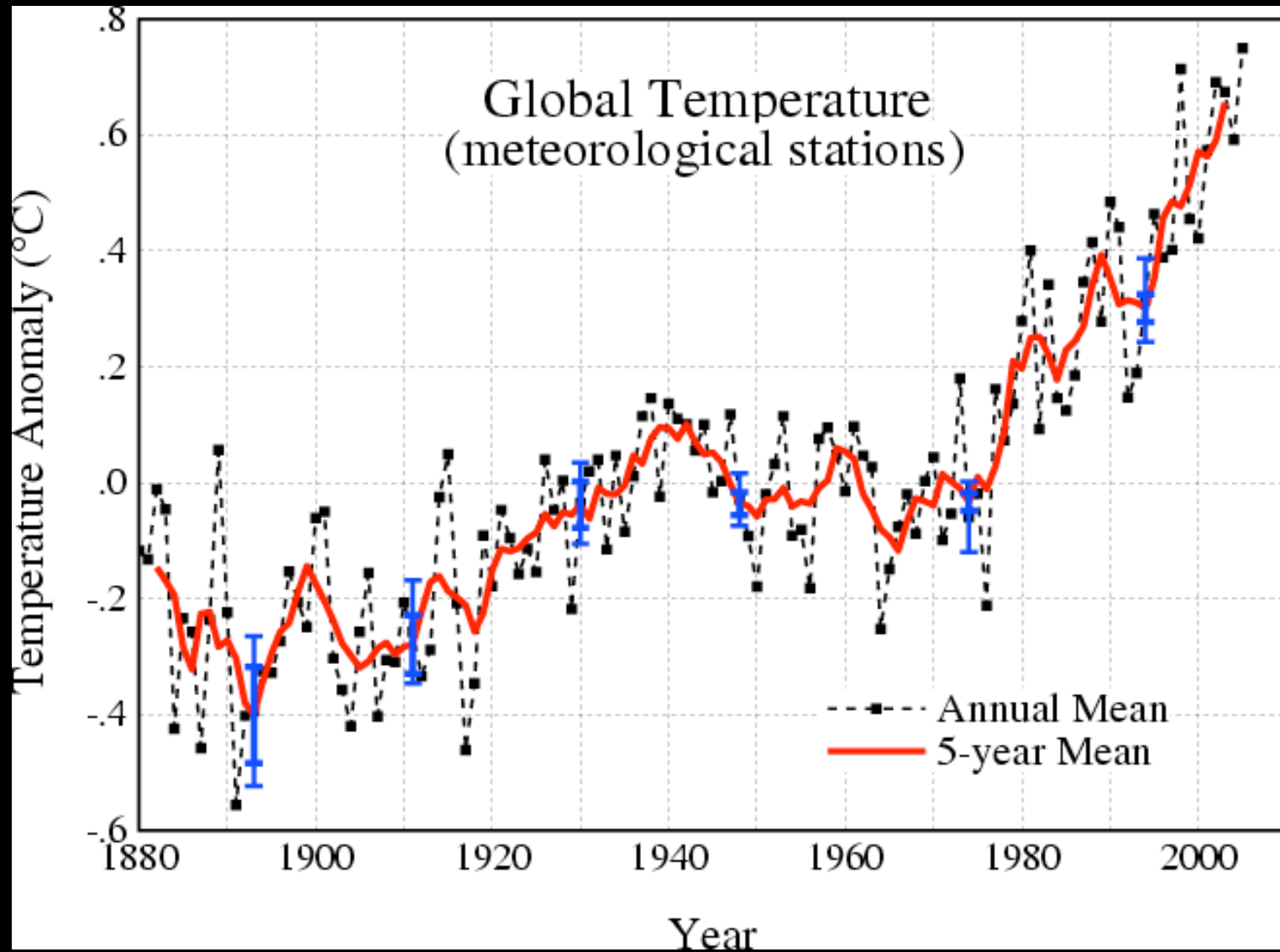
- 1) How anomalous is anthropogenic climate change (temperature and precipitation)
- 2) What is the Earth's "climate sensitivity" (T change for a doubling of CO₂?)
- 3) How much sea level rise is associated with a given global temperature change?
- 4) What are the causes and effects of abrupt climate change?

(a) Global atmospheric concentrations of three well mixed greenhouse gases



ice core CO_2 records confirm that the CO_2 trend began in the 1800's

- clear land for agriculture
- Industrial Revolution

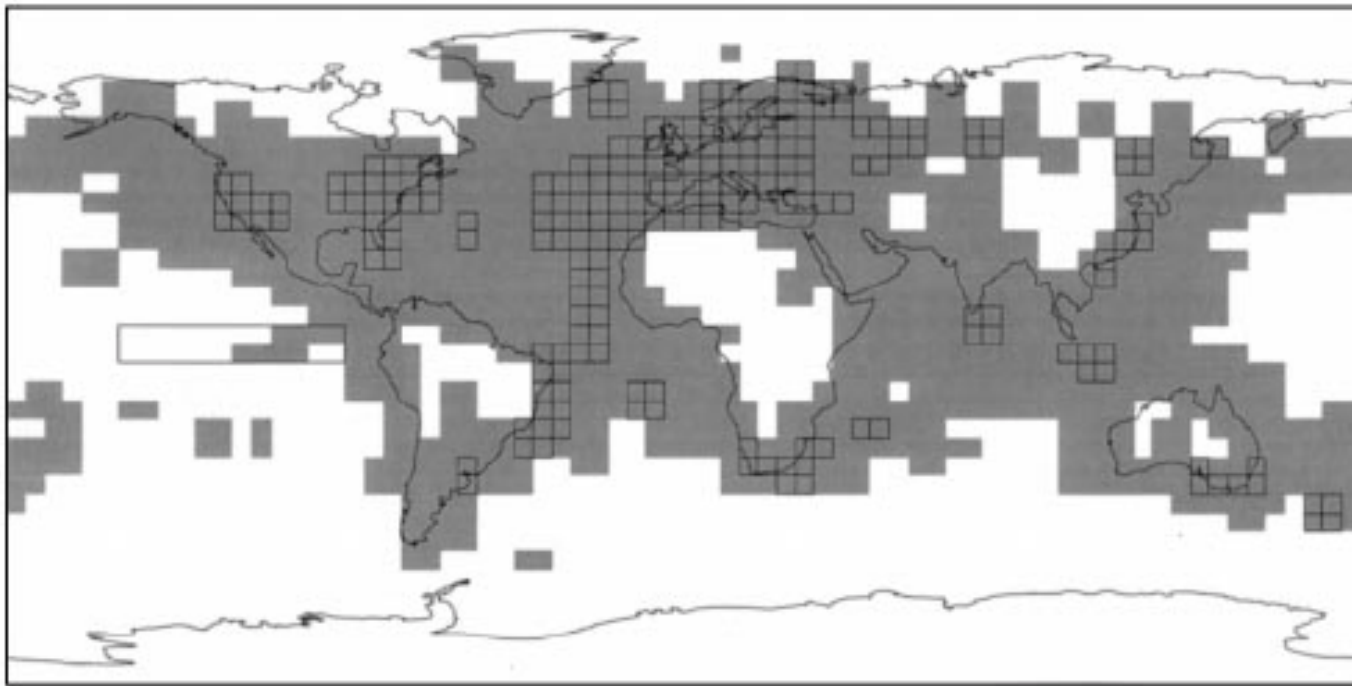


The 'instrumental' record of climate shows a $\sim 1^{\circ}\text{C}$ warming over the last century

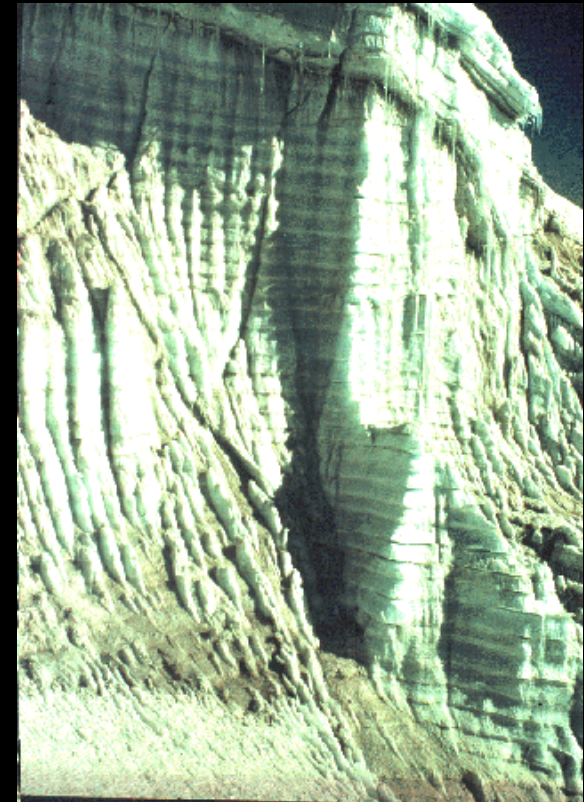
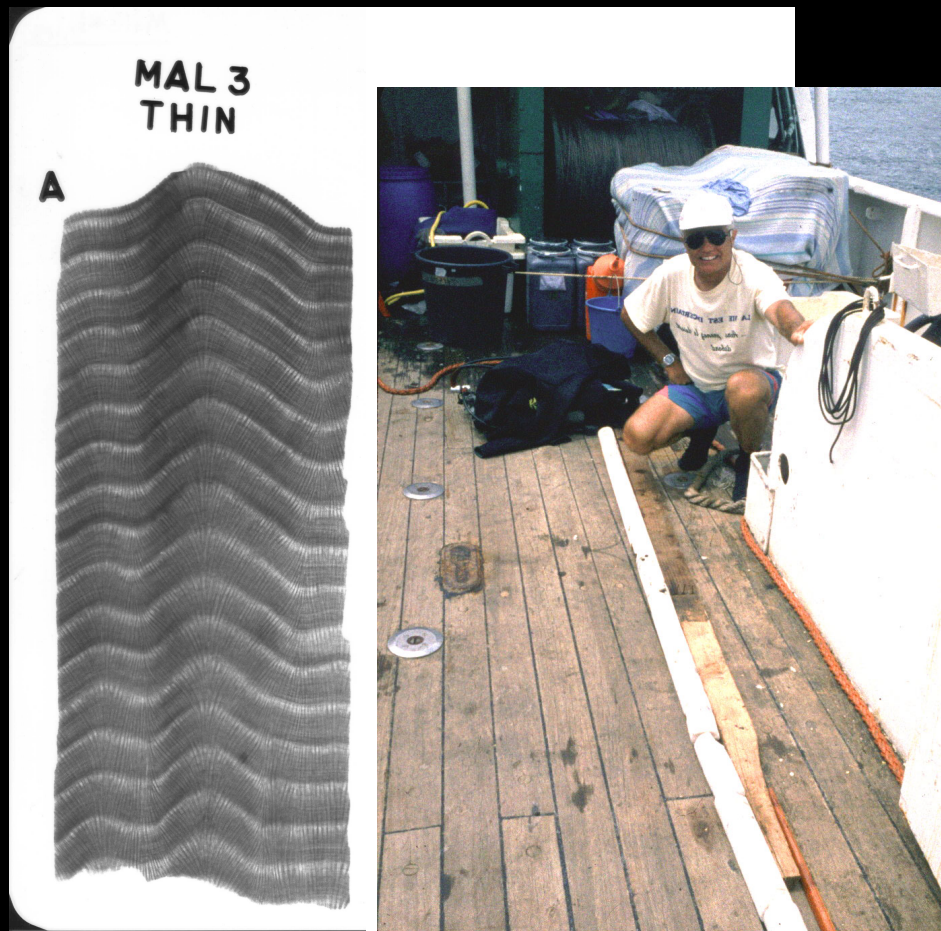
Quantifying recent temperature change is critical to separating natural and anthropogenic effects on climate

The instrumental record of climate
back to 1854 (squares)
back to 1902 (shaded area)

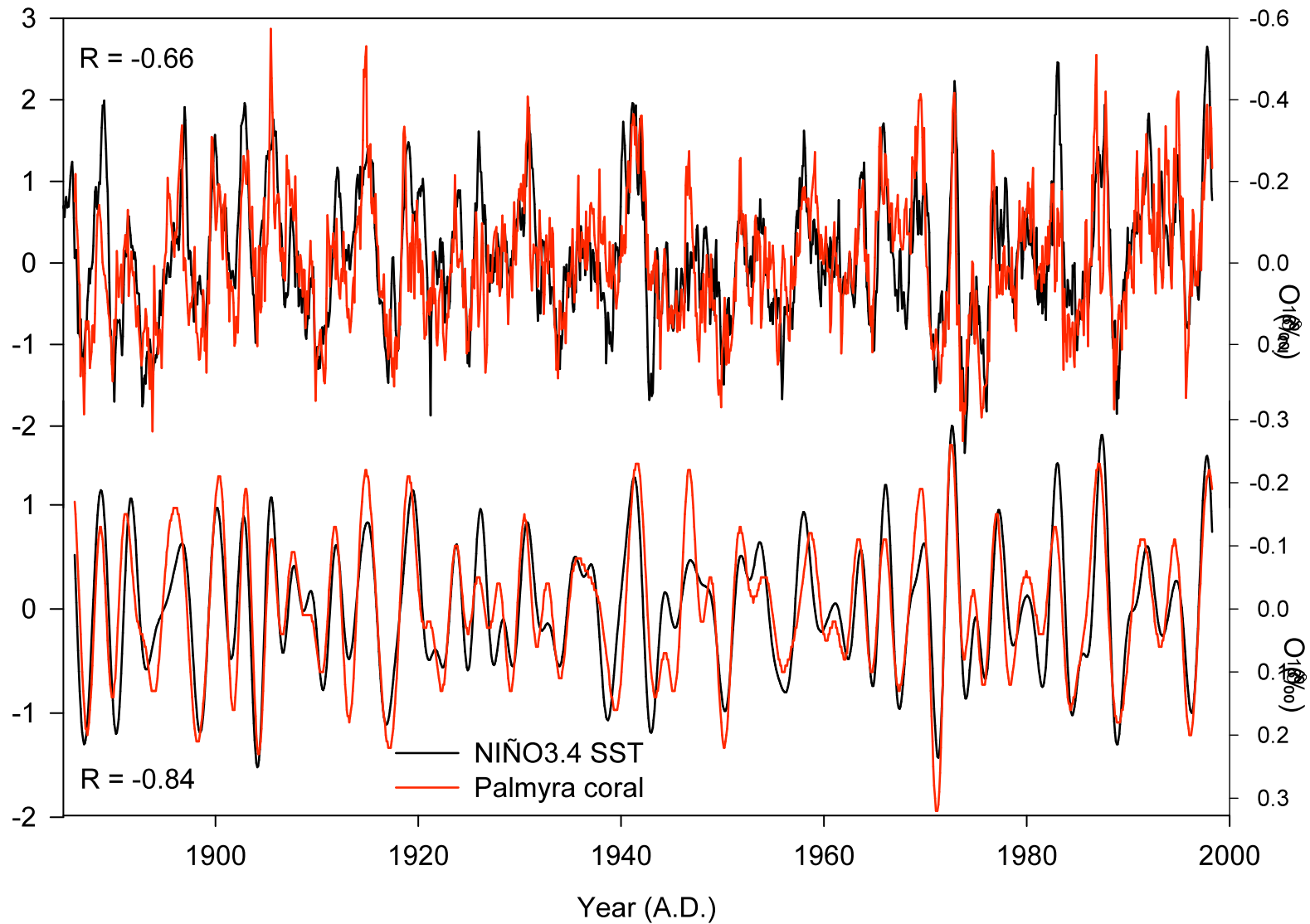
*so most of Pacific and southern Ocean only go back to ~1950



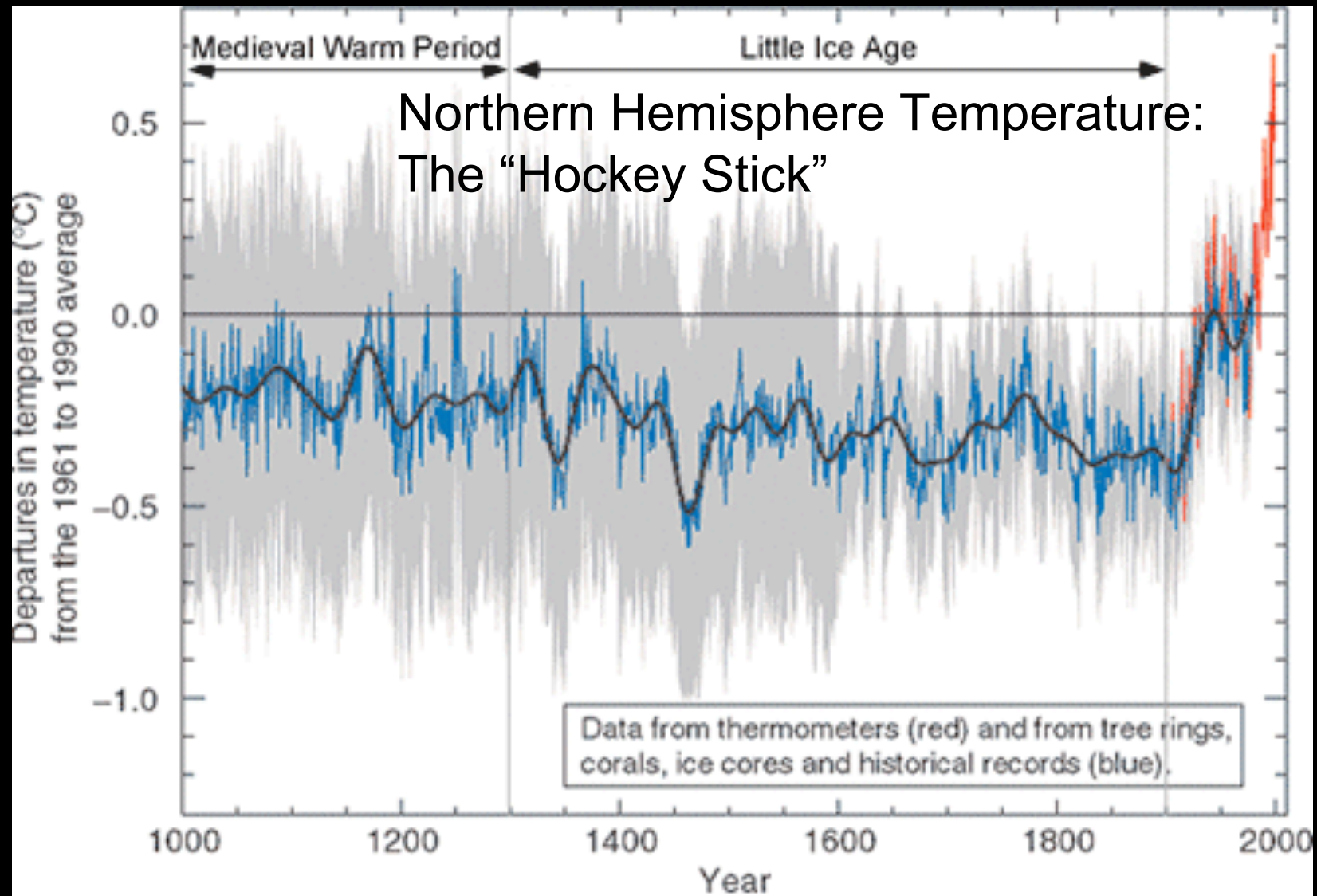
To understand how climate has changed in the past, we need to use records of climate preserved in ice cores, ancient tree rings, corals, and other “**paleoclimatic**” sources:
key is to CALIBRATE to temperature records



Coral geochemistry vs. tropical Pacific sea-surface temperature



Cobb et al., 2003

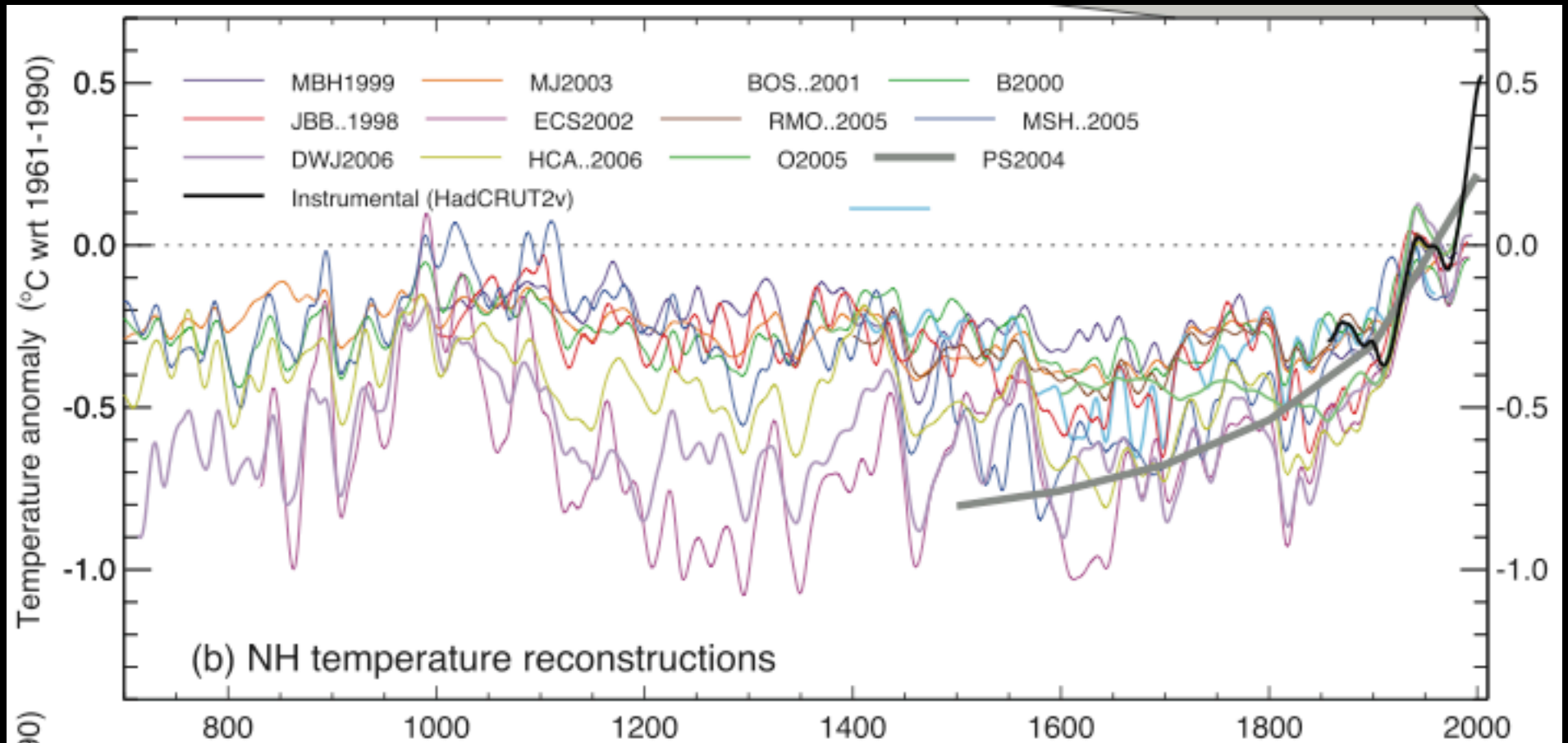


Key Points:

Mann et al., 1998

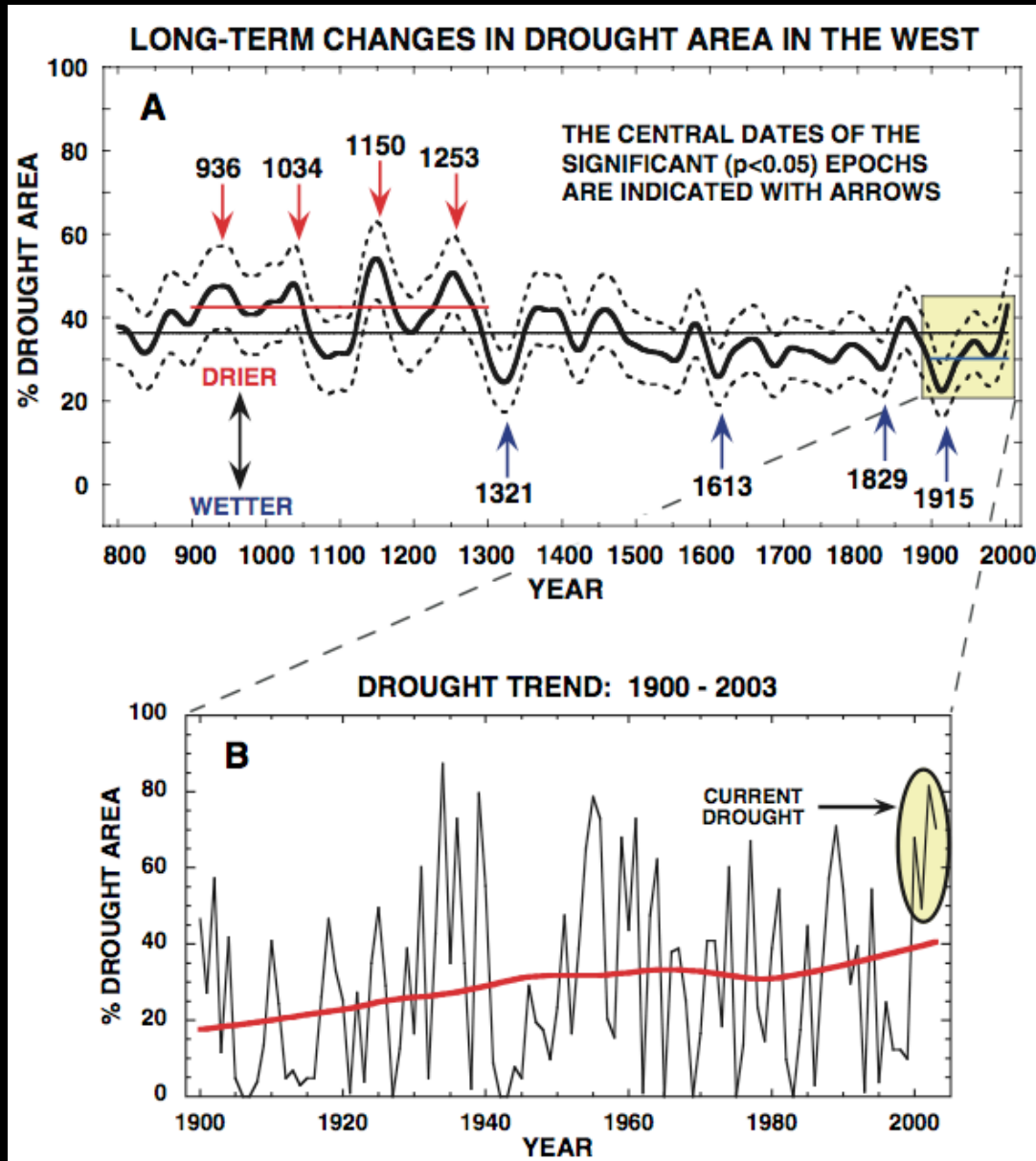
- error bars increase as you go back in time
- natural variability accounts for $<0.5^{\circ}\text{C}$ over the last millennium
- late 20th century temperature trend is unprecedented

Northern Hemisphere Temperature: Different brand of hockey sticks



IPCC AR4, 2007

Western US drought reconstructed by 602 tree ring records



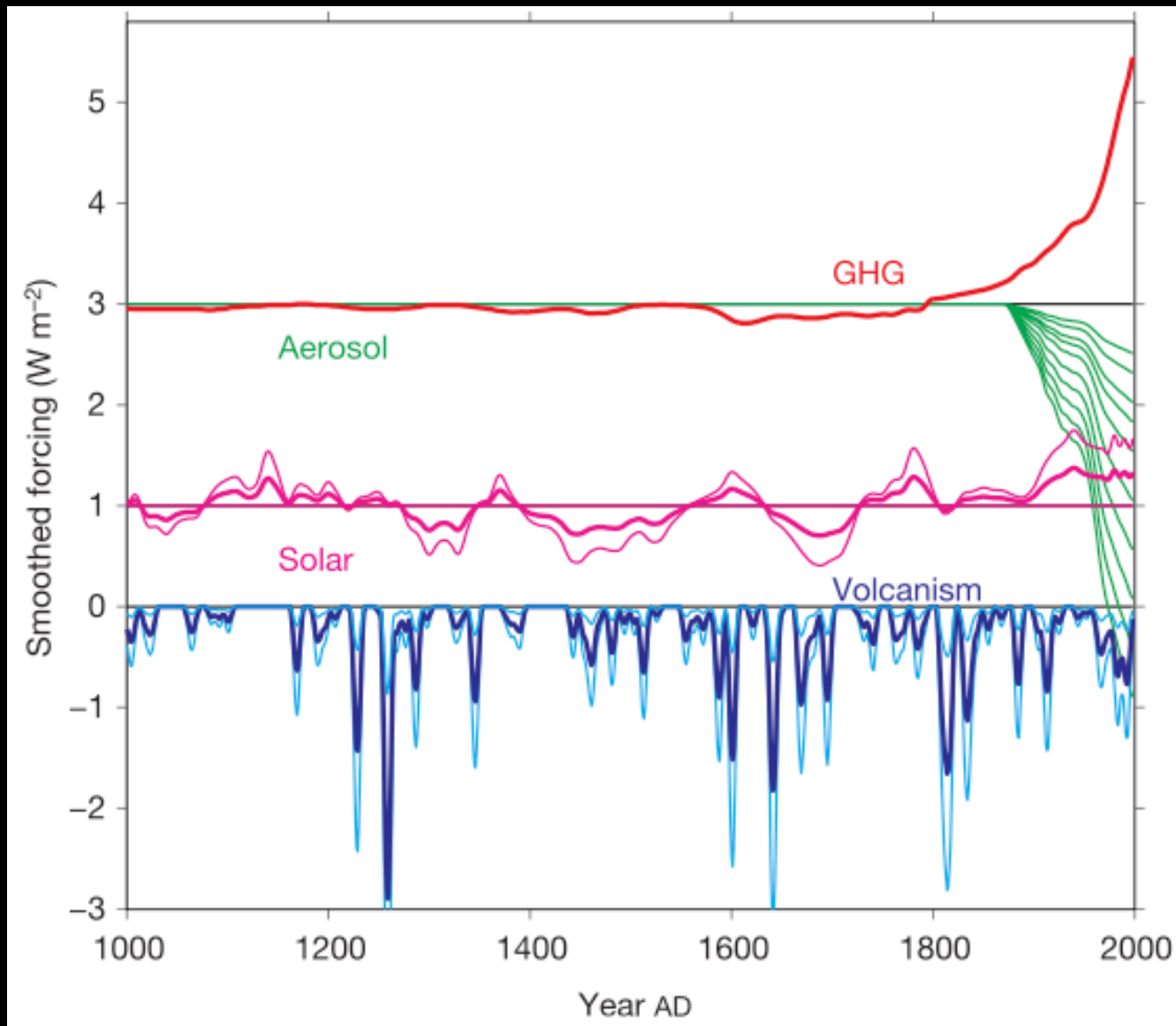
Key Points:

20th century drought is small compared to “megadroughts” ~1000 years ago

need additional paleo-data from key regions to understand causes of these extreme events
(role of volcanic & solar forcing?)

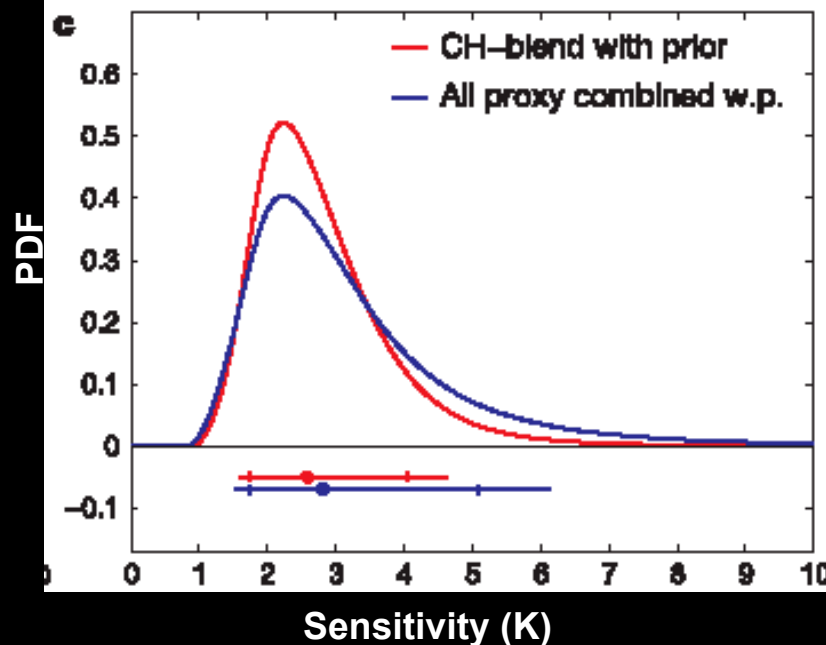
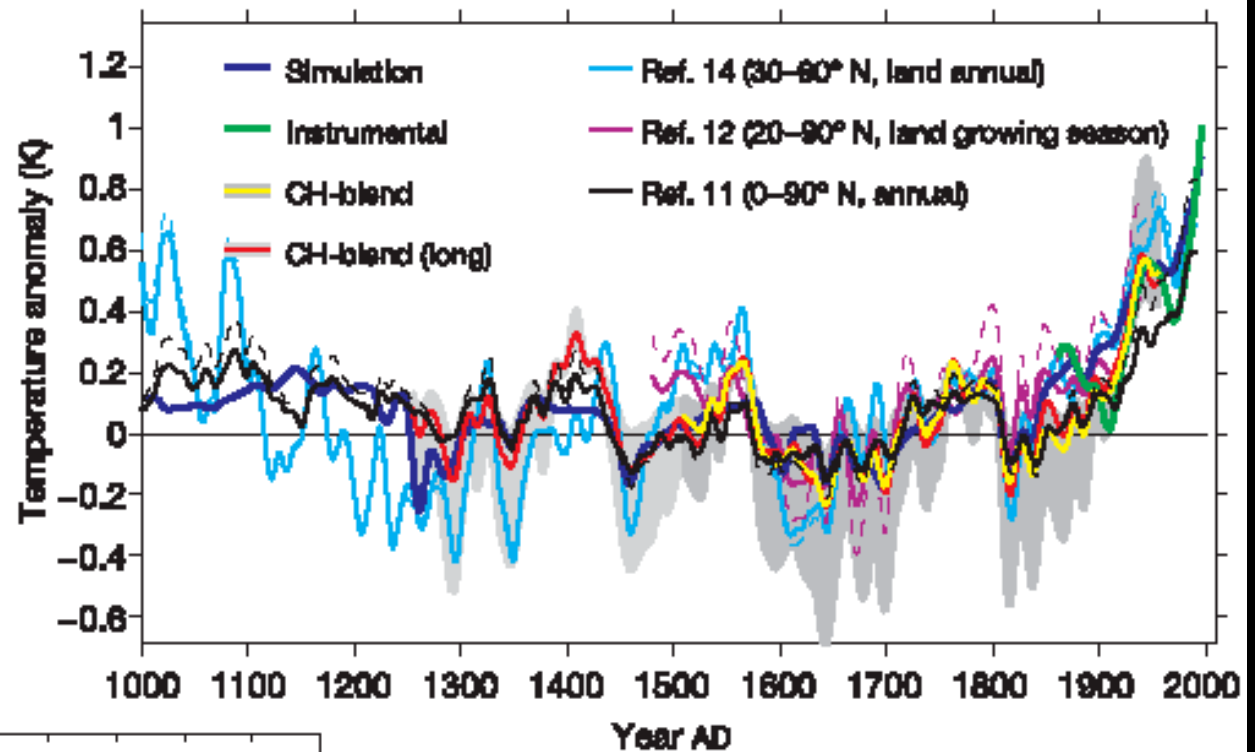
Cook et al., 2004

Given estimates of climate forcing over the last millennium, can calculate climate sensitivity



Hegerl et al., 2006

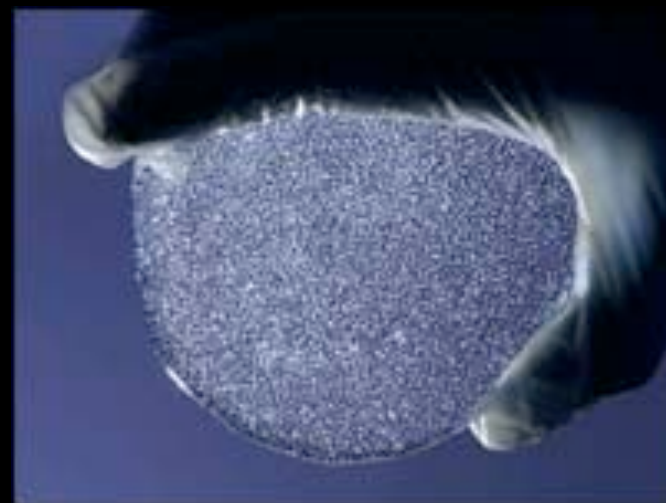
Energy balance
model
calculations
with sensitivities
of $\sim 2.5^{\circ}\text{C}$ to a
doubling of CO_2
best match
observed
paleo-temperatures



Hegerl et al., 2006

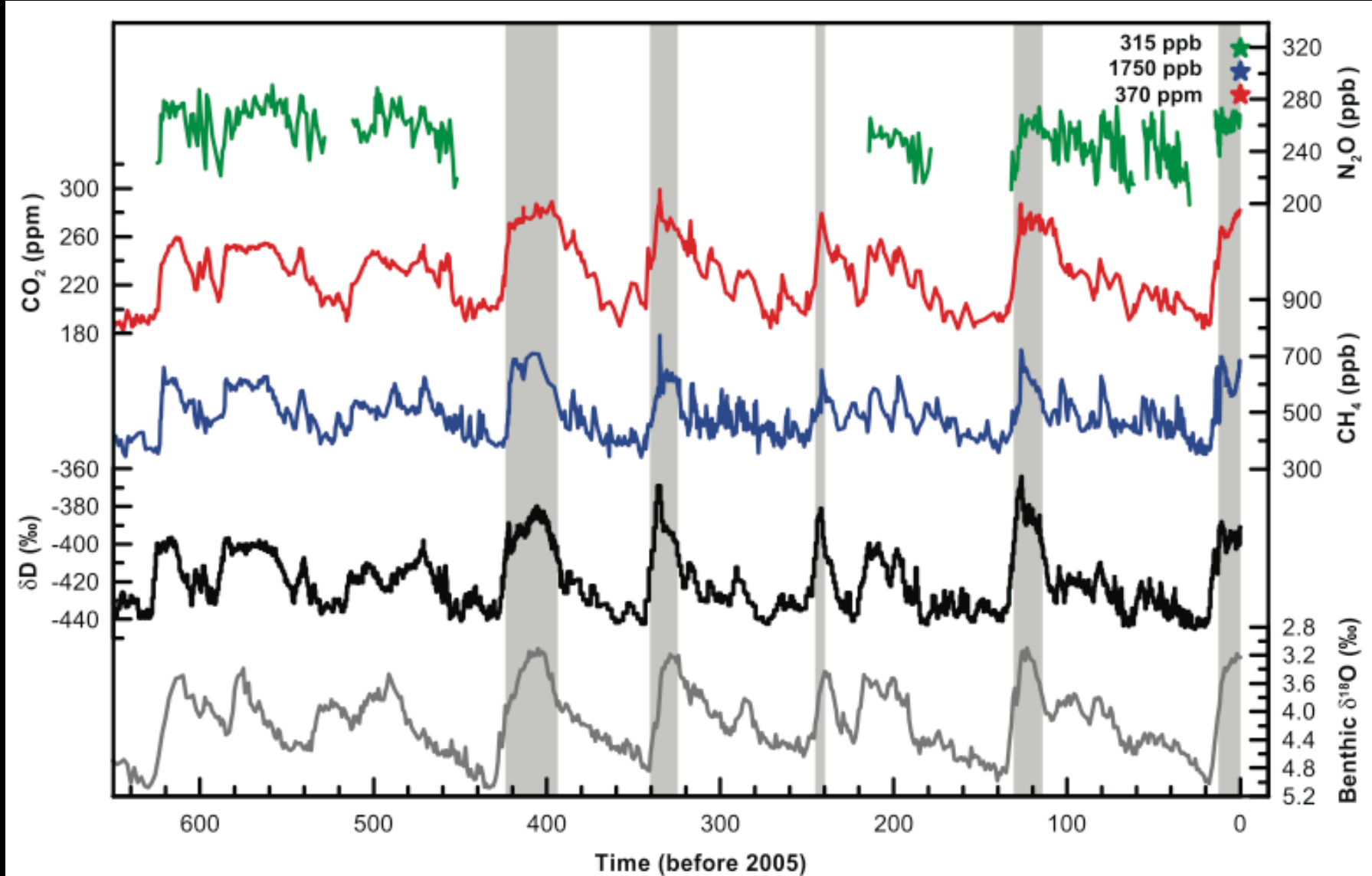


Ice core climate and CO₂ records



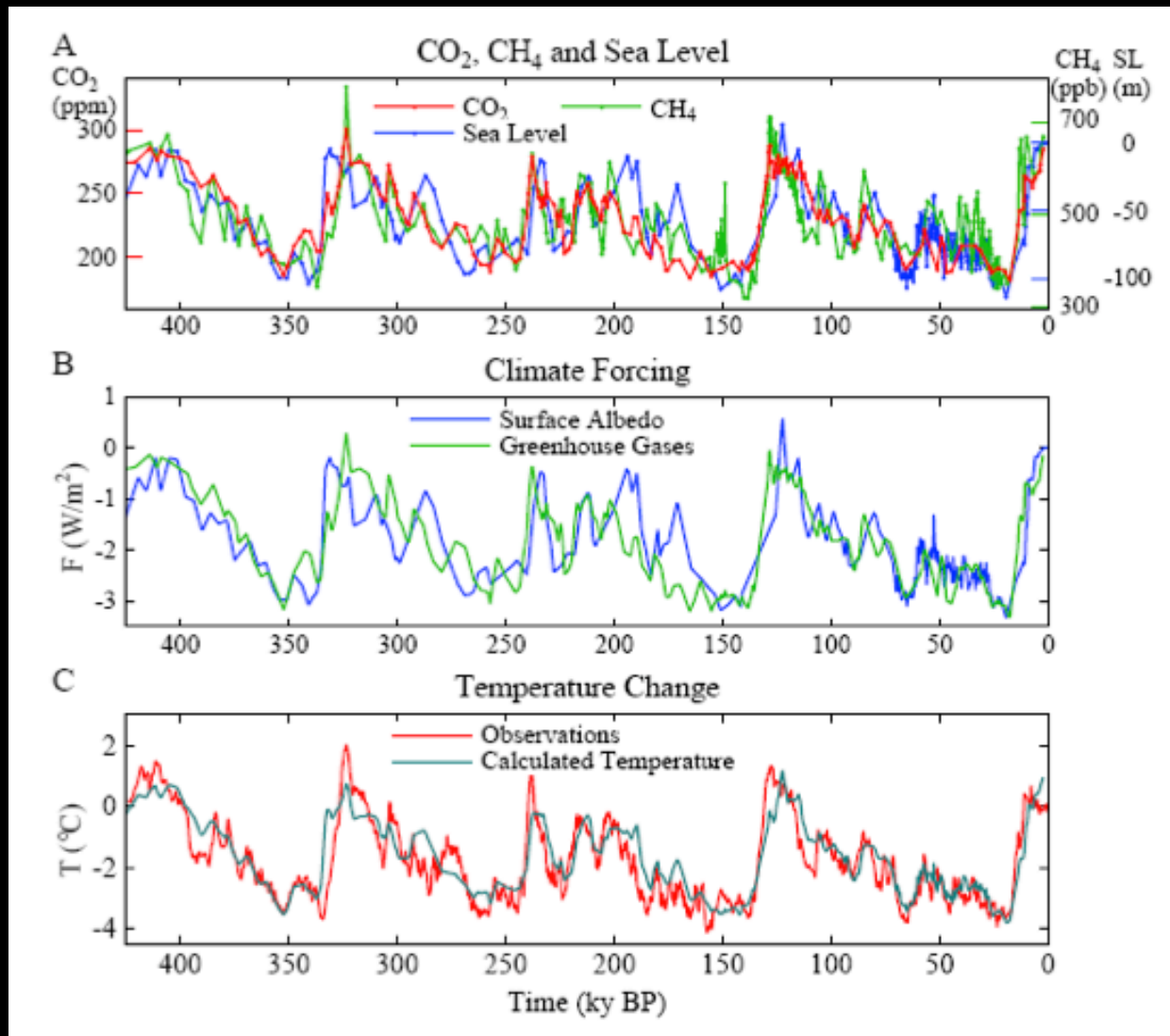
tiny gas bubbles
in the ice trap
ancient air samples

Atmospheric CO₂ and temperature over the past 650 thousand years



Climate sensitivity from glacial-interglacial climate change

-suggests climate sensitivity of 3°C to doubling of CO_2



Hansen, 2008; www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf

The uncertain climate future

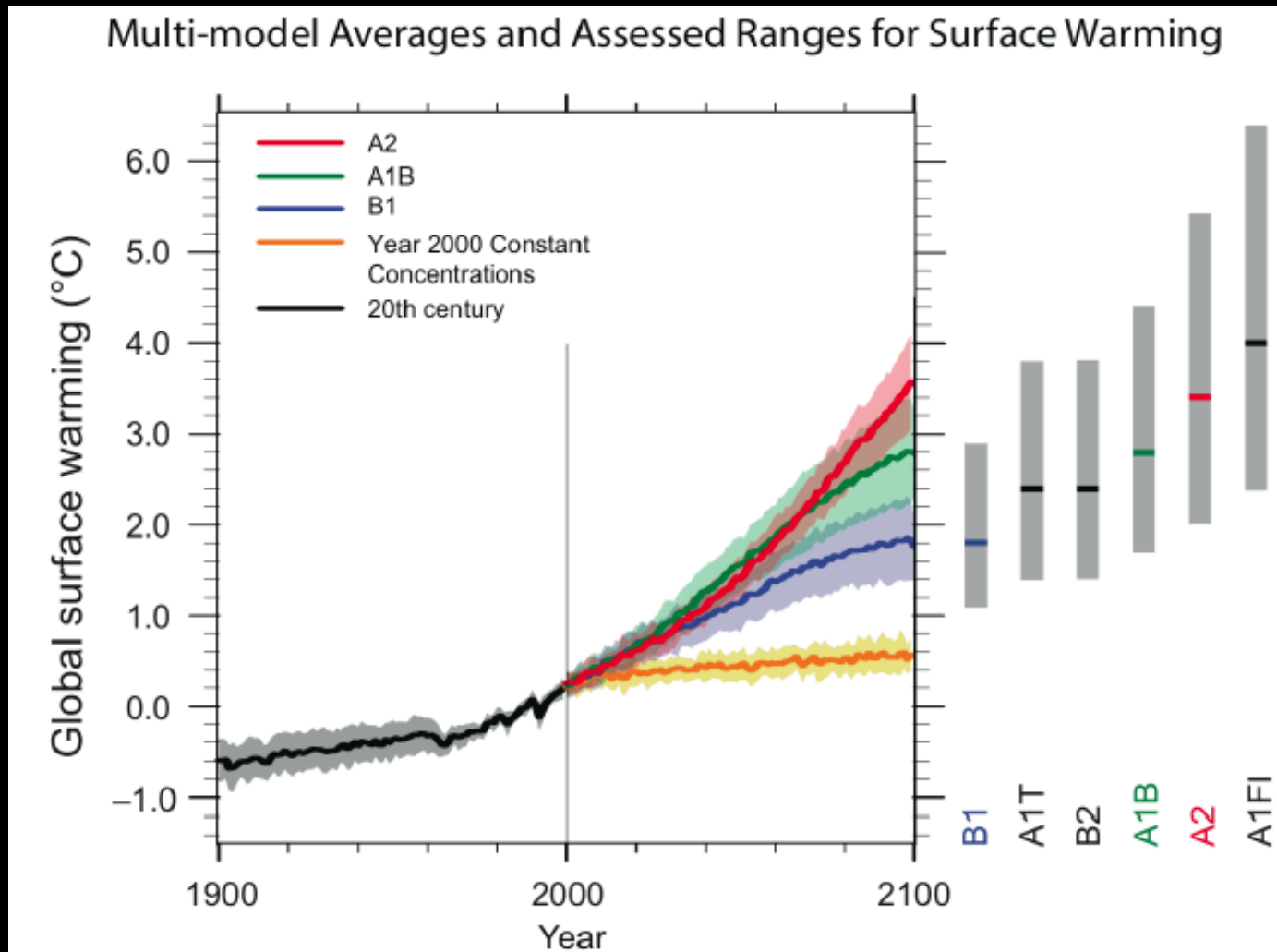
Range of scenarios:

Strict international agreements → CO₂ at 600ppm by 2100

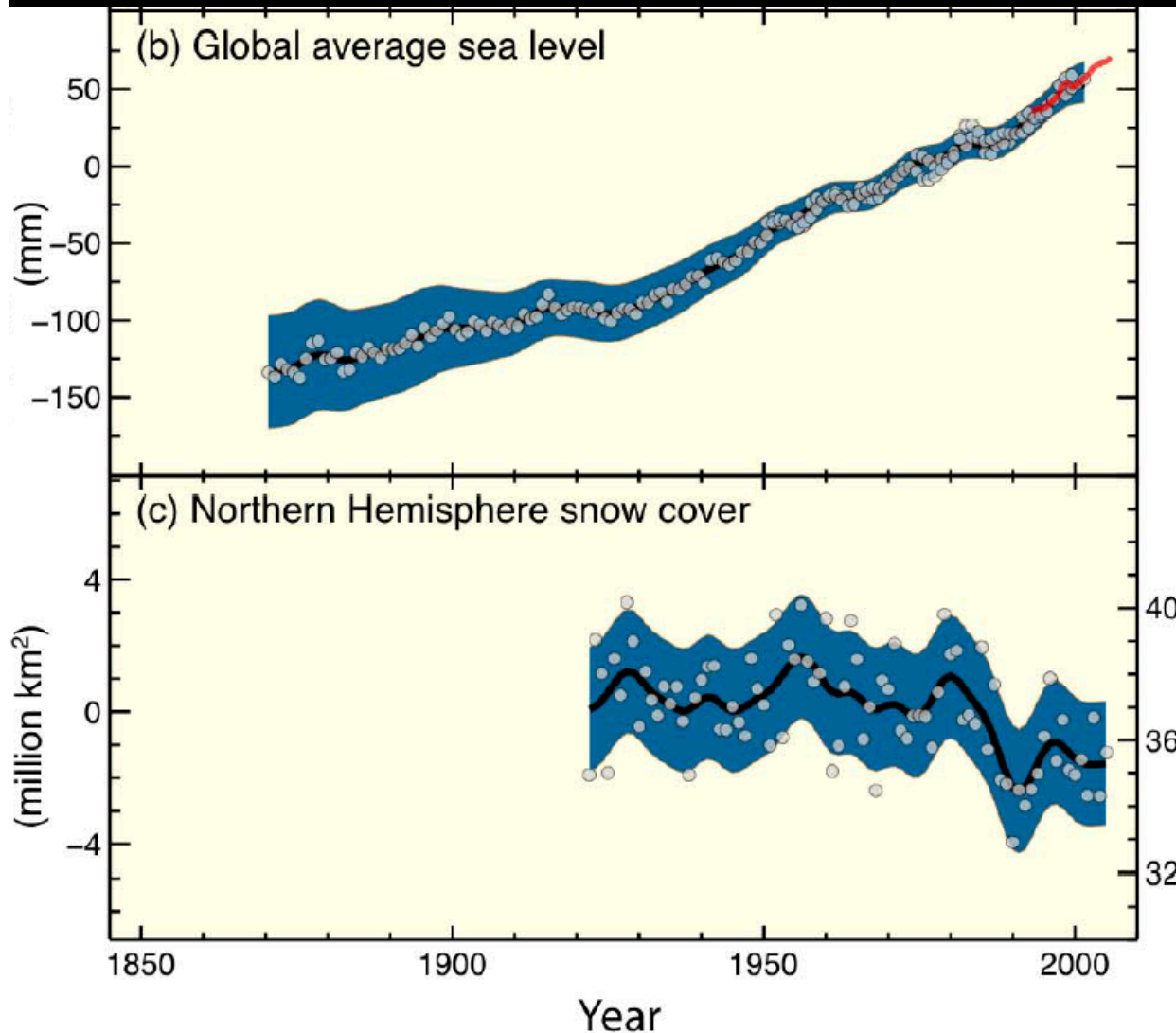
Mid-ground → 850ppm by 2100

Business as usual → up to 1550ppm by 2100

*390ppm today
280ppm 1800



The uncertain sea level future



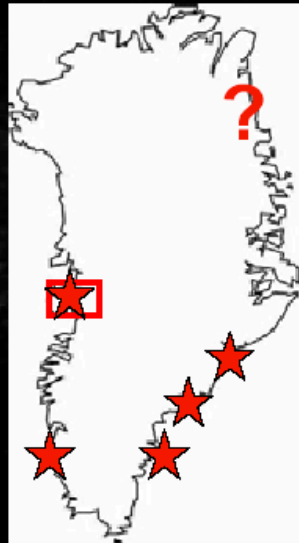
The Earth's ice is melting,
sea level has increased
~3 inches since 1960
~1 inch since 1993

-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

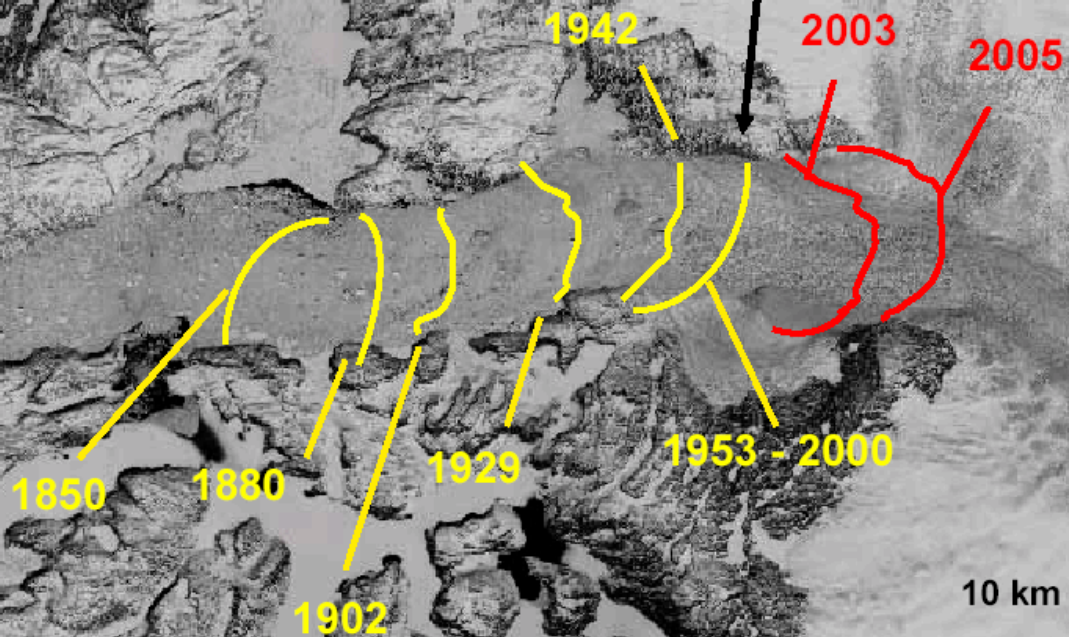


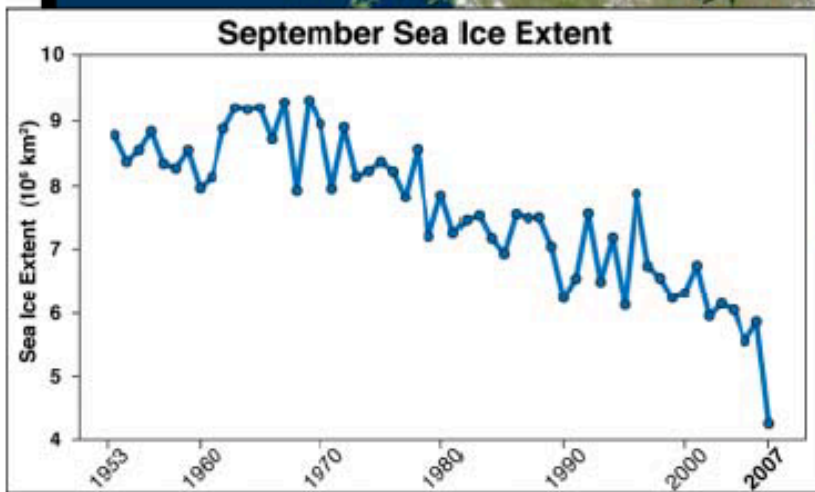
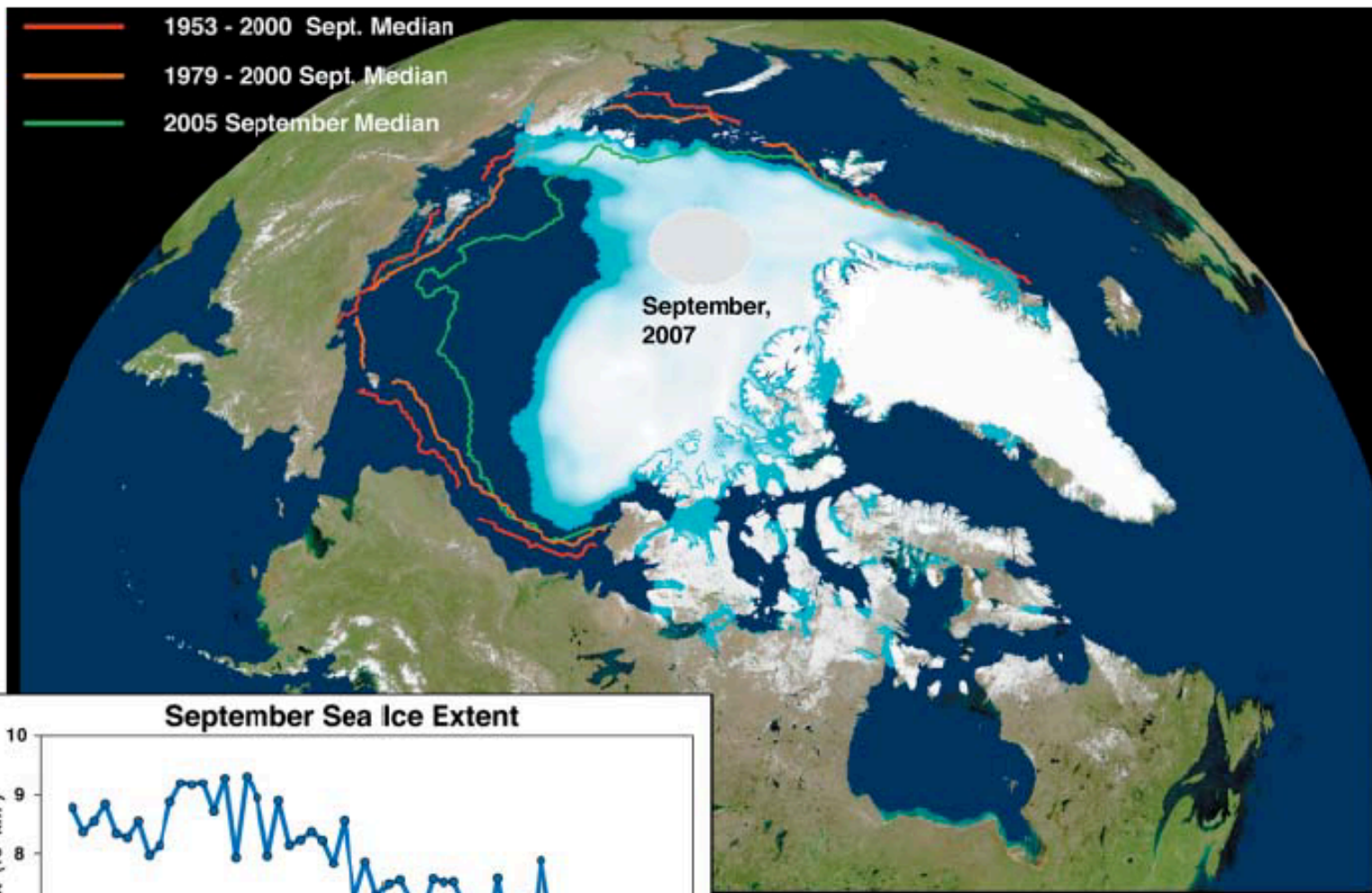
Near doubling of speed
between 2000 & 2003

~120 m thinning between
1997 & 2003

Stable for ~50 yrs

*Historic calving fronts
adapted from Weidick,
1995;
Sohn, Jezek and Van
der Veen 1999*



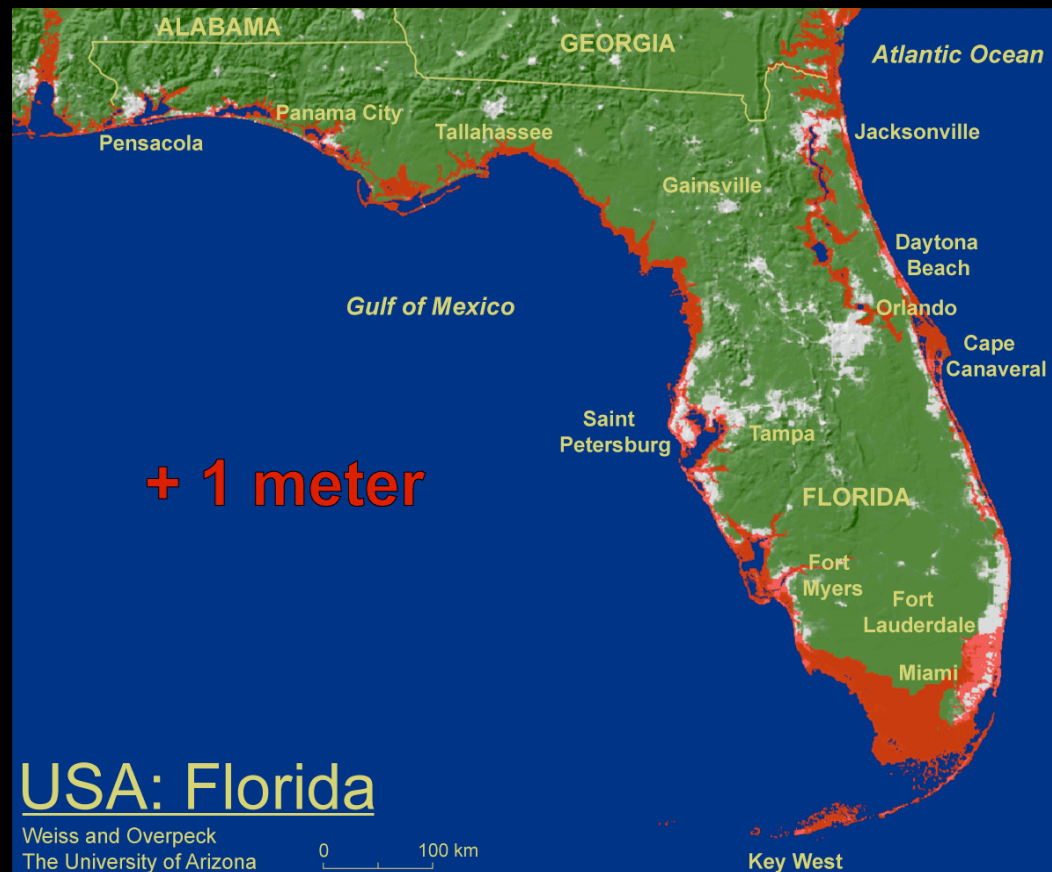


Stroeve et al, 2008

Sea level rise:

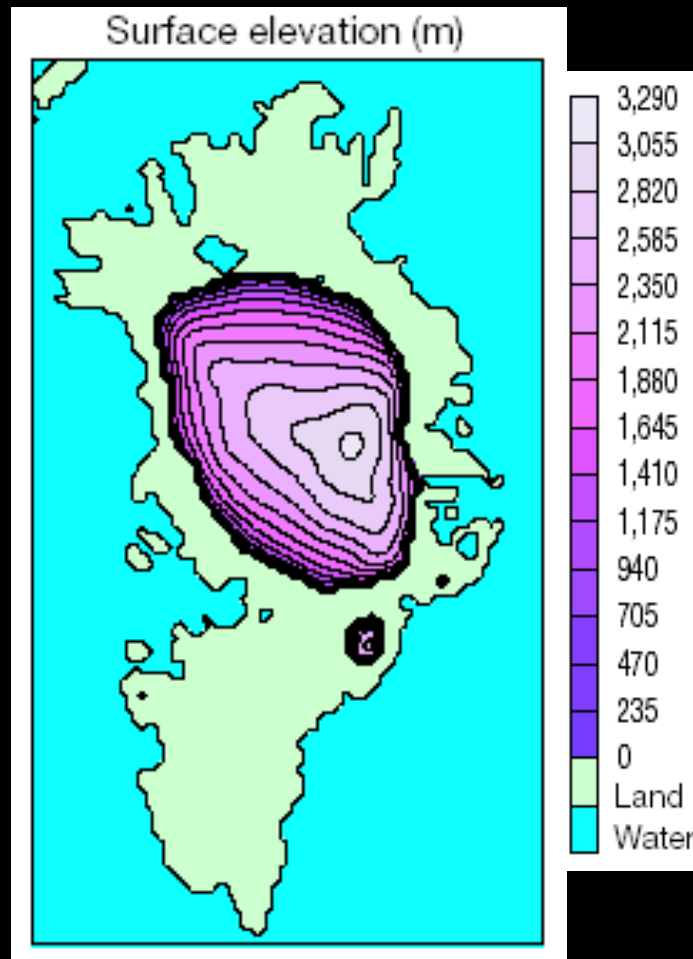
IPCC says 7" to 22" by 2100,
much more if rapid ice sheet collapse occurs

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



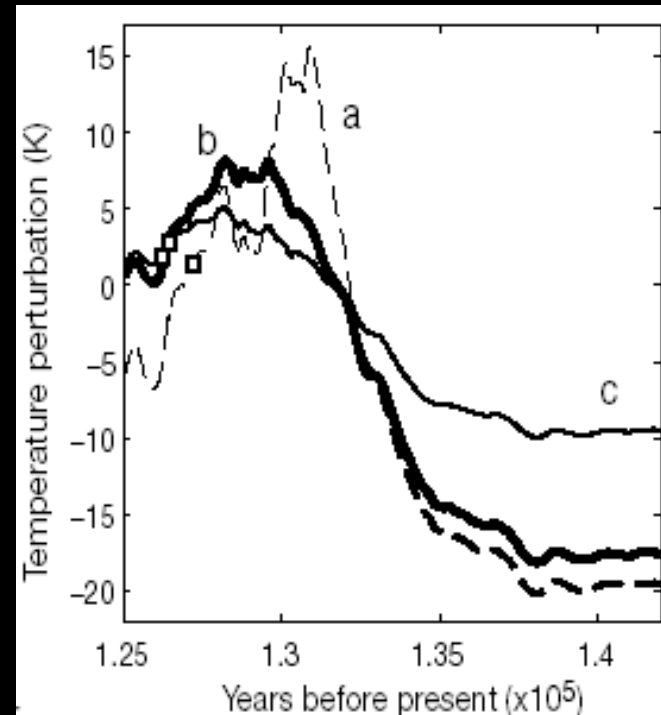
<http://www.geo.arizona.edu/dgesl/index.html>

During the last interglacial, temperatures were warmer than pre-industrial (by 5°C), and sea level was higher by 5-6m



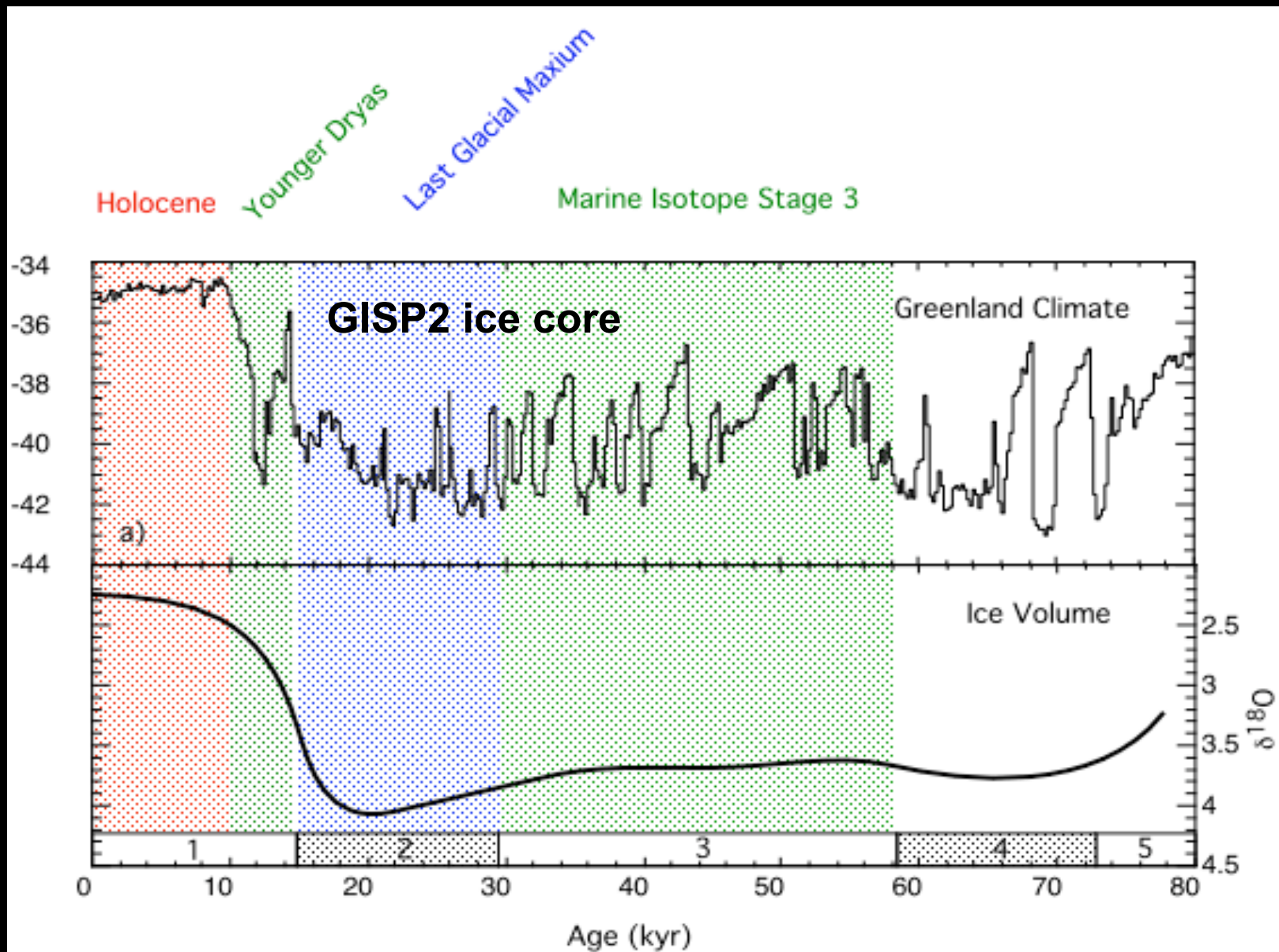
Cuffey et al., 2000

Greenland + West Antarctic = 14m

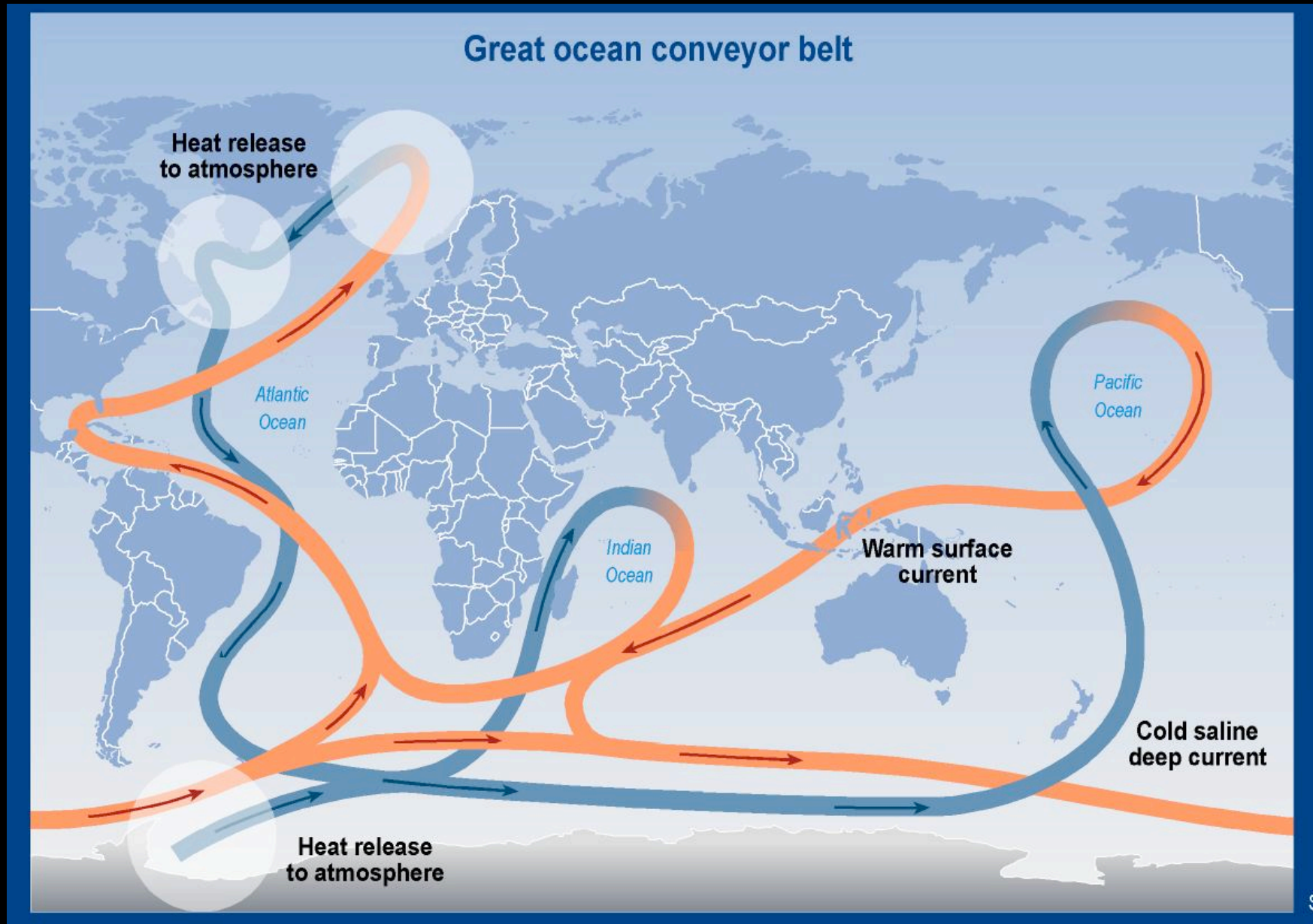


Location	Volume (km ³)	Potential sea-level rise (m)
East Antarctic ice sheet	26,039,200	64.80
West Antarctic ice sheet	3,262,000	8.06
Antarctic Peninsula	227,100	.46
Greenland	2,620,000	6.55
All other ice caps, ice fields, and valley glaciers	180,000	.45
Total	32,328,300	80.32

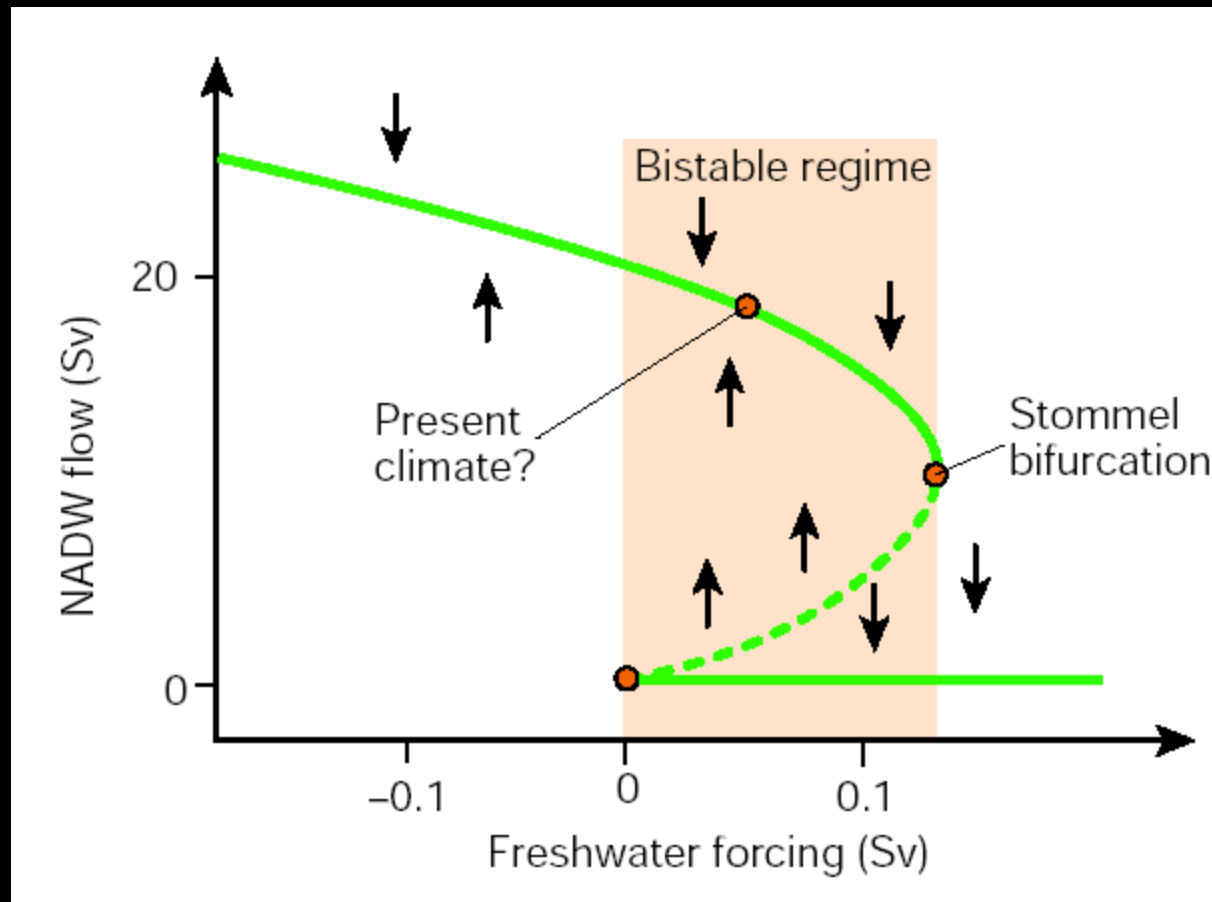
Abrupt Climate Change



What's the thermohaline circulation got to do with it?

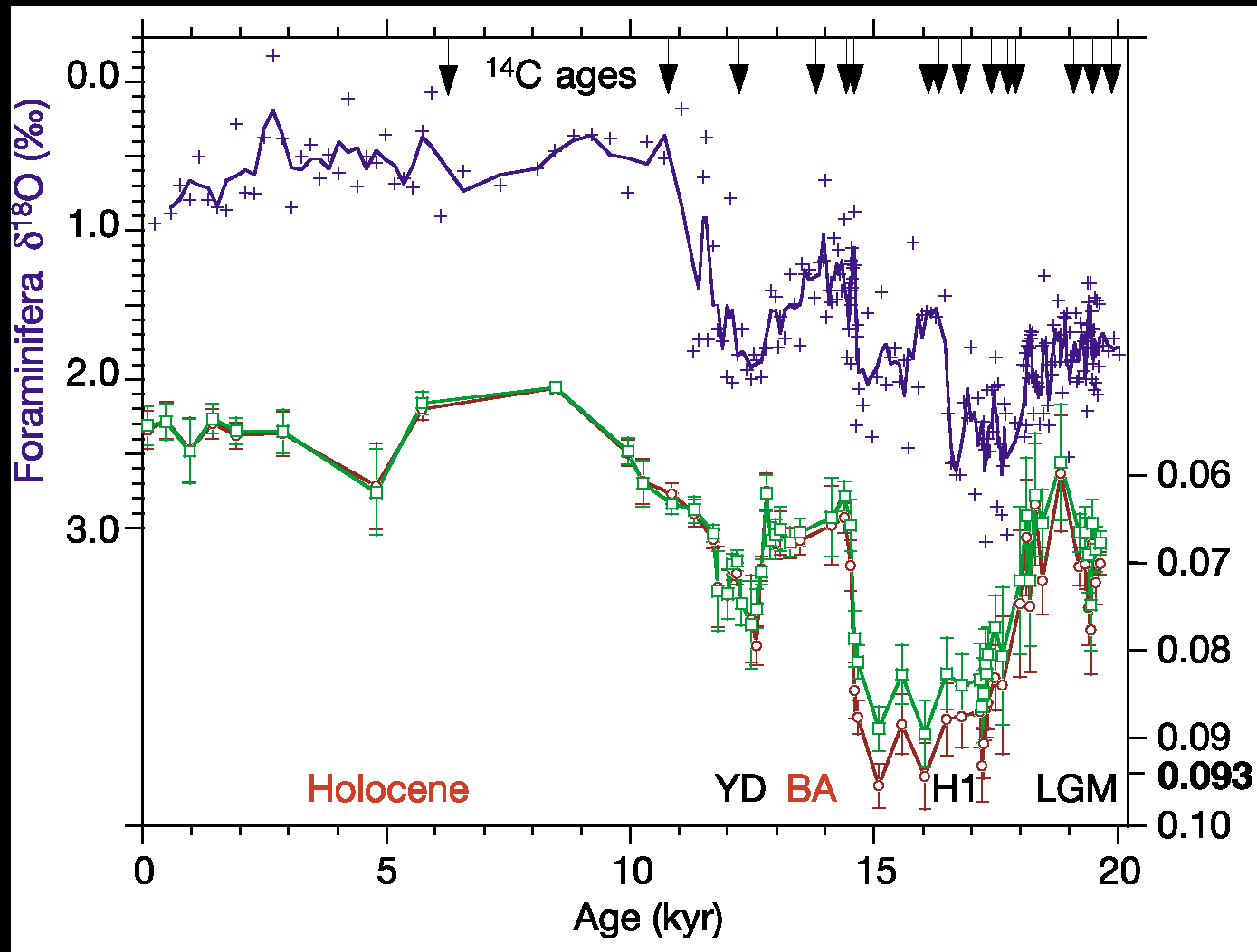


It is a system characterized by non-linear behavior



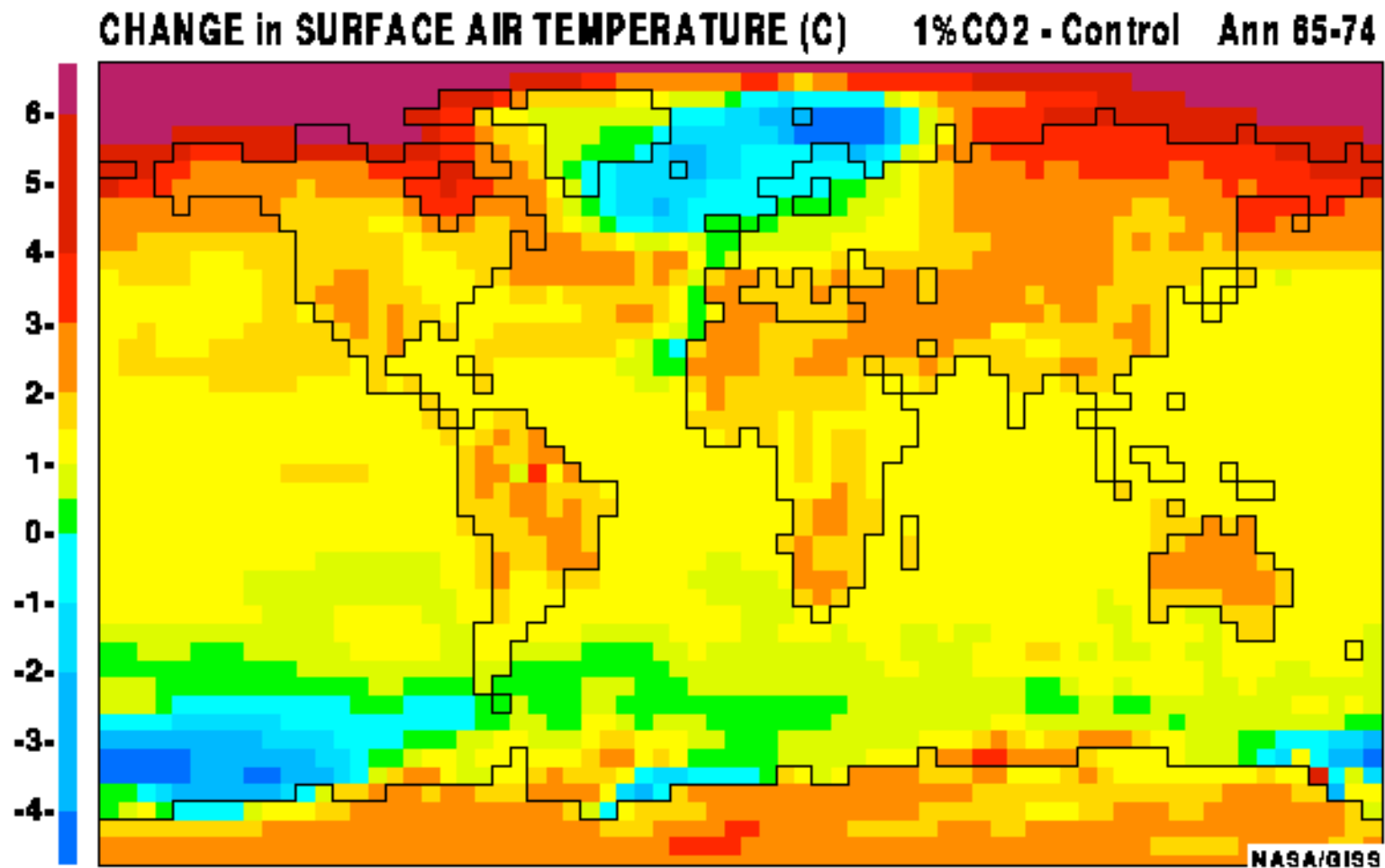
Ganopolski et al., 2001

Evidence of NADW shut down during past abrupt climate change events

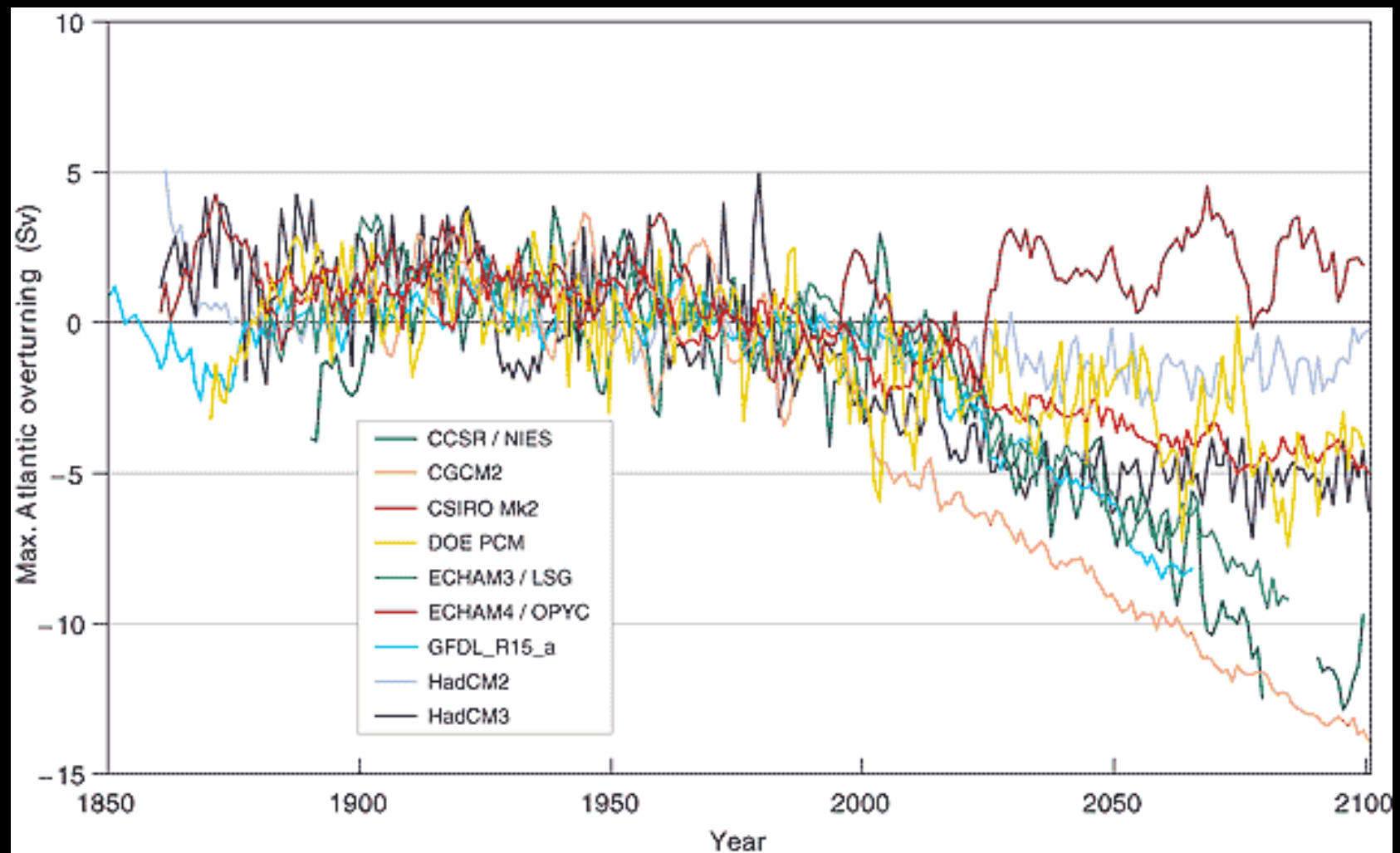


McManus et al., 2004

Climate effects of a full shut-down (model results)



Predictions of reduced Atlantic Overturning circulation in a Greenhouse world



IPCC TAR, 2001

Paleoclimate data...

- support conclusion that late 20th century temperatures are outside the range of natural variability
- can be used to probe regional precipitation responses to past and future climate forcing
- provide estimates of equilibrium climate sensitivity (more work needed to determine relationship between glacial/interglacial CO₂ and T)
- provide estimates of equilibrium sea level rise for given T change (rapidly expanding field of study)
- illustrate important non-linearities in the climate system which may be important in the 21st century

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