Title: From here to eternity: Global warming in geologic time

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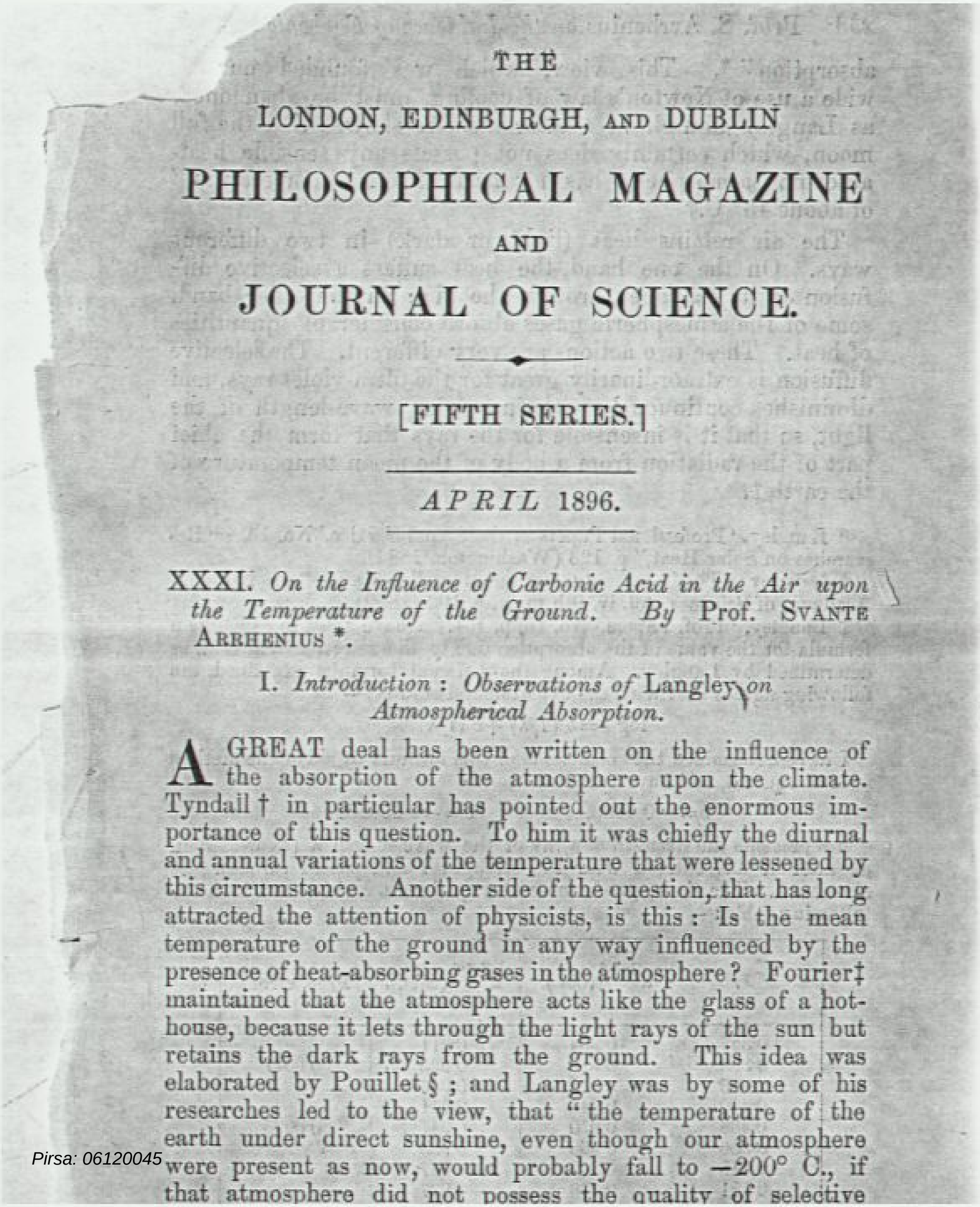
Abstract: Using results from models of the atmosphere/ocean/sediment carbon cycle, the impacts of fossil-fuel CO2 release will be examined Â– including the effect on climate many thousands of years into the future, rather than for just a few centuries as commonly claimed. Prof. Archer will explain how aspects of the Earth system, such as the growth or melting of the great ice sheets, the thawing of permafrost, and the release of methane from the methane hydrate deposits in the deep ocean, take thousands of years to respond to a change in climate. The duration of our potential climate adventure is comparable to the pacing of climate changes in the past, which enables us to use the geologic record of past climate changes to predict the trajectory of global warming into the deep future. In particular, the record of sea level variations in the past suggests that the ultimate sea level response to fossil fuel CO2 use could be 10 to 100 times higher than the Intergovernmental Panel on Climate Change (IPCC) forecast for the year 2100. <kw>models, greenhouse gas, temperature forecast, medieval warm, little ice age, Greenland, Heinrich Events, fossil fuel, Climber Model Hysteresis, Ganopolski, Buffett, methane hydrates, Palaeocene, Eocene, Thermal Maximum Event </kw>

From Here to Eternity

David Archer
University of Chicago

Global Warming
in Geologic Time


THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground. By* Prof. SVANTE ARRHENIUS *.

I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

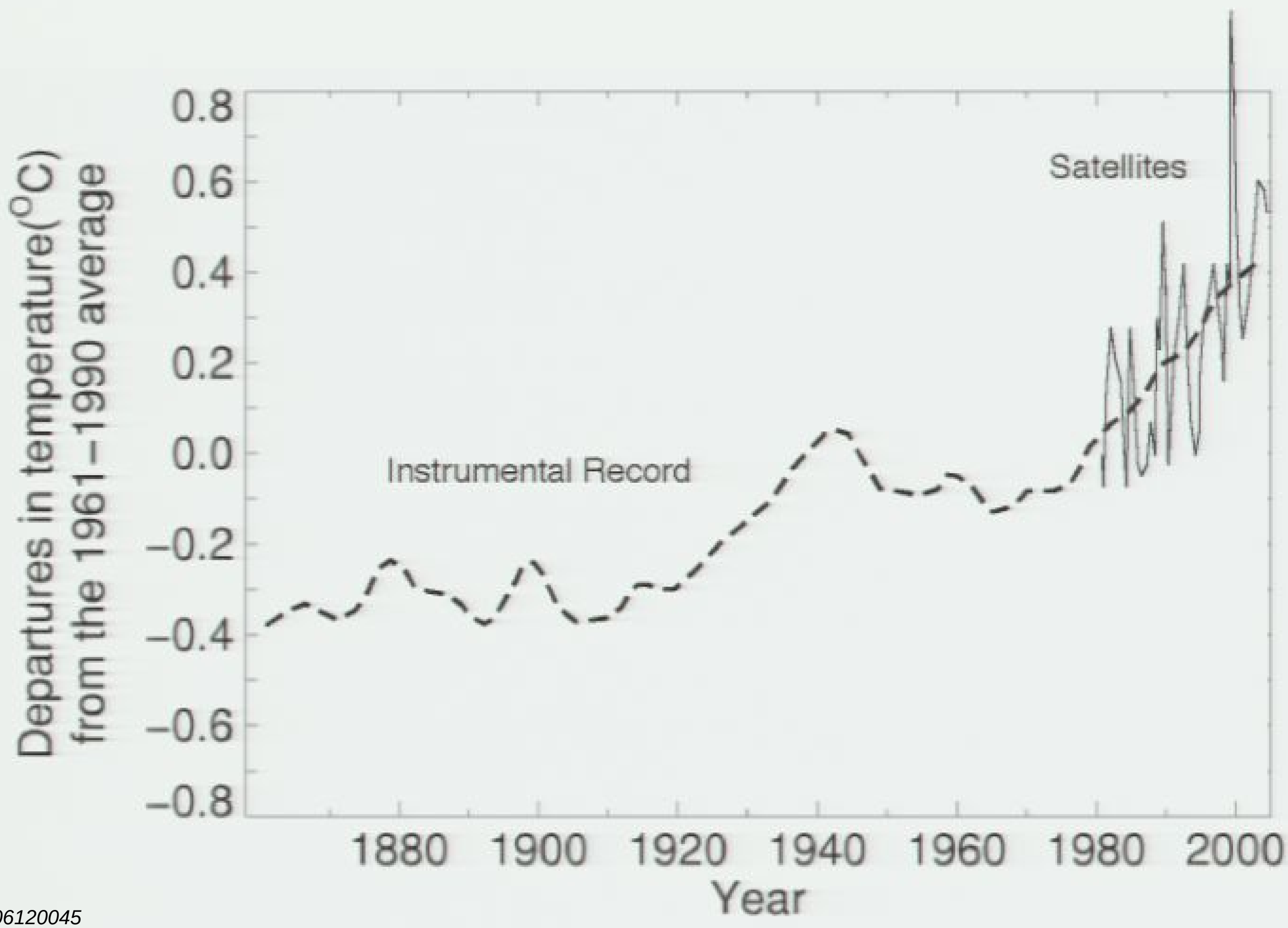
A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

Arrhenius, 1896

Predicted that doubling CO_2 would raise global temperature by 4-6°C.

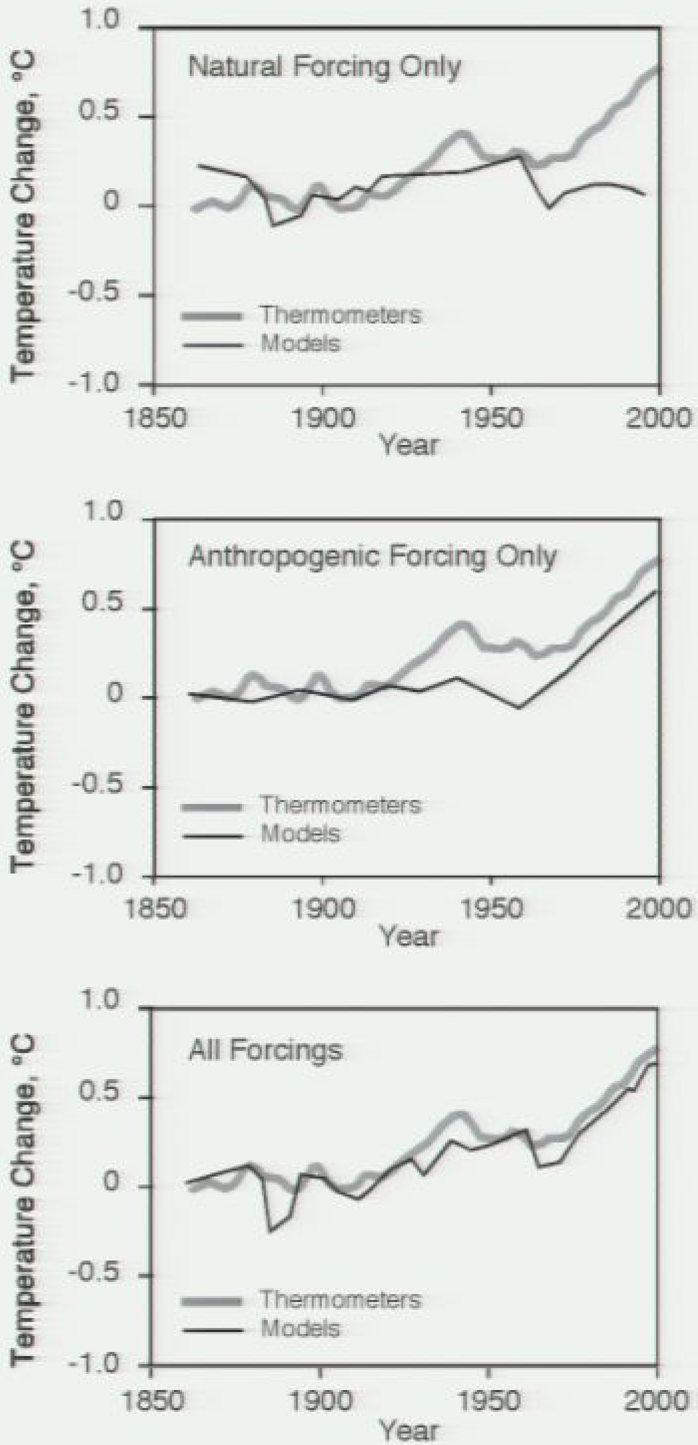
Now, of course, we predict 3-5°C (a century of progress!).

The Earth is Warming

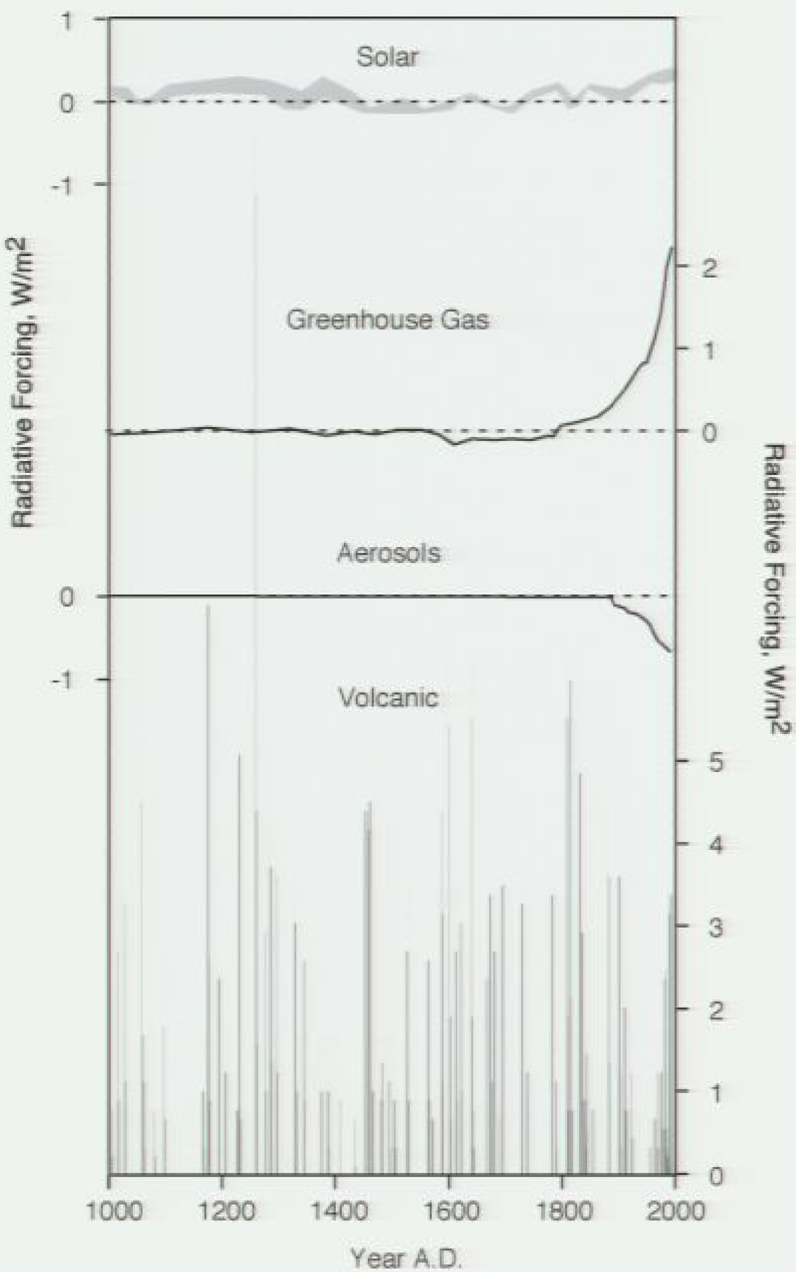


Satellites and weather stations now agree.

Ice sheets and glaciers are melting
around the world



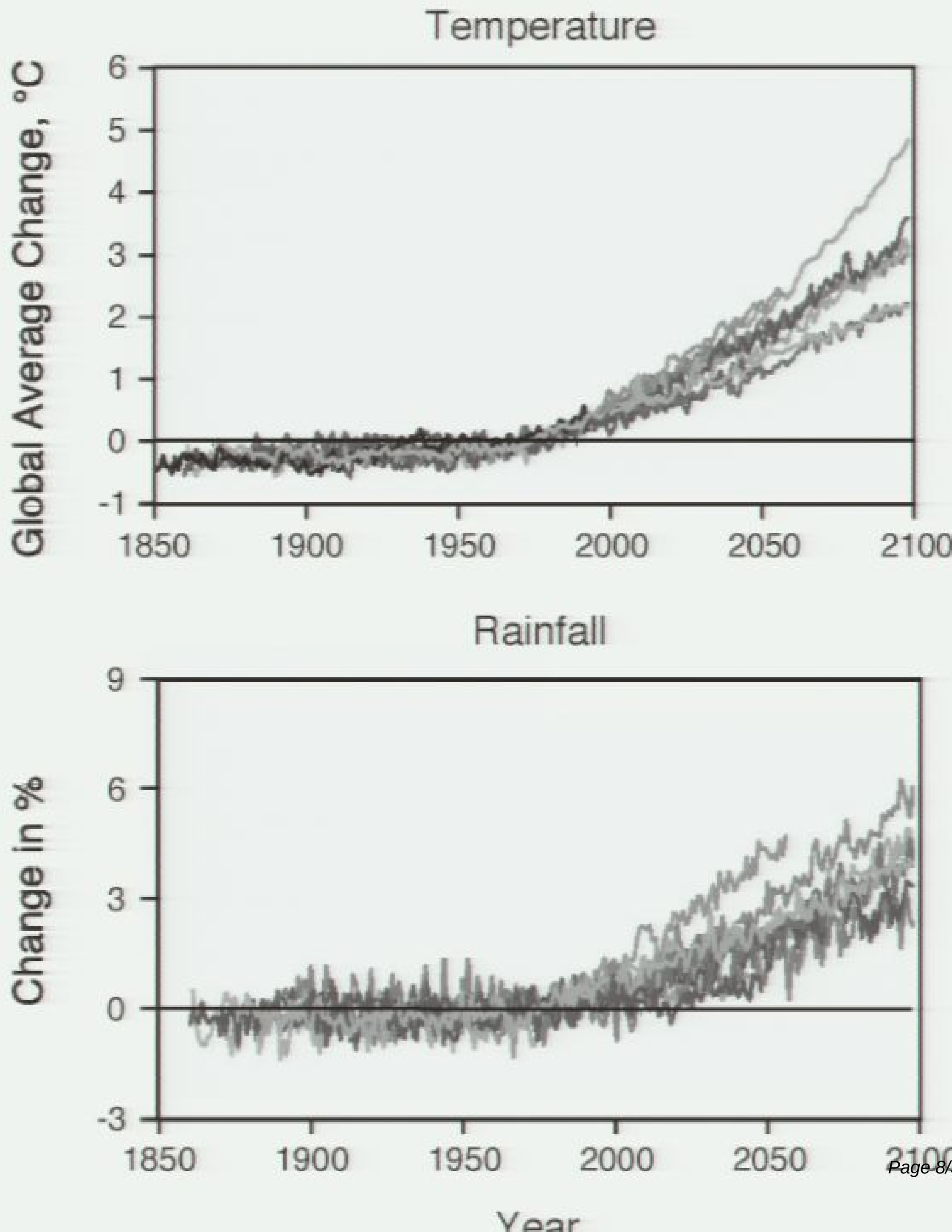
Climate models can explain the recent temperature changes, but only by taking into account both human and natural climate forcings



Only greenhouse gas forcing looks like the recent temperature rise.

Temperature Forecast:
2-4° C warming
by 2100

General increase
in precipitation
in a warmer
world.

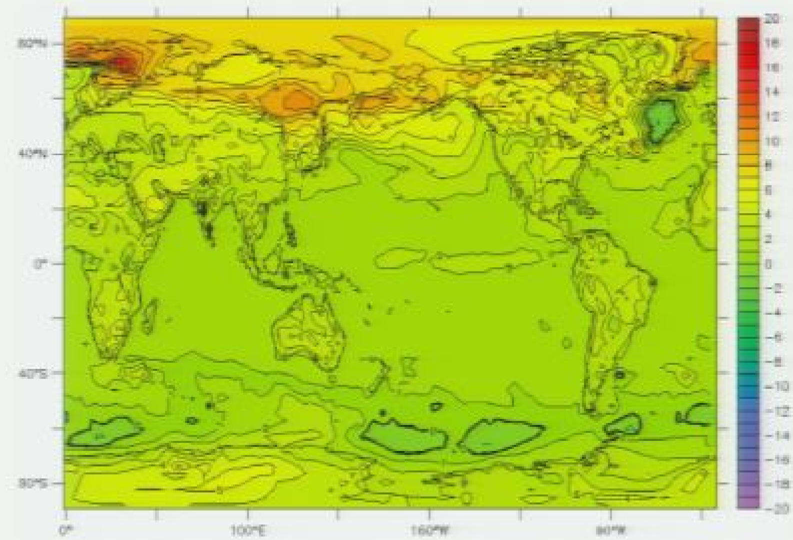


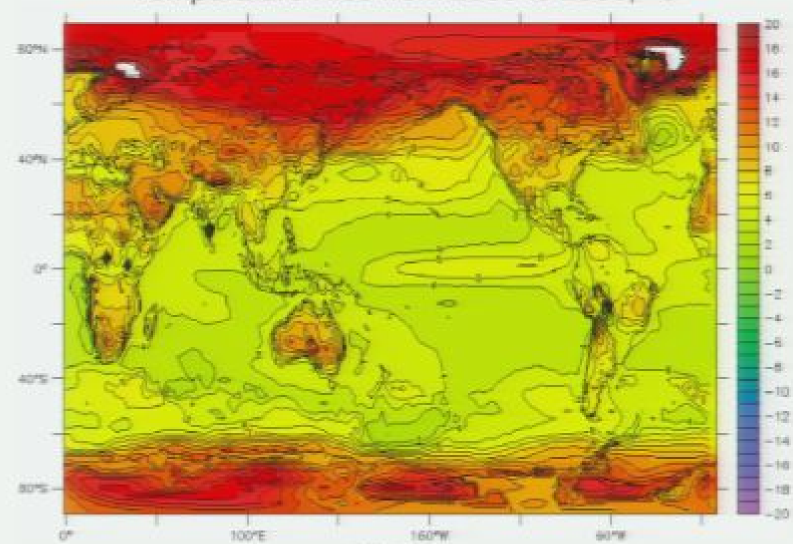
Temperature changes from 1750 (natural)

For the year 2100

And 2300

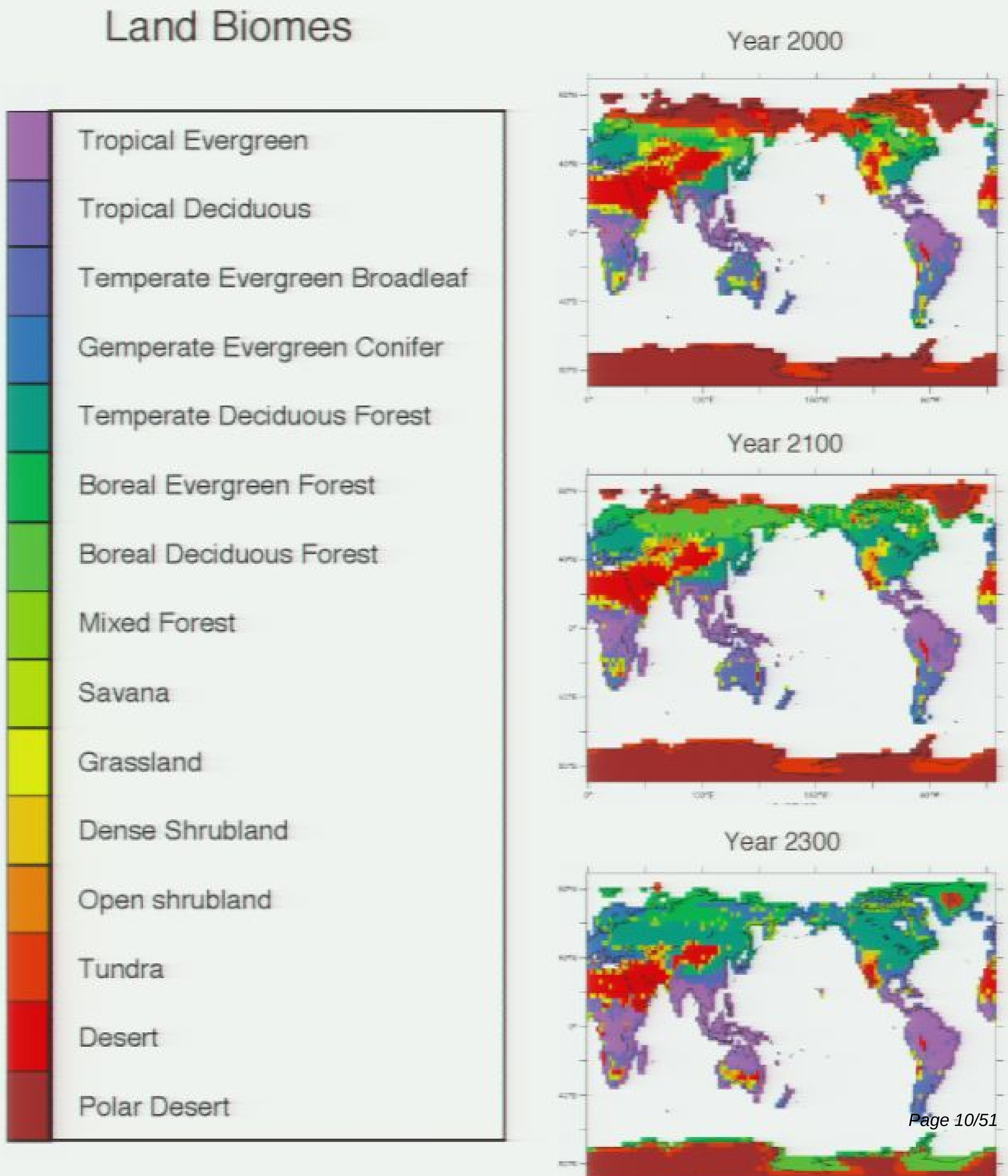
Warming is most intense in high latitudes





Climate determines the landscape of the Earth.

Tundra is lost by 2300.

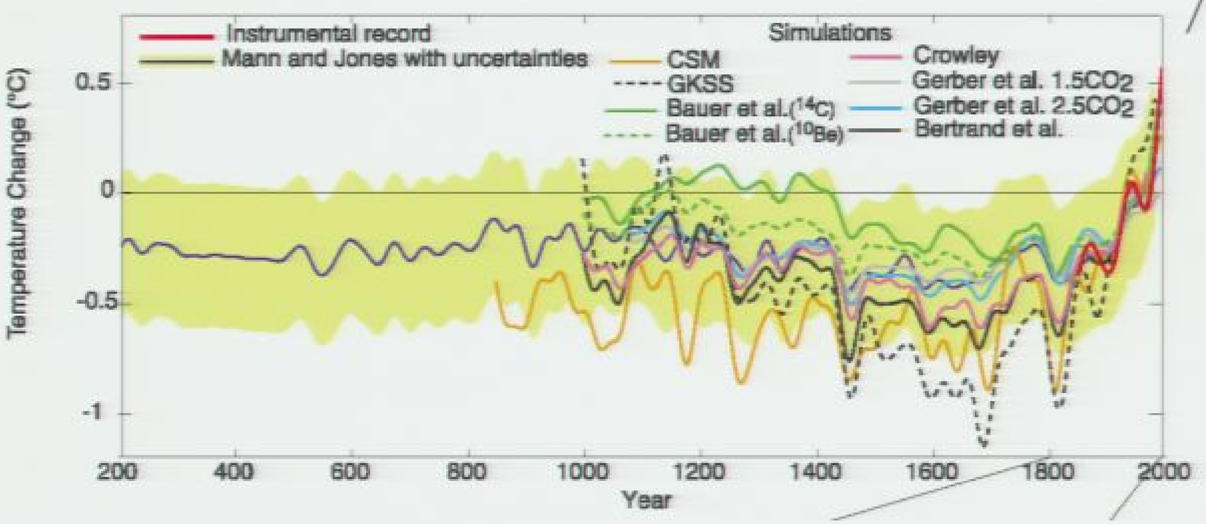


The Past

Medieval Warm,
0.5° Warm

Little Ice Age,
1° Colder

Present,
0.6° Warmer

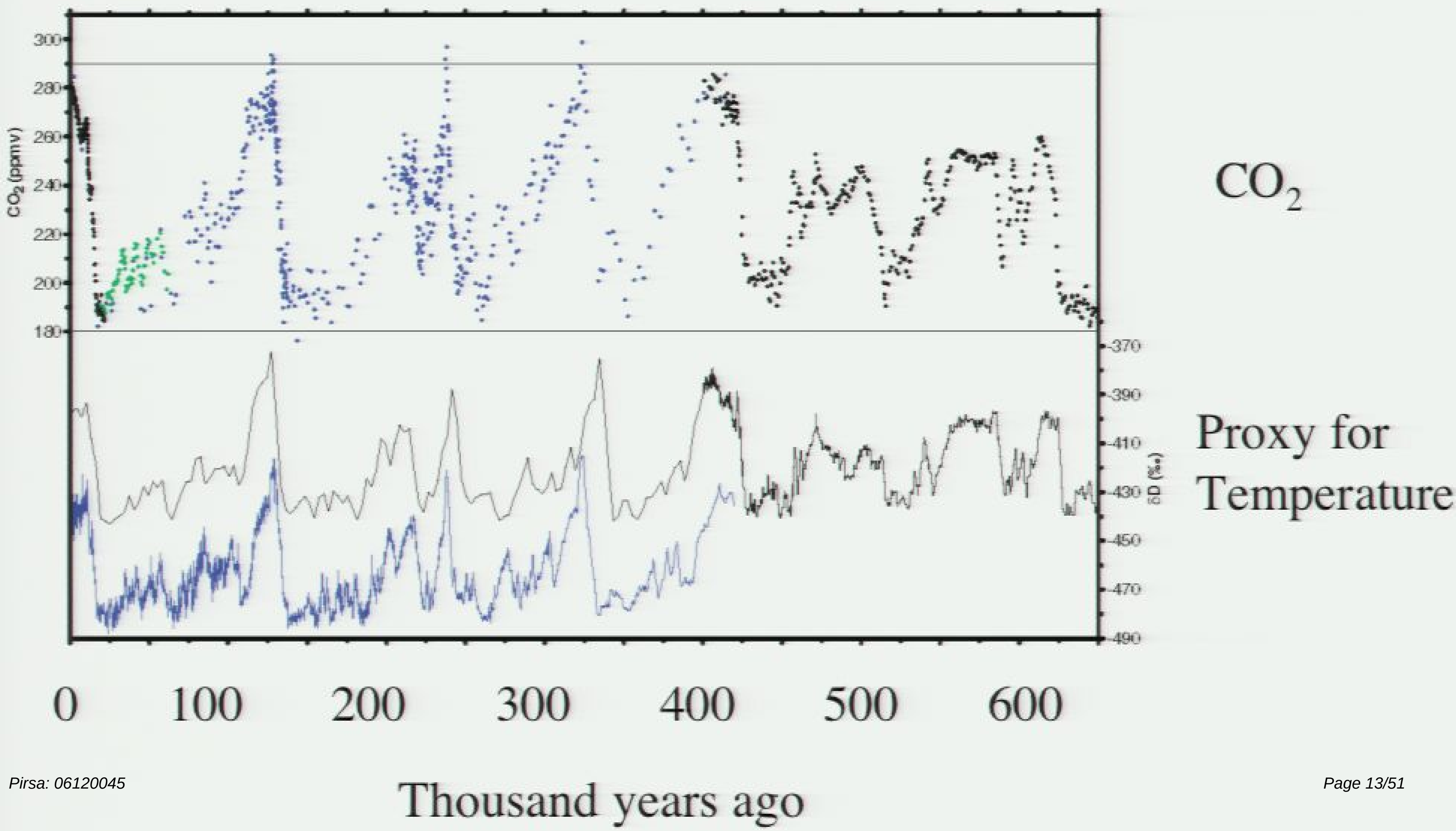


Current warming comparable to Medieval warm time

Lessons from the past

Present-day climate is comparable to medieval warm.
Real, noticable, but not globally catastrophic.

Glacial cycles in ice sheets and CO_2

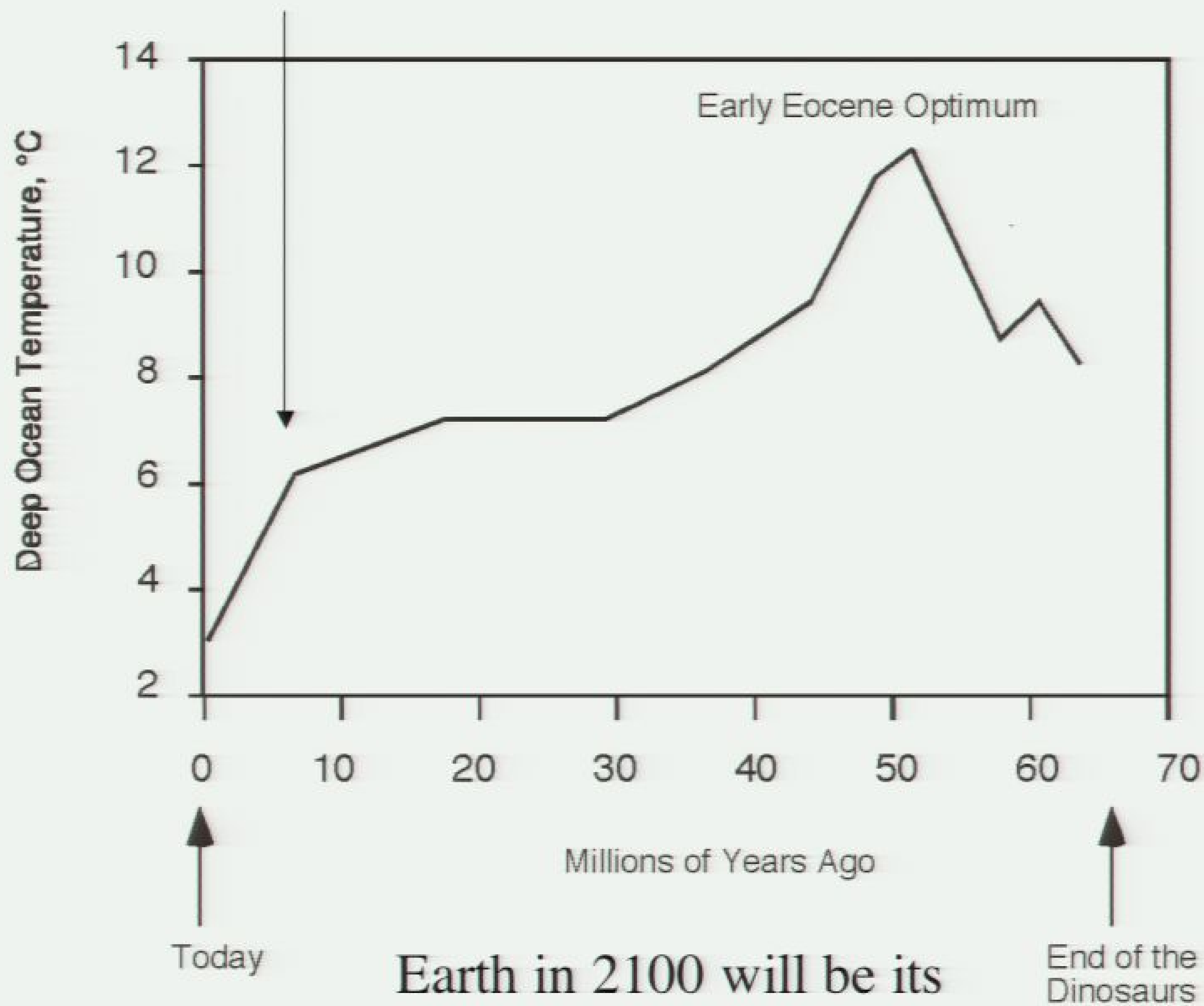


Lessons from the past

Present-day climate is comparable to medieval warm.
Real, noticable, but not globally catastrophic.

Temperature change in the coming century is more
comparable to the end of the last glacial time.

3° Warmer 5 Million Years Ago



Earth in 2100 will be its warmest in millions of years

Lessons from the past

Present-day climate is comparable to medieval warm.
Real, noticable, but not globally catastrophic.

Temperature change in the coming century is more
comparable to the end of the last glacial time,
but to a warmth unlike any in millions of years.

Lessons from the past

Present-day climate is comparable to medieval warm.
Real, noticable, but not globally catastrophic.

Temperature change in the coming century is more comparable to the end of the last glacial time, but to a warmth unlike any in millions of years.

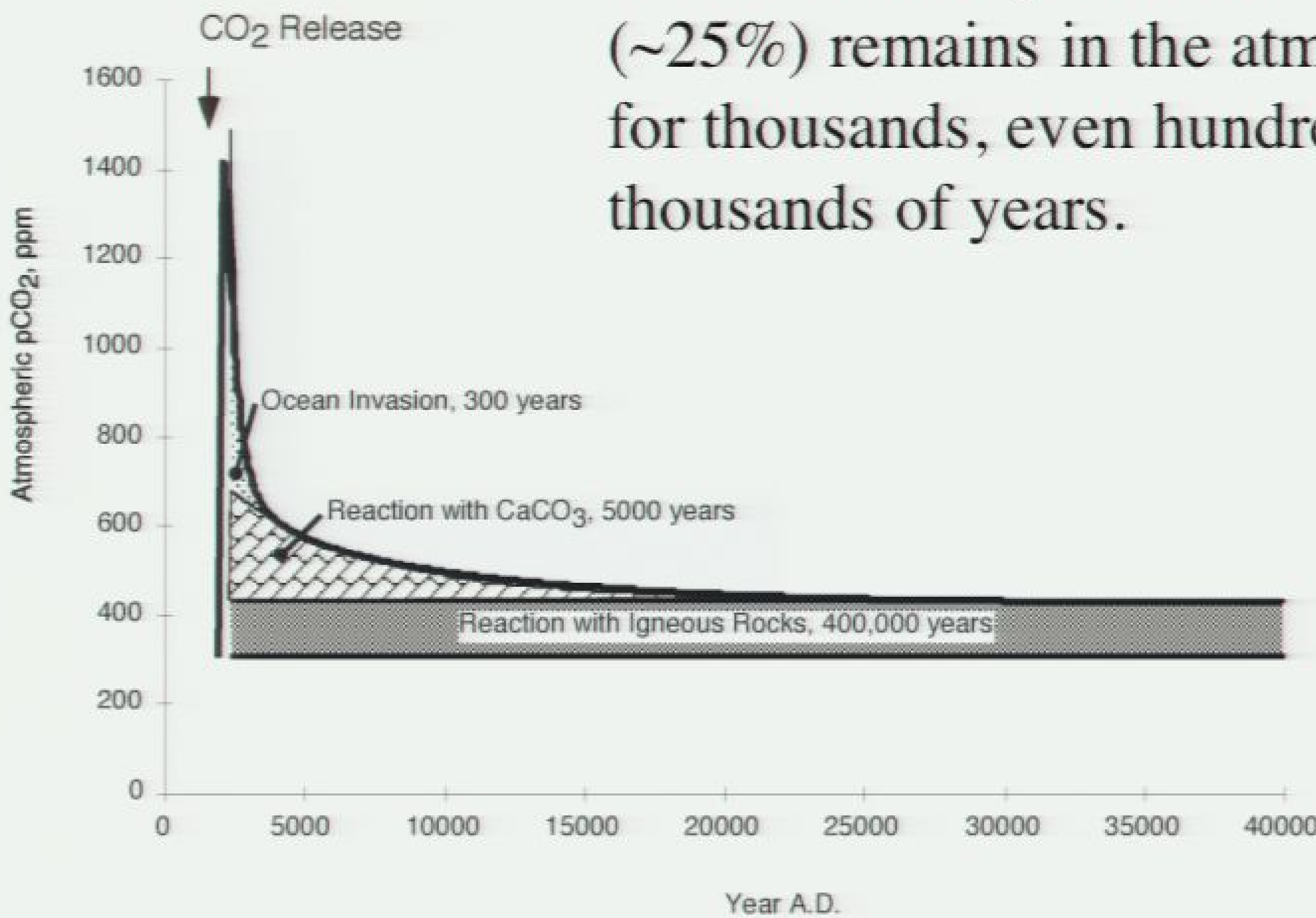
Another note from the past: climate changes can be abrupt and unpredictable, rather than the smooth changes that the models predict.

The Future

Fate of fossil fuel CO_2

Dissolves in the ocean	(centuries)
Uptake / release from terrestrial biosphere	(centuries)
Neutralization by $CaCO_3$	(5-10 kyr)
Lithification by weathering of silicate rocks	(400 kyr)

Most of the CO_2 goes away in a few centuries, but a fraction (~25%) remains in the atmosphere for thousands, even hundreds of thousands of years.



Archer, 1997 and 2005

IPCC 2001 got this wrong

Table 1: Examples of greenhouse gases that are affected by human activities. [Based upon Chapter 3 and Table 4.1]

	CO_2 (Carbon Dioxide)	CH_4 (Methane)	N_2O (Nitrous Oxide)	CFC-11 (Chlorofluoro -carbon-11)	HFC-23 (Hydrofluoro -carbon-23)	CF_4 (Perfluoro-methane)
Pre-industrial concentration	about 280 ppm	about 700 ppb	about 270 ppb	zero	zero	40 ppt
Concentration in 1998	365 ppm	1745 ppb	314 ppb	268 ppt	14 ppt	80 ppt
Rate of concentration change[b]	1.5 ppm/yr [a]	7.0 ppb/yr [a]	0.8 ppb/yr	–1.4 ppt/yr	0.55 ppt/yr	1 ppt/yr
Atmospheric lifetime	5 to 200 yr [c]	12 yr [d]	114 yr [d]	45 yr	260 yr	>50,000 yr

[a] Rate has fluctuated between 0.9 ppm/yr and 2.8 ppm/yr for CO_2 and between 0 and 13 ppb/yr for CH_4 over the period 1990 to 1999.

[b] Rate is calculated over the period 1990 to 1999.

[c] No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.

[d] This lifetime has been defined as an "adjustment time" that takes into account the indirect effect of the gas on its own residence time.

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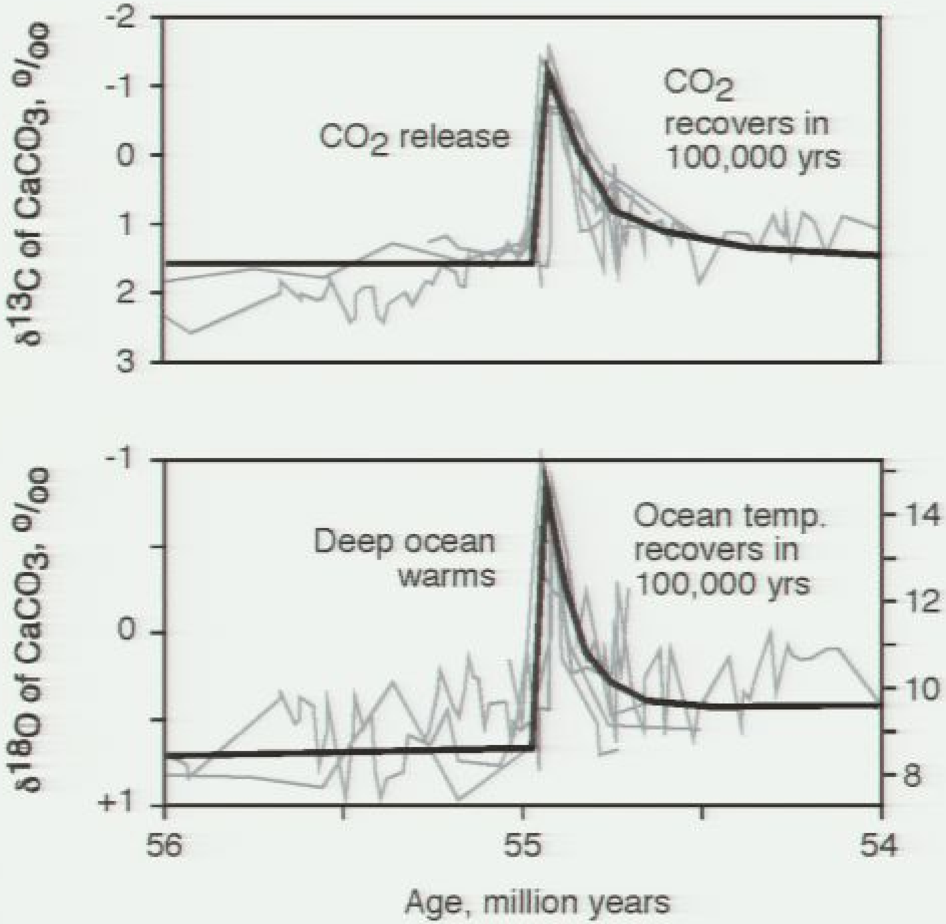
Since then, it's repeated everywhere

Airborne Fraction of a Large CO_2 Release

	Peak	1 kyr	10 kyr
Archer 2005	60%	33%	15%
Lenton 2006	67-75%	14-16%	10-15%
Brovkin in prep.	67%	57%	26%
Goodwin subm.	50%	40%	
Ridgwell subm.	50%	34%	12%
Tyrell subm.	70%	42%	21%

Paleocene/Eocene Thermal Maximum Event
55 Myr Ago



A natural release of CO_2, comparable to the potential fossil fuel release.

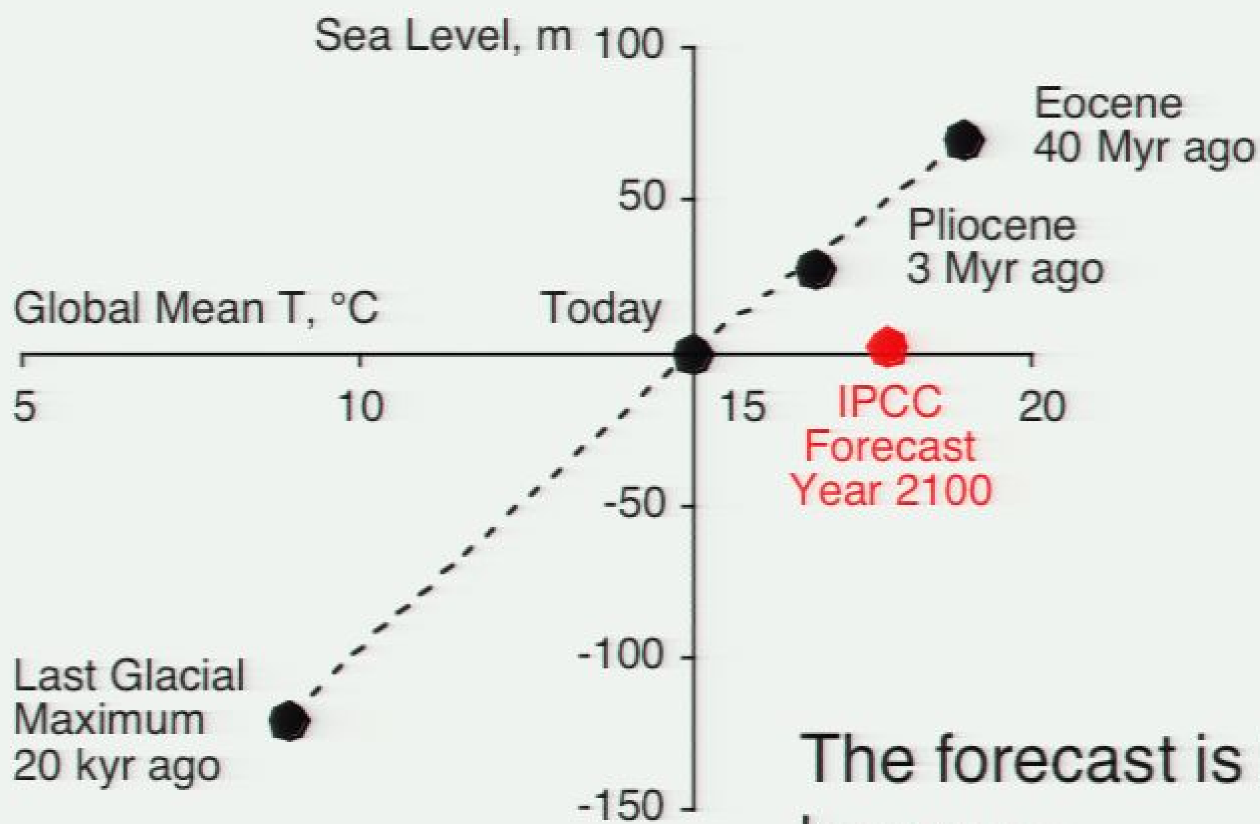
Warming, with a recovery that took 100,000 years.

Long-Term Temperature Impact

	1 kyr	10 kyr
2000 Gton C	3°	1.5°
5000 Gton C (all the coal)	5°	3°

Assumes 3°C warming for doubling CO_2

Sea Level



The forecast is low because
melting ice is slow

Long-Term Temperature Impact

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5000 Gton C	5°	3°

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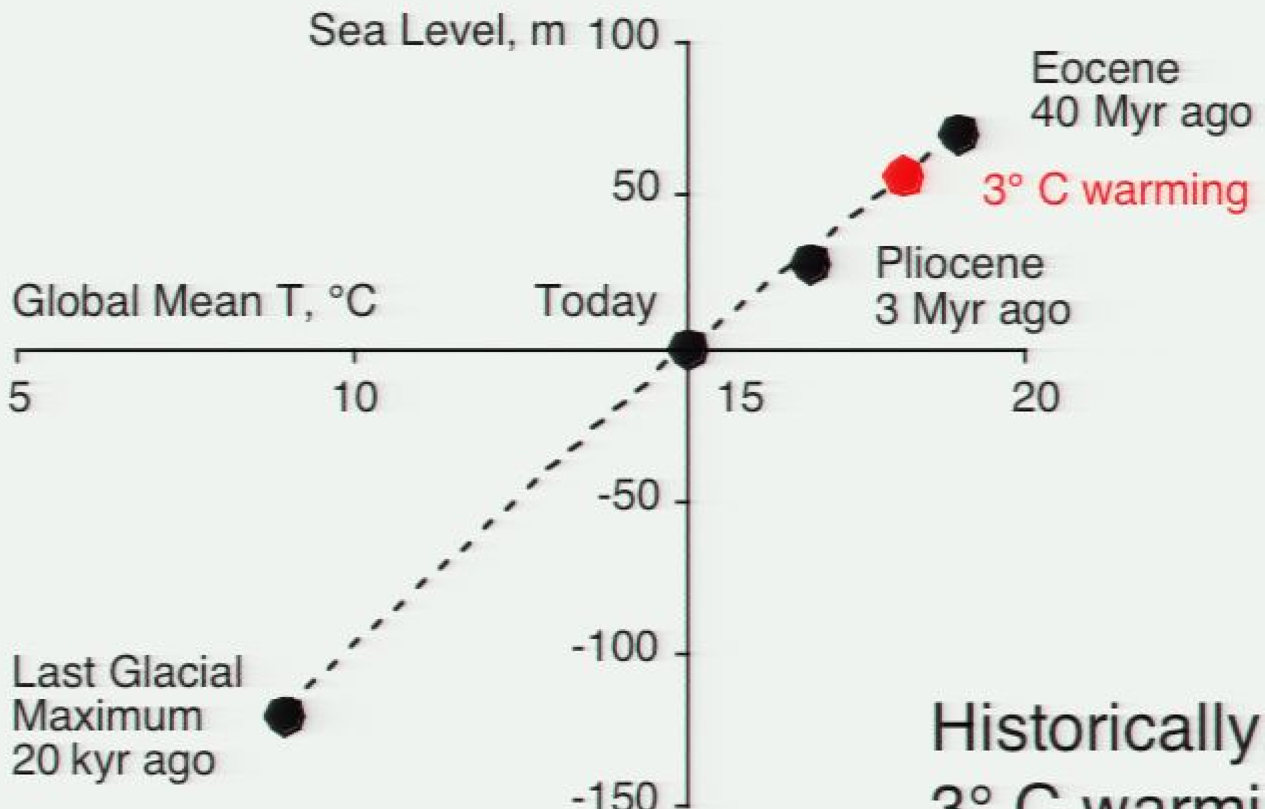
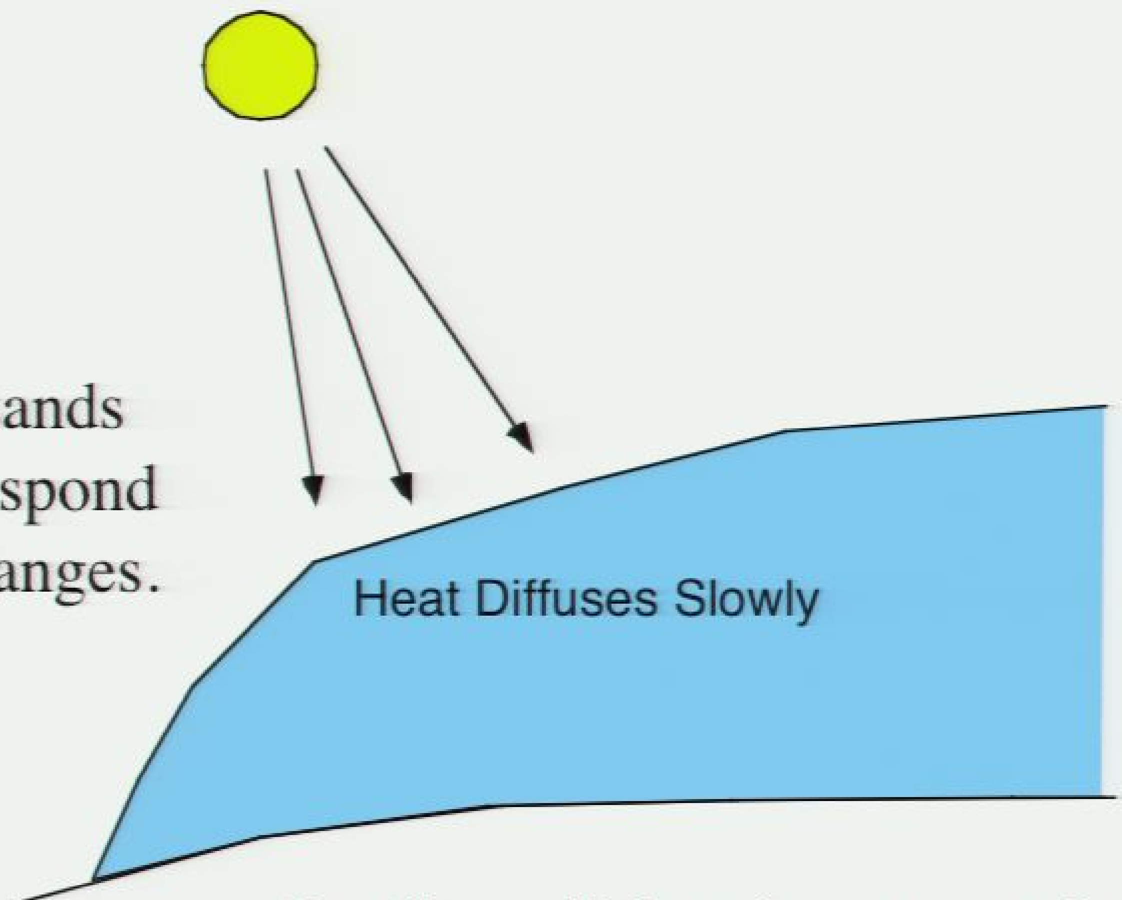
Sea Level



Historically,
3° C warming
is a big deal.

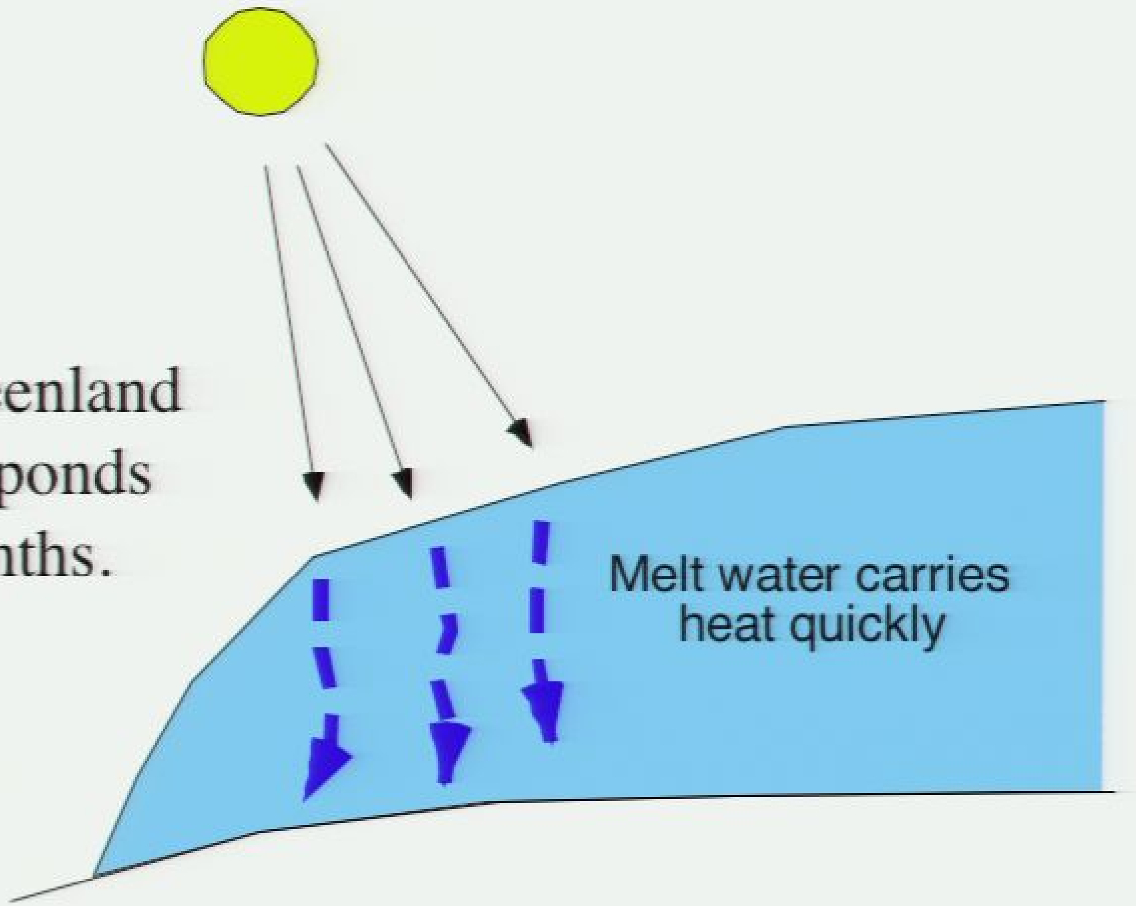
Ice sheet models are probably too sluggish.

It takes thousands of years to respond to climate changes.



Ice flows if there's water at the bed

The real Greenland ice sheet responds in a few months.



We don't know how water gets through the ice.

A moulin in Greenland where water submerges into the ice.

Zwalley et al (2002)

Earthquakes under Greenland ice

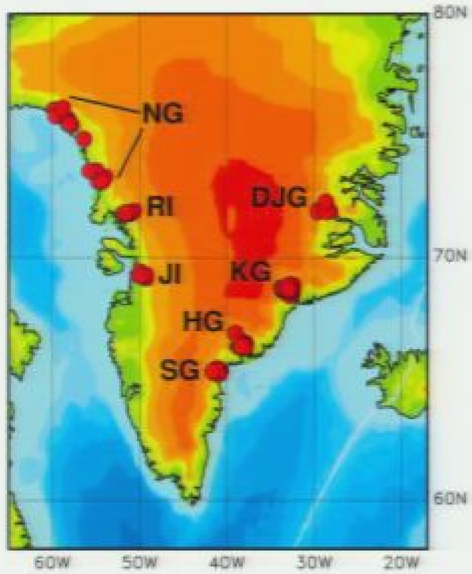


Fig. 1. Topographic map of southern Greenland and vicinity. The locations of 136 glacial earthquakes defining seven groups are indicated with red circles: DJG, Daugaard Jensen Glacier (5 events); KG, Kangerdlugssuaq Glacier (61); HG, Helheim Glacier (26); SG, southeast Greenland glaciers (6); JI, Jakobshavn Isbrae (11); RI, Rinks Isbrae (10); NG, northwest Greenland glaciers (17). Owing to the tight clustering of the earthquakes, many of the individual symbols on the map overlap.

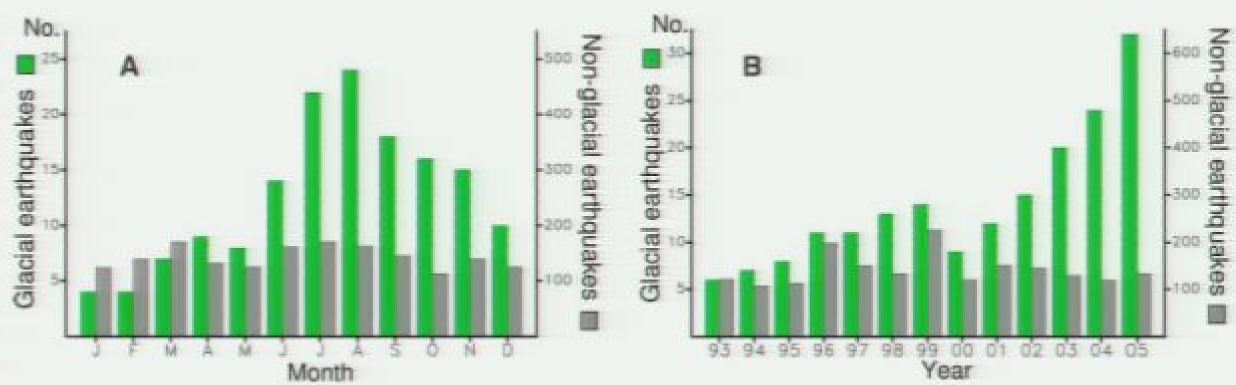
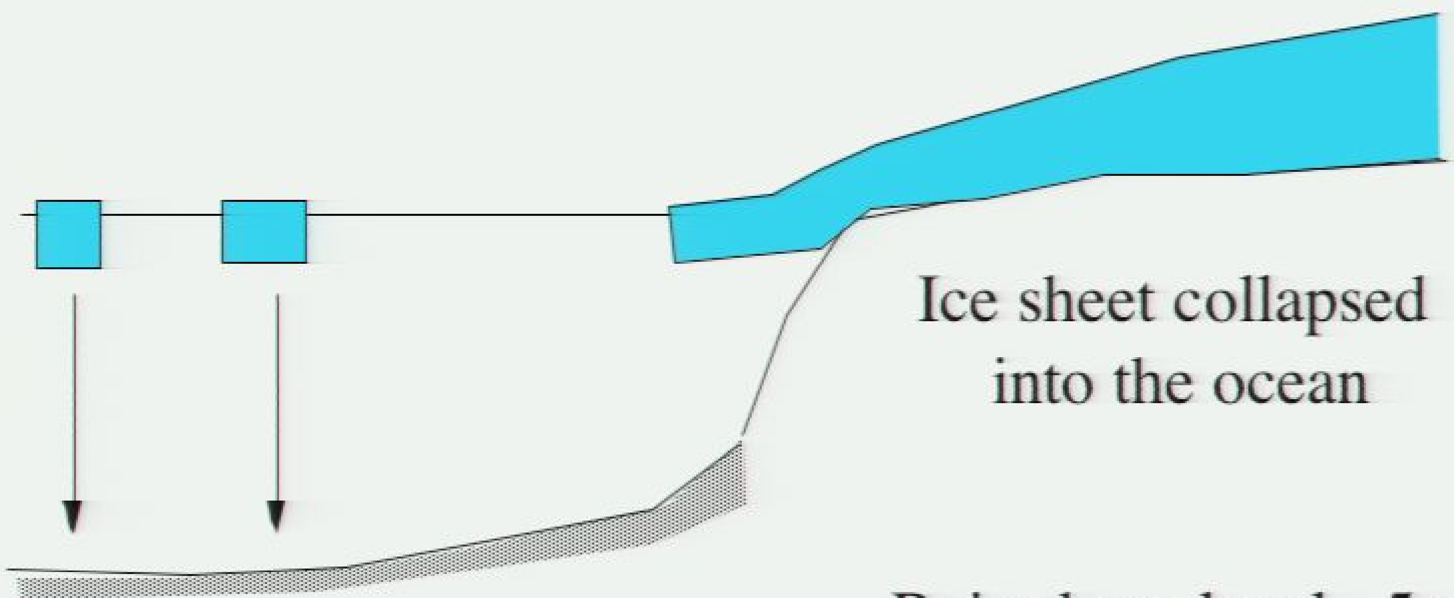


Fig. 2. (**A**) Histogram showing seasonality of glacial earthquakes on Greenland. Green bars show the number of detected Greenland glacial earthquakes in each month during the period 1993 to 2004. Gray bars show the number of earthquakes of similar magnitude detected elsewhere north of 45°N during the same period. (**B**) Histogram showing the increasing number of Greenland glacial earthquakes (green bars) since at least 2002. No general increase in the detection of earthquakes north of 45°N (gray bars) is observed during this time period.

Ekstrom et al., 2006

Heinrich Events 30-70 kyr ago



Ice sheet collapsed
into the ocean

Ice Rafted Debris
(layers of rocks in
ocean sediments)

Raised sea level ~5 m
in a few centuries.
Could the Greenland
ice sheet start doing this?

Meltwater Pulse 1A 19kyr ago

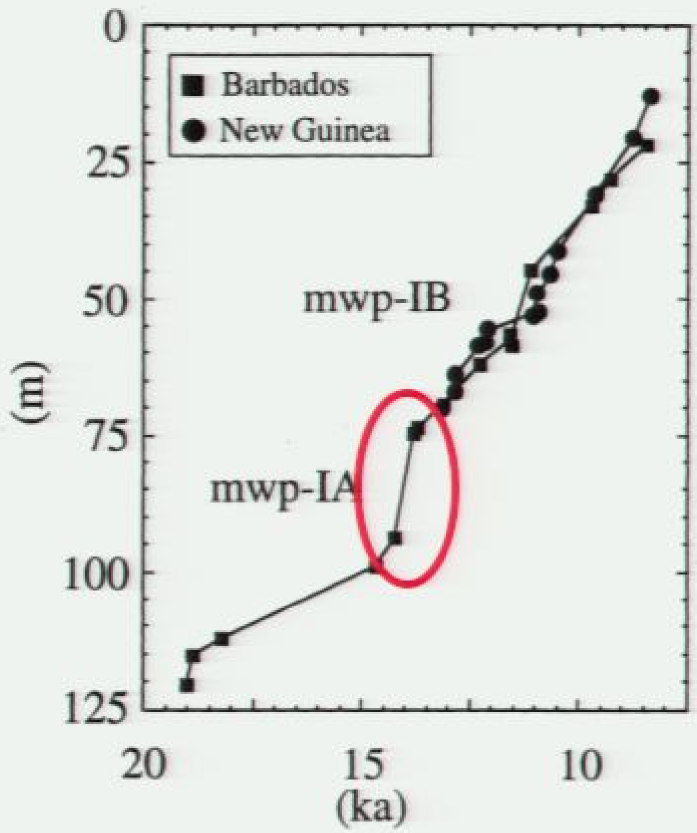
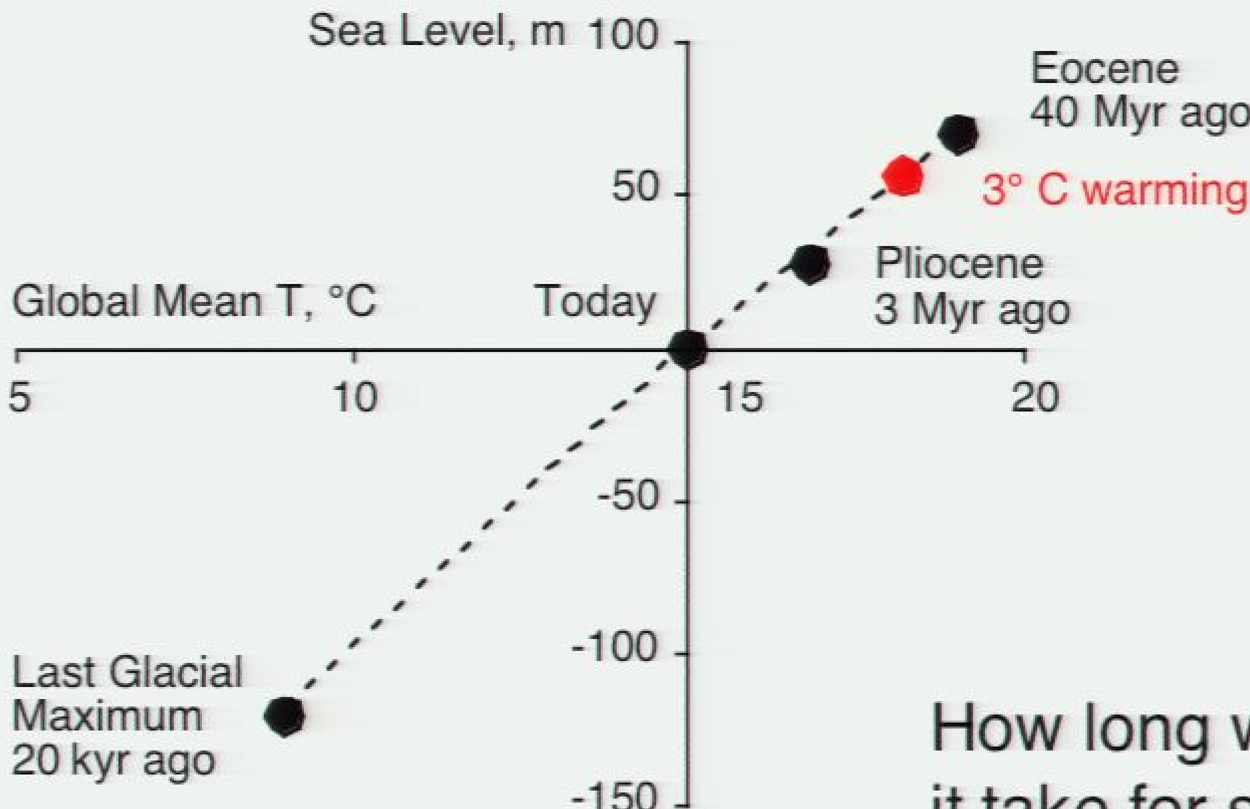


Figure 1. Coral records of sea level dated by U/Th from Barbados [*Bard et al.*, 1990a, 1993] and New Guinea [*Edwards et al.*, 1993]. Two periods of rapid rise of sea level are identified as mwp-IA and mwp-IB.

1.5 to 3 Greenlands in 1-5 centuries.

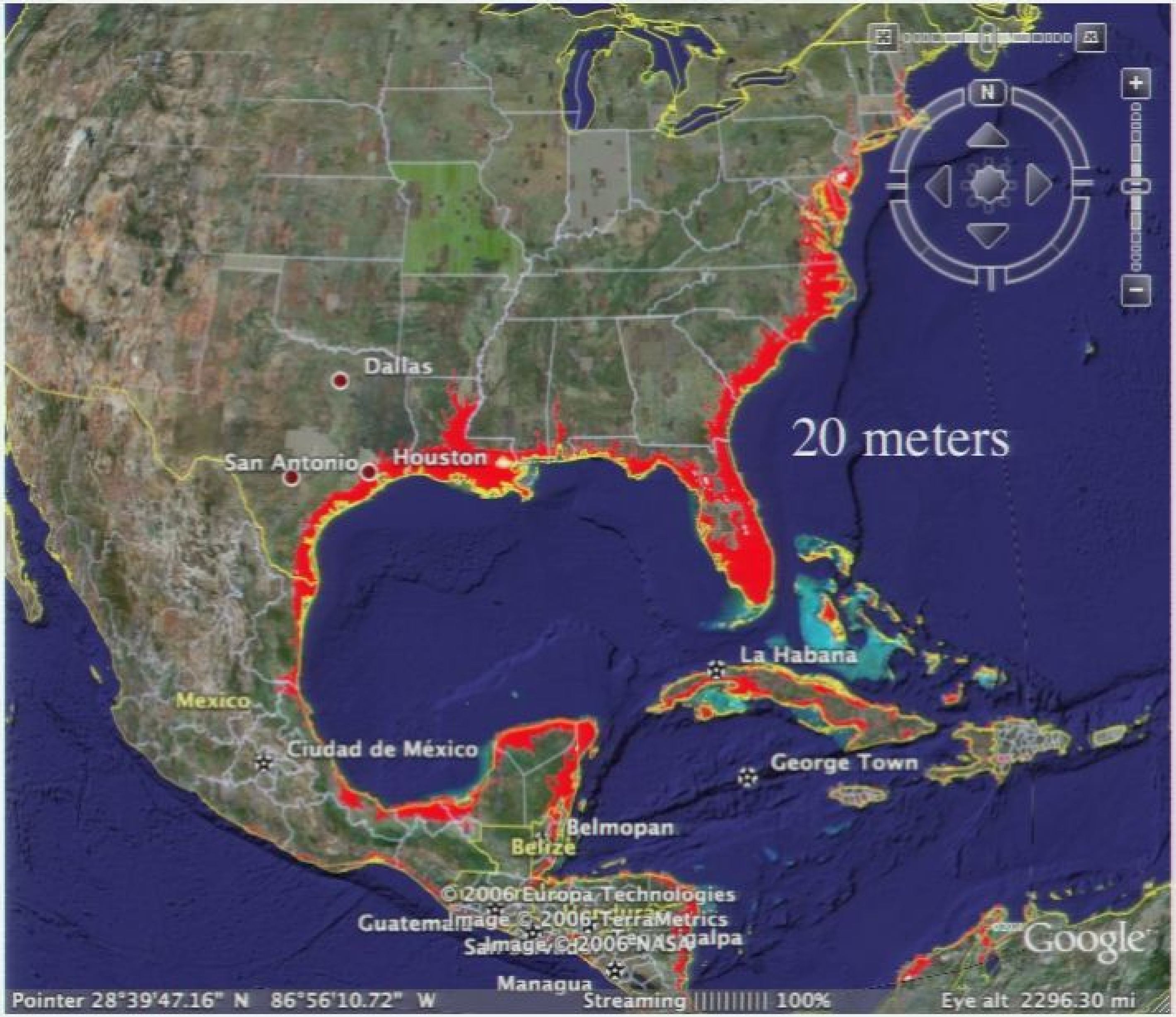
We're not even sure where this water came from.

Sea Level

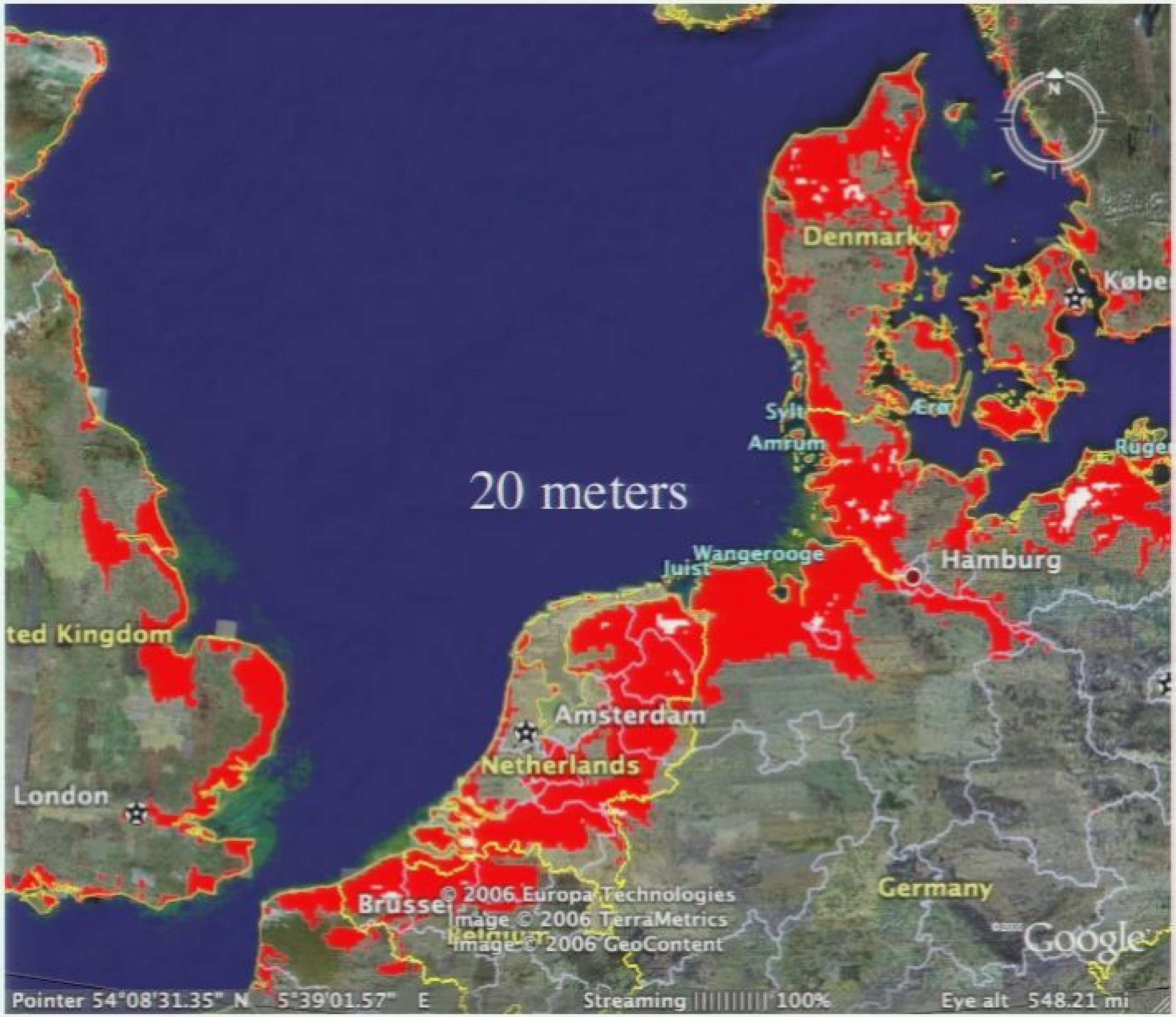


How long will it take for sea level to rise?

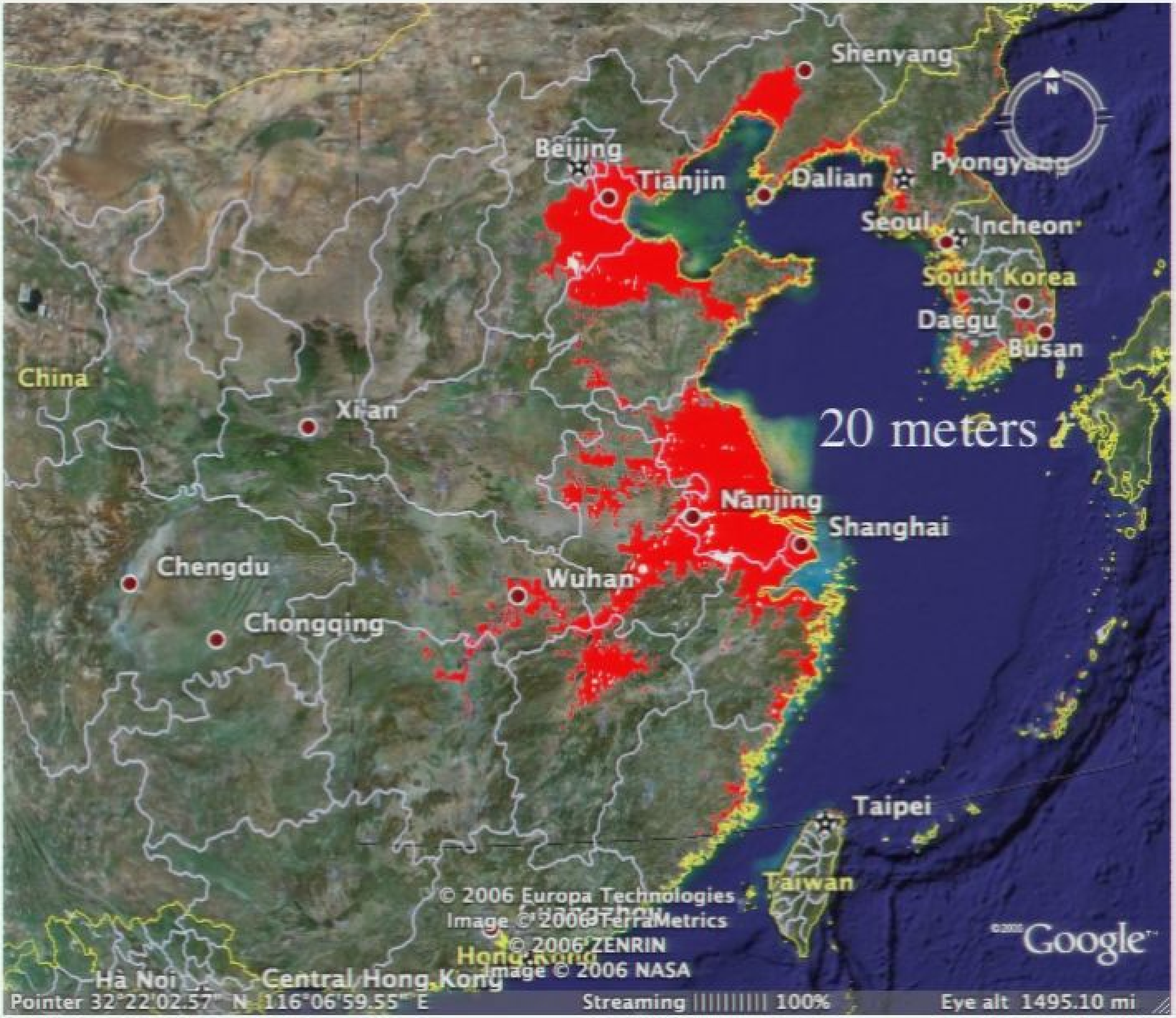
U.S. East and Gulf coasts



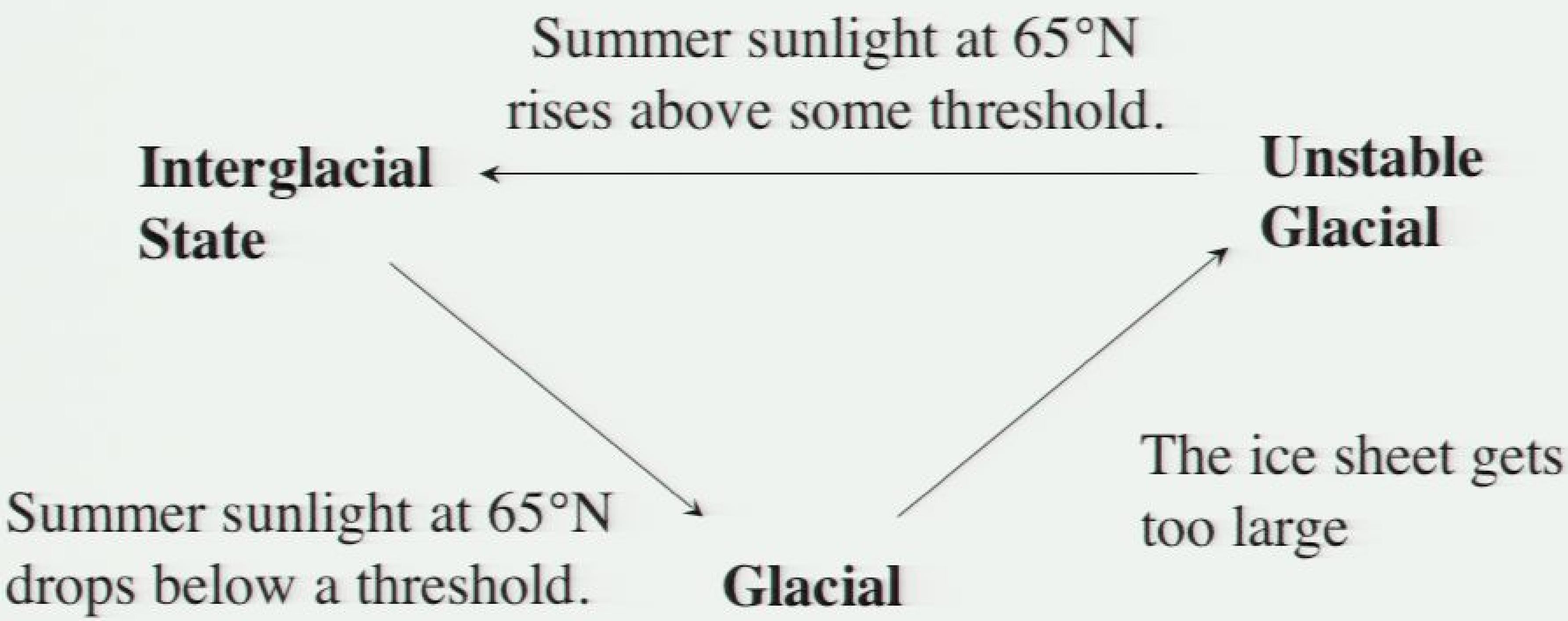
Low Countries of Europe



Yangtze Delta, China

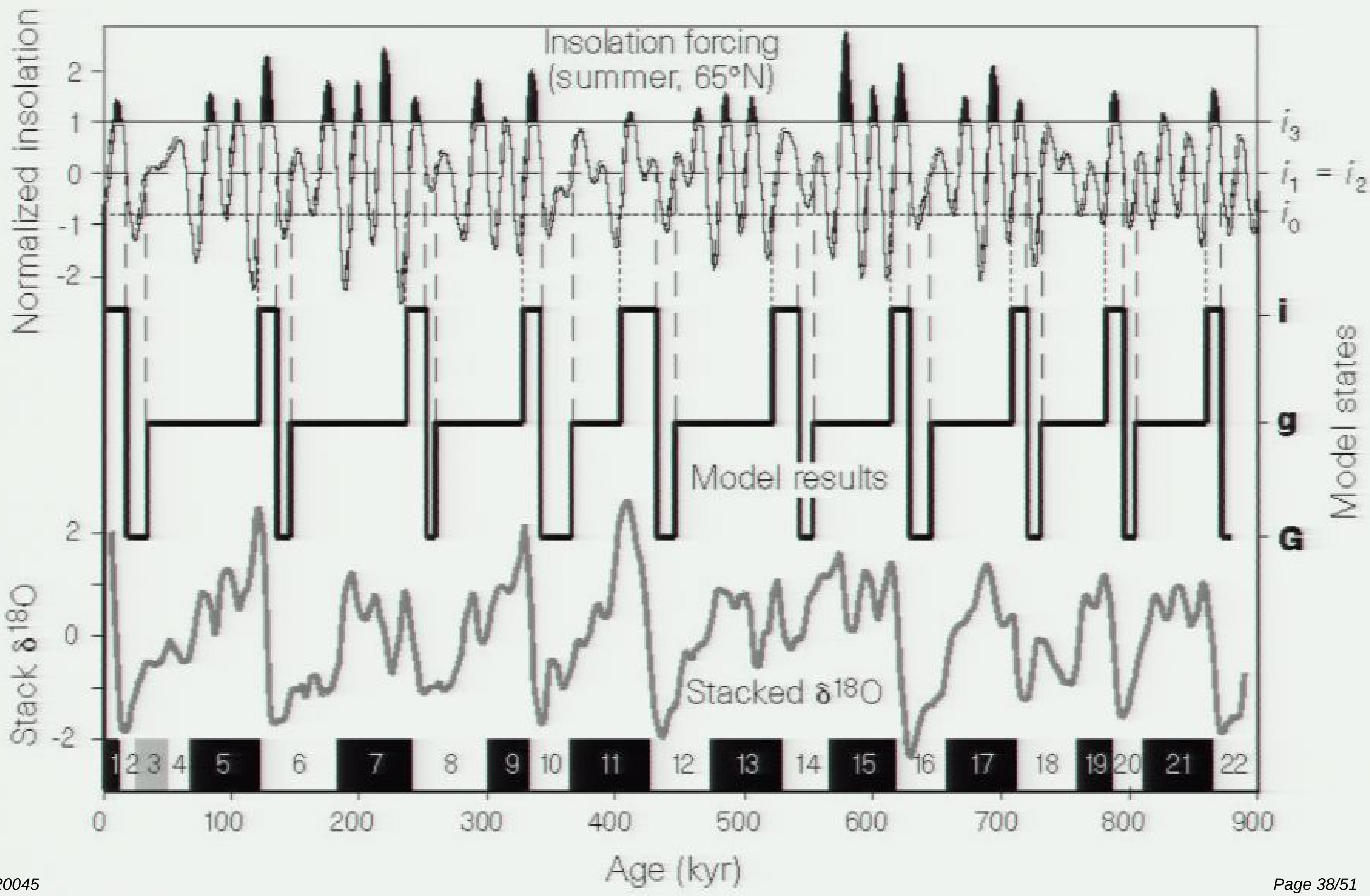


Fossil Fuel Carbon and Ice Ages



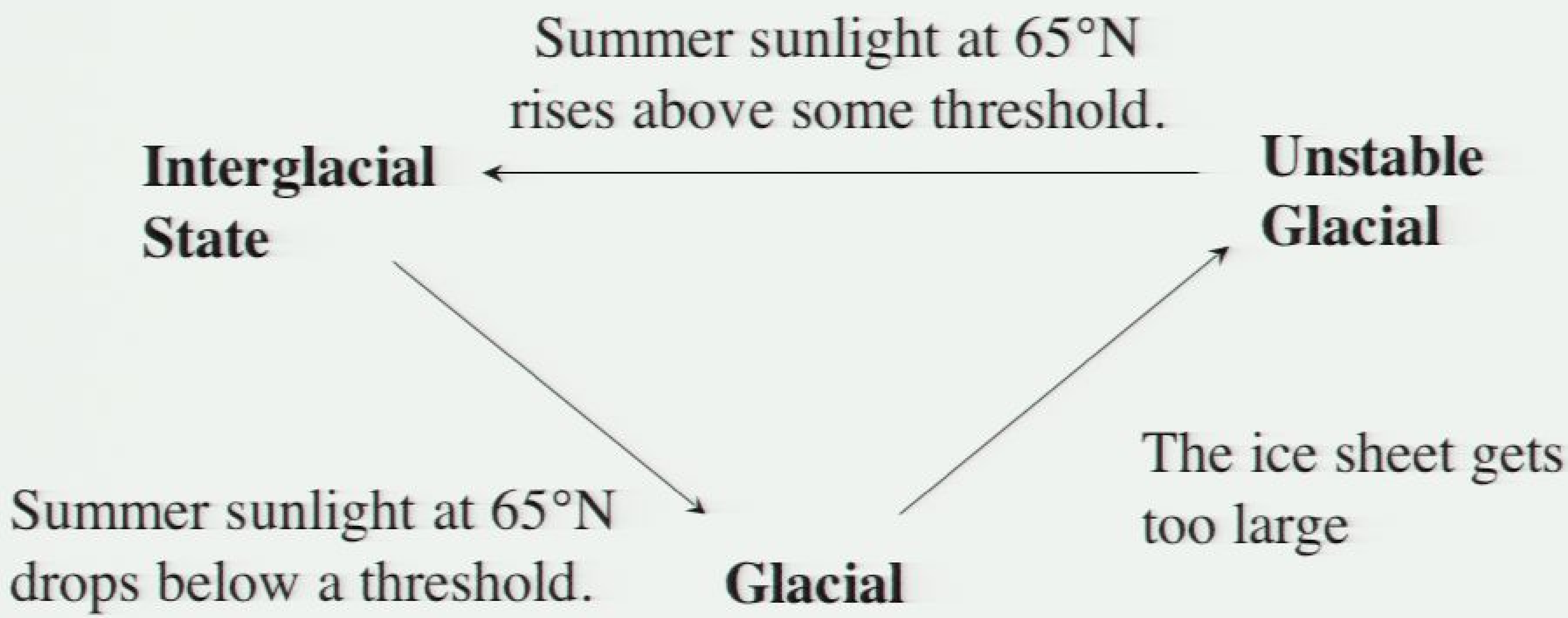
Paillard, 1998

35 kyr sticky switch model



Paillard, 1998

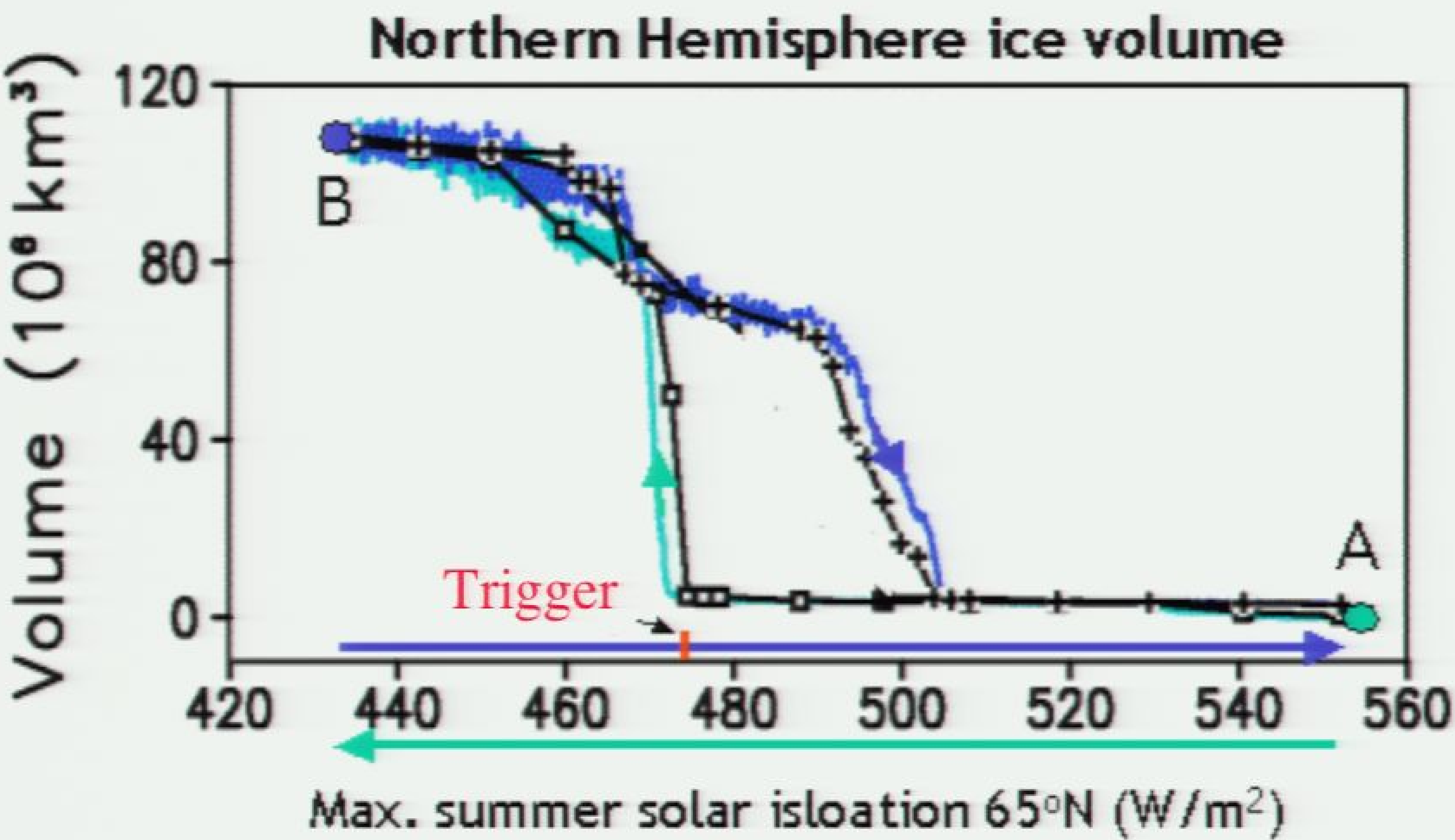
Fossil Fuel Carbon and Ice Ages

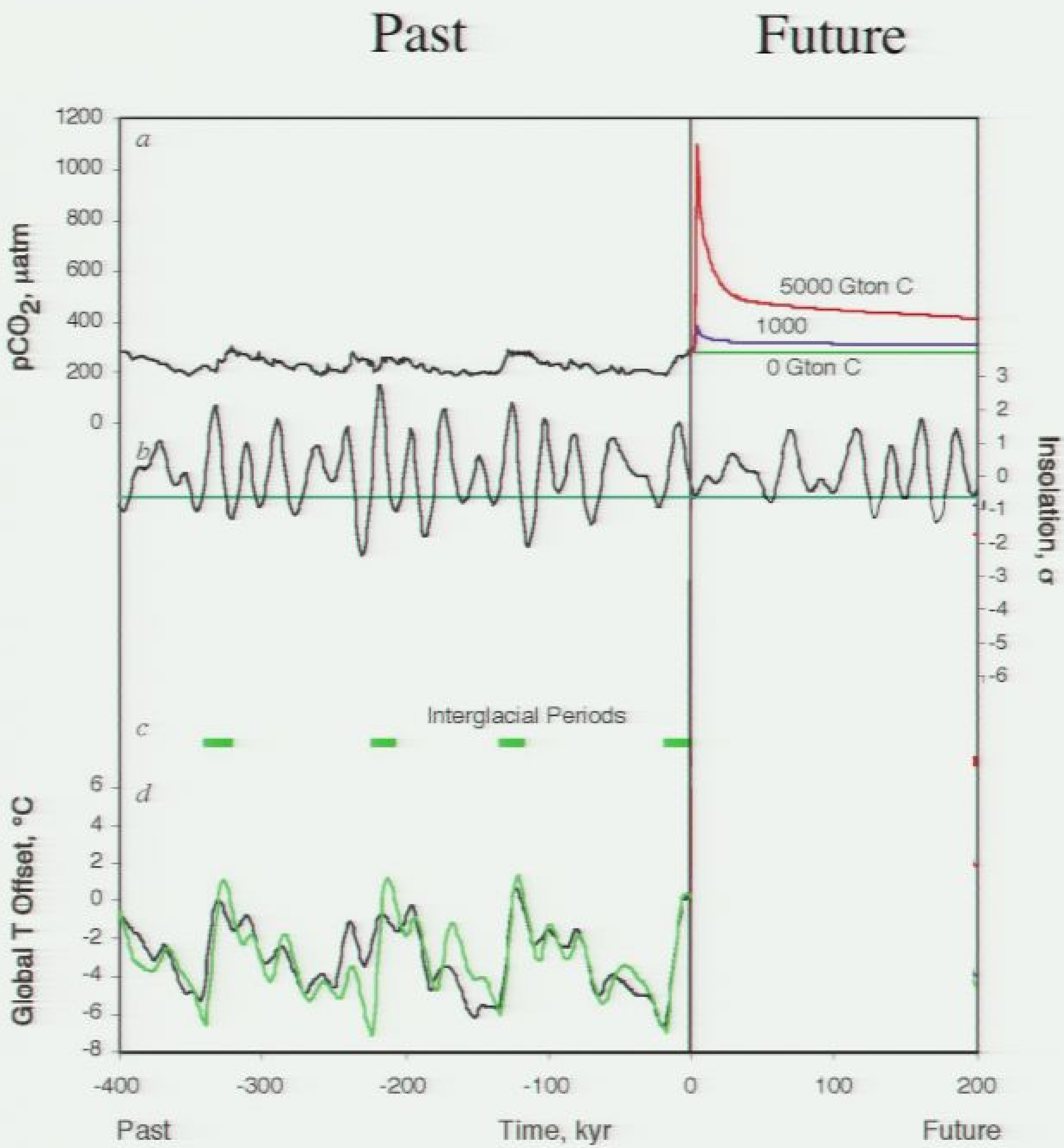


The Trigger

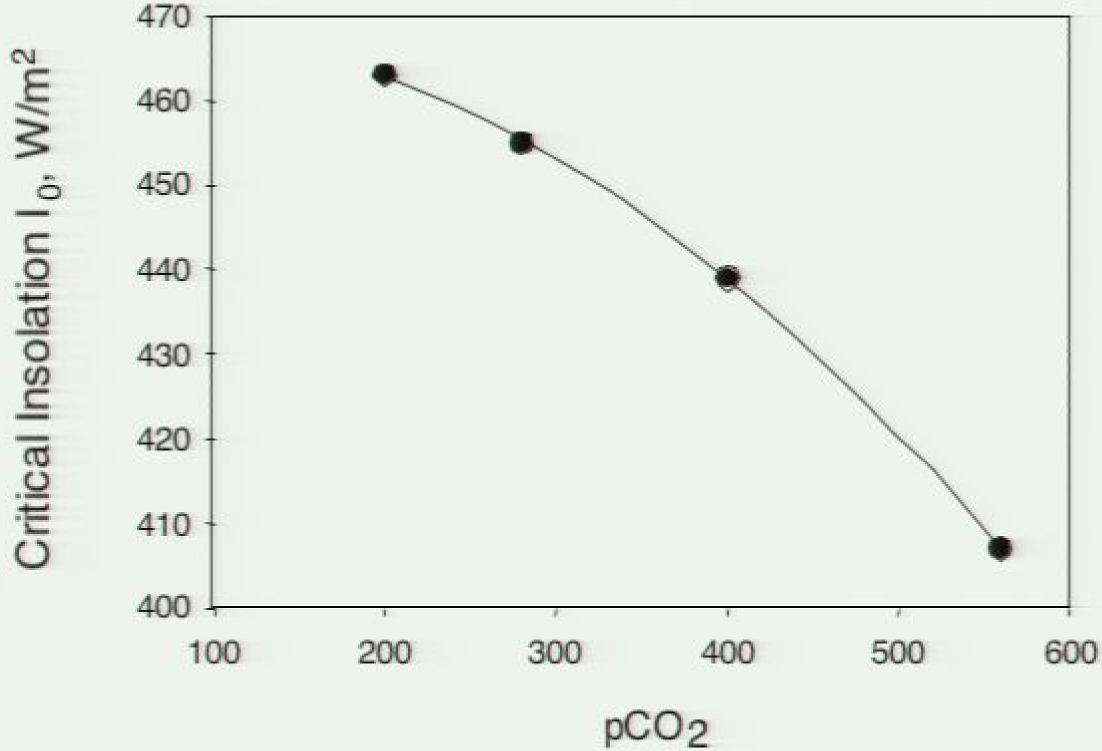
Paillard, 1998

CLIMBER Model Hysteresis



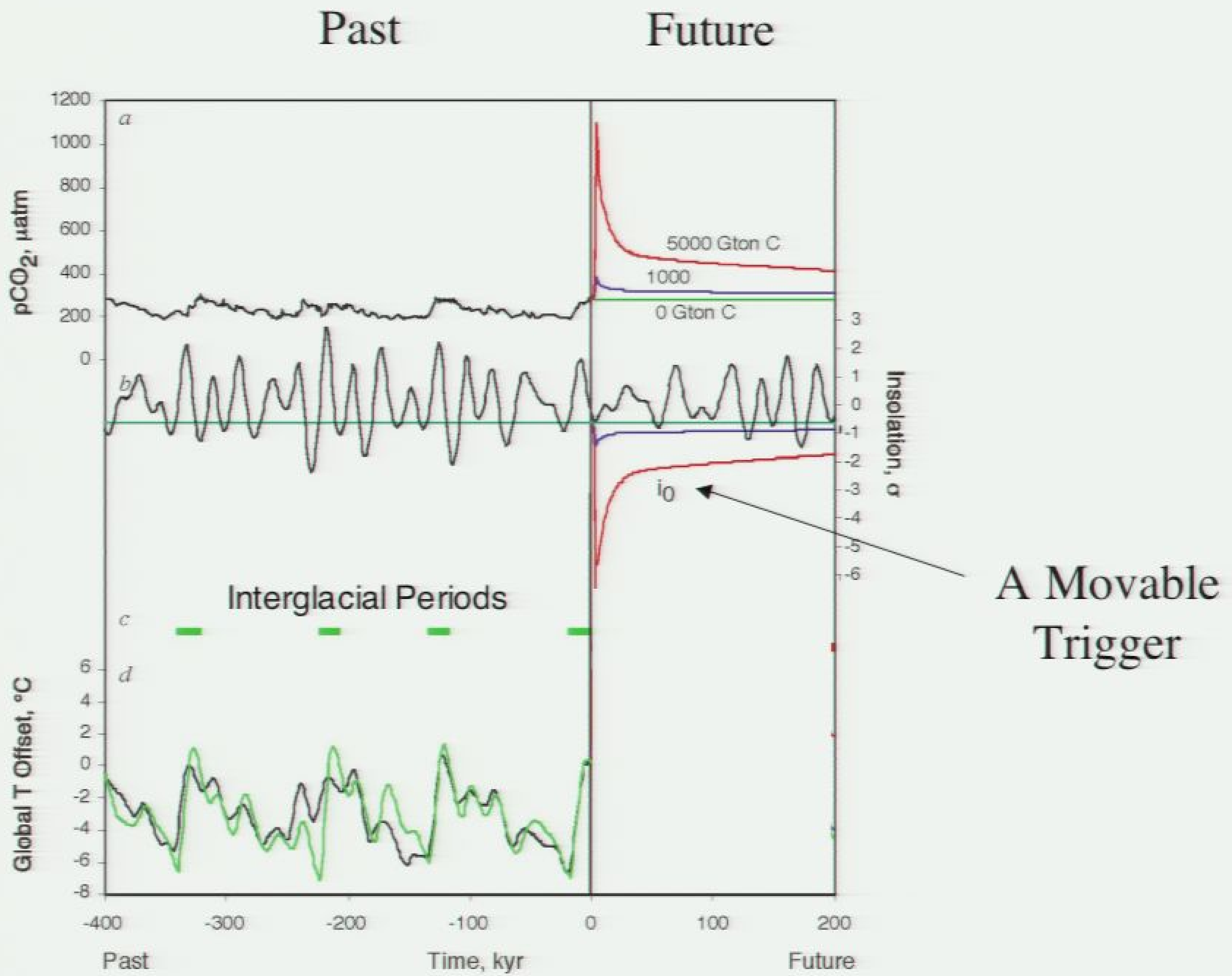


Archer and Ganopolski, 2005

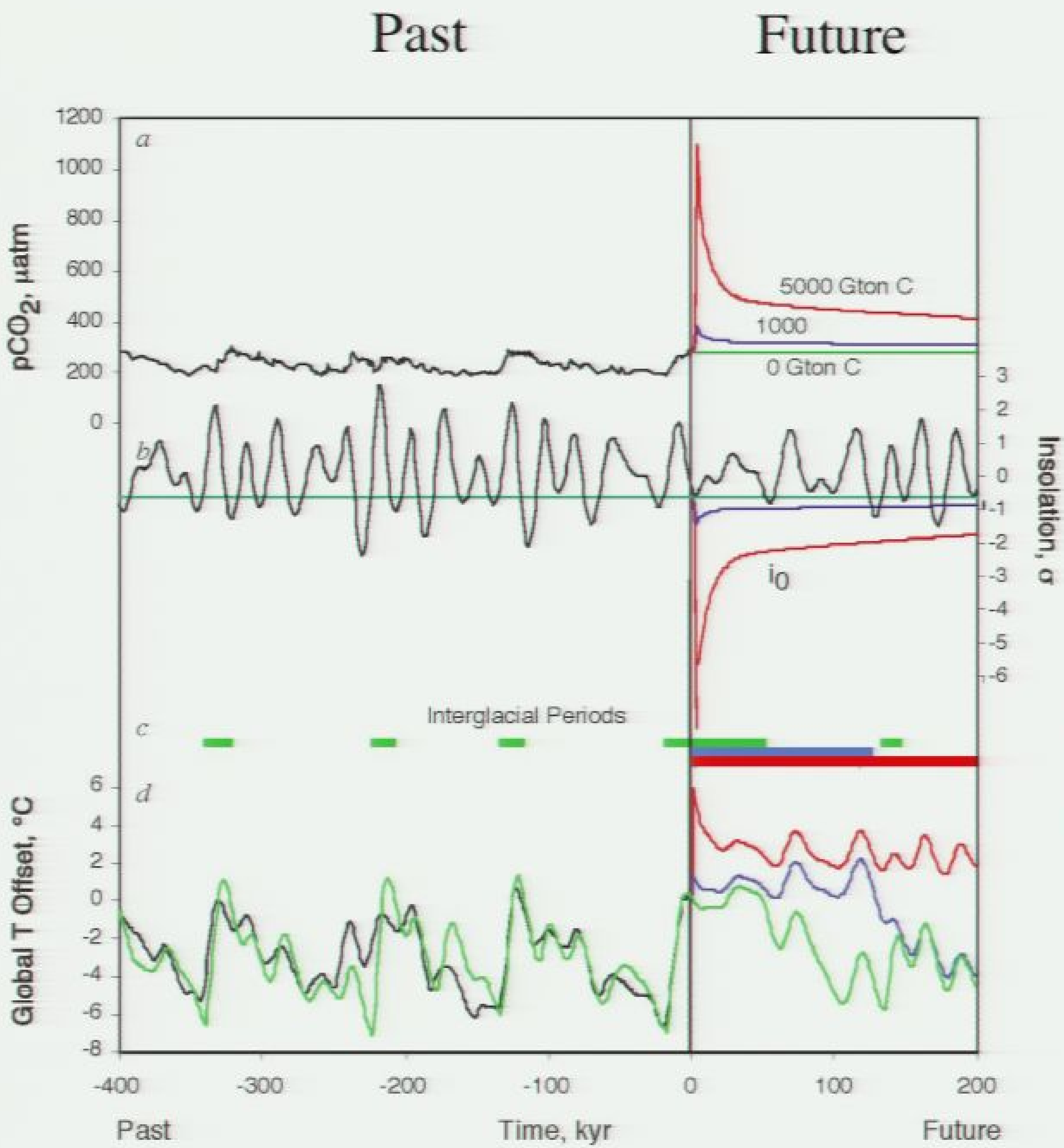


If CO_2 is higher, it takes a stronger sunlight change to trigger formation of an ice sheet.

Archer and Ganopolski, 2005



Archer and Ganopolski, 2005

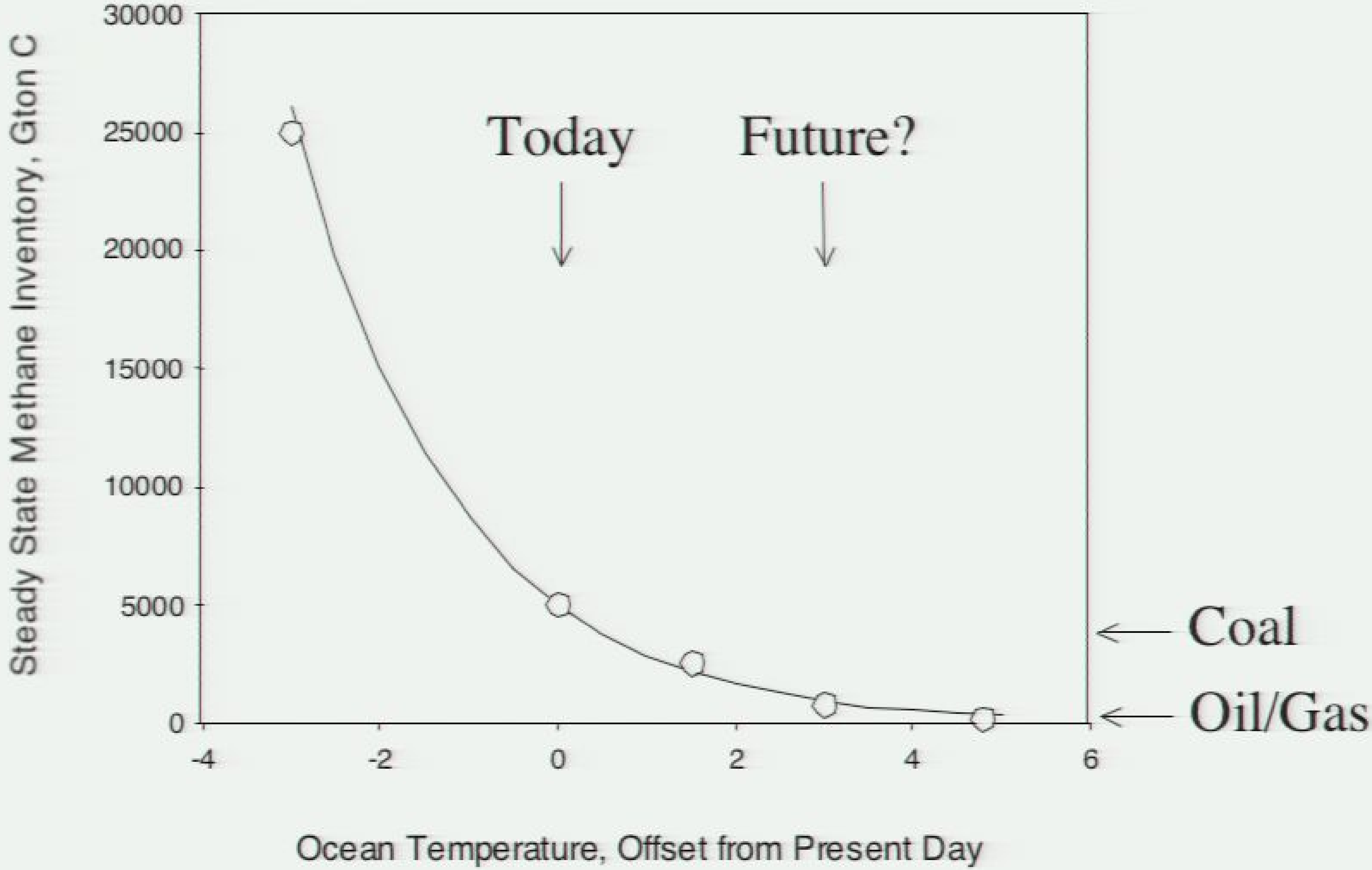


No Ice Age
for 500 Millennia

Archer and Ganopolski, 2005

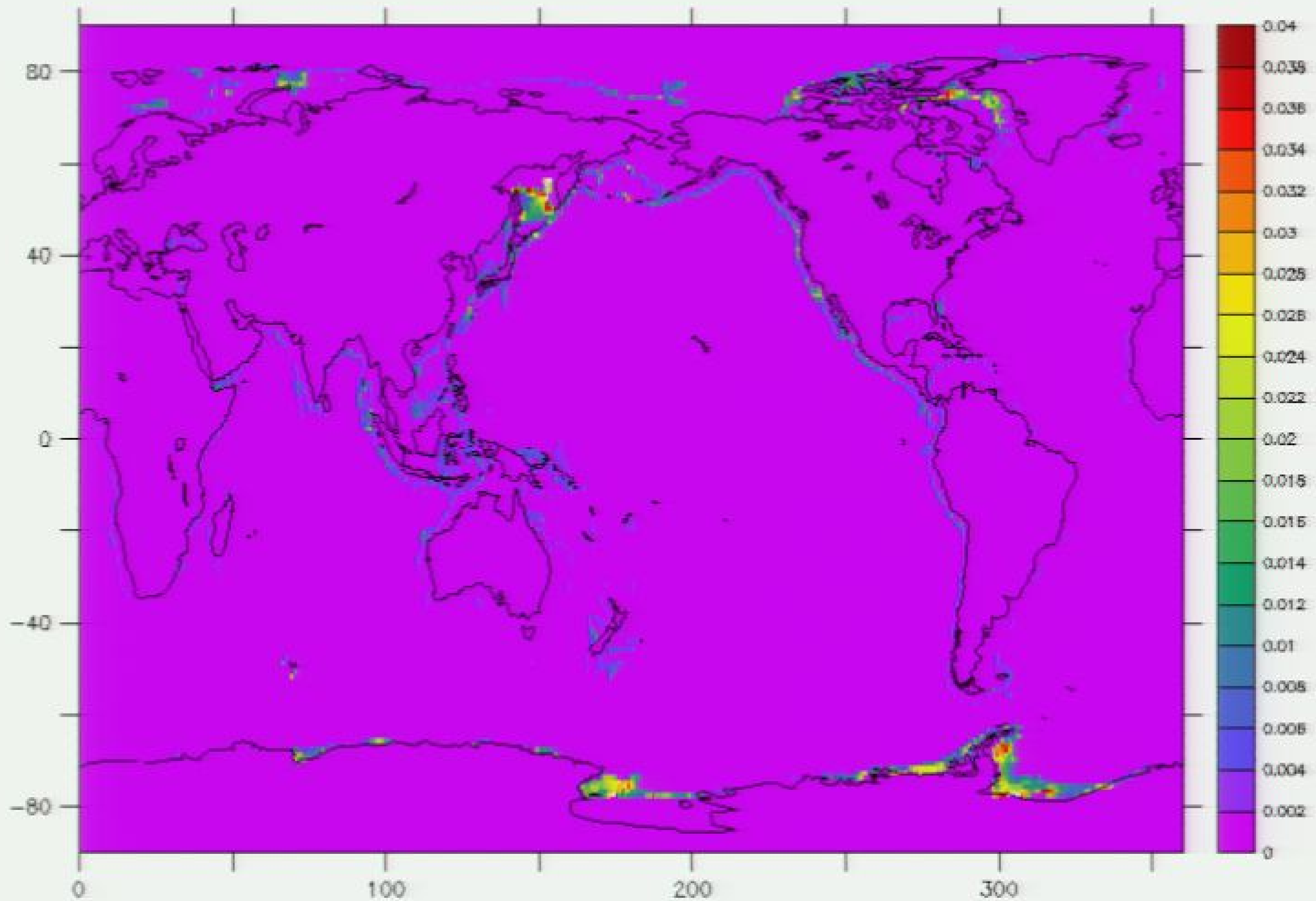
Methane Hydrates

Methane Hydrates

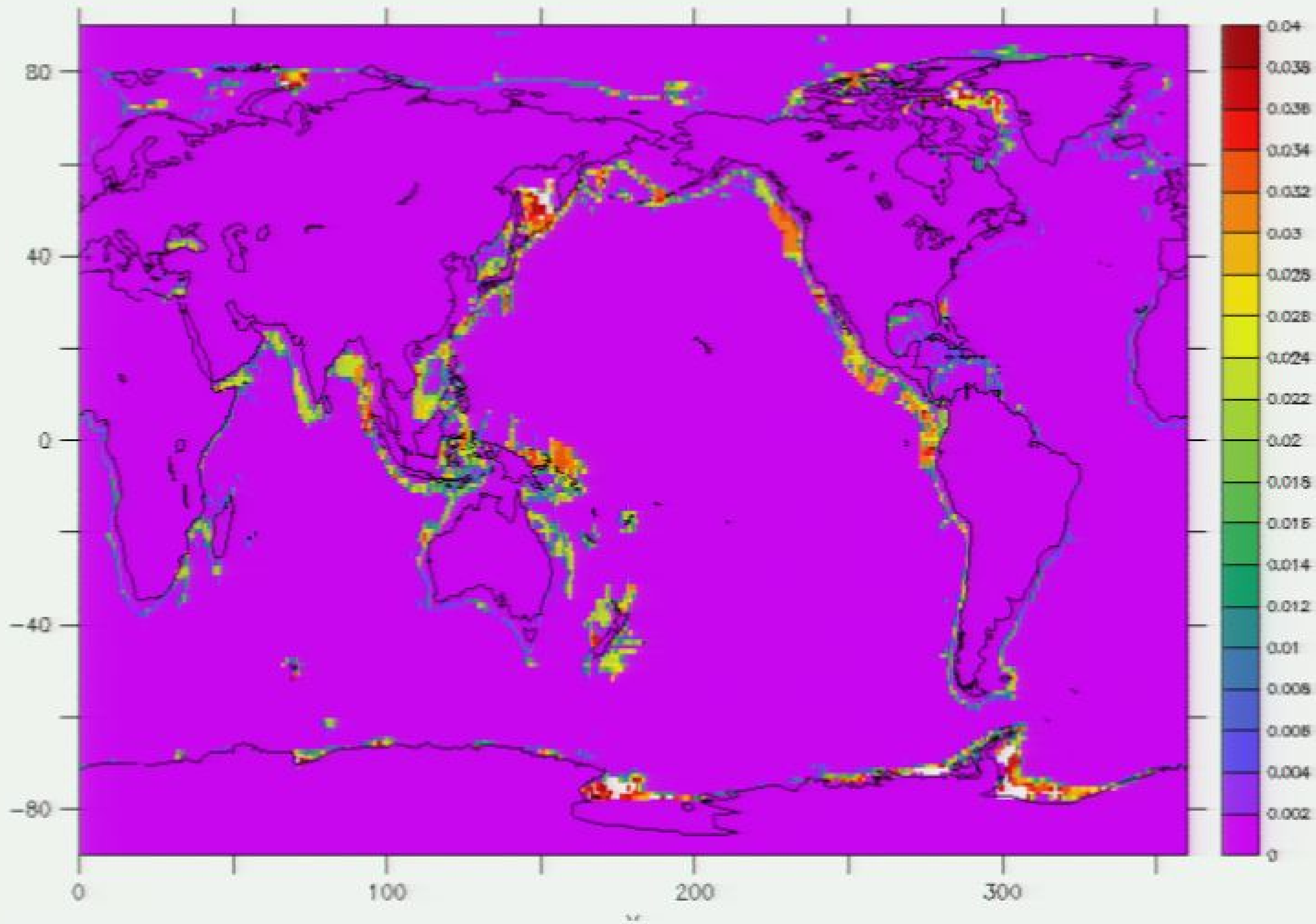


Buffett and Archer, 2005

Bubble Volume, %



Bubble volume upon melting, %



Hydrates bottom line

Probably won't catastrophically blow out in the coming century, because it takes a long time to warm the deep ocean and into the sediment.

On time scales of millennia and longer, the hydrates could release carbon to match our fossil fuel carbon release.

From Here to Eternity

The long lifetime of nuclear waste matters to people.

Why would the long lifetime of global warming
be any different?

What to do?

We have already emitted about 300 billion metric tons of carbon from fossil fuels and deforestation.

We could ultimately emit about 700 billion metric tons and just avoid a “dangerous climate change of 2° C.

The 400 billion metrics tons we haven’t released yet is about equivalent to the remaining oil and gas reservoirs. Just stop burning coal.