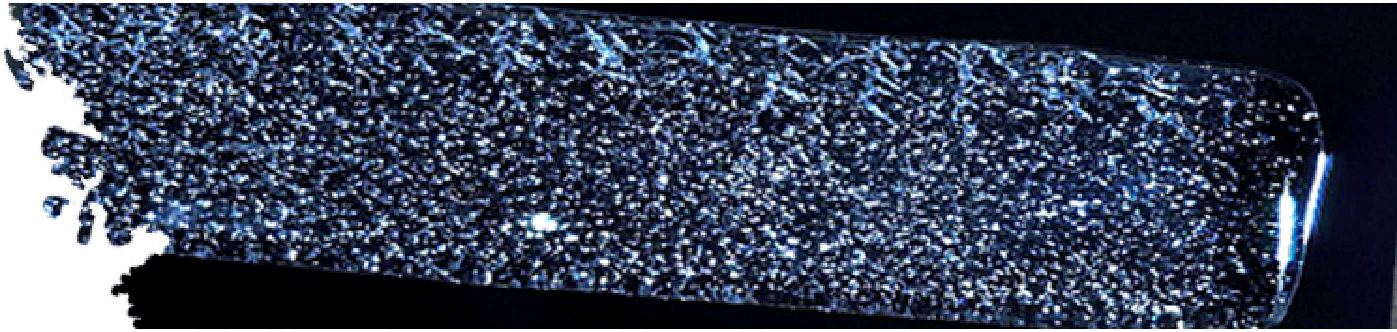

Greenhouse gases in the Earth system: a palaeoclimate perspective

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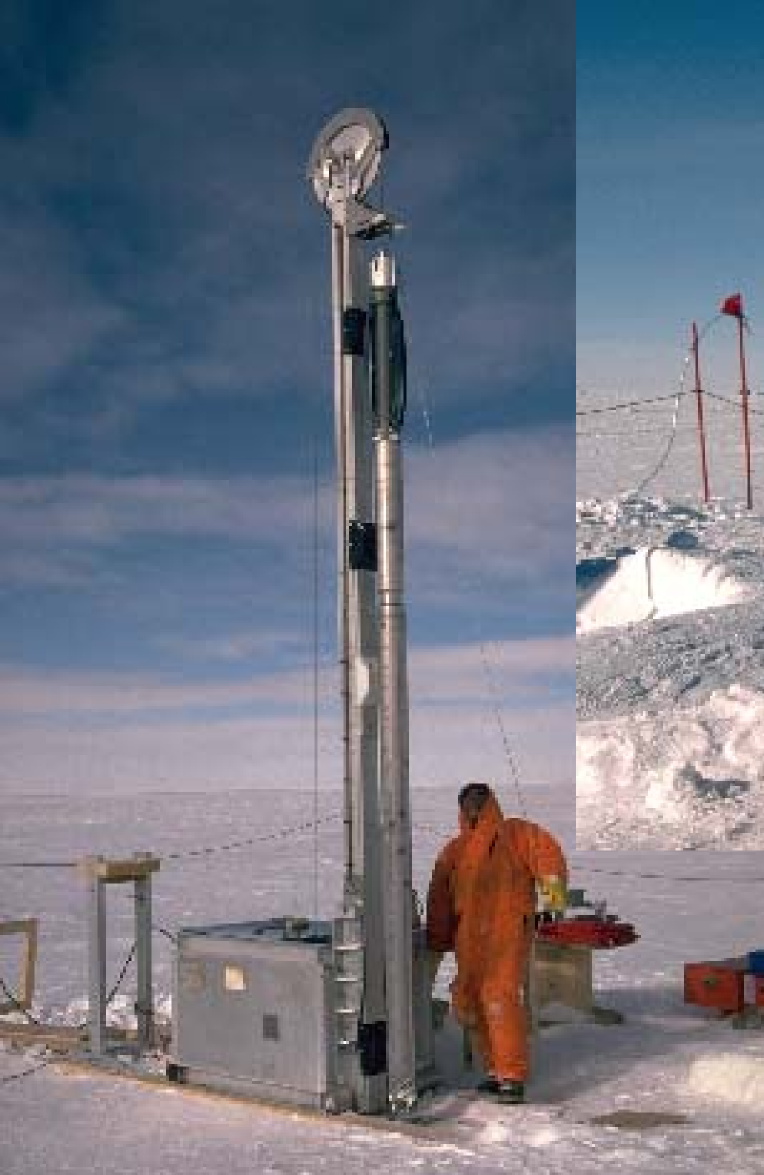
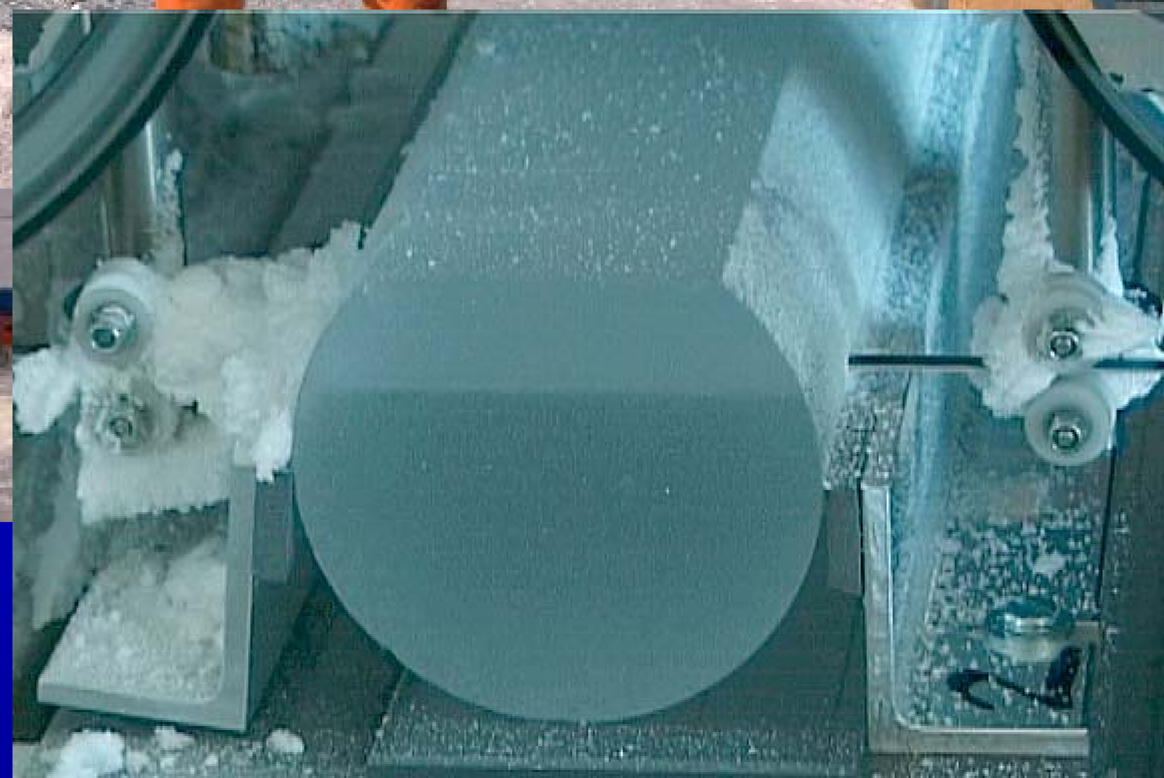
British Antarctic Survey

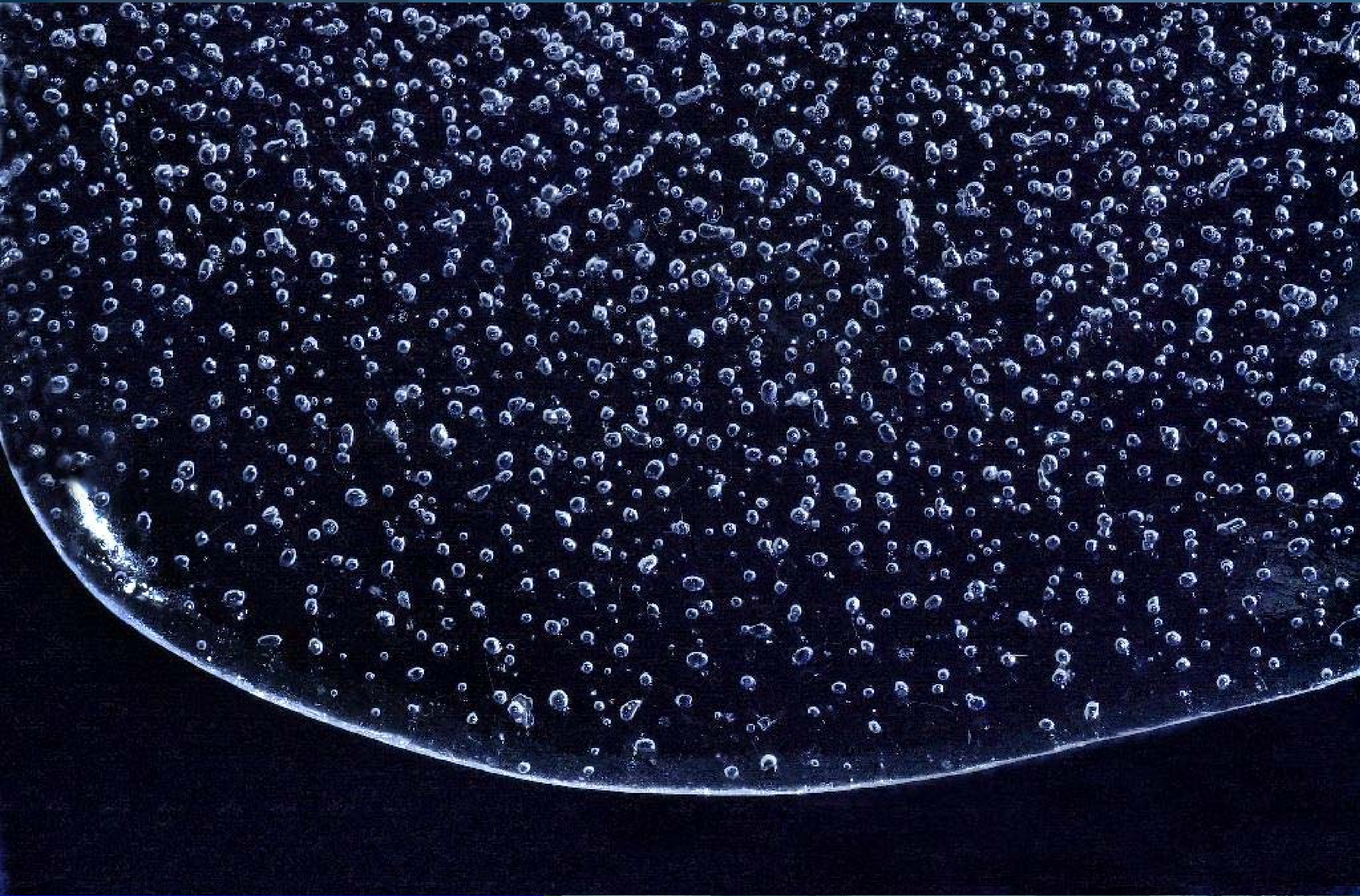
NATURAL ENVIRONMENT RESEARCH COUNCIL

Why palaeo greenhouse gases?

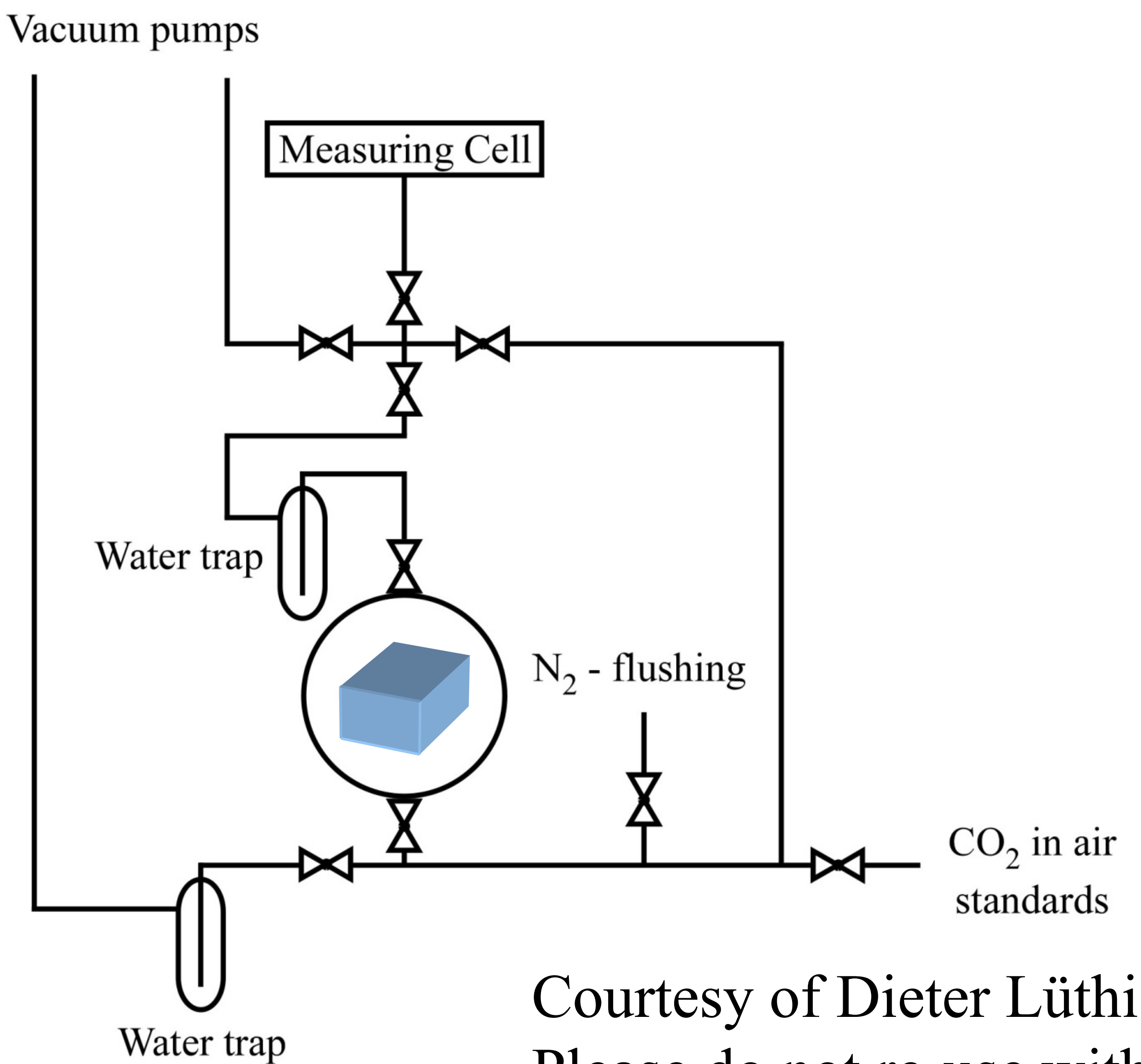
- What happened before regular atmospheric measurements started?
- How do recent changes compare with natural variability?
- Can we understand natural cycles – important if we want to underpin estimates of (future) feedbacks
- How did Earth respond to high CO_2 climates?
- Can we find analogues for large carbon releases in the past, to test effects and recovery?





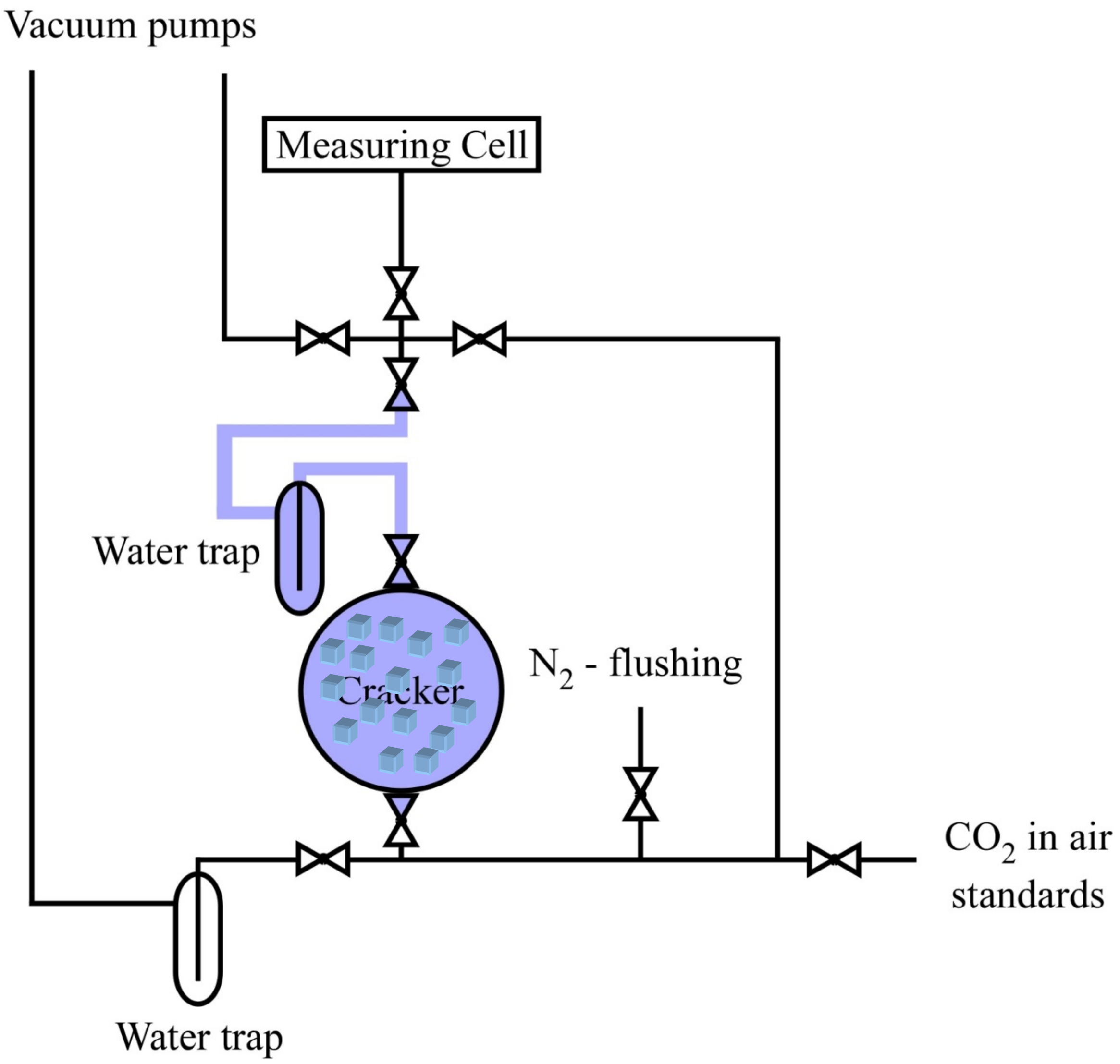


Cracker measurement procedure

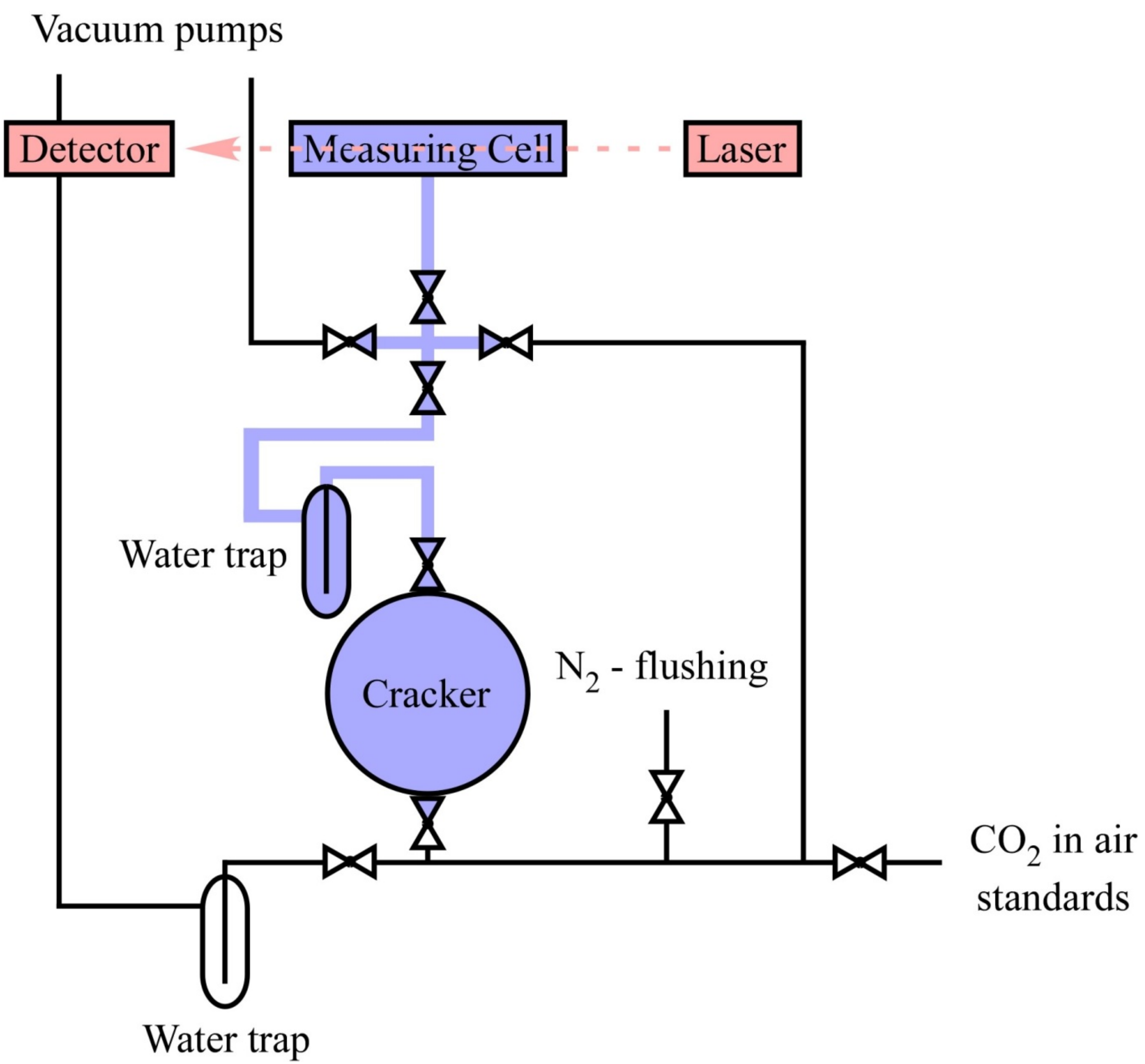


Courtesy of Dieter Lüthi (Bern)
Please do not re-use without permission

Cracker measurement procedure

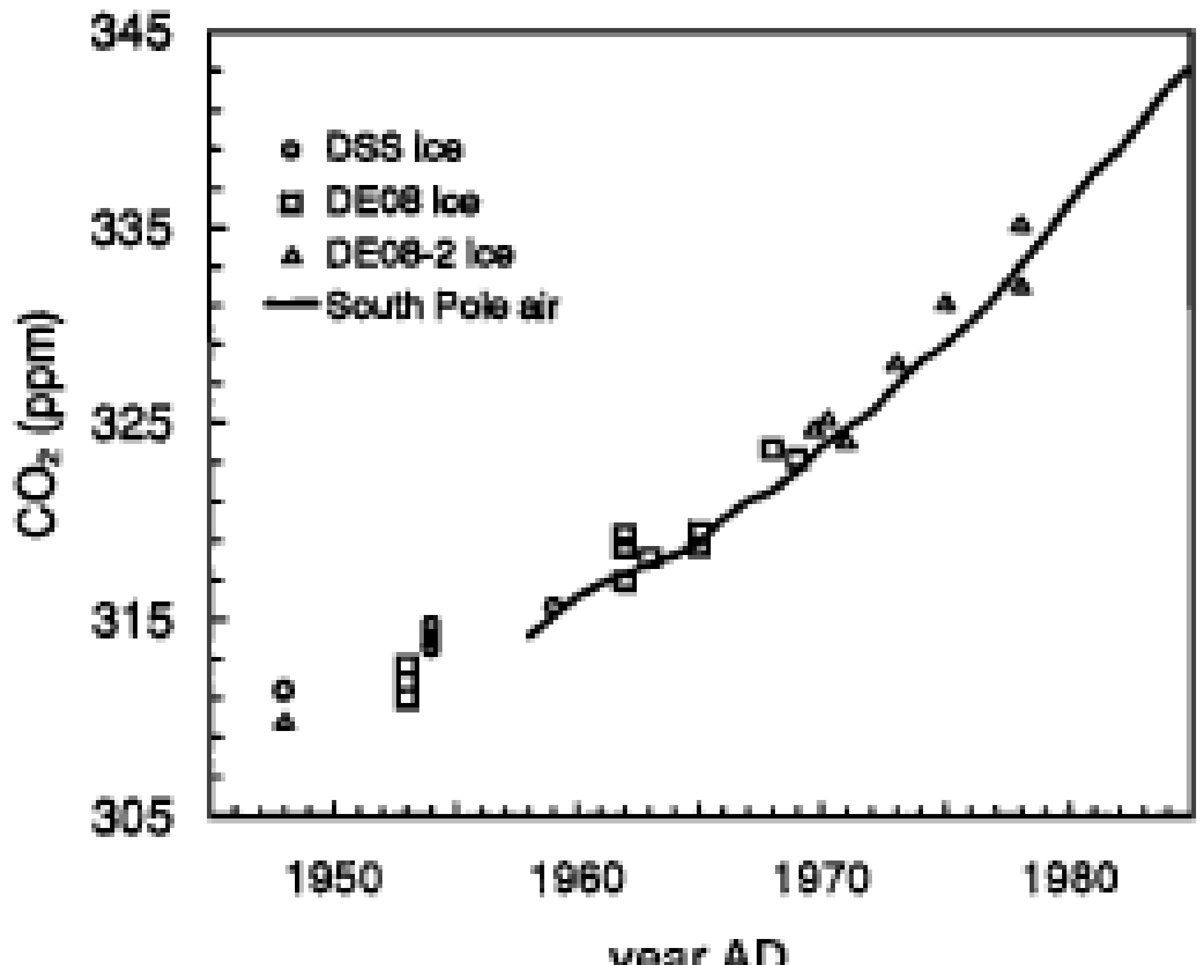


Cracker measurement procedure



(Note: other extraction procedures are also used)

Validating ice core measurements

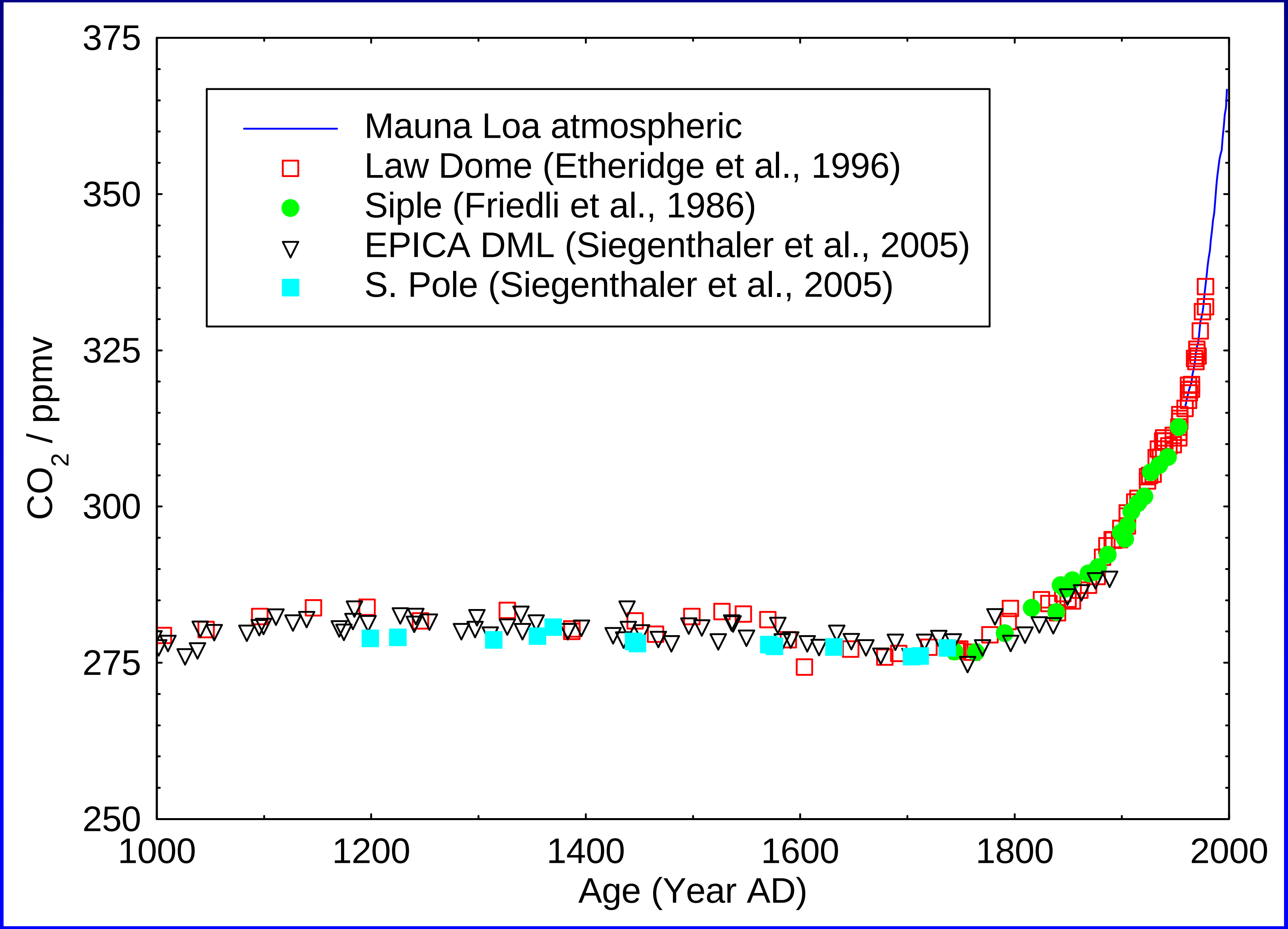


Etheridge et al (1996), JGR 101, 4123

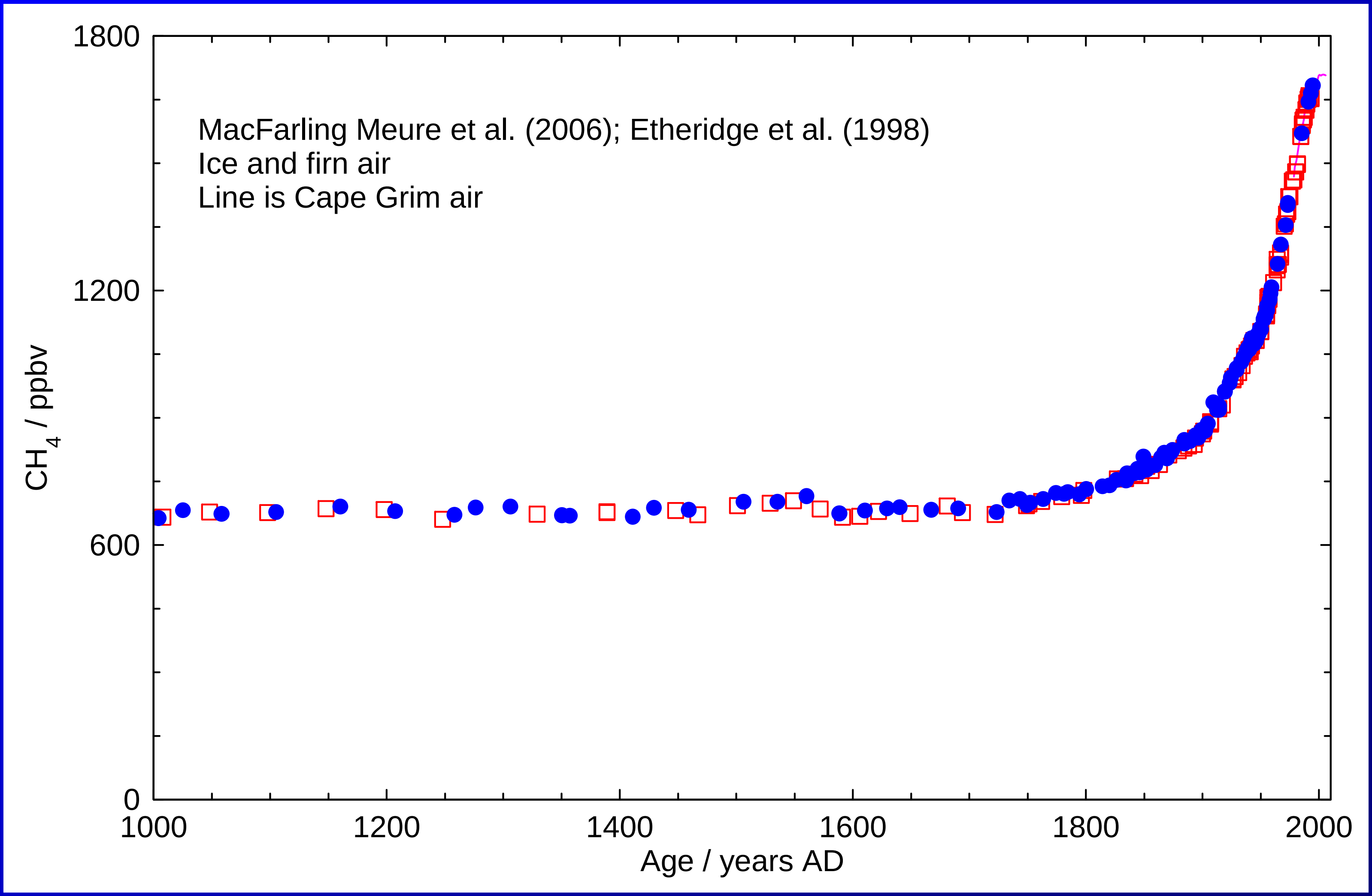
The basic argument of greenhouse warming

- Physics tells us that increasing the concentrations of greenhouse gases traps heat and requires climate on average to warm
- The concentration of major greenhouse gases has increased significantly due to human activities

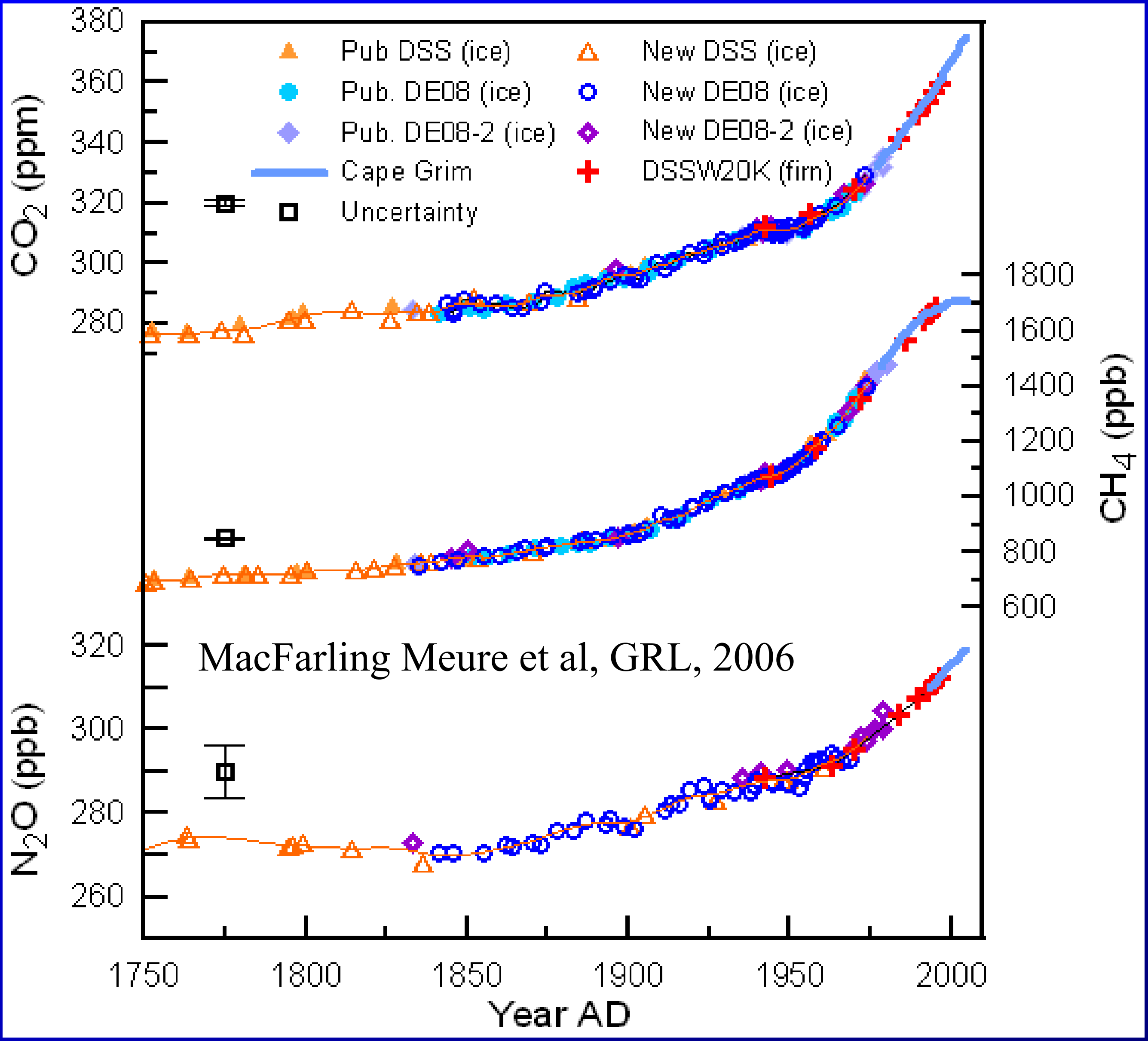
Recent past – CO_2



Recent past - methane



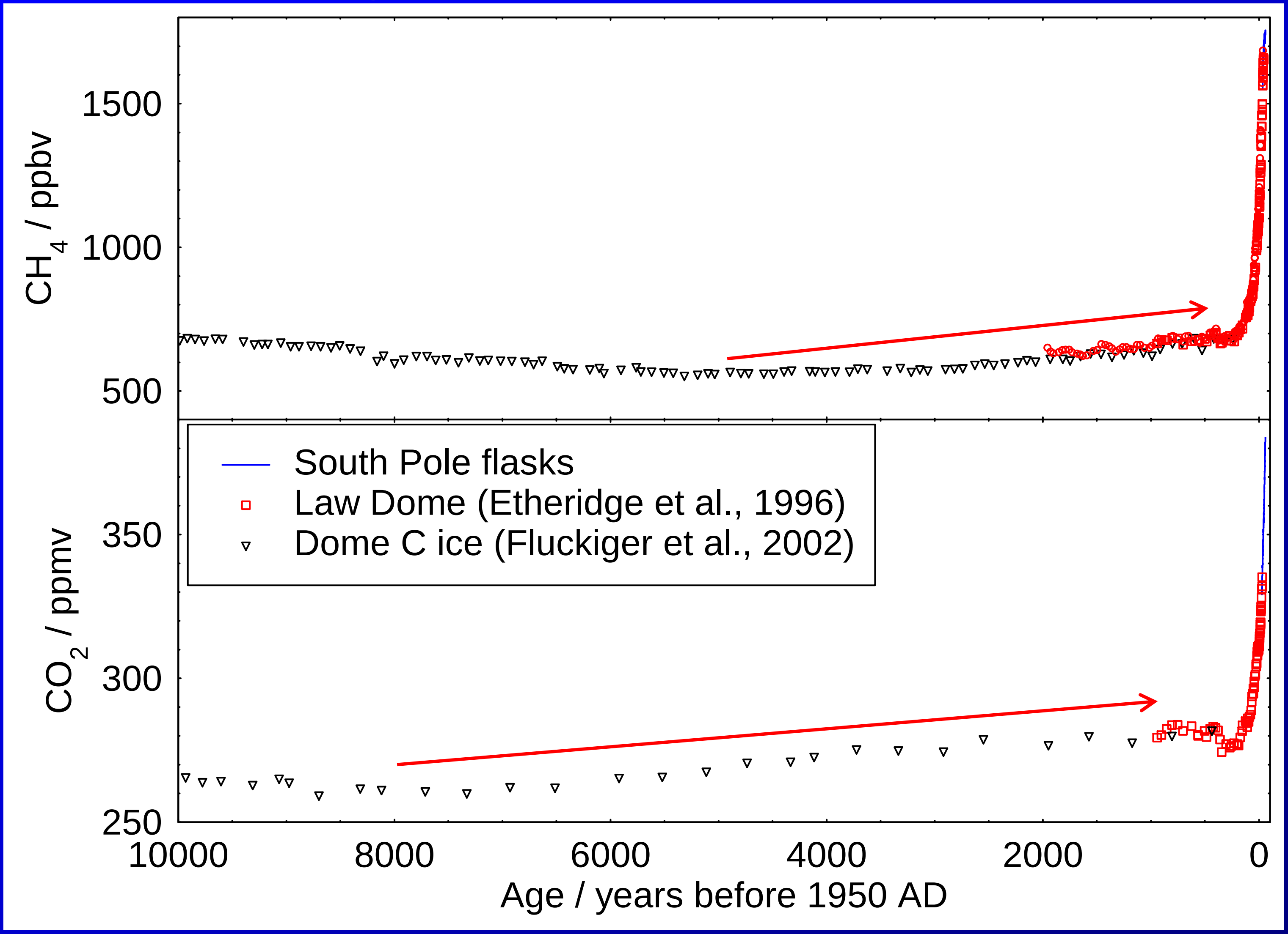
The atmosphere over the past 250 years



Greenhouse gases

Gas	Pre-industrial	Present-day
CO_2	275-284 ppmv	388 ppmv
CH_4	~750 ppbv	~1800 ppbv
N_2O	~270 ppbv	322 ppbv

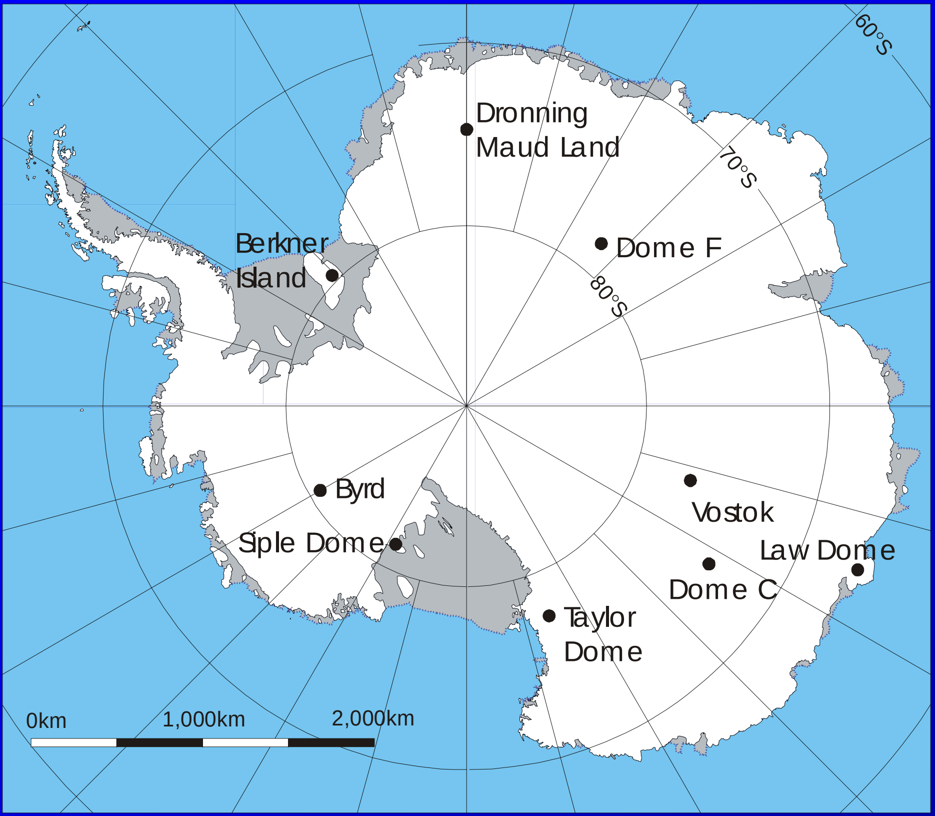
Greenhouse gases over the Holocene (10 kyr)



Slow/small increase: natural or anthropogenic?

Ruddiman 2003 (Clim. Change, 61, 261-293)

European Project for Ice Coring in Antarctica (EPICA)

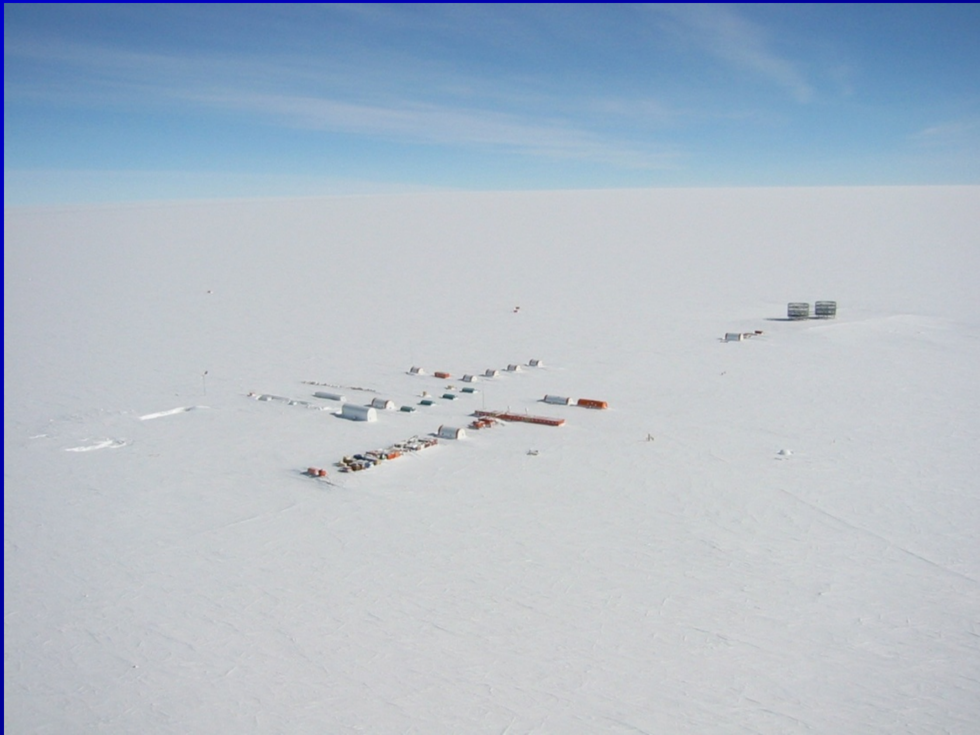


Dome C

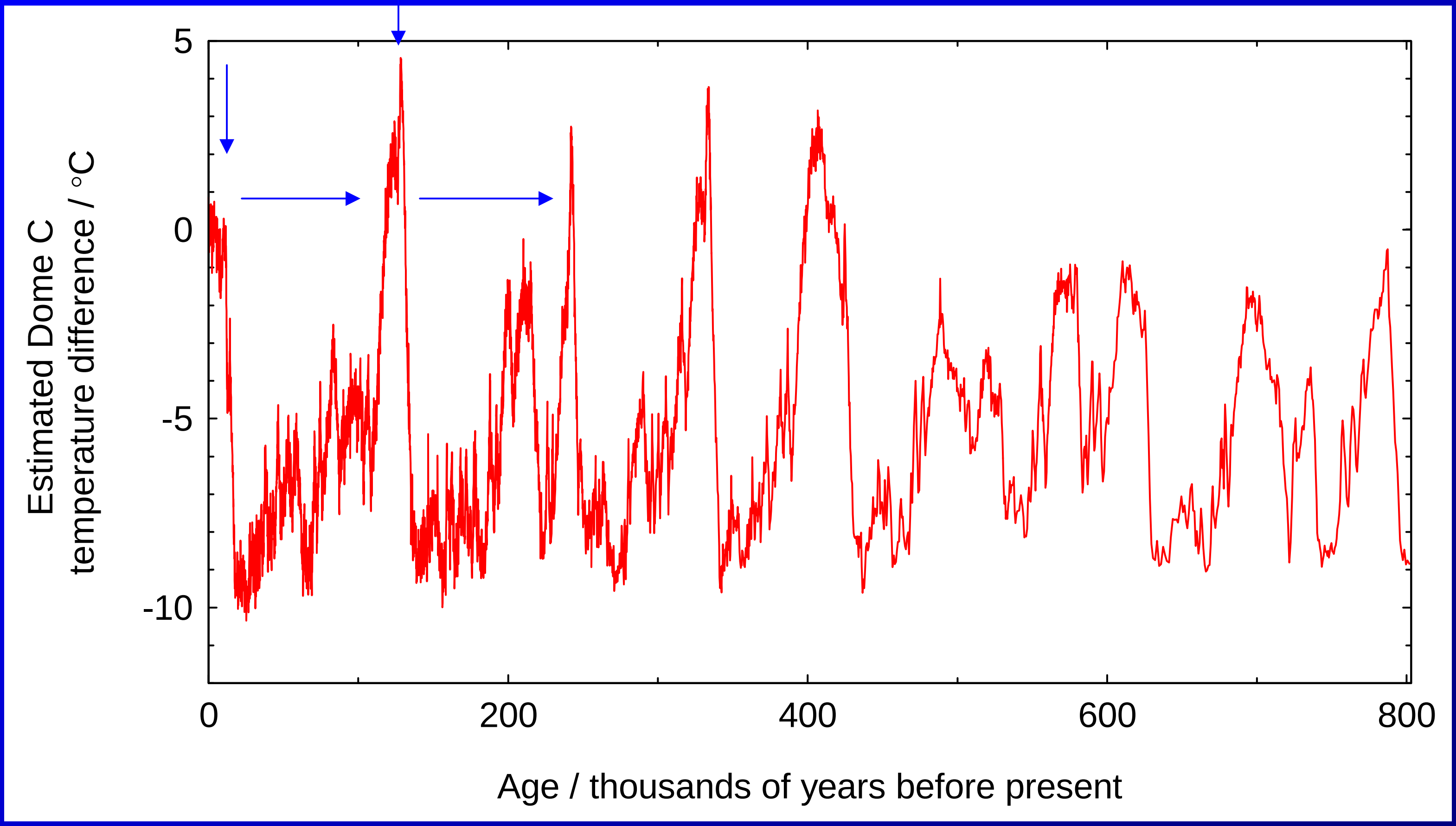
75ºS; 3233 m asl

Mean T:-54.5ºC

Core to 3270 m

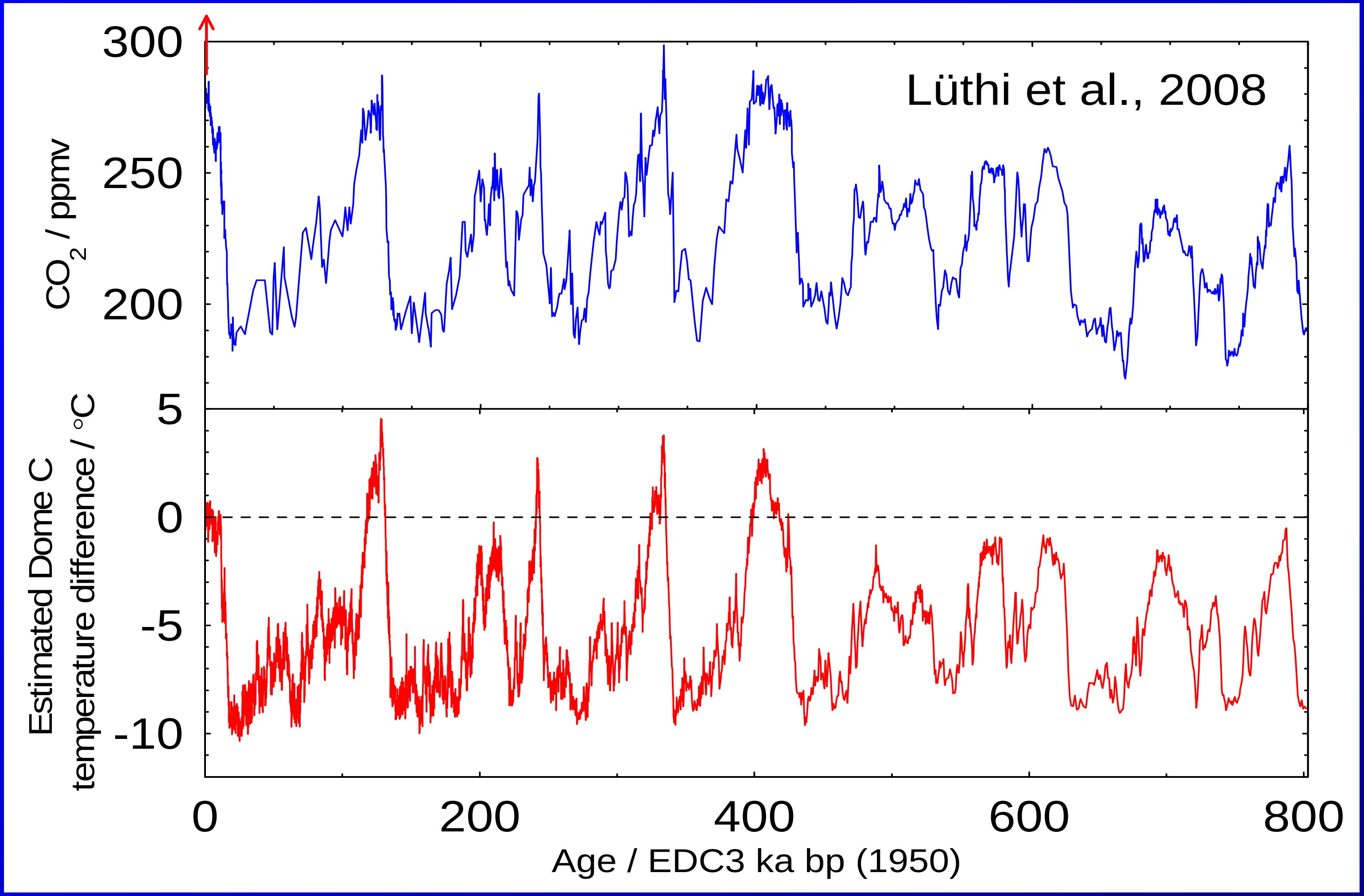


Estimated Antarctic temperature (based on water isotopes)

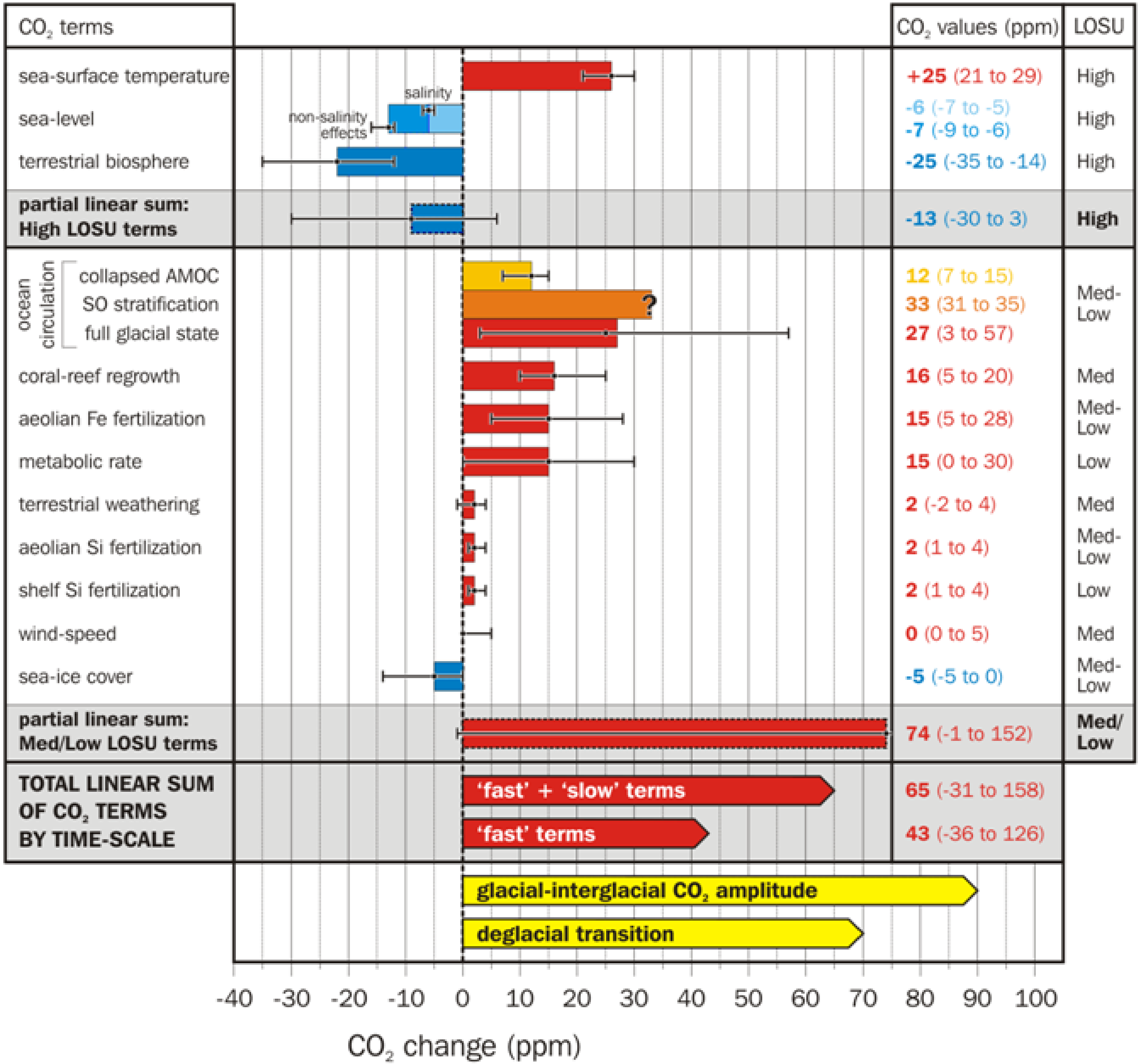


EPICA Community Members, *Nature*, *429*, 623-628, 2004;
Jouzel et al., Science, 2007

What does CO_2 do in a changing climate?

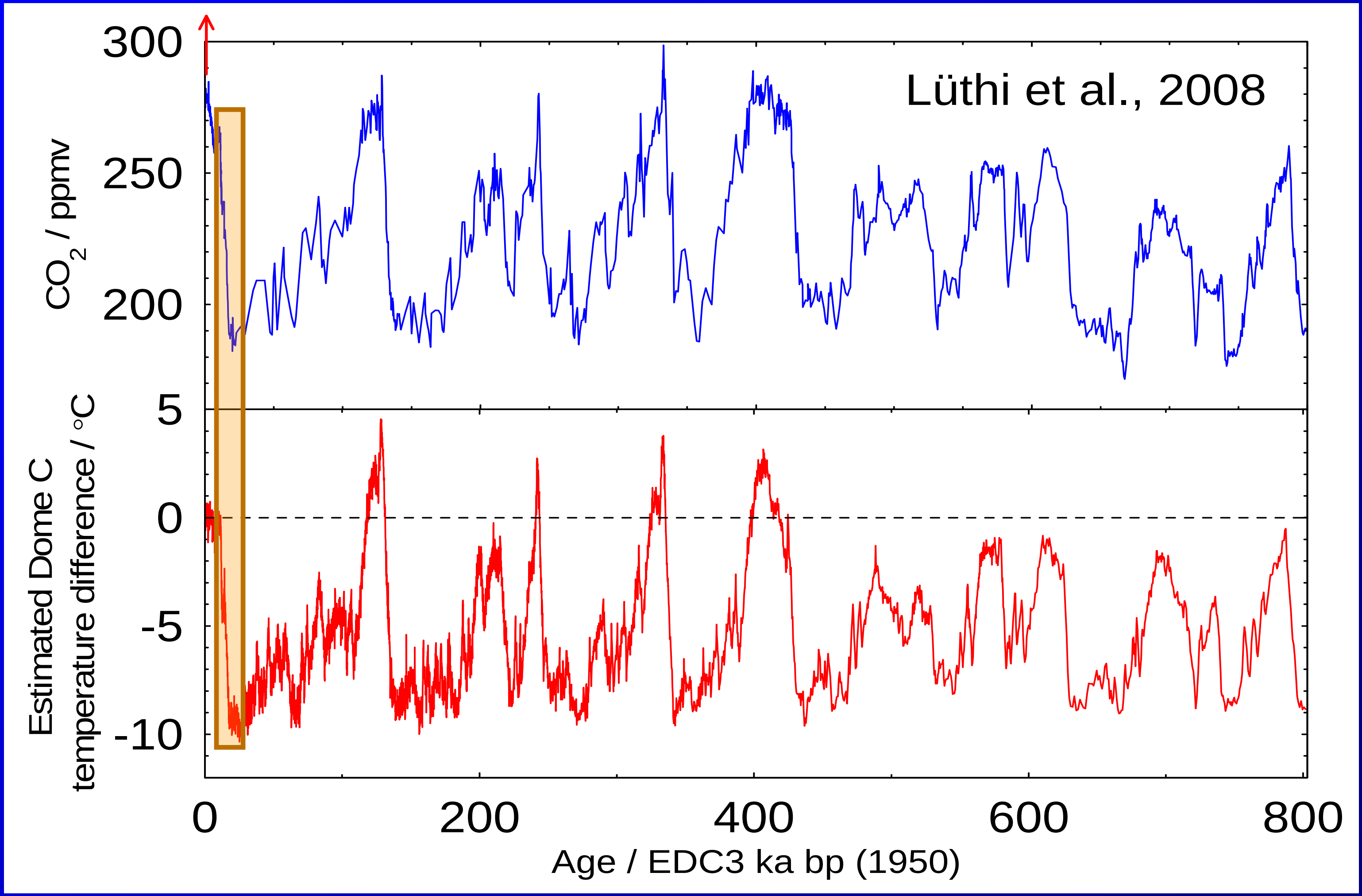


- CO_2 responsible for 30-50% of the glacial-interglacial warming
- probably controlled mainly through processes in the Southern Ocean



Estimates courtesy of Andy Ridgwell (see Kohfeld and Ridgwell AGU for more details)

CO_2 / climate phasing

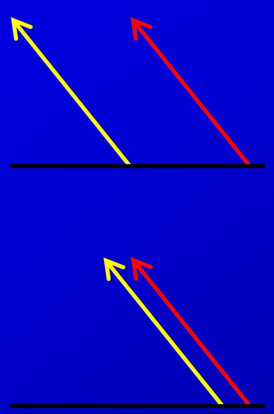


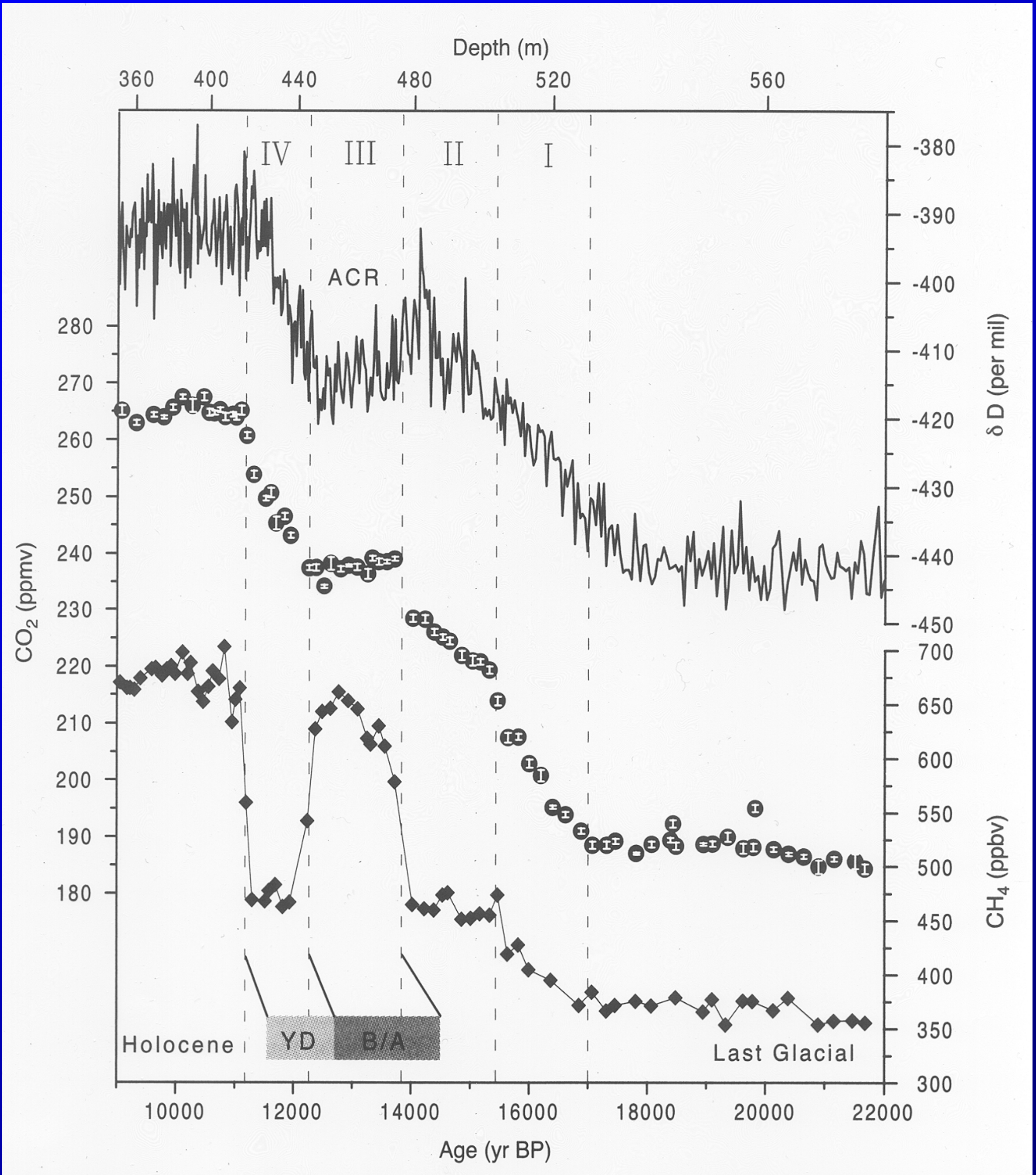
Dome C detailed CO_2

Monnin et al (2001)

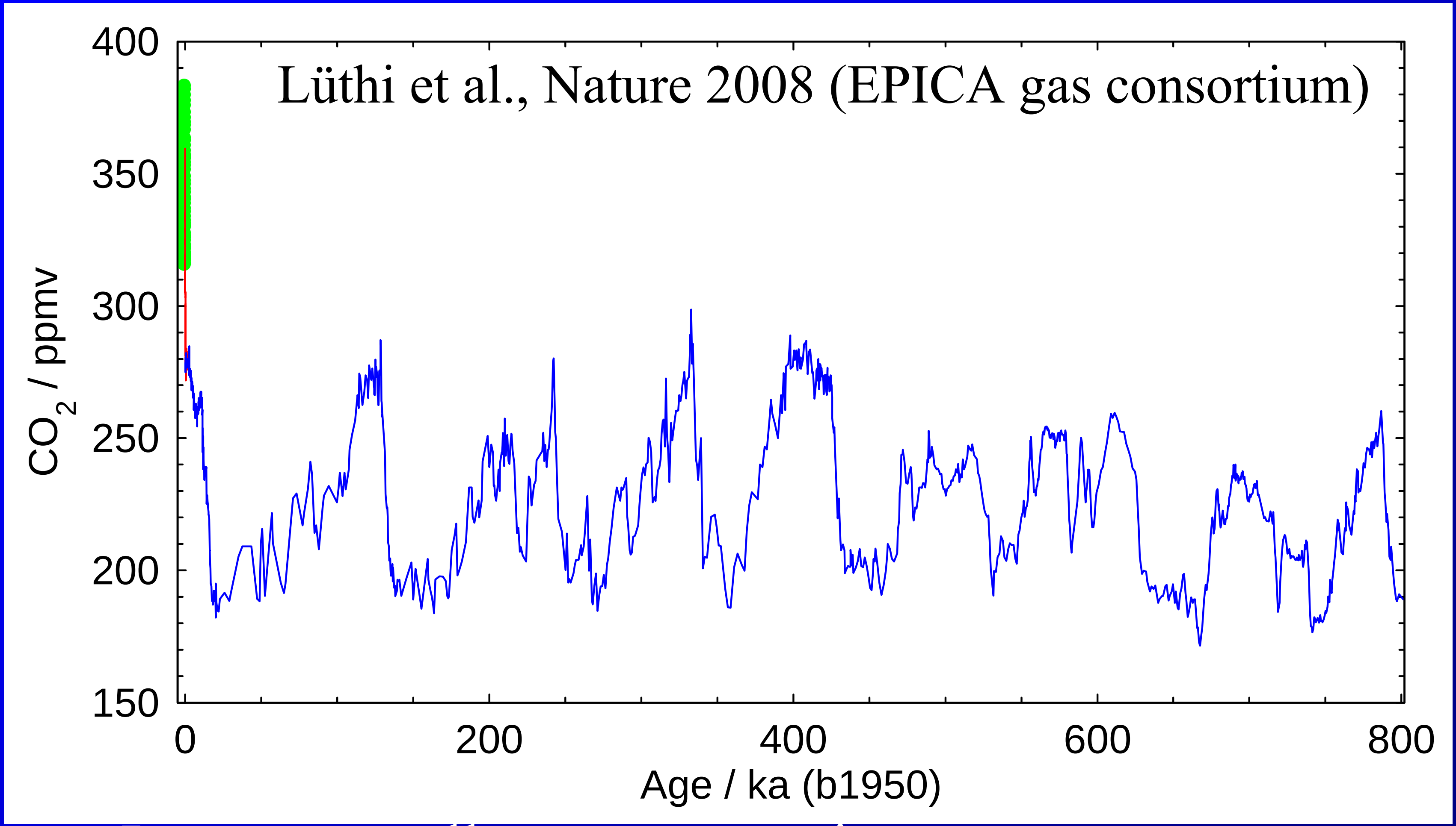
Science 291, 112-114

Phasing is consistent with CO_2 as an amplifier



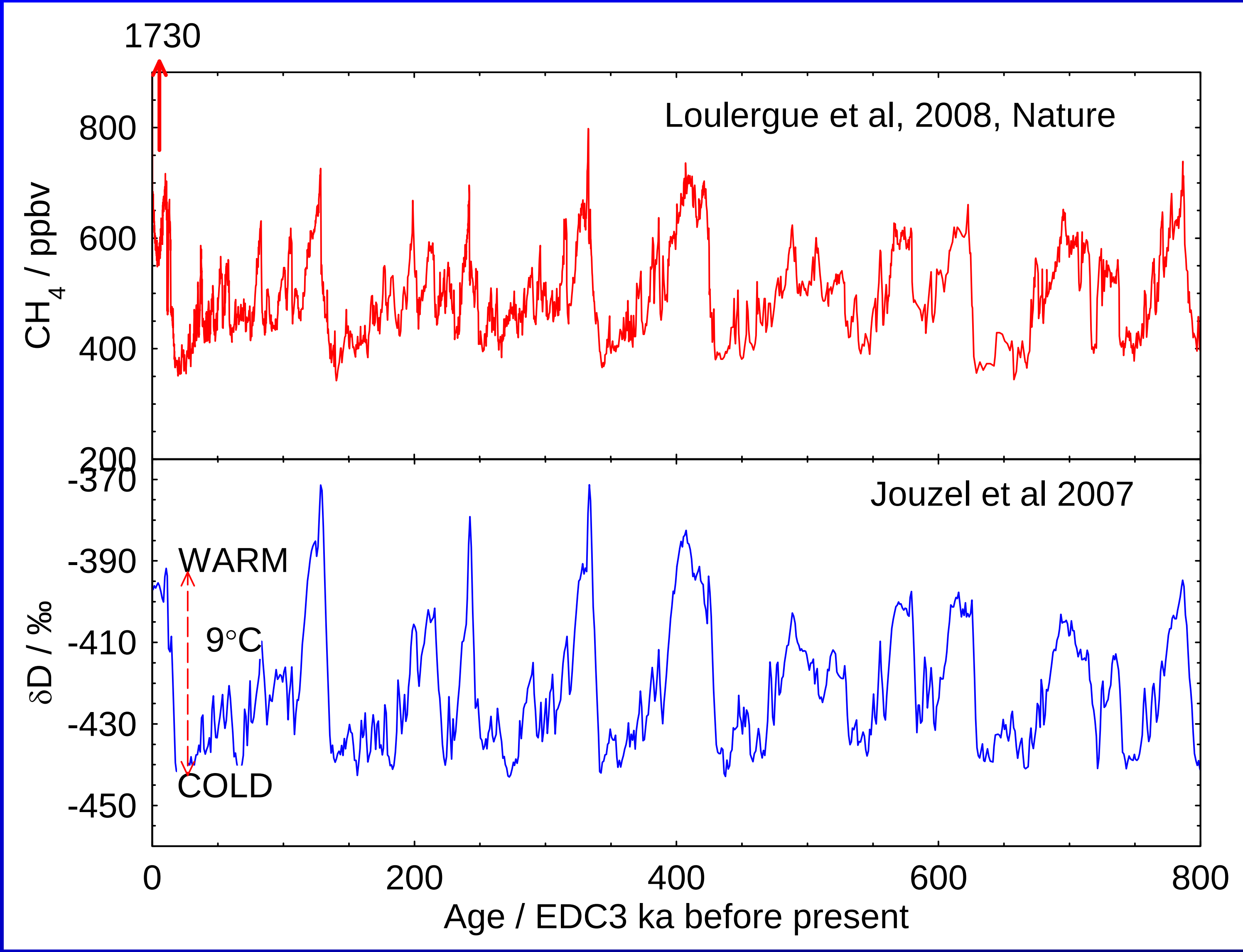


But we are out of the range of the last 800 ka



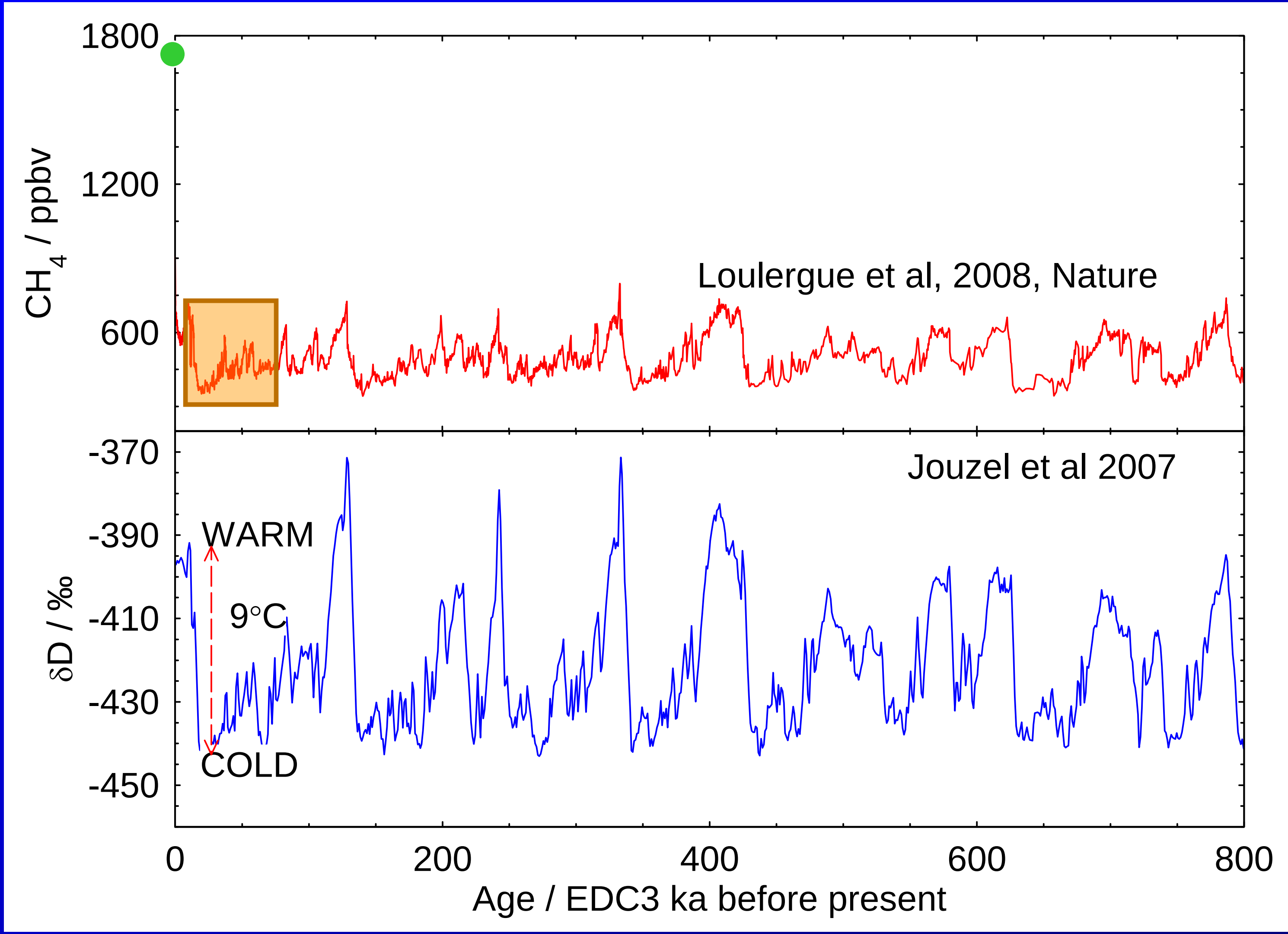
- In rate as well as concentration:
  - Fastest multicentennial rate in last termination was ~20 ppmv in 1000 years
  - 20 ppmv increase in last 11 years

CH_4



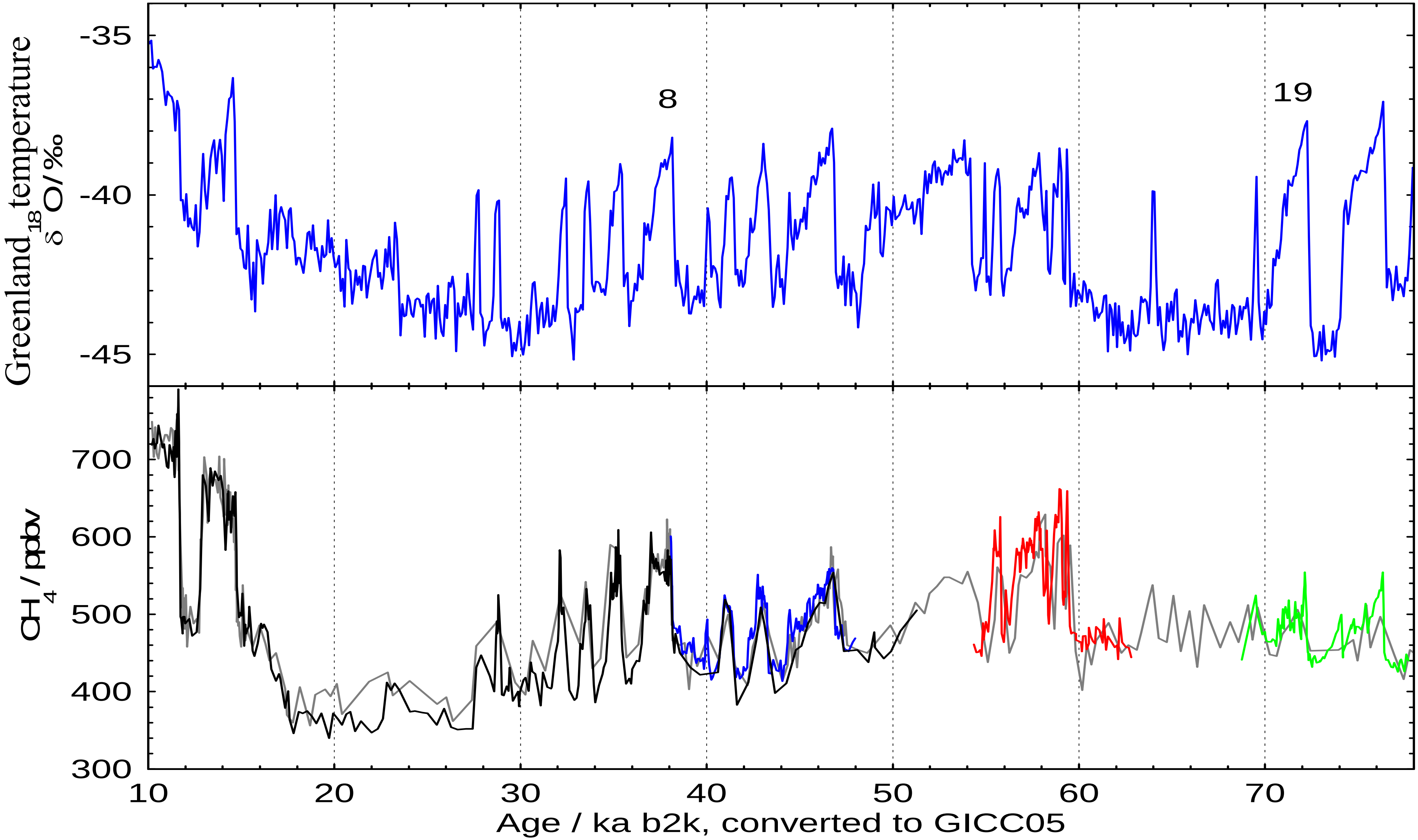
1730
800
600
400
200
CH_4 / ppbv
Loulergue et al, 2008, Nature
-370
-390
-410
-430
-450
δD / ‰
WARM
9°C
COLD
Jouzel et al 2007
0
200
400
600
800
Age / EDC3 ka before present

But the late Pleistocene holds no analogue for the present

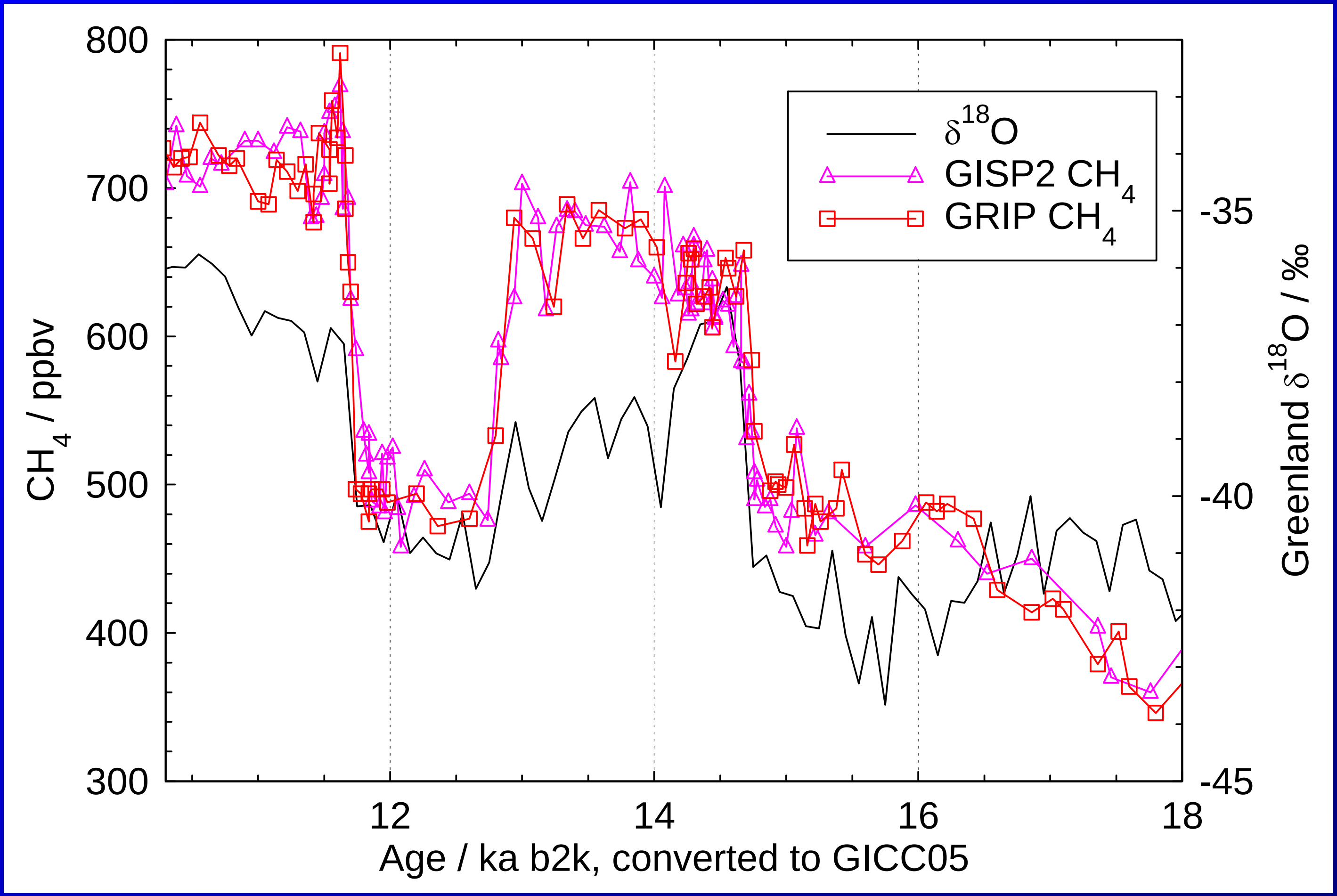


And natural changes are dwarfed by the anthropogenic influence

Rapid events in CH_4



Last termination



Based on Blunier and Brook (2001) and earlier papers

Causes of change (CH_4)

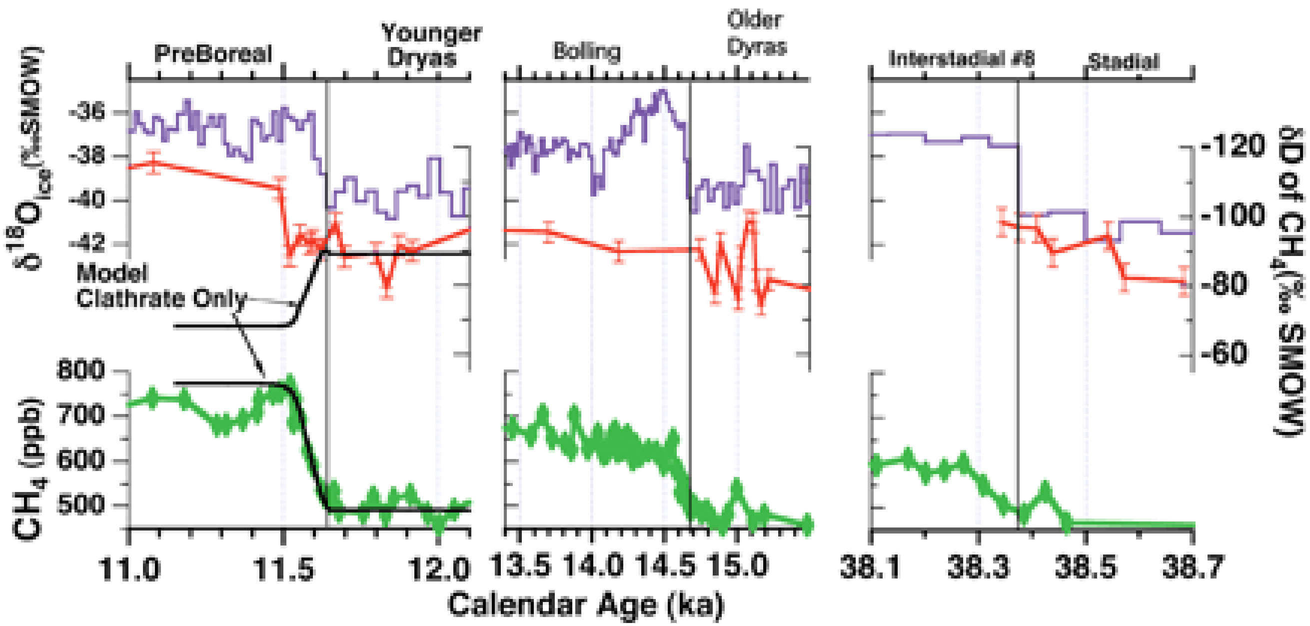
Sources

- Wetlands
  - Northern
  - Tropical
- Methane hydrates
- Biomass burning
- Others (vegetation,….)

Sinks

- OH change
  - Temperature
  - Water vapour
  - Competition (VOCs)

Isotopic evidence suggests no major role for hydrates, and perhaps biomass burning



δD of CH_4

Sowers, Science 2006

Concludes marine clathrates are not important for these warming events

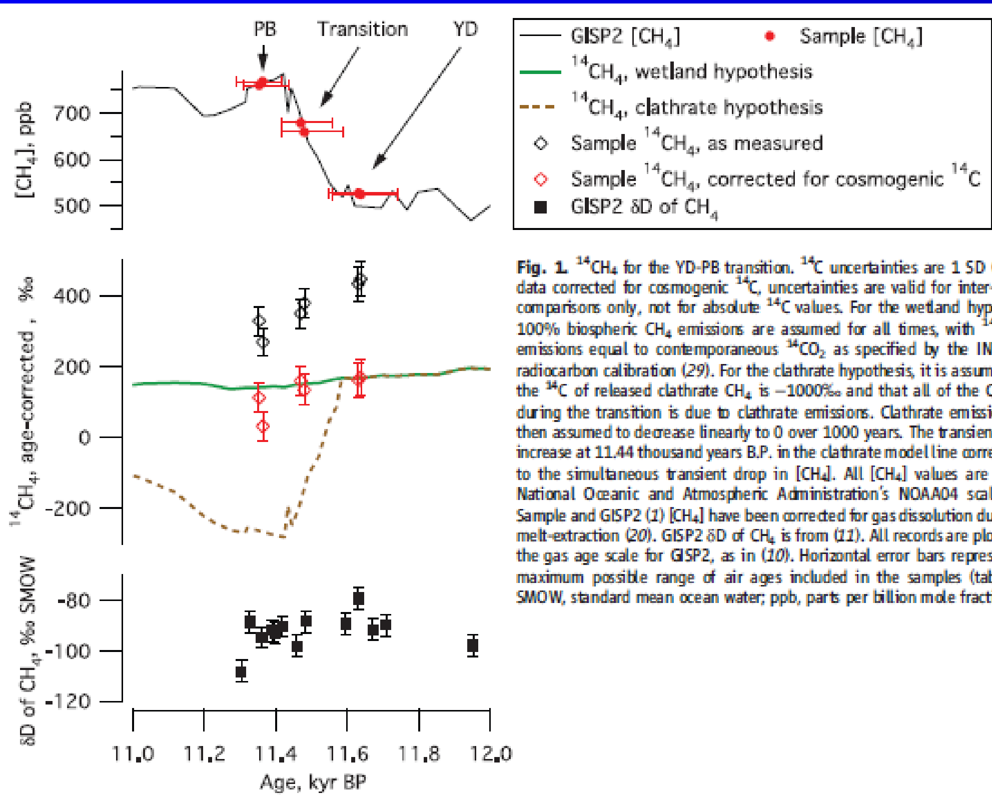
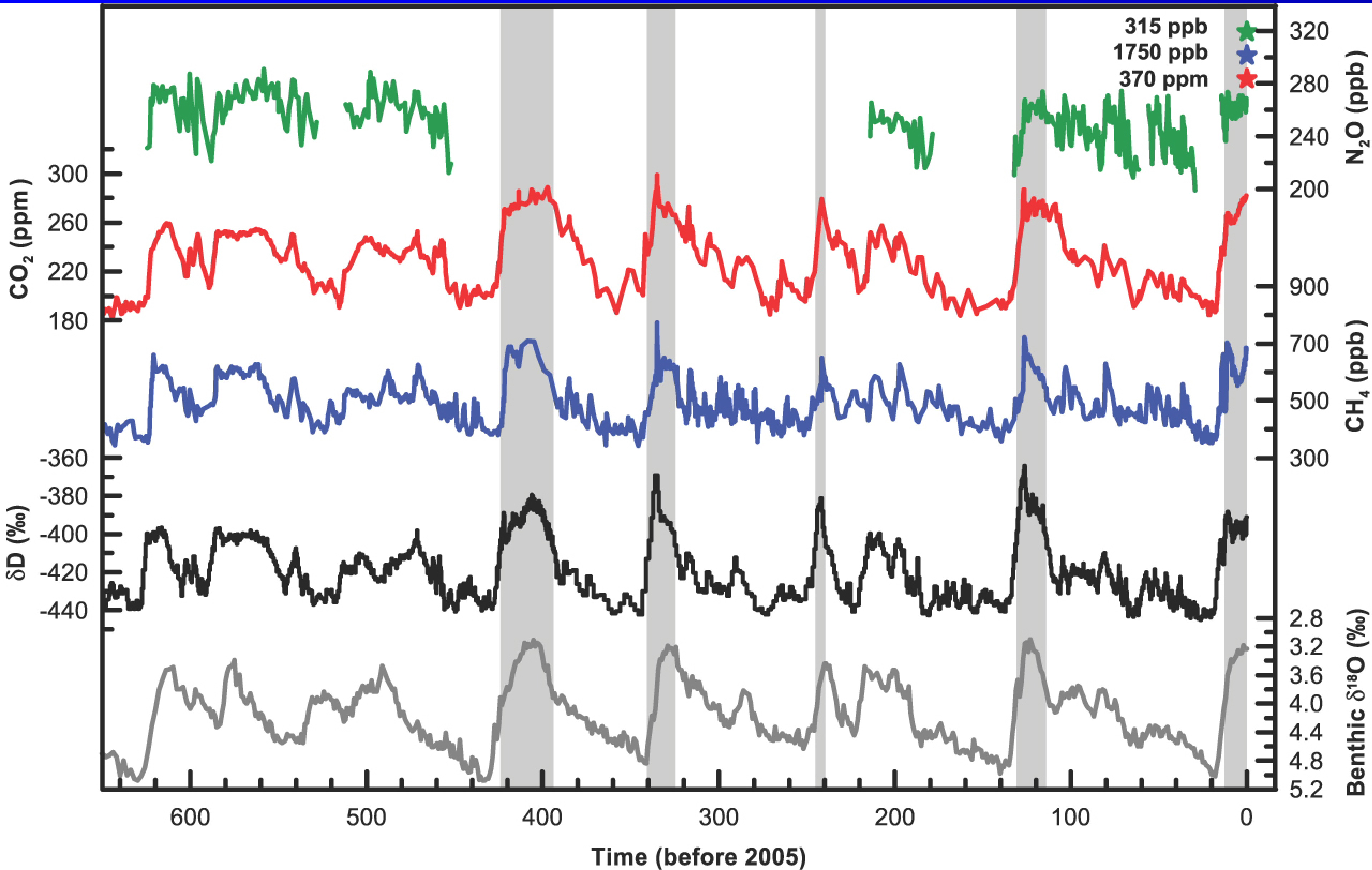


Fig. 1. $^{14}CH_4$ for the YD-PB transition. ^{14}C uncertainties are 1 SD (σ). For data corrected for cosmogenic ^{14}C, uncertainties are valid for inter-sample comparisons only, not for absolute ^{14}C values. For the wetland hypothesis, 100% biospheric CH_4 emissions are assumed for all times, with $^{14}CH_4$ of emissions equal to contemporaneous $^{14}CO_2$ as specified by the INTCAL04 radiocarbon calibration (*29*). For the clathrate hypothesis, it is assumed that the ^{14}C of released clathrate CH_4 is −1000‰ and that all of the CH_4 rise during the transition is due to clathrate emissions. Clathrate emissions are then assumed to decrease linearly to 0 over 1000 years. The transient $^{14}CH_4$ increase at 11.44 thousand years B.P. in the clathrate model line corresponds to the simultaneous transient drop in [CH_4]. All [CH_4] values are on the National Oceanic and Atmospheric Administration's NOAA04 scale (*30*). Sample and GISP2 (*1*) [CH_4] have been corrected for gas dissolution during air melt-extraction (*20*). GISP2 δD of CH_4 is from (*11*). All records are plotted on the gas age scale for GISP2, as in (*10*). Horizontal error bars represent the maximum possible range of air ages included in the samples (table S1). SMOW, standard mean ocean water; ppb, parts per billion mole fraction.

No evidence of fossil ^{14}C at transition

Large blocks from Pakitsoq, Greenland. Petrenko et al., 2009, Science

N_2O also lower in cold periods

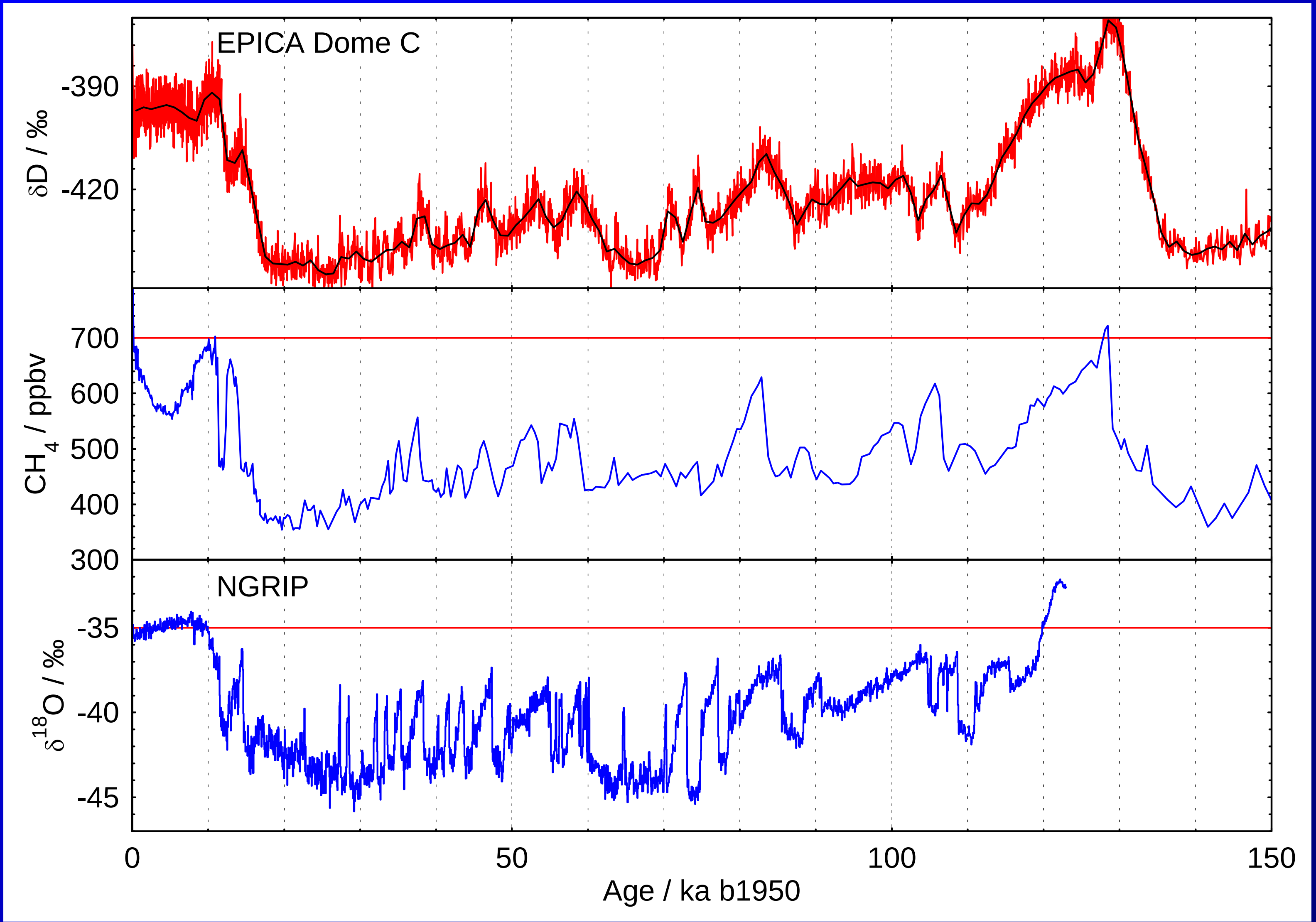


Glacial/interglacial change

- Response of CO_2 exchange with Southern Ocean needs to be understood
- Response of wetlands and or other sources/sinks to changing climate – larger than expected

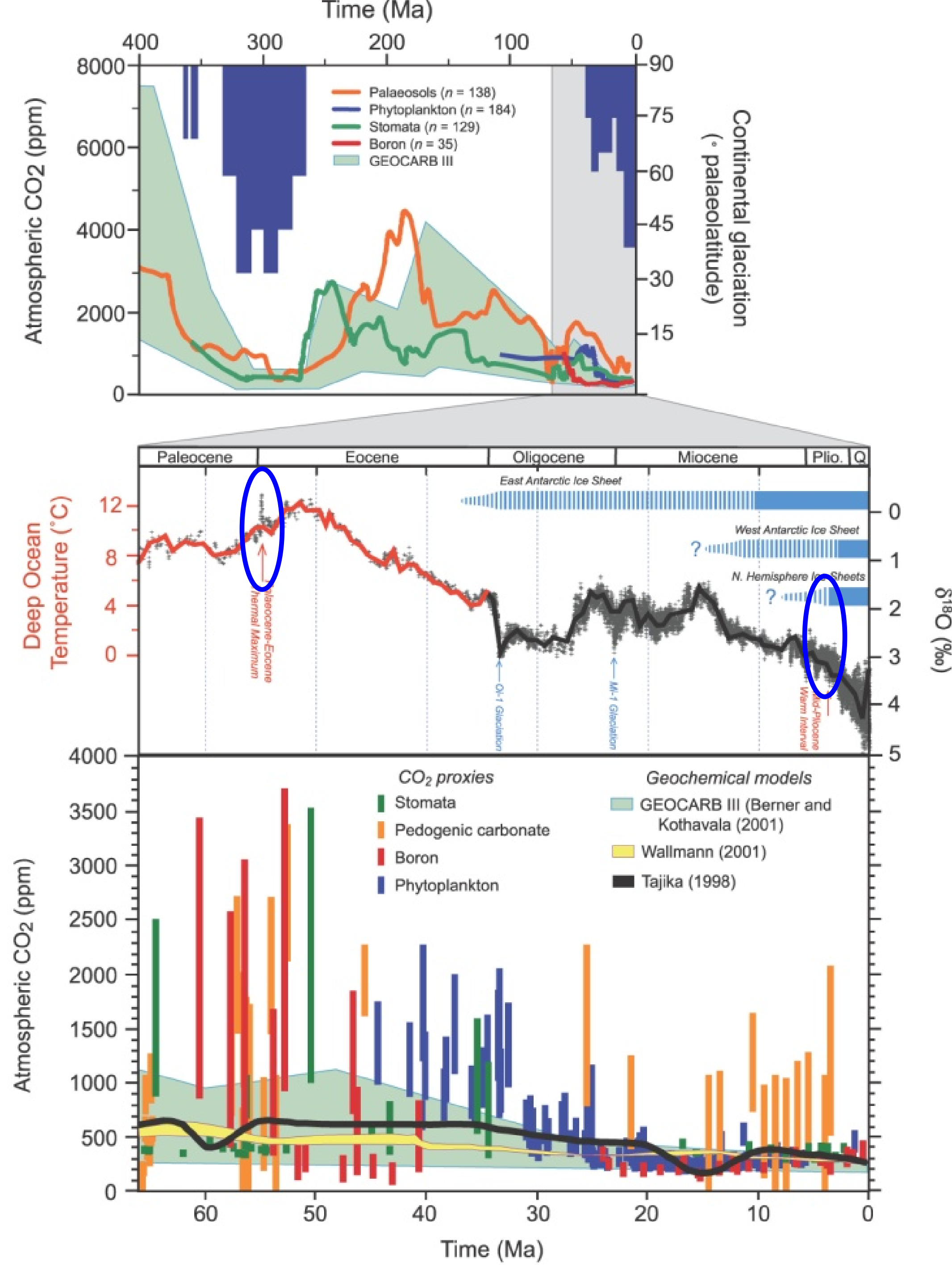
❑ What can we learn from warmer climates and deeper time

Last interglacial – how did CH_4 react to Arctic warmth?

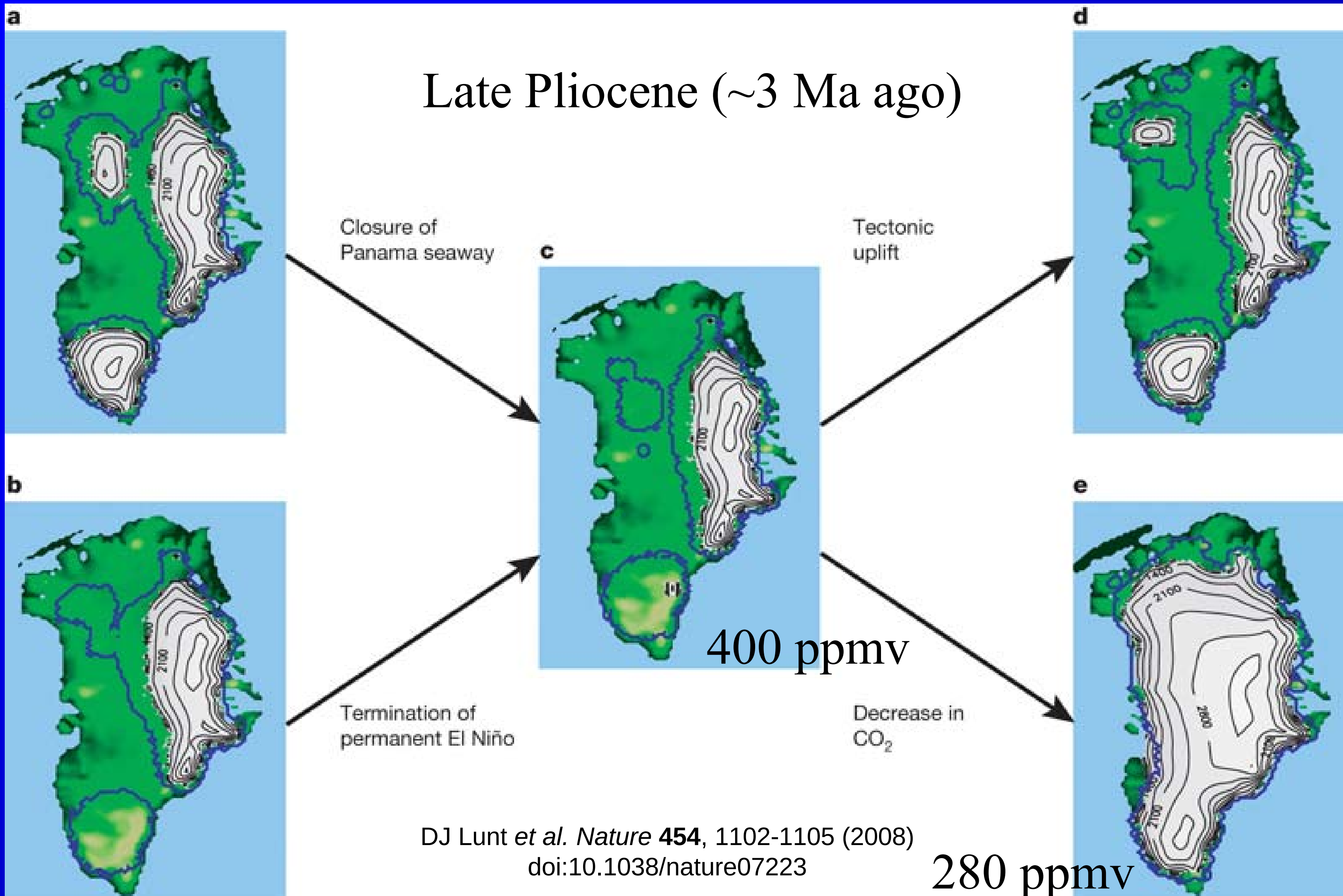


Deeper time

Geologic record generally indicates that periods of higher CO_2 were warmer and with less ice on Earth. But substantial difficulties in clearly defining the palaeogeography, climate or CO_2 content further back in time



CO_2 control of onset of glaciations?

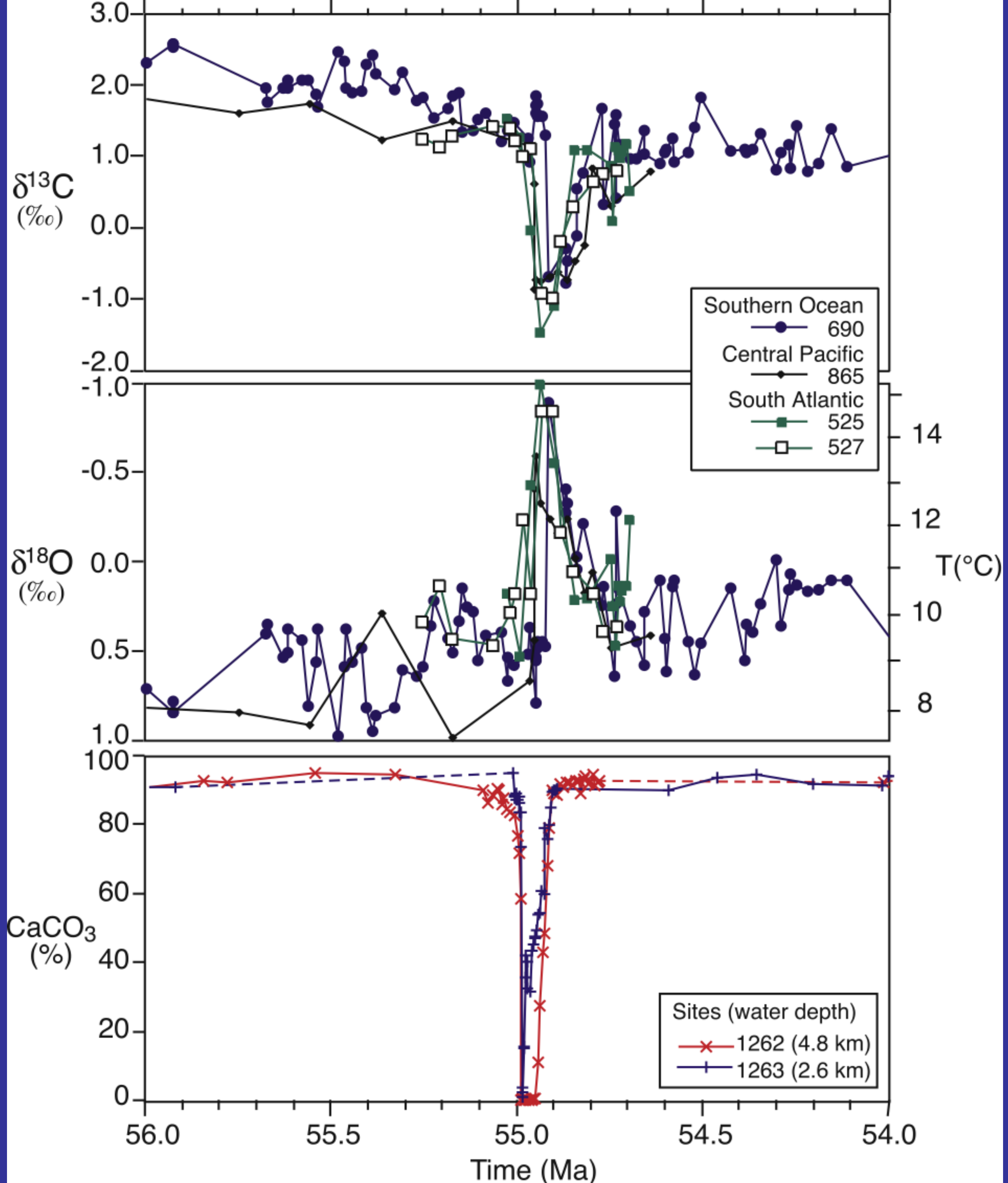


PETM

Palaeocene- Eocene

Thermal Maximum

Closest analogue to the modern increase in greenhouse gases



IPCC Fourth Assessment Report
WG1 Palaeoclimatology

Summary

- Ice cores show us the unprecedented extent and rate of the recent increase in greenhouse gases and therefore radiative forcing
- Large changes in Quaternary challenge us to understand natural cycles and test our knowledge of feedbacks (especially wrt ocean carbon and wetland methane)
- Last interglacial might be used to seek reassurance against large methane releases under warming
- State of the planet in other warm periods as a model test
- PETM: model system for large carbon release?