European Geosciences Union – General Assembly 2006
GEOPHYSICAL INFORMATION FOR TEACHERS (GIFT) WORKSHOP

Greenhouse gas natural trends : what do we learn from ice core analyses ?

EPICA Dome Concordia drilling trench
© S. Drapeau, IPEV

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L G G E
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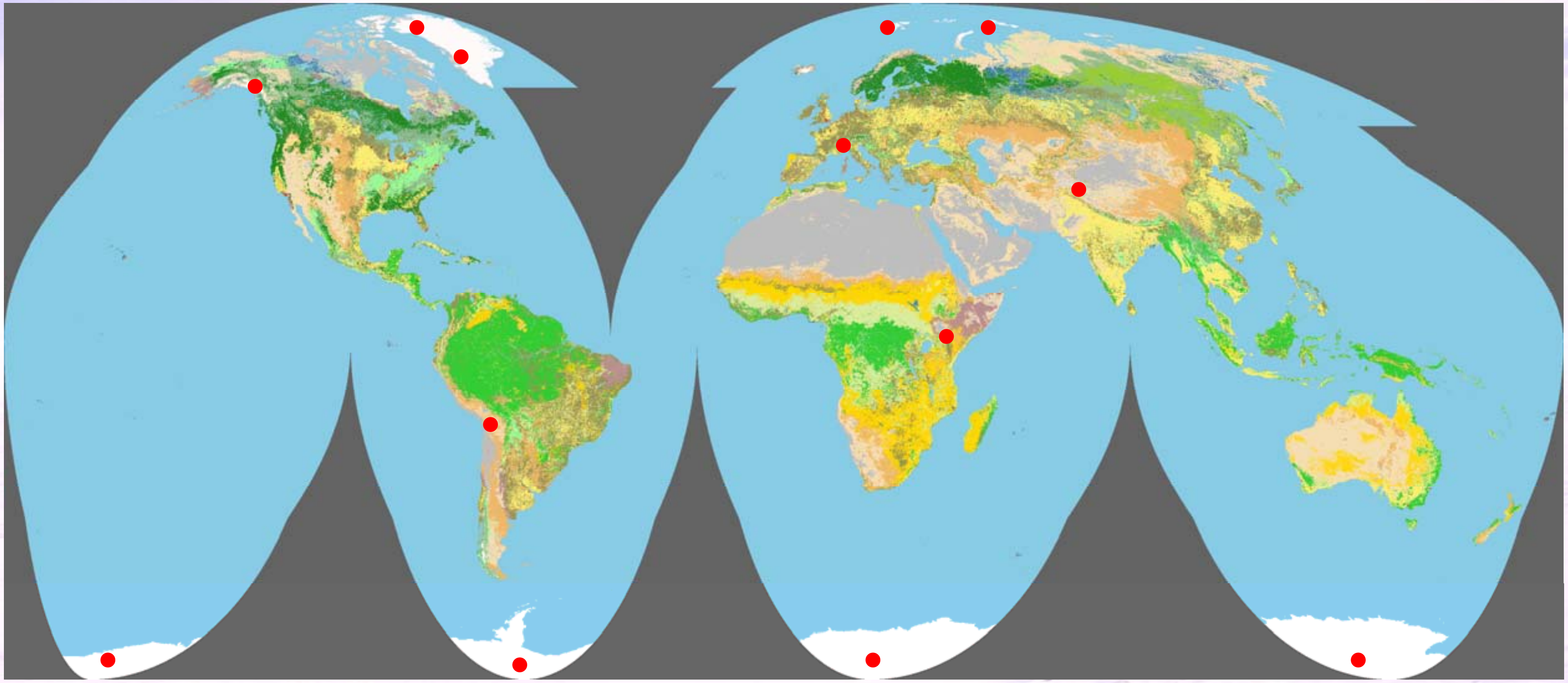
Outline

- Introduction to ice cores and gas trapping
- Why the future brings us to the past
- « Facts » on past greenhouse gas changes
- Where we stand regarding explanations of past greenhouse gas changes
- Where we want to go during IPY and beyond…

Specificity of ice cores as archives



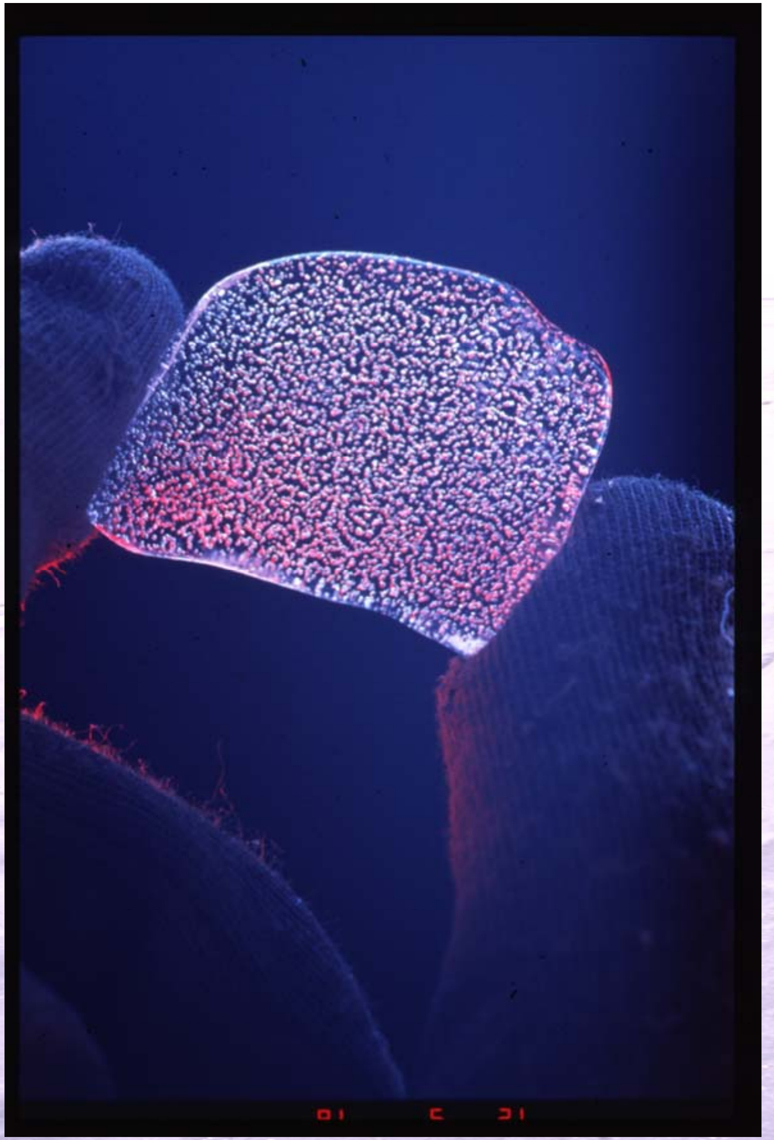
Advantages	Disadvantages
• Temporal resolution • Range of parameters • Regional to global significance • No biology in the transfer function	• Only on poles or mountains • A few 100,000 years coverage • Physics and chemistry of transfer function not always straightforward

Parameters accessible in natural ice

Natural ice through polarized light
(sample size : ~2 x 3,5 cm)
© V. Lipenkov, LGGE-CNRS

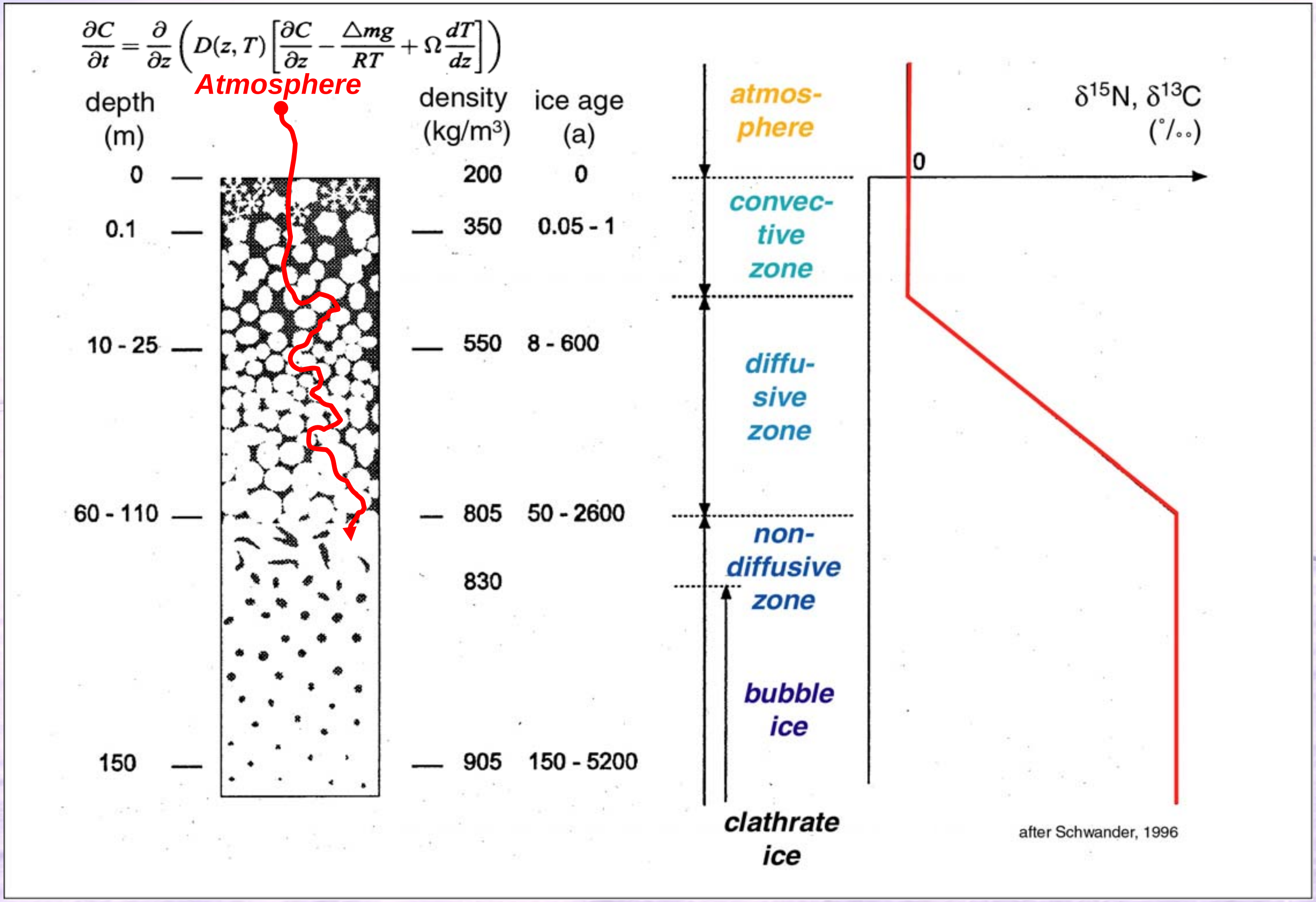
- Temperature (isotopes of H_2O)
- Accumulation (stratigraphy, ^{10}Be)
- Aerosols of natural origin :
  - Marine (Cl^-, Na^+, $SO_4^=$, MSA,...)
  - Continental (dust, Al, Ca^{++}, NH_4^+, organic acids)
  - Volcanic (Cl^-, $SO_4^=$)
  - Cosmic (Ir, ^{10}Be)
- Aerosols of anthropogenic origin :
  - $SO_4^=$, NO_3^-, heavy metals, ^{137}Cs,…
- **Atmospheric composition (N_2, O_2, CO_2, CH_4, N_2O, CO,…)**

How does mother Nature put atmospheric samples in air bubbles trapped in natural ice ?



Bubbles in polar ice
© D. Etheridge, CSIRO, Australia

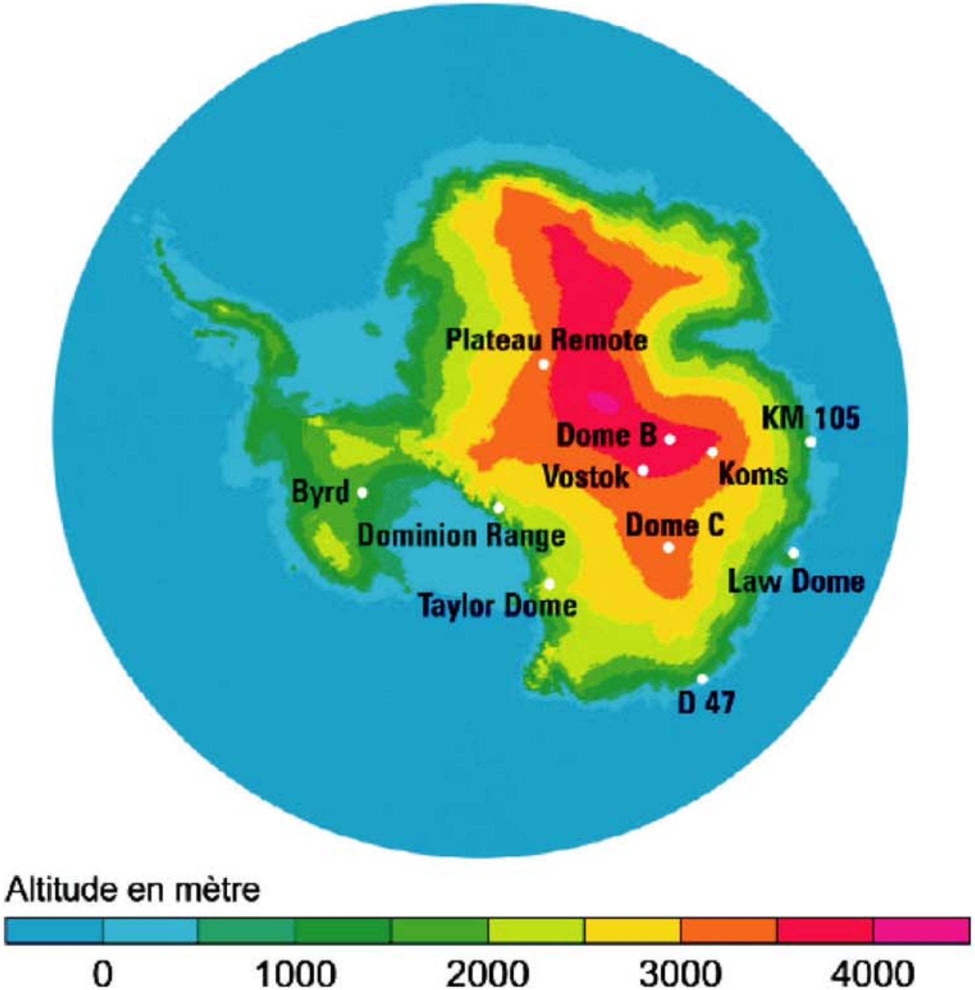
Gas diffusion and trapping in polar firn



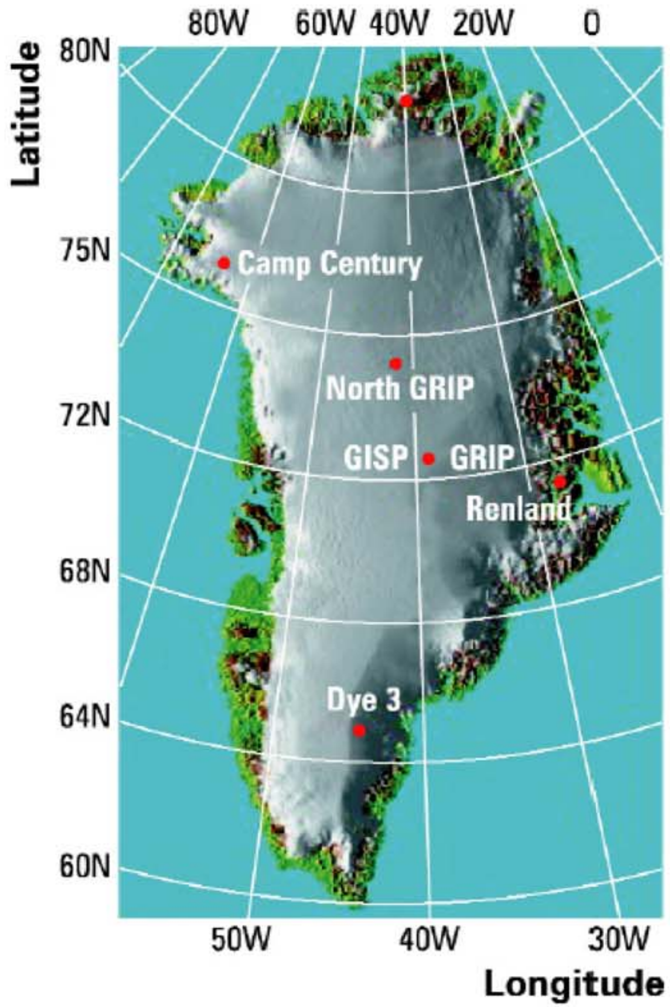
Adapted from Schwander, NATO ASI, 1996

The gas composition in polar firn and then in air bubbles results from molecular diffusion, gravitational settling and thermal diffusion

Antarctica

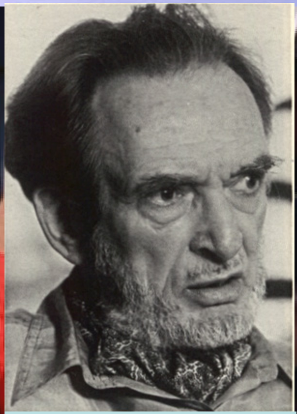


Greenland

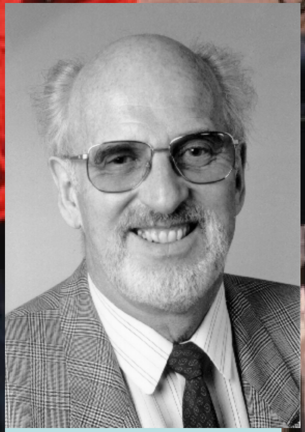


1968-2006 : 38 years of international efforts to drill deep ice cores

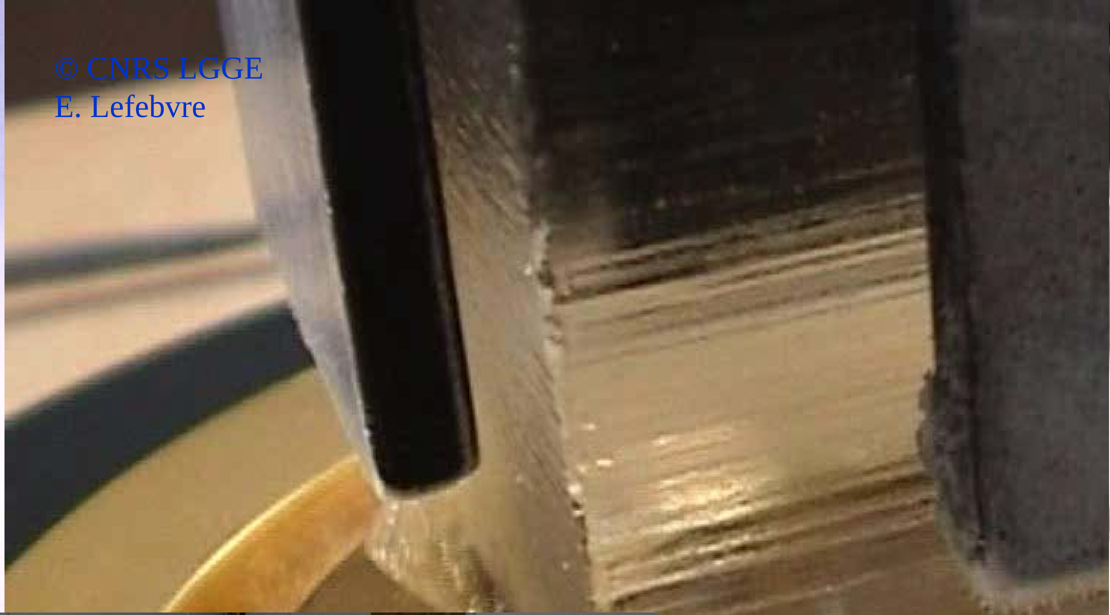
Claude Lorius
Vostok station
1983

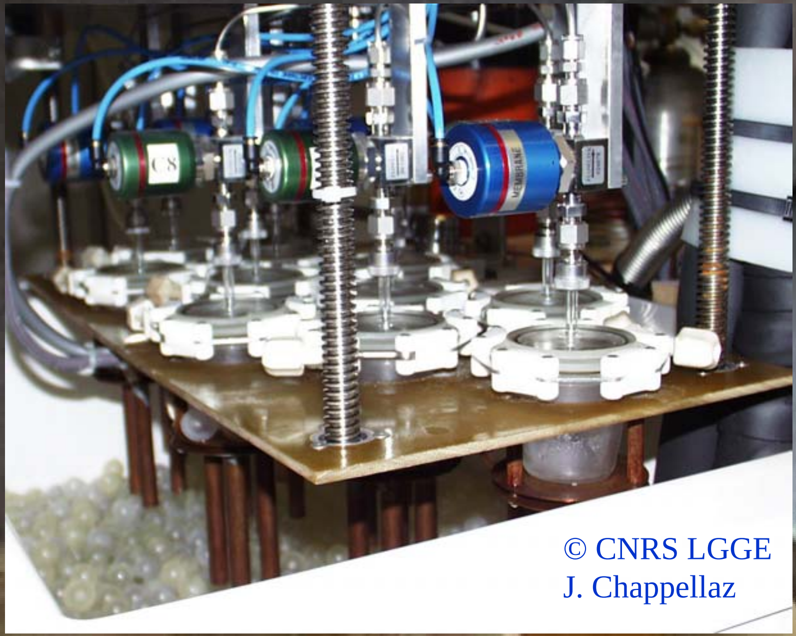


Willi Dansgaard



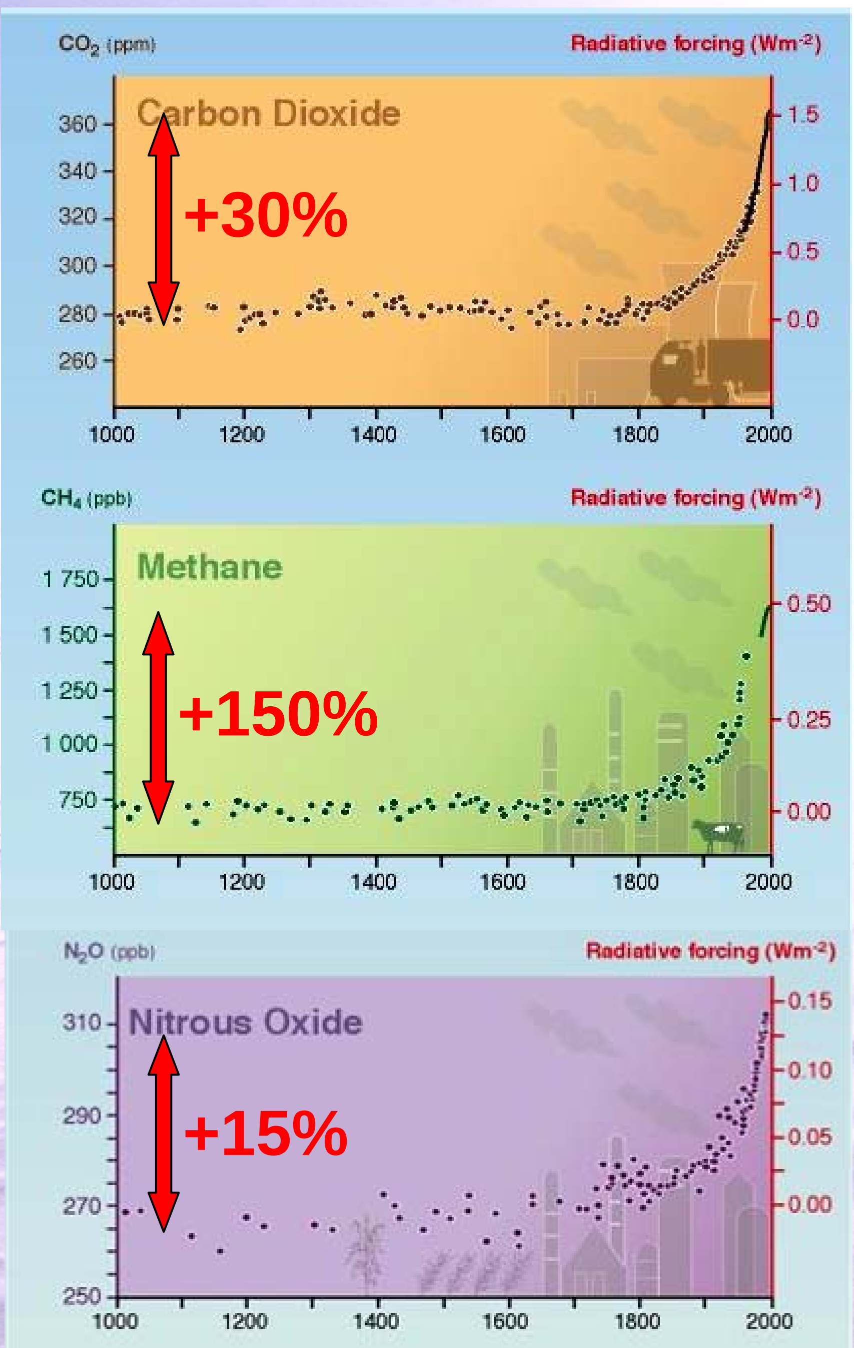
Hans Oeschger

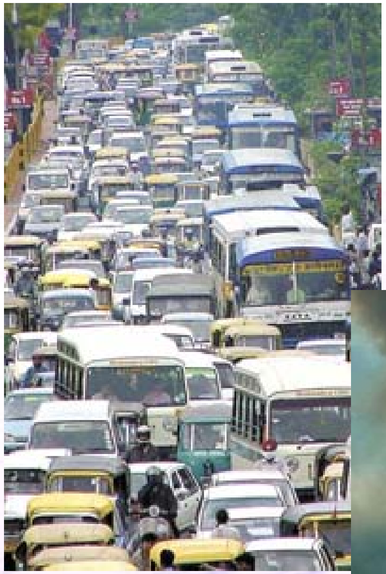




- **Gas extraction:**
  - **Melting**
  - **Melting/refreezing**
  - **Crushing**
  - **Sublimating**
- **Gas analysis:**
  - **Gas chromatography**
  - **Laser absorption**
  - **Mass spectrometry**

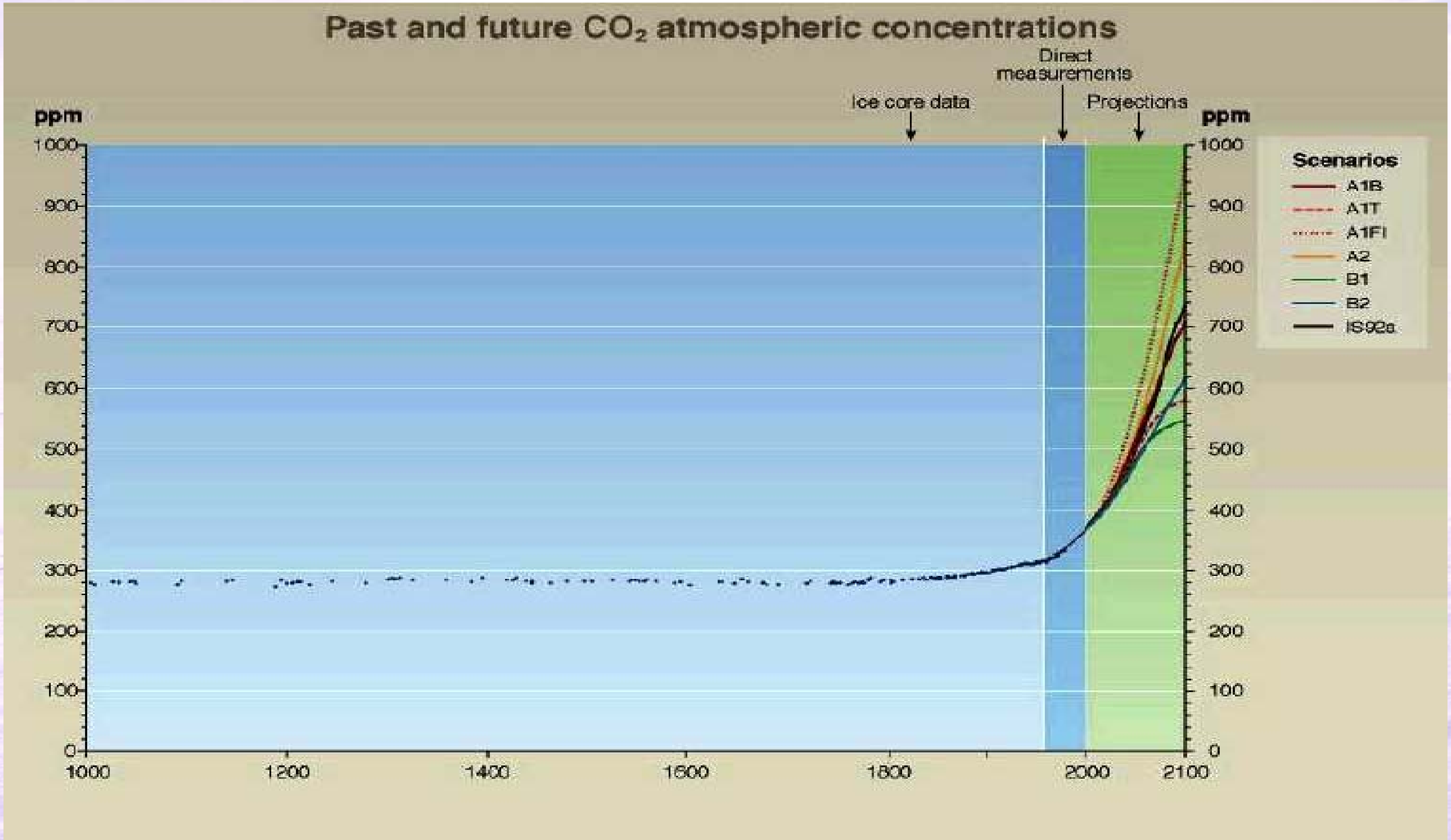
The ice-core warning: GHG anthropogenic increase





2001 IPCC report

Ice-core lessons from the past:
A key for the future

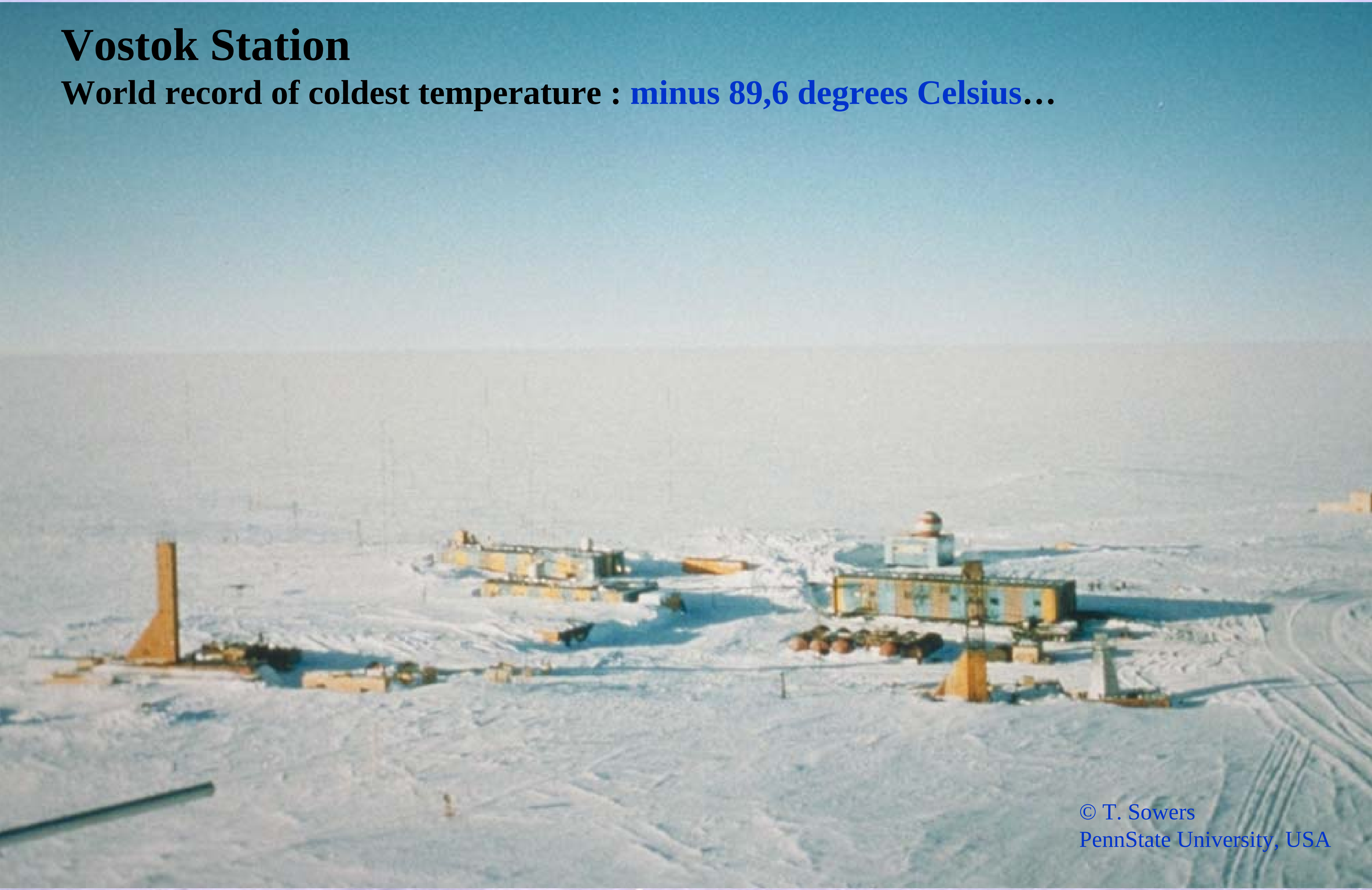


Uncertainties on future GHG mixing ratios are linked to anthropogenic emission scenarios but also to natural feedbacks; looking into the past allows one to constraint the climate/GHG links

Four Glacial-interglacial cycles: Vostok

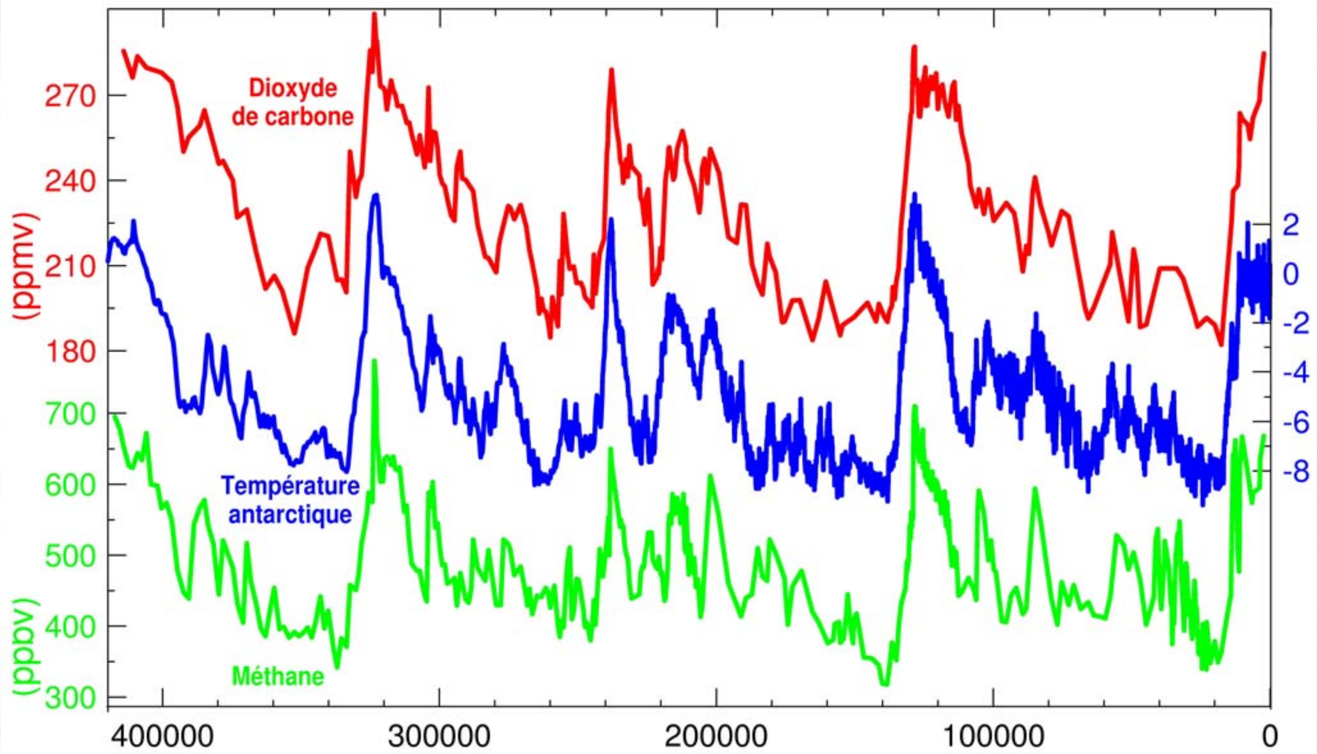
Vostok Station

World record of coldest temperature : minus 89,6 degrees Celsius…



© T. Sowers
PennState University, USA

Four Glacial-interglacial cycles: Vostok



TIME

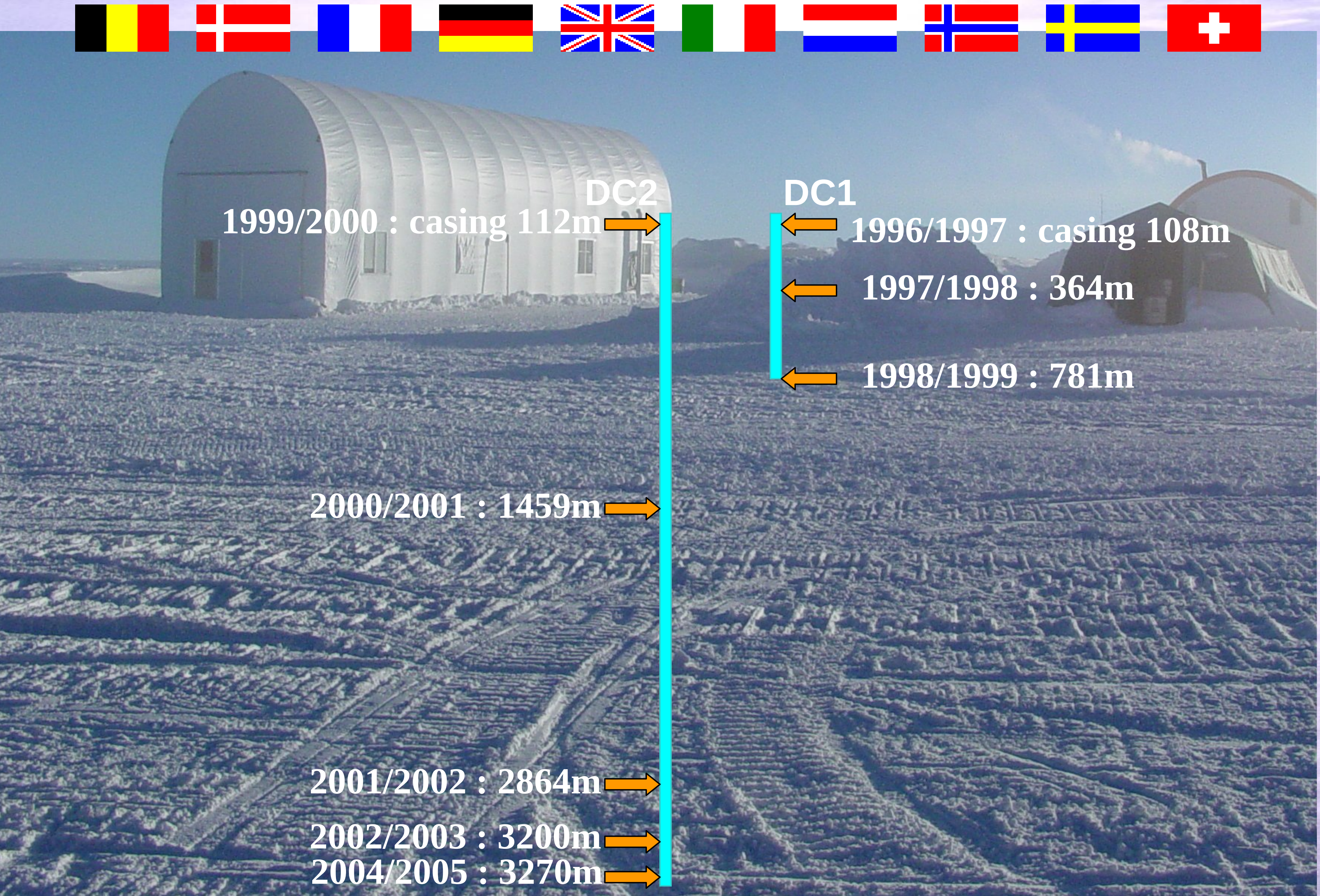
Petit et al., Nature 1999

High co-variance of temperature, carbon dioxide and methane

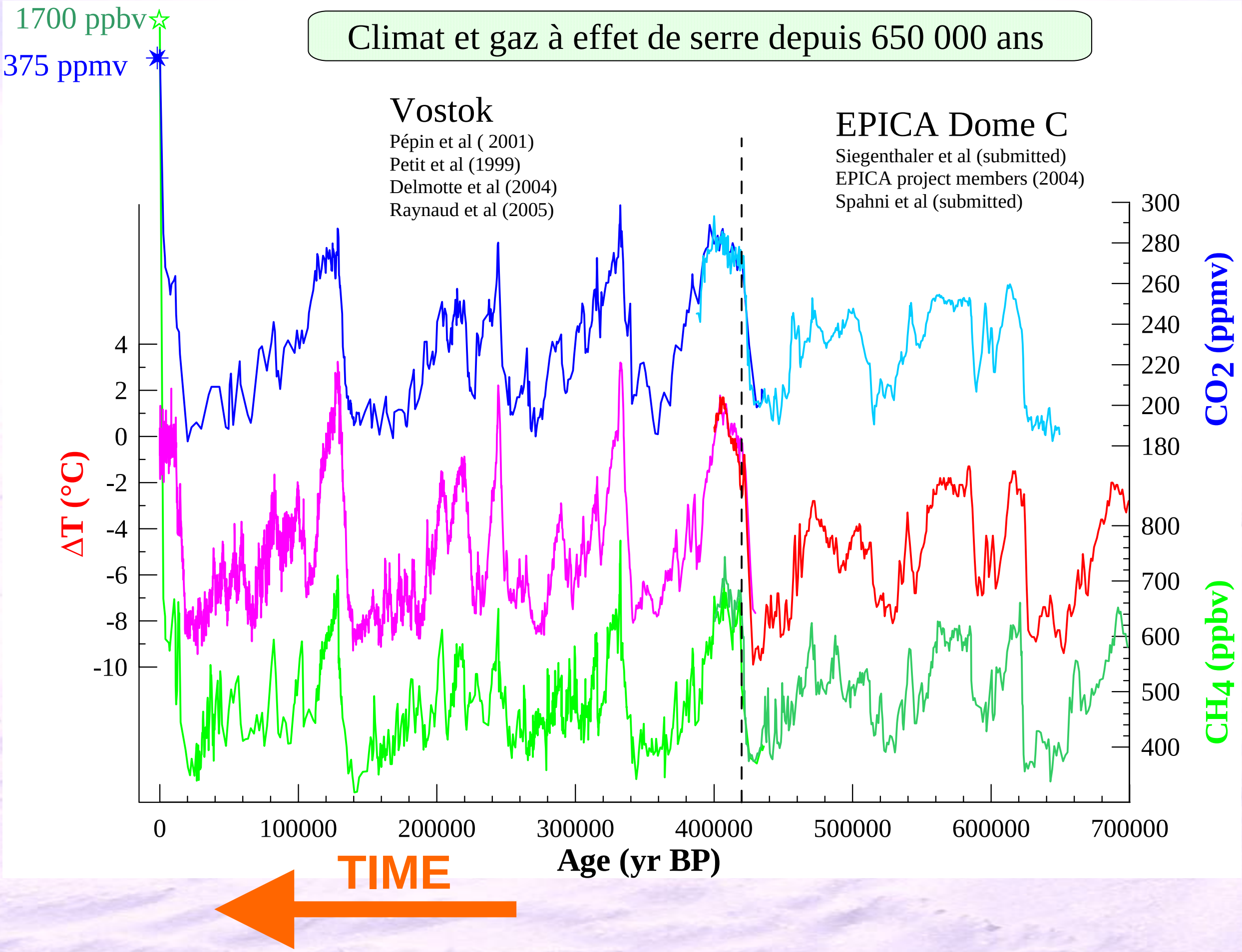
Maximum range of natural changes : **CO_2 : 185-300 ppmv (~20 ppmv / °C)**

CH_4 : 350-800 ppbv (~75 ppbv / °C)

Eight Glacial-interglacial cycles: EPICA/Dome C



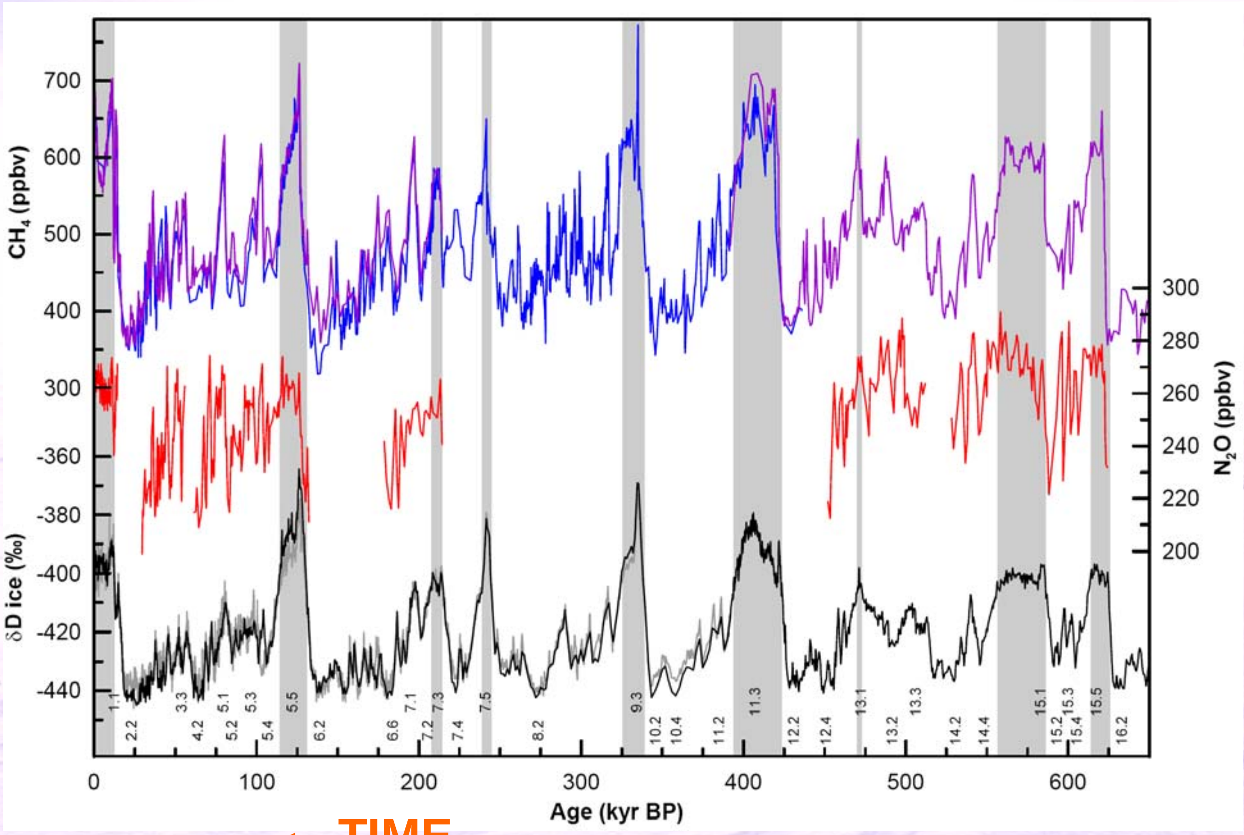
Six Glacial-interglacial cycles: EPICA/Dome C



Maximum range of natural changes :

CO_2 : 185-300 ppmv (~20 ppmv / °C)
CH_4 : 350-800 ppbv (~75 ppbv / °C)

Six Glacial-interglacial cycles: N_2O



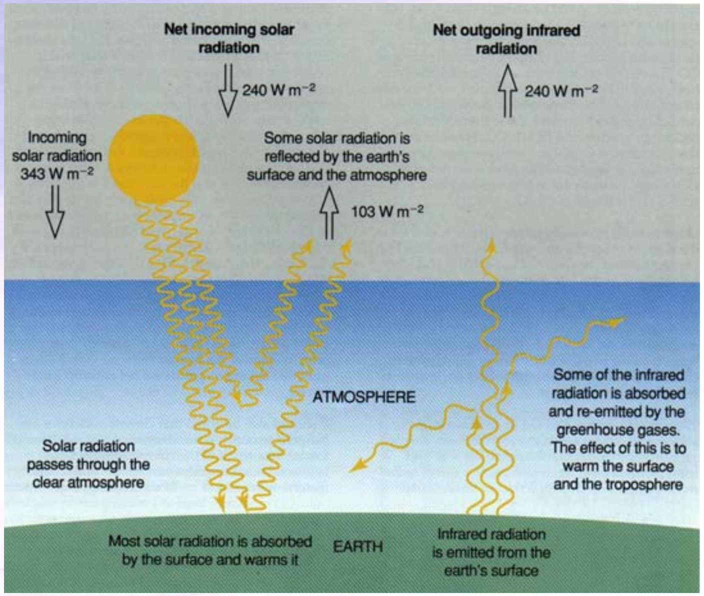
Spahni et al. Science, 2005

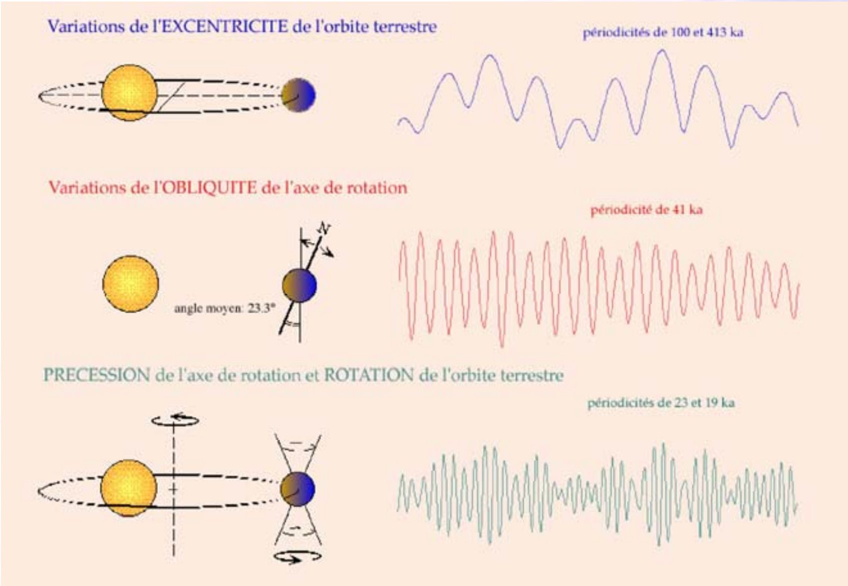
TIME

Maximum range of natural changes :

CO_2 : 185-300 ppmv (~20 ppmv / °C)
CH_4 : 350-800 ppbv (~75 ppbv / °C)
N_2O : 200-275 ppbv (~15 ppbv /°C)

Learning from the past: GHG as climatic feedbacks





Energy balance from glacial to interglacial conditions :

+2.6 ± 0.5 W/m² from the combined effect of CO_2, CH_4 and N_2O

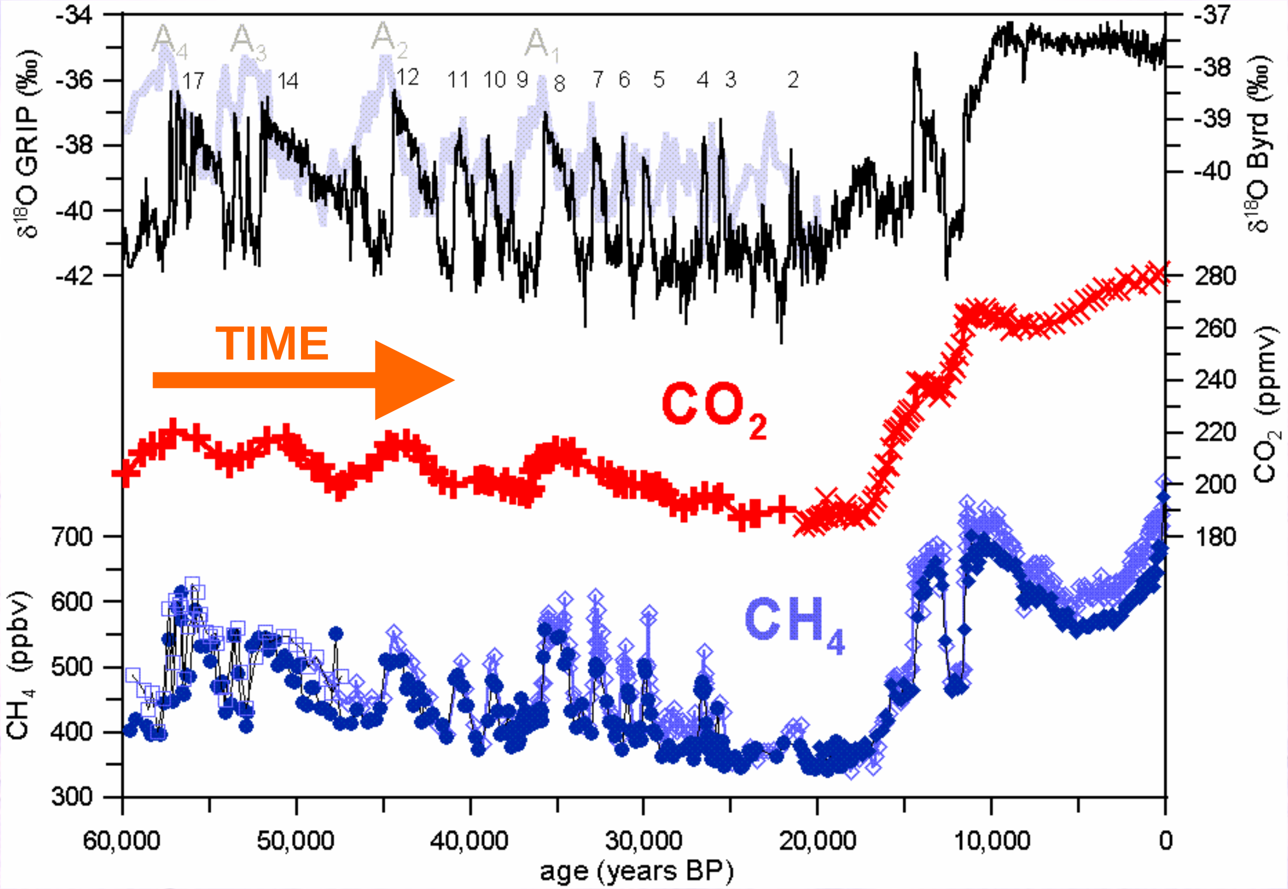
+3.5 ± 1 W/m² from the albedo effect (snow, ice and vegetation)

+0.5 ± 1 W/m² from dust and aerosols

Sequence of events from ice core data suggests :

- **early warming in the South, forced by insolation**
- **GHG amplification**
- **albedo, dust and aerosol amplification**

Learning from the past: the timing of events

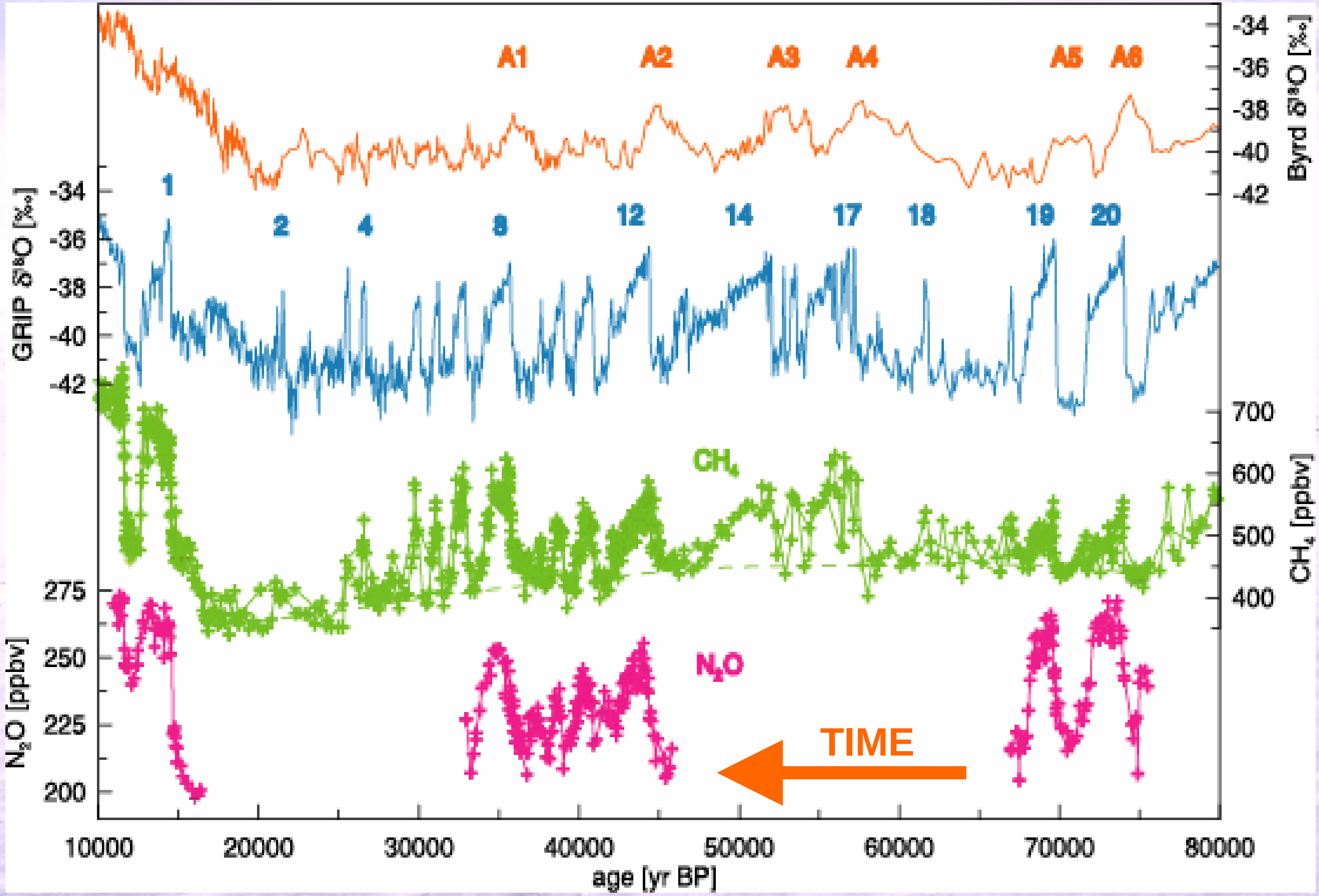


Stauffer et al., 2002 and ref. therein

CO_2 : **20 ppmv variability correlated with Antarctic temperature**

CH_4 : **- 100-200 ppbv variability associated with changes in North Atlantic and Greenland climate**
- synchronous with t° or lags by a few decades
- increases over 50 to 150 yr

Learning from the past: the timing of events



Flückiger et al., GBC 2004

N_2O : relatively large (40-50 ppbv) variability associated with D-O events, but for long-lasting events N_2O increases earlier than CH_4 and Greenland T

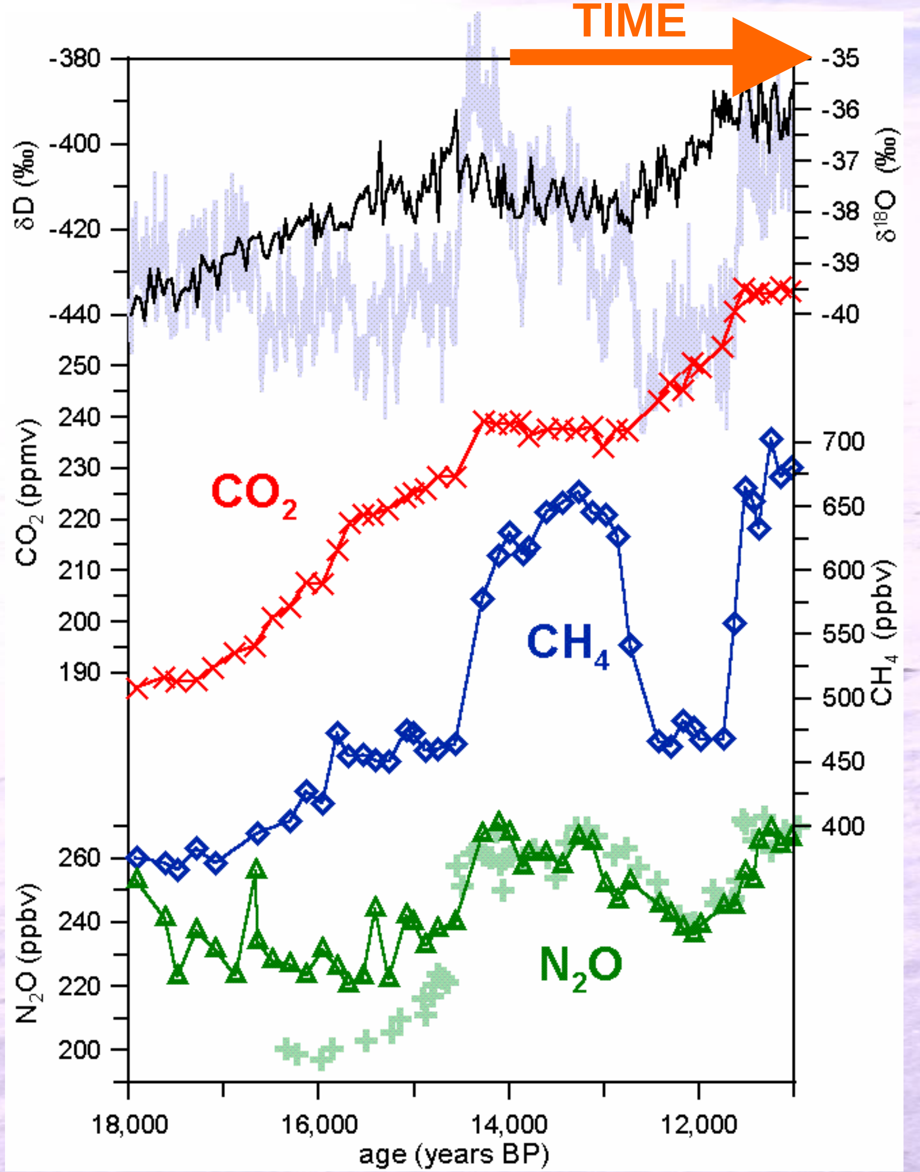
Learning from the past: the timing of events

The last Glacial-interglacial transition

CO_2 : parallels Antarctic warming

CH_4 : parallels N. Atlantic warming

N_2O : parallels N. Atlantic warming but with slower response than CH_4



Stauffer et al., 2002 and ref. therein

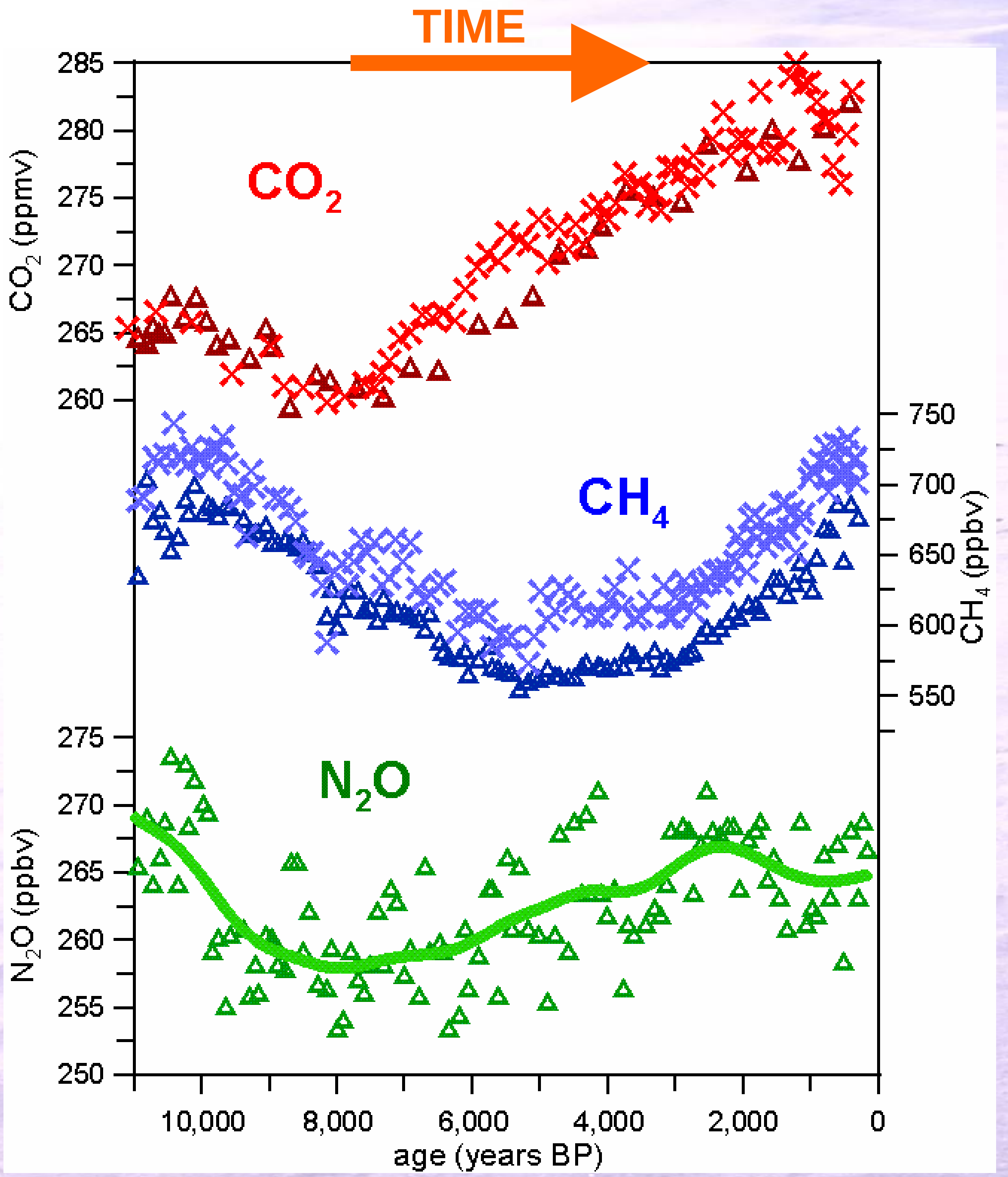
Learning from the past: the timing of events

The Holocene

CO_2 : 20 ppmv change with minimum around 8000 yr BP

CH_4 : 150 ppbv change with minimum around 5000 yr BP

N_2O : 15 ppbv change with minimum around 8000 yr BP



Stauffer et al., 2002 and ref. therein

Summary of ice-core observations relevant to the climate/GHG relationship

All GHG : range of natural variability appears remarkably narrowed and associated either with northern or southern climate records

CO_2 : slow (millennial) evolution mostly correlated with Southern latitude climate, except during the Holocene and the glacial inceptions

CH_4 : rapid (centennial) evolution mostly correlated with Northern Atlantic climate, except during the Holocene

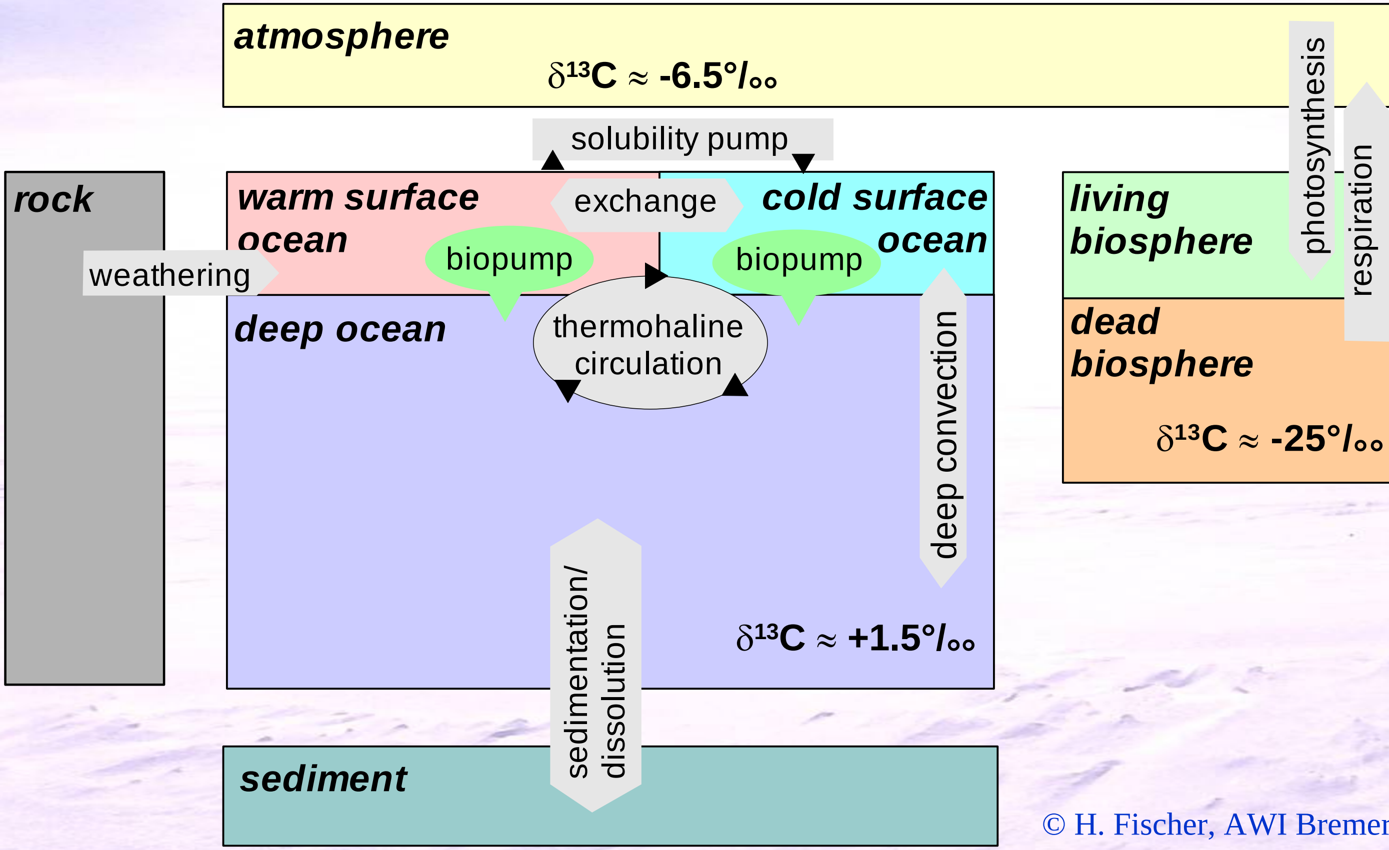
N_2O : depending on the time period, mimics CO_2 (Holocene) or CH_4 (D-O events, deglaciation)

What explanations ?

- Ice core measurements cannot answer alone
- A combination of other observations (marine and continental realms) and modelling is required
- The search for the holy grail continues…

- But… Here is where we stand…

Causes of CO_2 natural variability

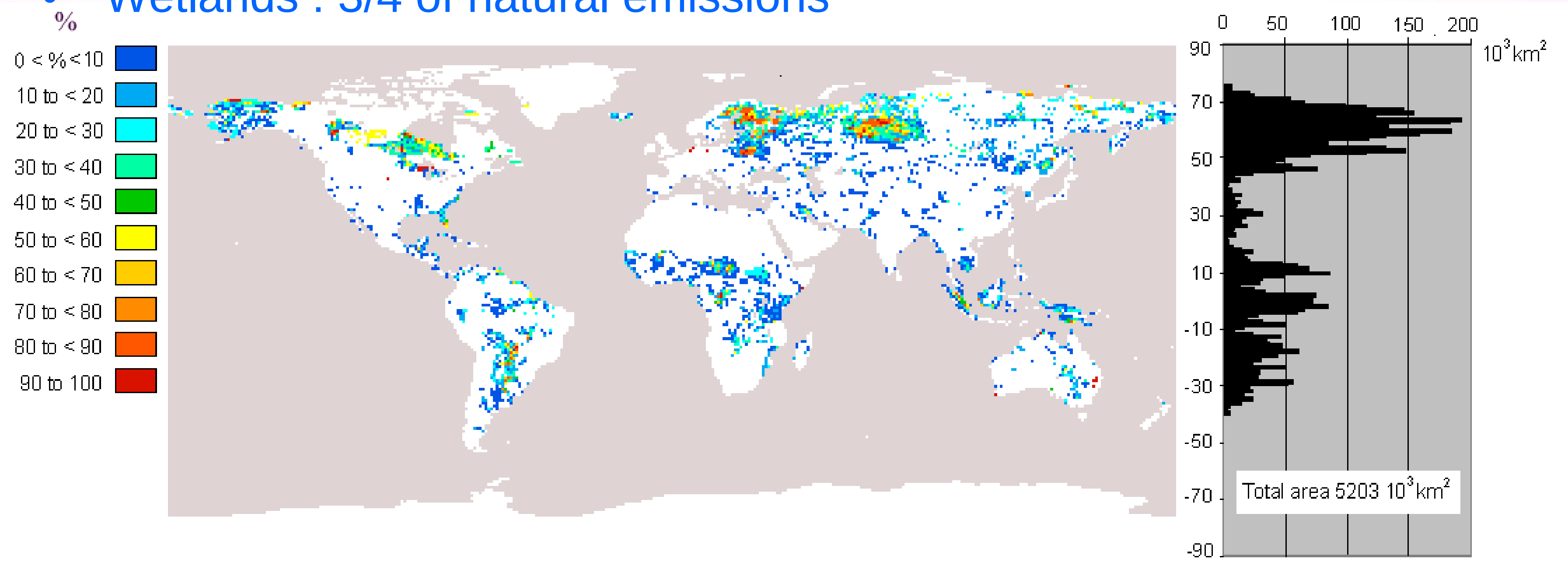


Probable dominant role of processes within the Southern ocean (surface temperature, sea-ice extent, iron fertilisation, surface/deep ocean exchange)

Increase since 8000 yr BP (and maybe « high » CO_2 during glacial inceptions) possibly related with continental biomass reduction

Causes of CH_4 natural variability

- Wetlands : 3/4 of natural emissions



Matthews and Fung, GBC, 1987

Boreal versus Tropical ?

Causes of CH_4 natural variability

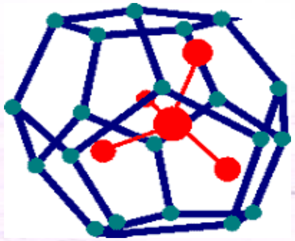
- Oxidative capacity of the atmosphere

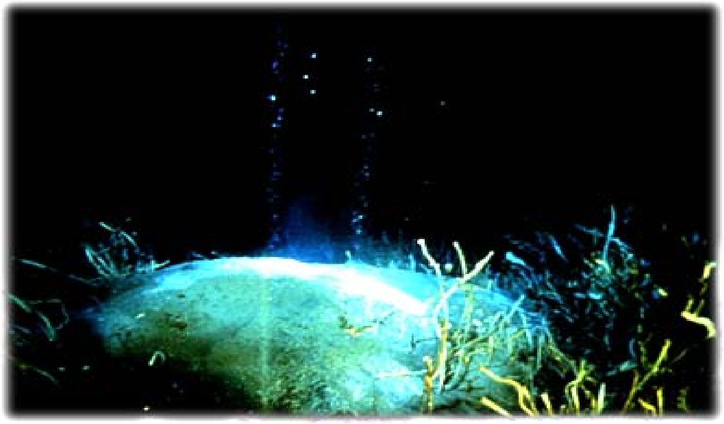
Type of model *(reference)*	**Difference between OH at Last Glacial Maximum and OH today (in %)** *A positive number means more OH at the Last Glacial Maximum*
Bi-dimensional photochemical *(Valentin, thesis U. Mainz, 1990)*	+30-40%
Uni-dimensional photochemical *(Pinto and Khalil, Tellus 1991)*	+20%
Uni-dimensional photochemical *(Lu and Khalil, Tellus 1992)*	+40%
Uni-dimensional photochemical multi-box *(Thompson et al., Tellus 1993)*	+32%
Uni-dimensional photochemical convective with two boxes *(Crutzen and Bruhl, Geophys. Res. Lett. 1993)*	-5%
Bi-dimensional coupled climate-chemistry *(Martinerie et al., J. Geophys. Res. 1995)*	+13%
Uni-dimensional coupled climate-chemistry *(Karol et al., J. Geophys. Res. 1995)*	-63% à +5%
Tri-dimensional forced with climate simulations *(Valdes et al., Geophys. Res. Lett. 2005)*	+25%*
Tri-dimensional coupled climate-chemistry *(Kaplan et al., Global Biogeochem. Cycles 2006)*	+28%*

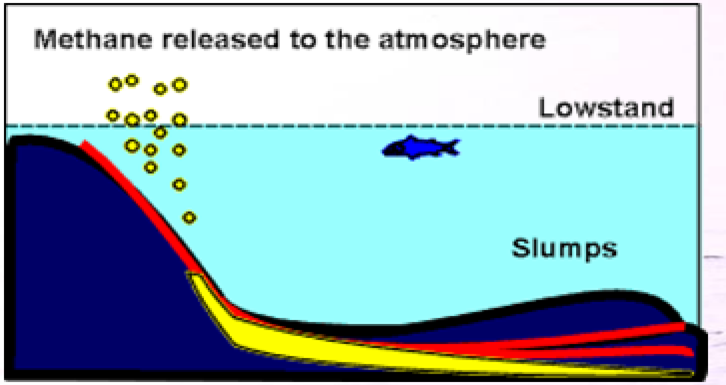
Amplifying role but requires a source forcing

Causes of CH_4 natural variability

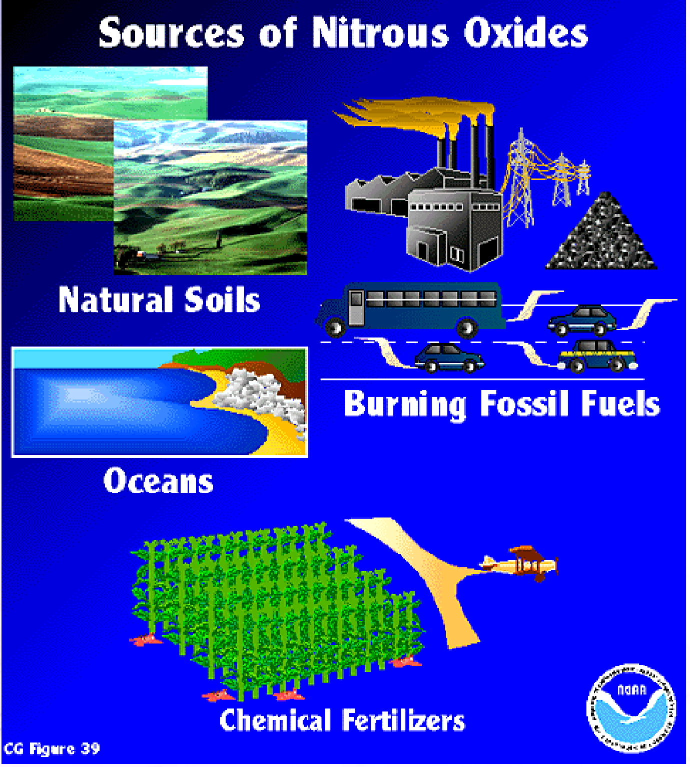
- Hydrates







Where decadal CH_4 changes have been measured in ice cores, they do not support a catastrophic hydrate degassing scenario



Causes of N_2O natural variability

The natural N_2O budget involves nitrification and denitrification in tropical soils (~2/3) and in the open & coastal oceans (~1/3)

N_2O changes during the last glaciation are associated with observed enhanced primary production and denitrification in upwelling zones of the global ocean. Could explain part of the amplitude and timing of N_2O

But preliminary isotopic measurements on the N_2O molecule in ice cores suggest a ~constant continent/ocean N_2O source ratio…

Role of troposphere/stratosphere exchange on N_2O residence time ?
Role of solar modulation on N_2O photodissociation (sink) ?

Conclusion: what do we learn from GHG measurements in ice cores ?

- The range of GHG natural changes is remarkably narrow in the course of the last six glacial-interglacial cycles ; GHG played a major role in amplifying insolation changes driving the natural climate changes

- The strong coupling between the natural evolution of CO_2, CH_4 and N_2O mixing ratios and climate implies that future natural feedbacks with climate warming must be expected

- Although the potential mechanisms are known, the exact nature of this coupling still remains much unclear and therefore the causes and amplitude of future feedbacks. At least for carbon dioxide, the southern ocean should scrutinized.

- Ice cores have not yet given their last word…

Perspectives on ice-core measurements of greenhouse gases and other related trace gases

Development of the isotopic fingerprint

But small sample size and high accuracy are challenging…

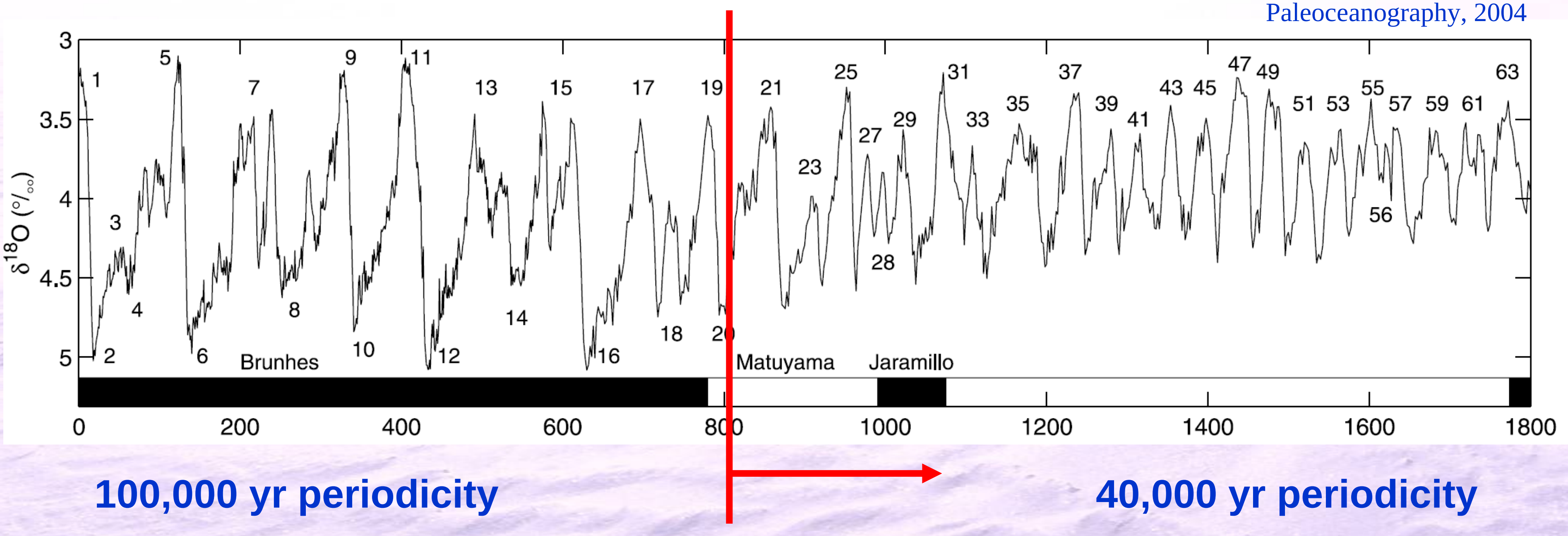
Isotopologue	Abundance (10^{-15}g per g of ice)	Constraint
$^{13}CH_4$	15 - 30	Biomass burning
CH_3D	0,2 - 0,5	Hydrates + OH at transient
^{13}CO	2 - 4	CH_4 oxidation
$C^{18}O$	0,4 - 0,9	Combustion sources
$C^{17}O$	0,1 - 0,2	OH change
$^{13}CO_2$	6000 - 12000	Continent/Ocean Biosphere
$^{15}N_2O$	3 - 5	N Cycle soil/ocean microbiology in ice
$N_2{}^{18}O$	1,5 - 3	
$N^{15}NO$	0,7 - 1,5	Tropo/strato exchange + solar cycle

Perspectives on ice-core measurements of greenhouse gases and other related trace gases

International Partnership in Ice Core Sciences (IPICS)

International Polar Year : in search for the oldest ice in Antarctica

Lisiecki and Raymo, Paleoceanography, 2004



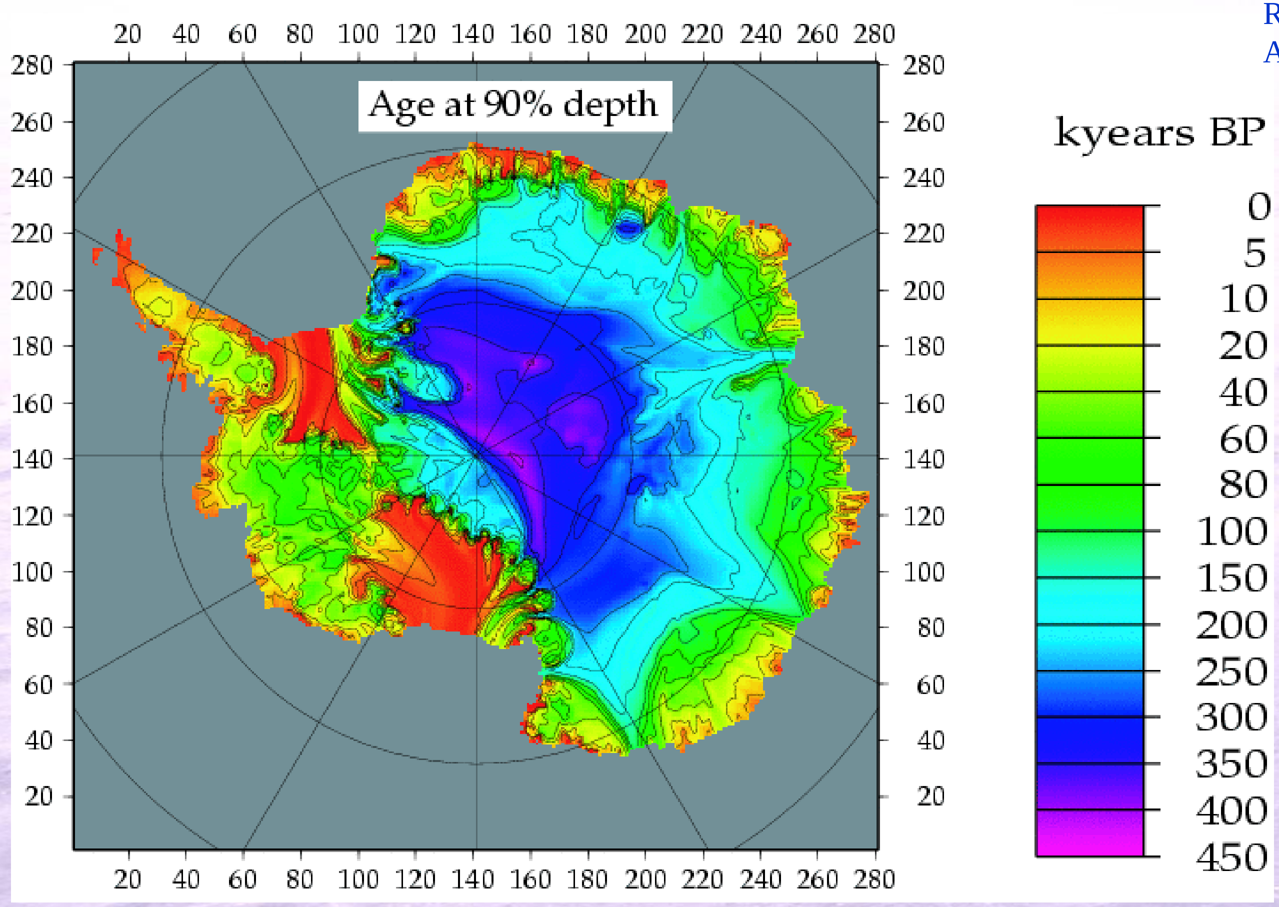
Higher CO_2 atmospheric levels before 1 M yr ago ?

Perspectives on ice-core measurements of greenhouse gases and other related trace gases

International Partnership in Ice Core Sciences (IPICS)

International Polar Year : in search for the oldest ice in Antarctica

Rybak and Huybrechts, Ann. Glaciology, 2003



Thank you for your attention…

The EPICA / Dome C European drilling and science team