European Geosciences Union – General Assembly 2008

GEOPHYSICAL INFORMATION FOR TEACHERS (GIFT) WORKSHOP

Natural variations of atmospheric CO_2 and CH_4 from ice cores

EPICA Dome Concordia drilling trench
© S. Drapeau, IPEV

Jérôme Chappellaz

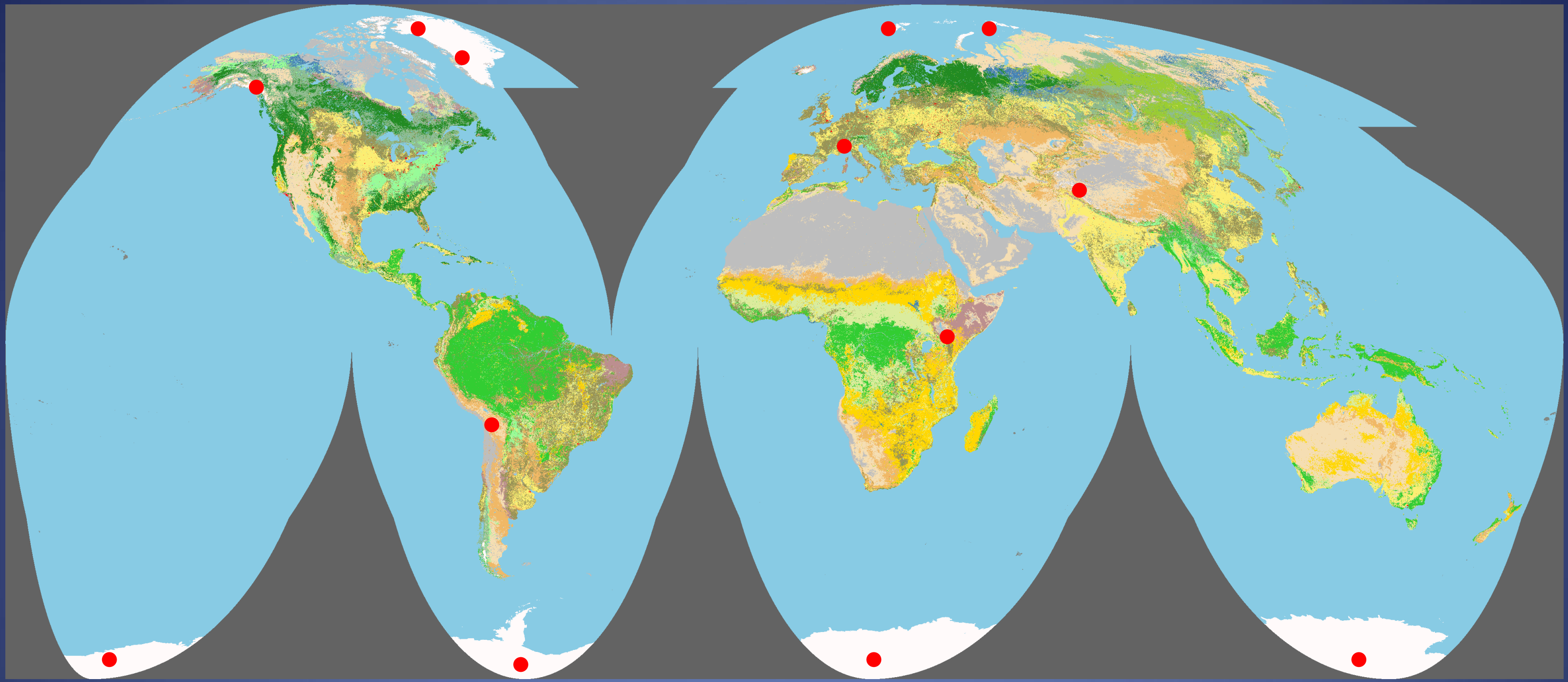
Laboratoire de Glaciologie et Géophysique de l ’Environnement, Grenoble, France

LGGE
Laboratoire de Glaciologie et Géophysique de l'Environnement

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



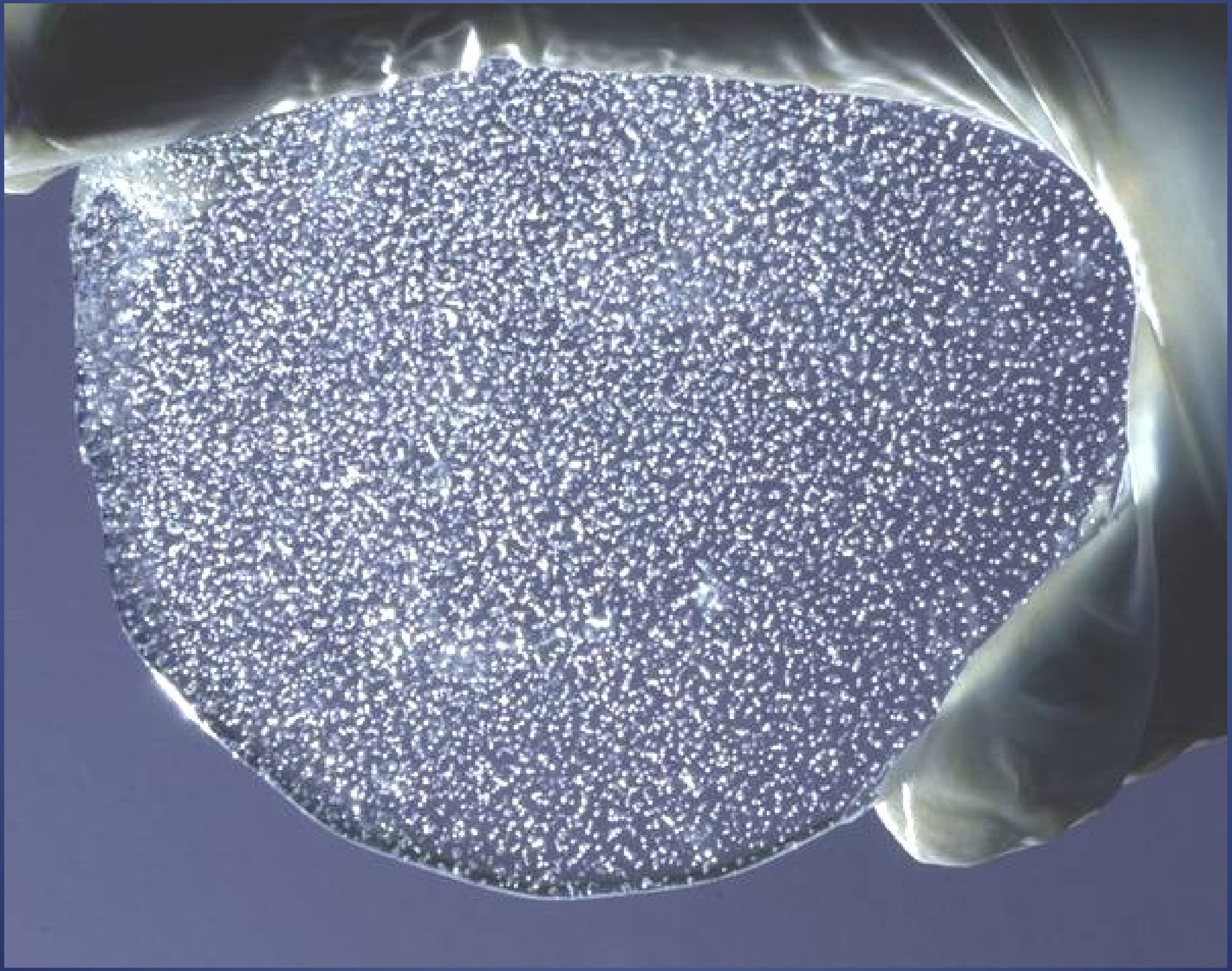
Advantages	Disadvantages
• Temporal resolution • Range of parameters • Regional to global significance • No biology in the transfer function	• Only on poles or mountains • A few 100,000 years coverage • Physics and chemistry of transfer function not always straightforward

Parameters accessible in natural ice

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

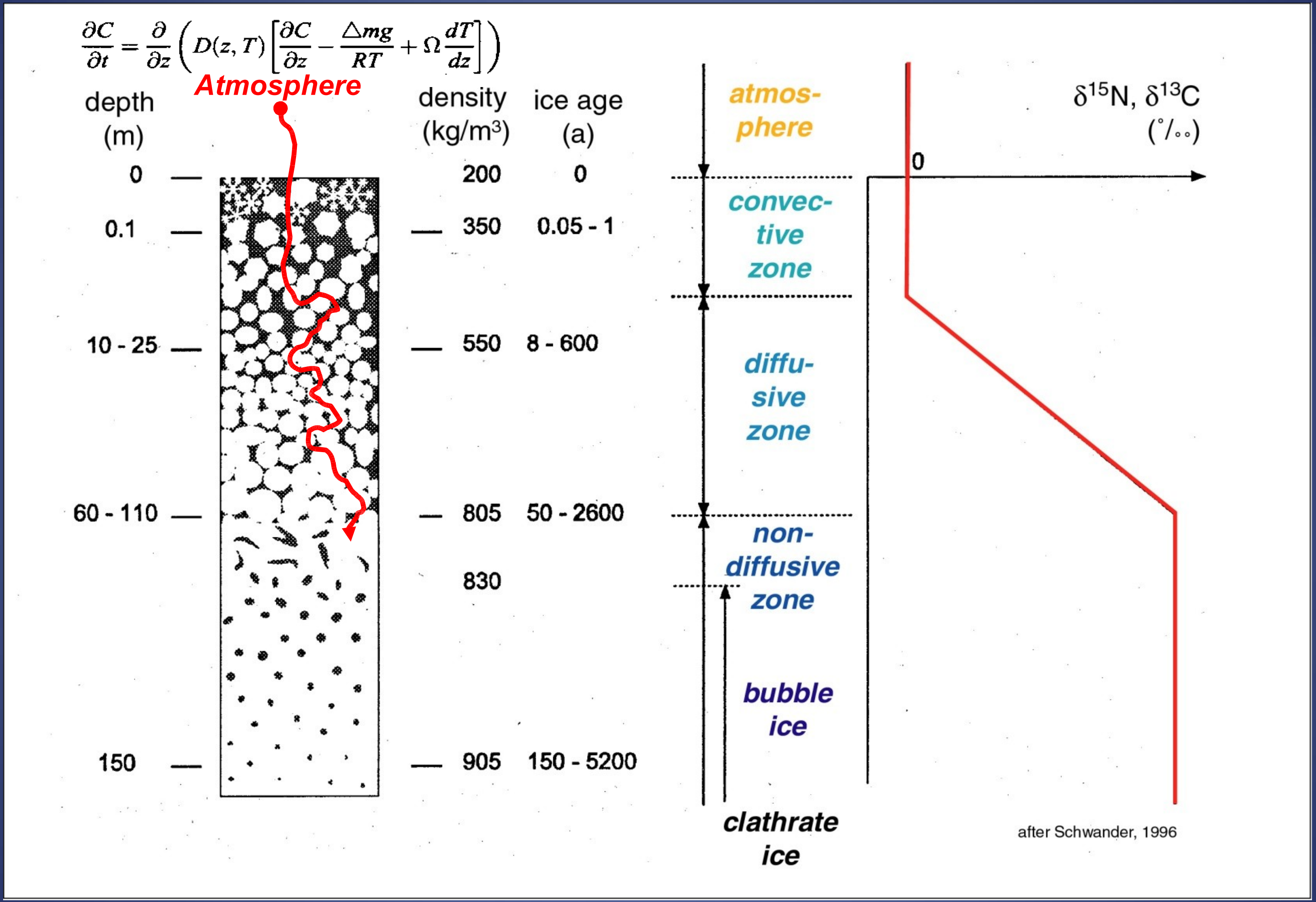
- Temperature (isotopes of H_2O)
- Accumulation (stratigraphy, ^{10}Be)
- Aerosols of natural origin :
  - Marine (Cl^-, Na^+, $SO_4^=$, MSA,...)
  - Continental (dust, Al, Ca^{++}, NH_4^+, organic acids)
  - Volcanic (Cl^-, $SO_4^=$)
  - Cosmic (Ir, ^{10}Be)
- Aerosols of anthropogenic origin :
  -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

How does Nature make an atmospheric archive in air bubbles trapped in natural ice ?



Bubbles in polar ice

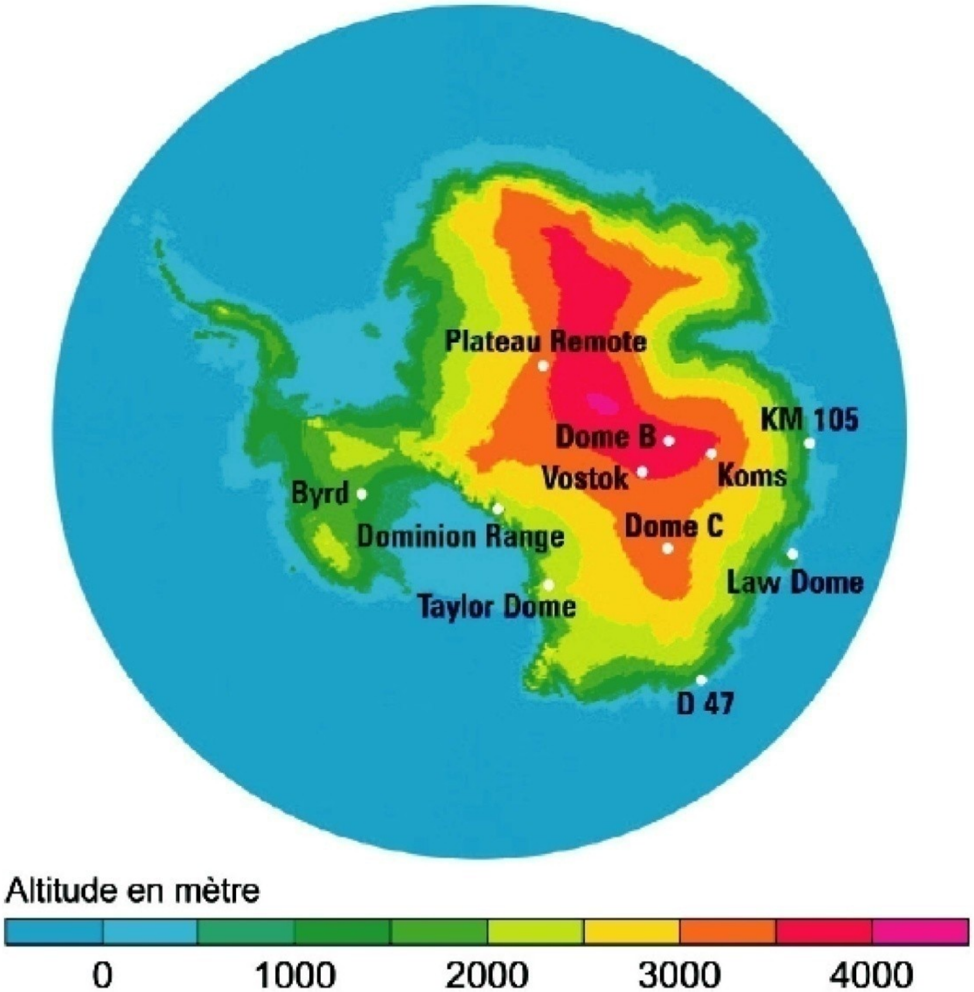
Gas diffusion and trapping in polar firn



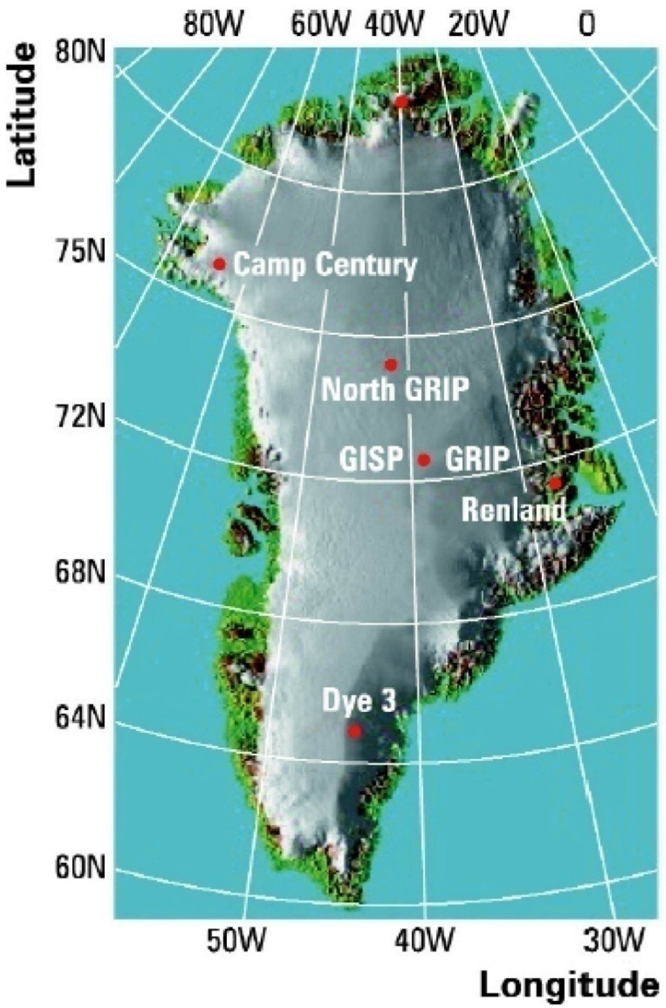
Adapted from Schwander, NATO ASI, 1996

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

Antarctica

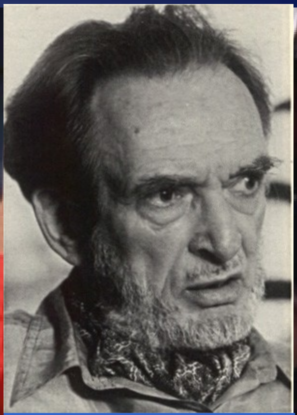


Greenland

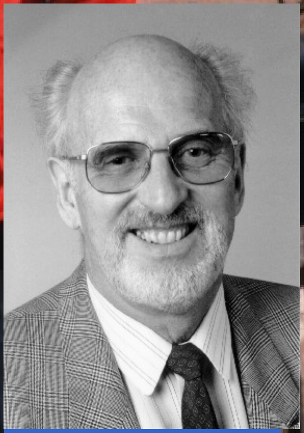


1968-2008 : 40 years of international efforts to drill deep ice cores

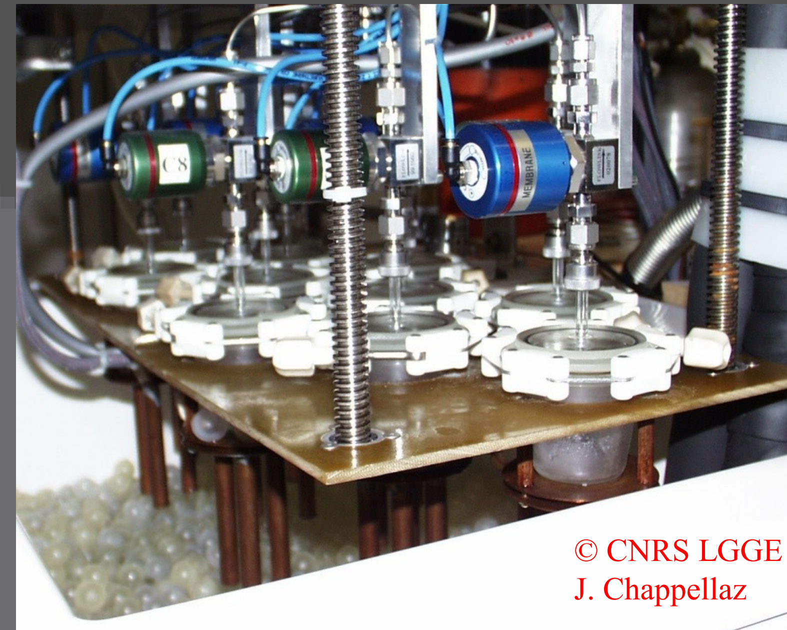
Claude Lorius
Vostok station
1983



Willi Dansgaard

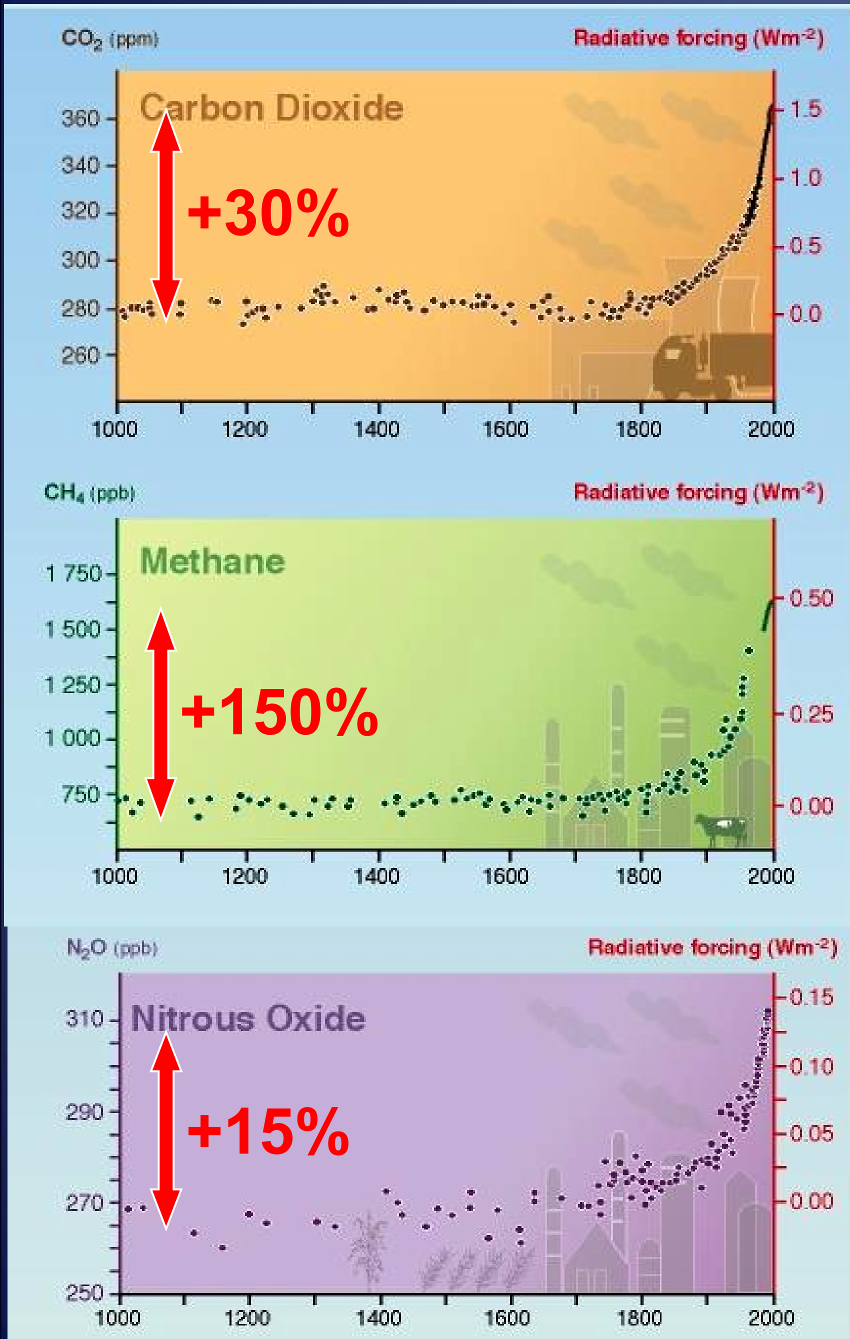


Hans Oeschger



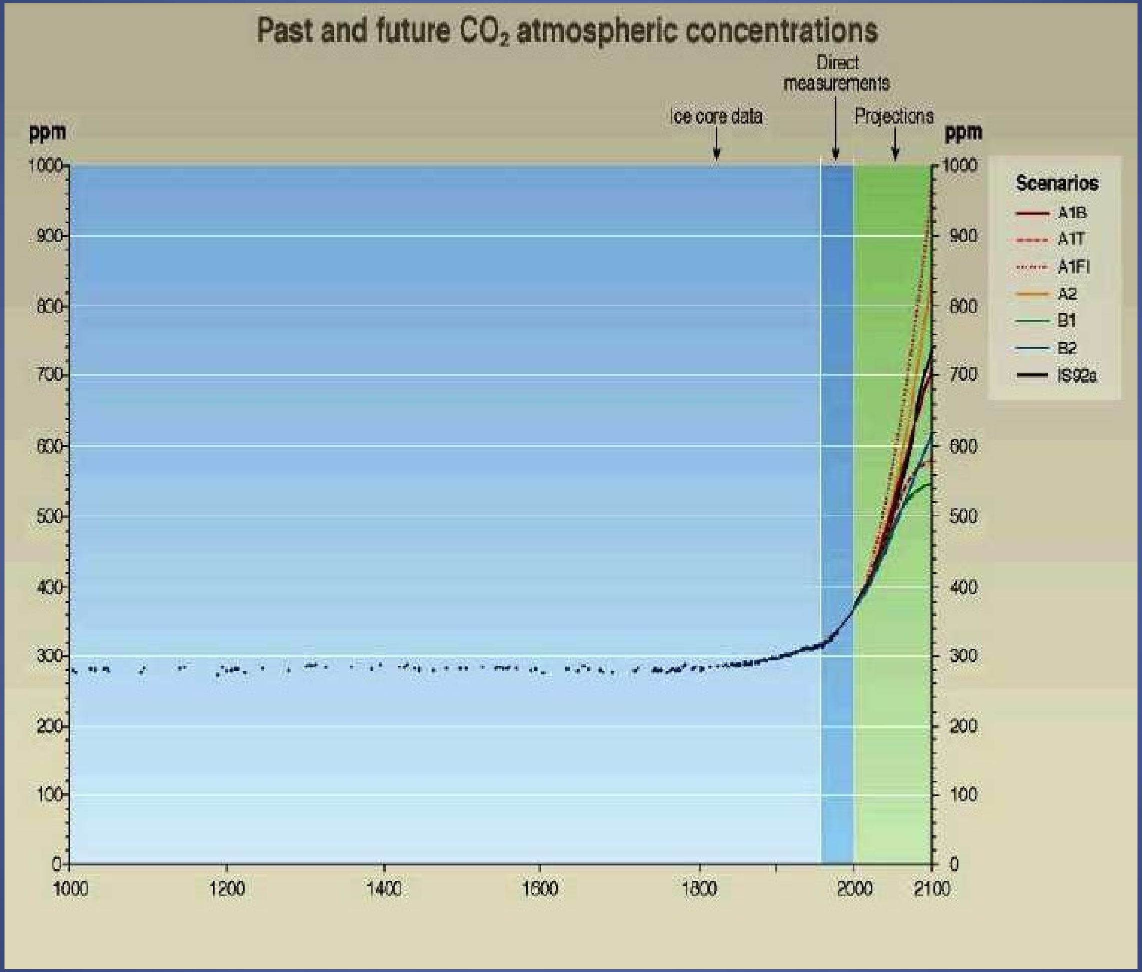
- **Gas extraction:**
  - **Melting**
  - **Melting/refreezing**
  - **Crushing**
  - **Sublimating**
- **Gas analysis:**
  - **Gas chromatography**
  - **Laser absorption**
  - **Mass spectrometry**

The ice-core warning: GHG anthropogenic increase



2001 IPCC report

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

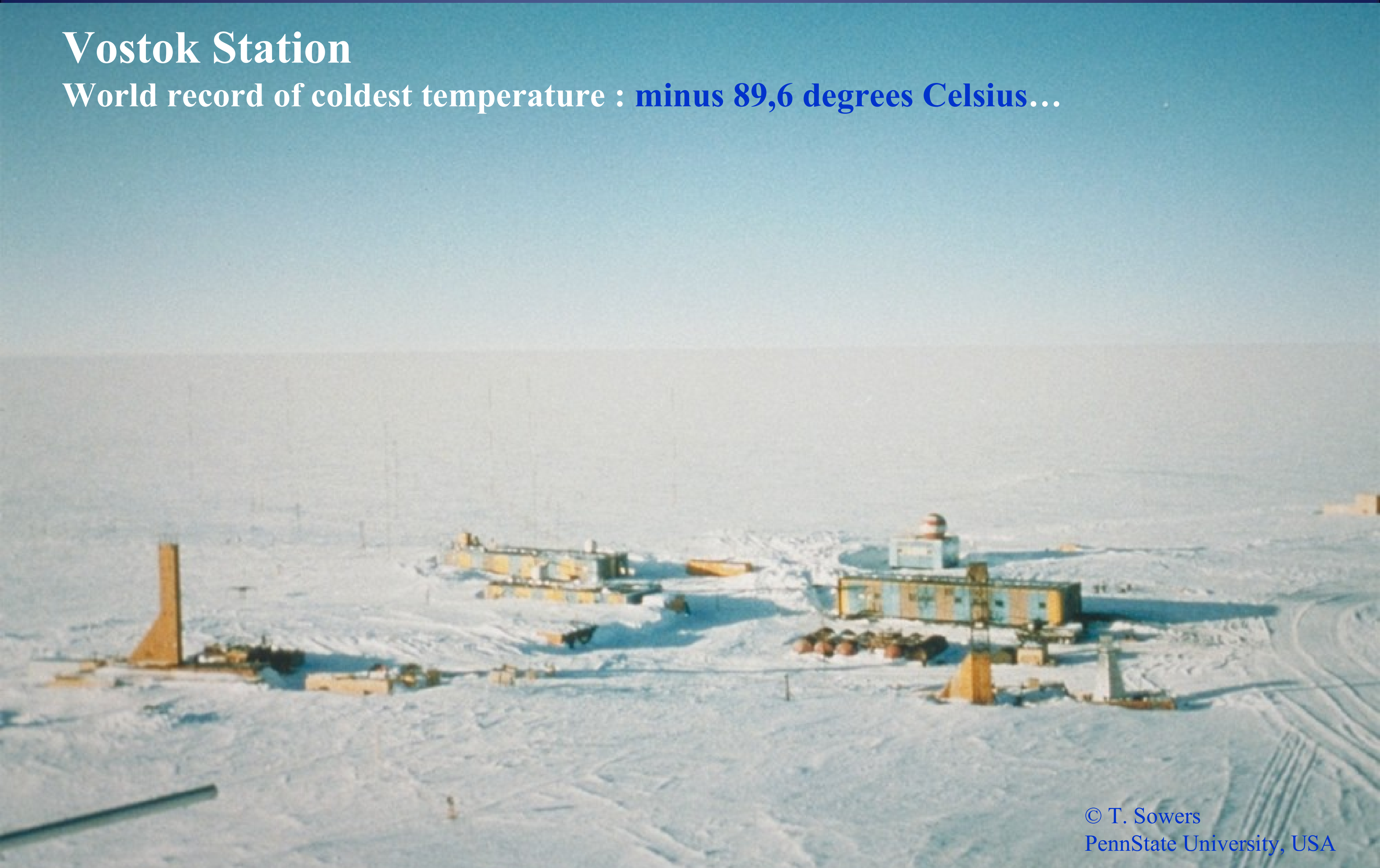


Uncertainties on future GHG mixing ratios are linked to anthropogenic emission scenarios but also to natural feedbacks; looking into the past allows one to constraint the climate/GHG links

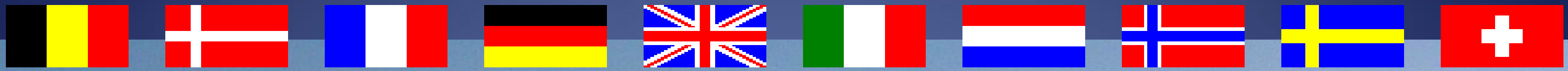
Four Glacial-interglacial cycles: Vostok

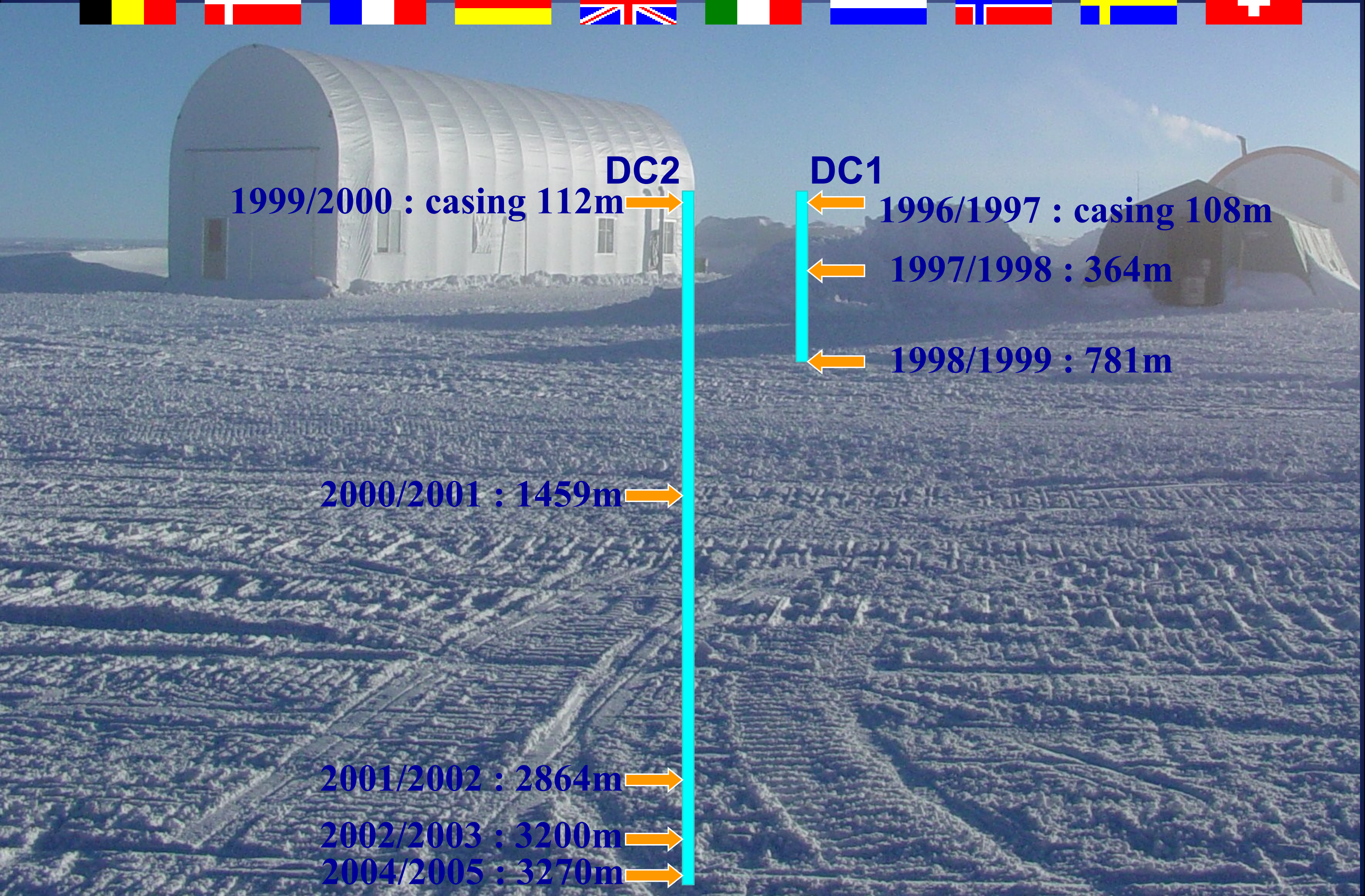
Vostok Station

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

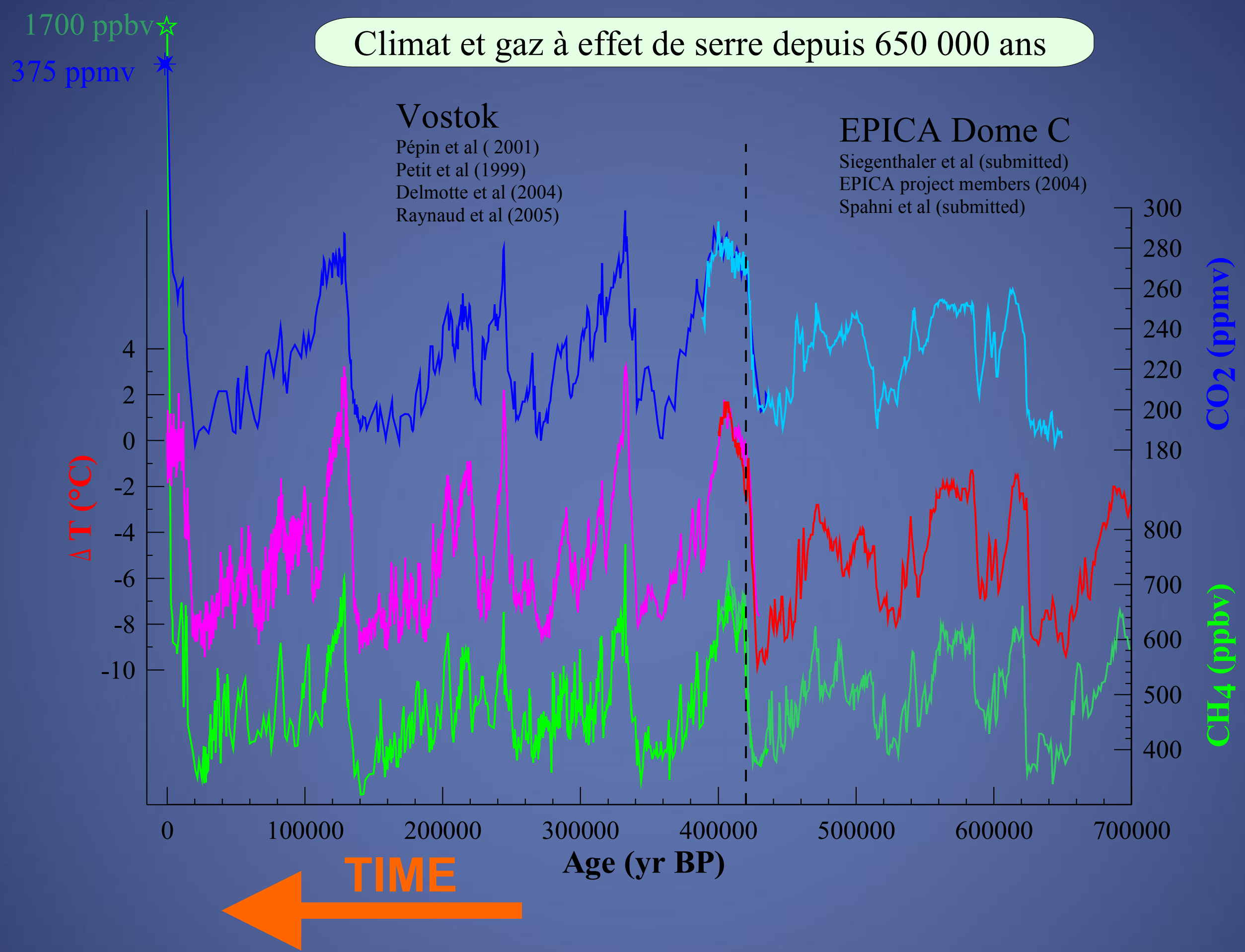


Eight Glacial-interglacial cycles: EPICA/Dome C





Six Glacial-interglacial cycles: EPICA/Dome C

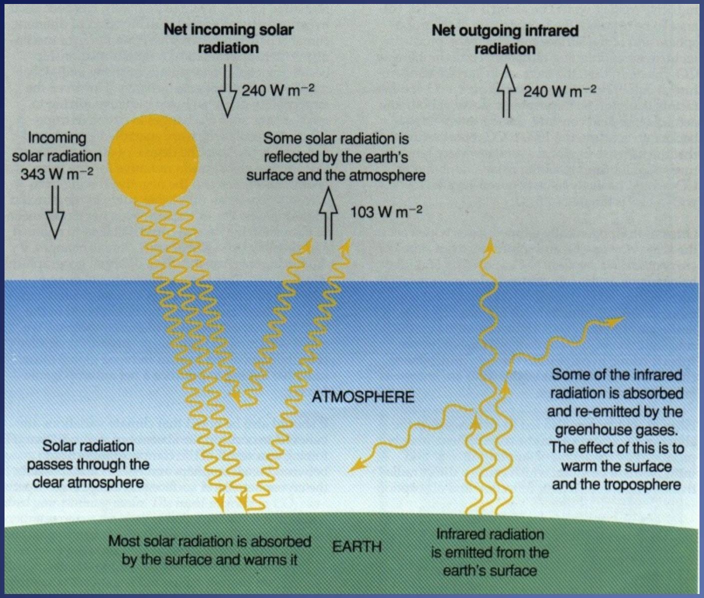


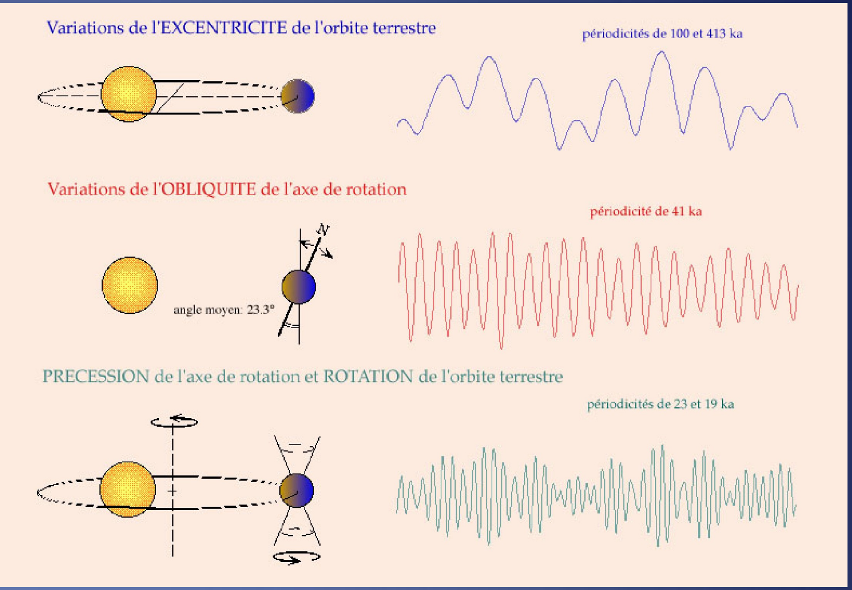
High co-variance of temperature, carbon dioxide and methane

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

CH_4 : 350-800 ppbv (~75 ppbv / °C)

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

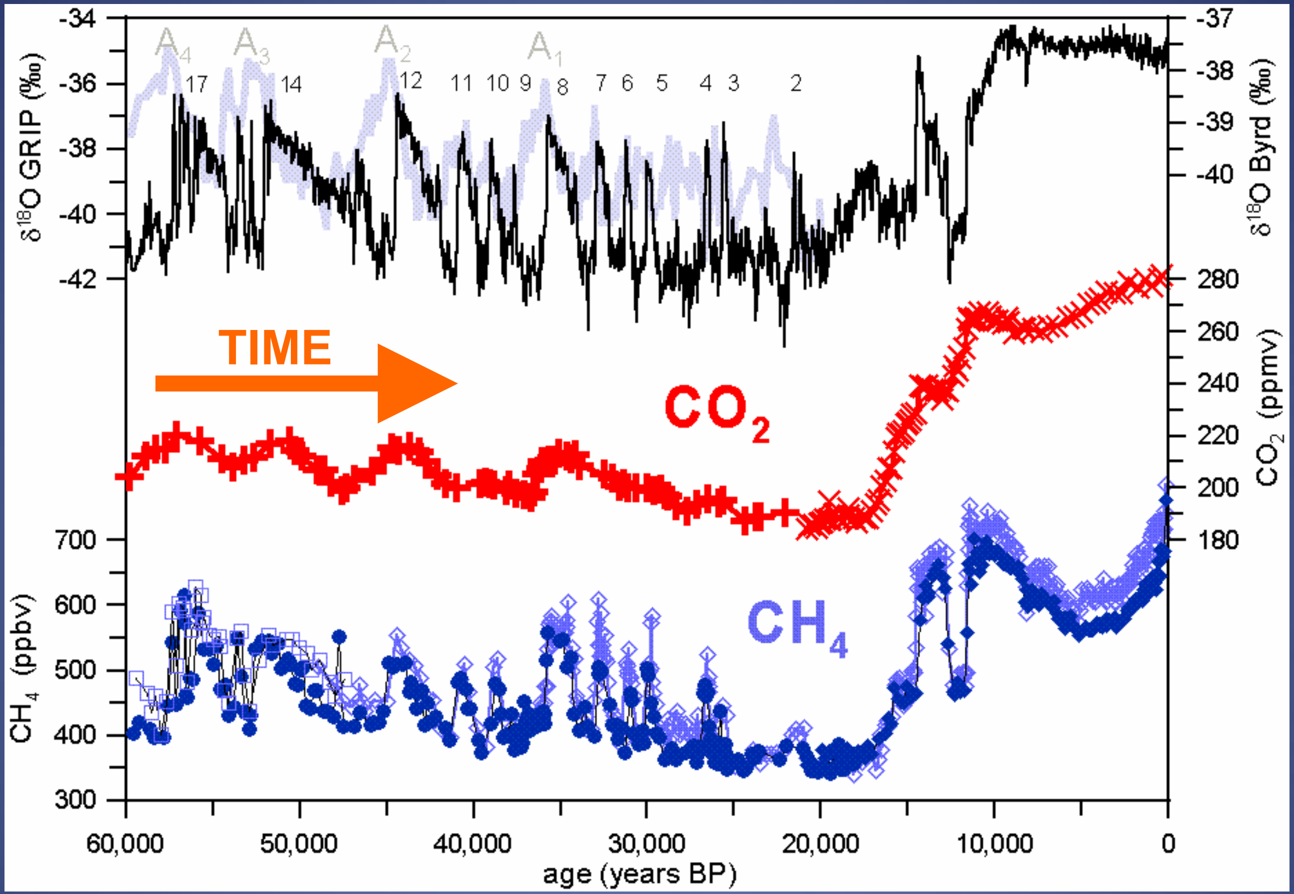
+3.5 ± 1 W/m² from the albedo effect (snow, ice and vegetation)

+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**

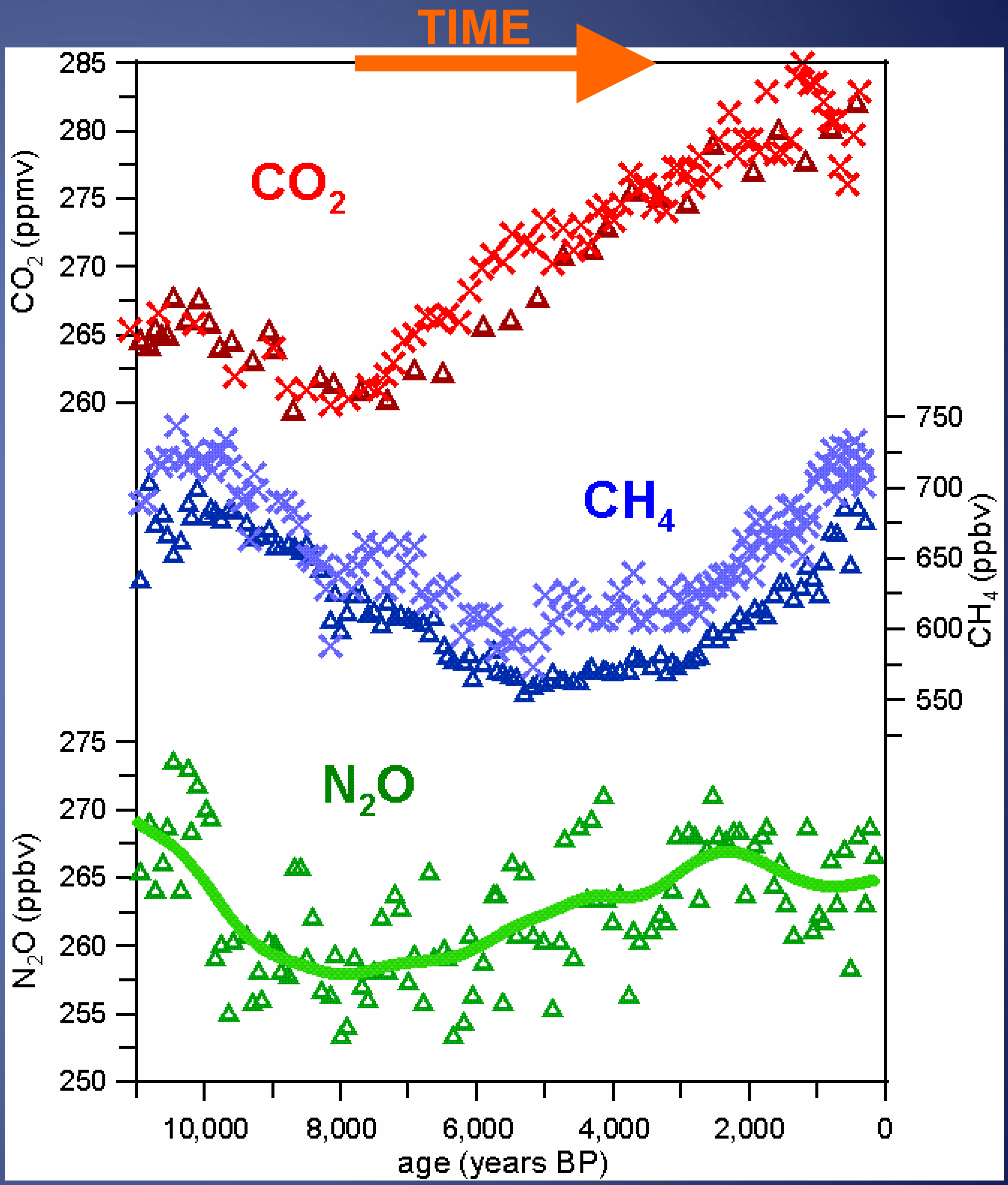
CH_4 : **- 100-200 ppbv variability associated with changes in North Atlantic and Greenland climate**
- synchronous with t° or lags by a few decades
- increases over 50 to 150 yr

Learning from the past: the timing of events

The Holocene (last 10,000 yr)

CO_2 : 20 ppmv change with minimum around 8000 yr BP

CH_4 : 150 ppbv change with minimum around 5000 yr BP



Stauffer et al., 2002 and ref. therein

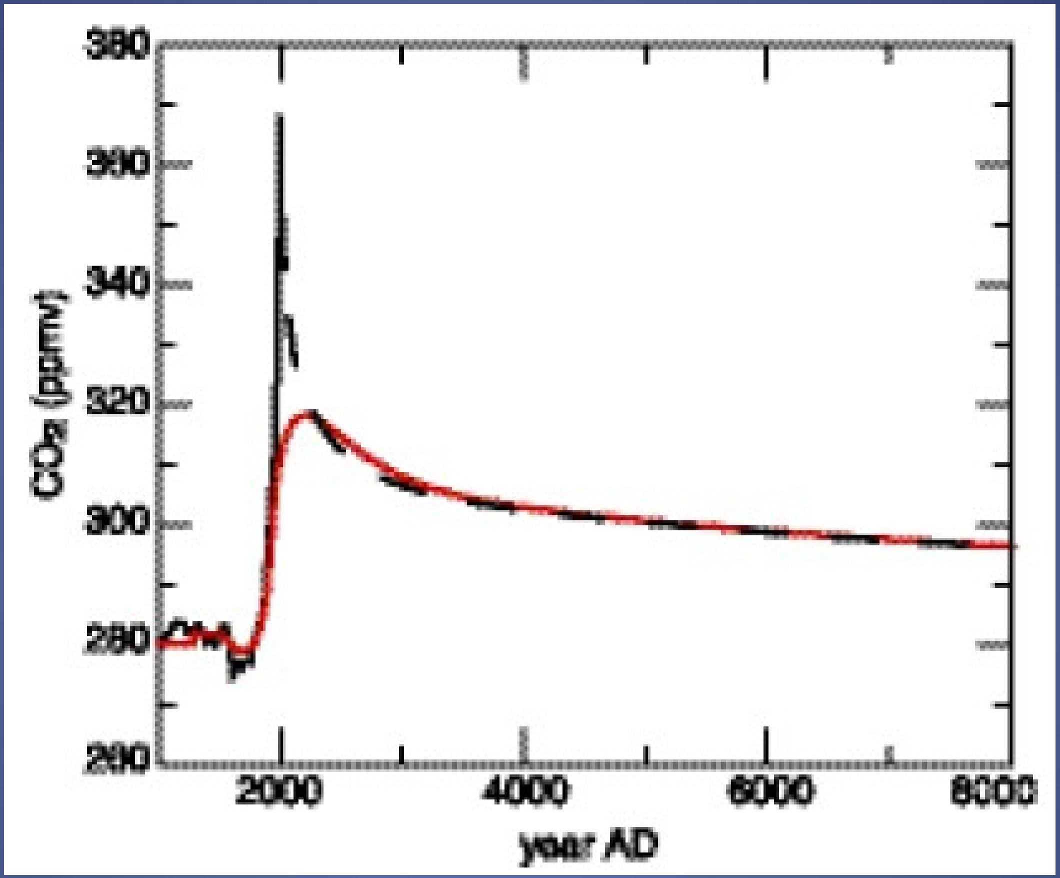
Summary of ice-core observations relevant to the climate/GHG relationship

Range of GHG 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

How exceptional is the current CO_2 level and trend ?



Raynaud et al., 2002

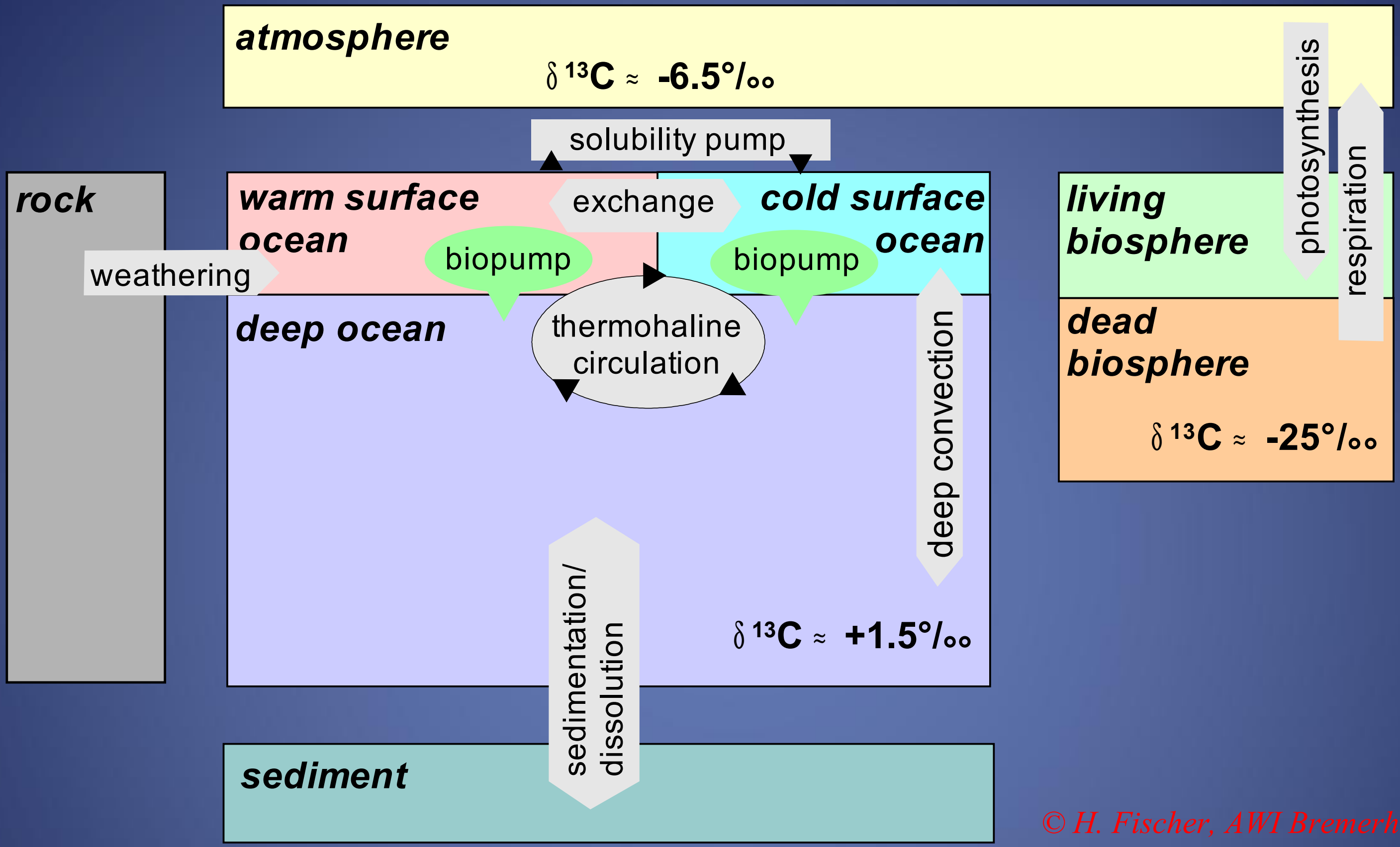
Anthropogenic increase up to the year 2000, followed by human carbon emissions set to zero : this would clearly stand out in the ice core record, even under gas trapping conditions similar to those at Vostok

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

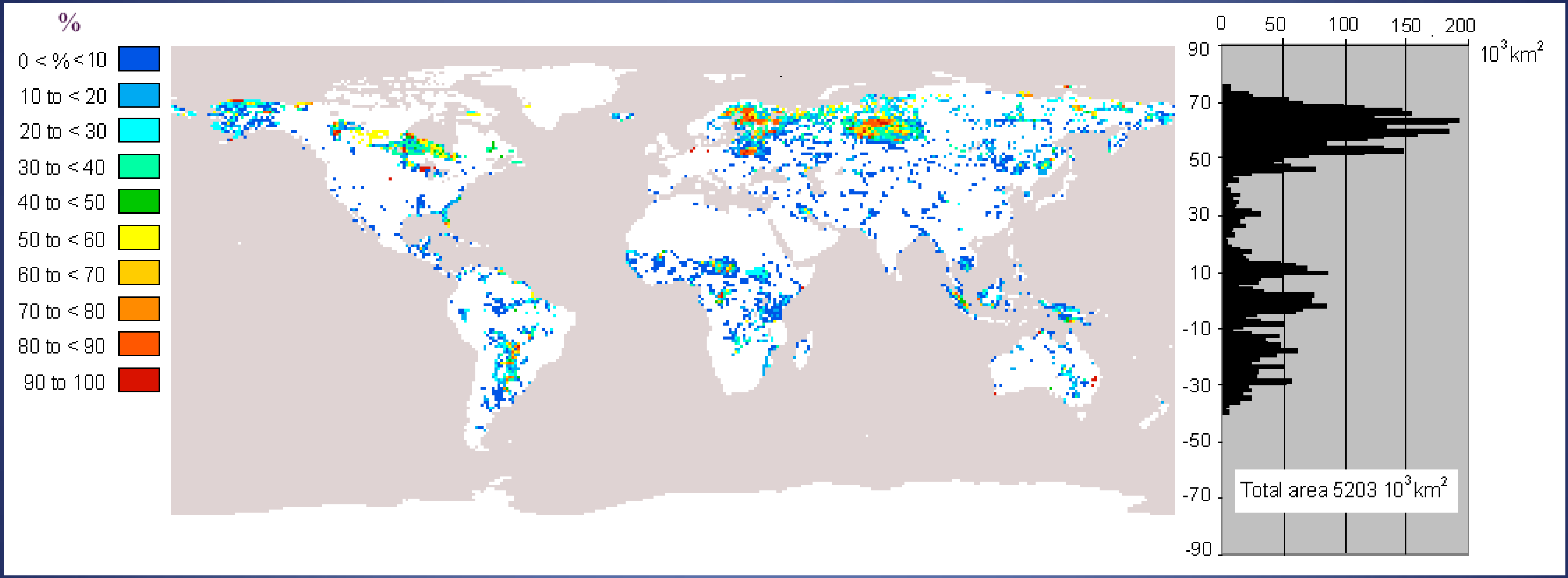


Probable dominant role of processes within the Southern ocean (surface temperature, sea-ice extent, iron fertilisation, surface/deep ocean exchange)

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 ?
Modulation at precessional periodicities through tropical wetlands
Boreal wetlands switch on during deglaciations

Biomass burning ? Would have remained relatively constant

Causes of CH_4 natural variability

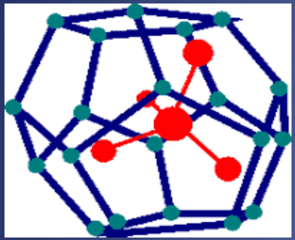
- Oxidative capacity of the atmosphere (OH radicals)

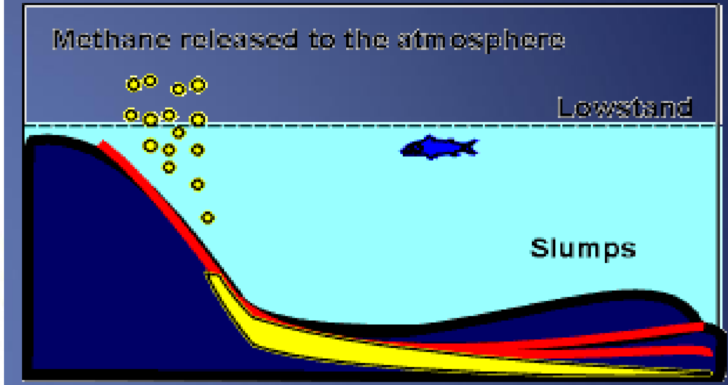
Type of model *(reference)*	Difference between OH at Last Glacial Maximum and OH today (in %) *A positive number means more OH at the Last Glacial Maximum*
Bi-dimensional photochemical *(Valentin, thesis U. Mainz, 1990)*	+30-40%
Uni-dimensional photochemical *(Pinto and Khalil, Tellus 1991)*	+20%
Uni-dimensional 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 (scenario contradicted by amplitude of CH_4 change, sustained high levels, N_2O co-variations, isotopes in CH_4)

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

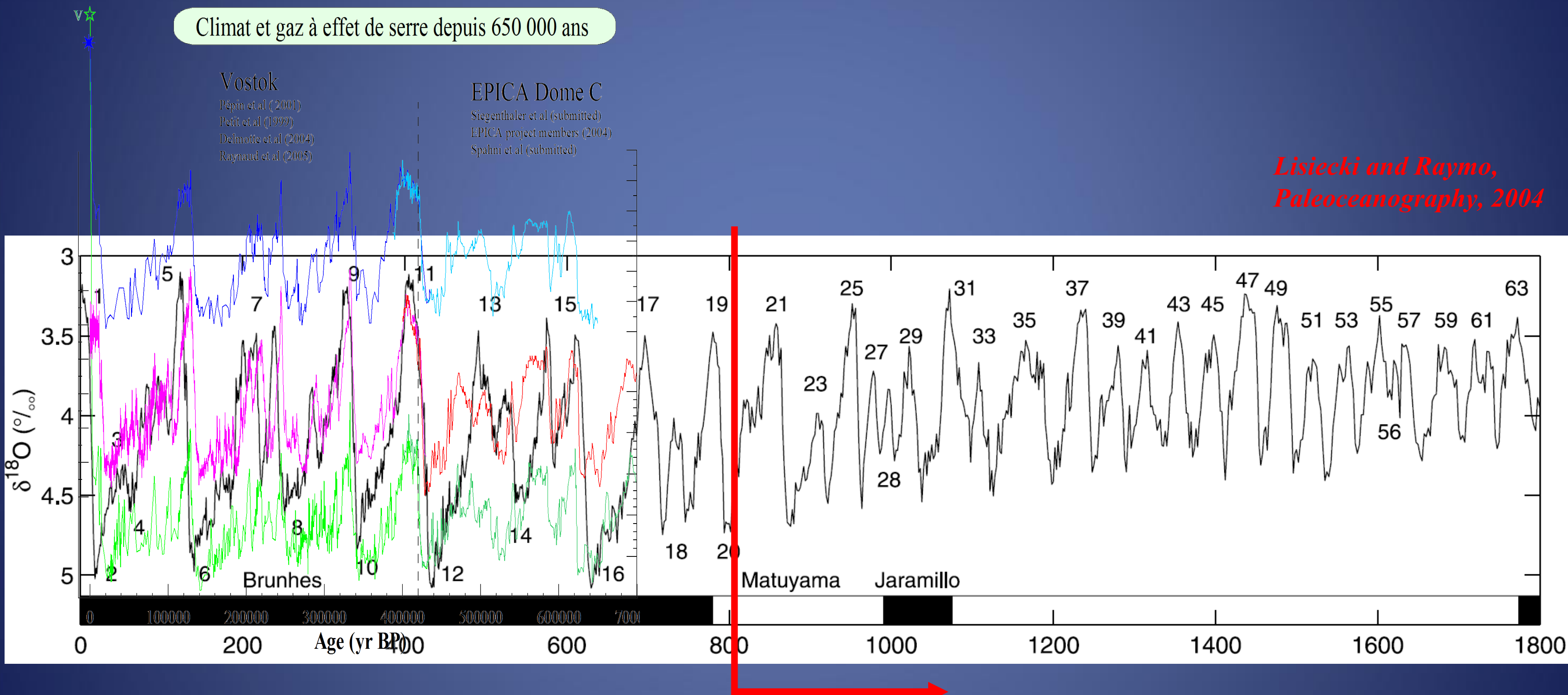
- The strong coupling between the natural evolution of CO_2 and CH_4 mixing ratios and climate implies that future natural feedbacks with climate warming must be expected

- 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.

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



100,000 year Periodicity

40,000 year Periodicity

Is CO_2 responsible for the change in climate rythm,

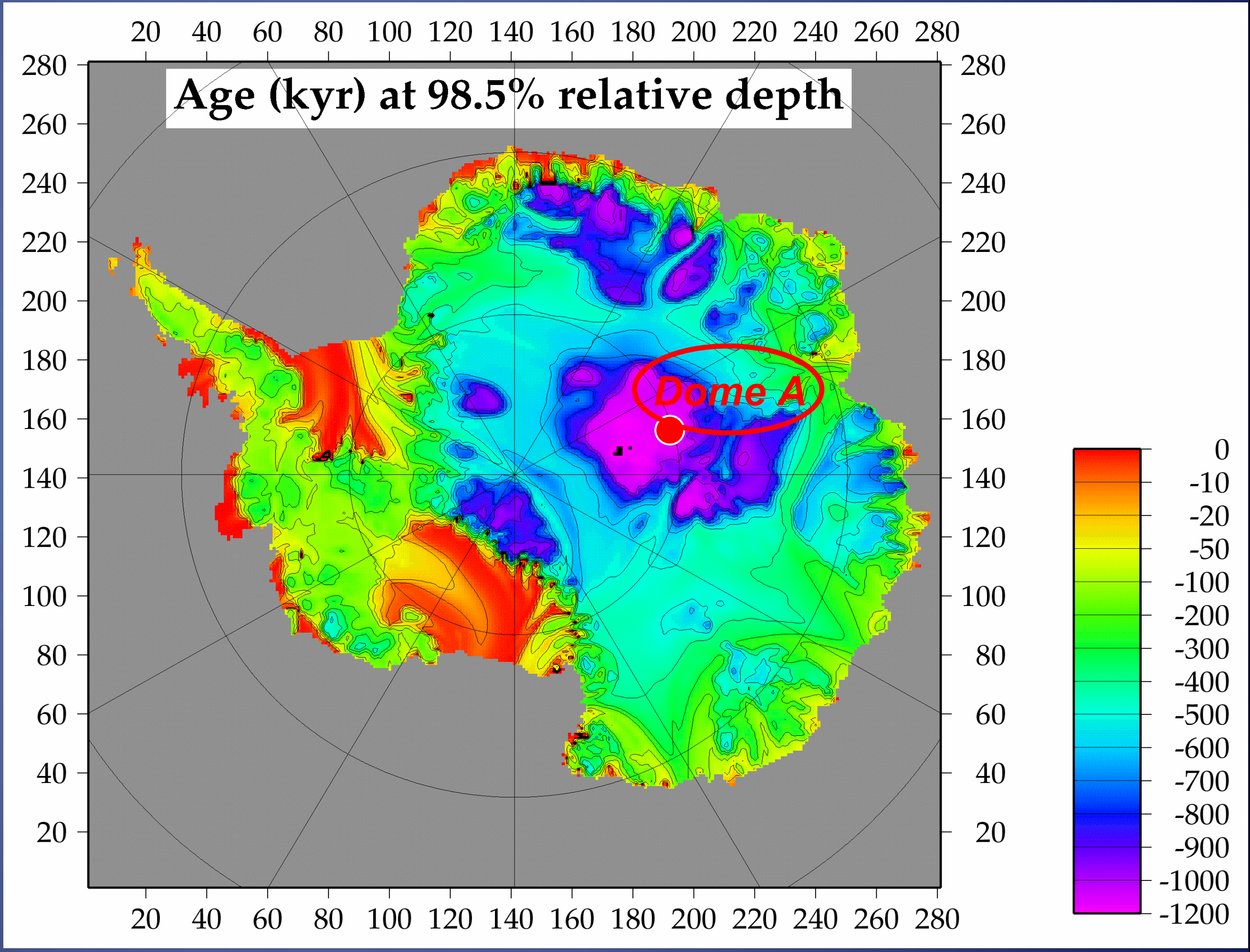
about 1 Million years ago ?

IPICS: The oldest ice core: A 1.5 million year record of climate and greenhouse gases from Antarctica

Steps:

3. Reconnaissance studies
4. Pinpoint the exact locations of the drill site(s)
5. Assemble teams and money
6. Drilling and science

Time frame : 2007-2017



Rybak and Huybrechts, Ann. Glaciology, 2003

Thank you for your attention…

First winter-over at Concordia station, Antarctica, austral winter 2005