Past climate from ice cores North and South

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Outline

I- Polar regions in the climate system

II- Climate archives in ice caps

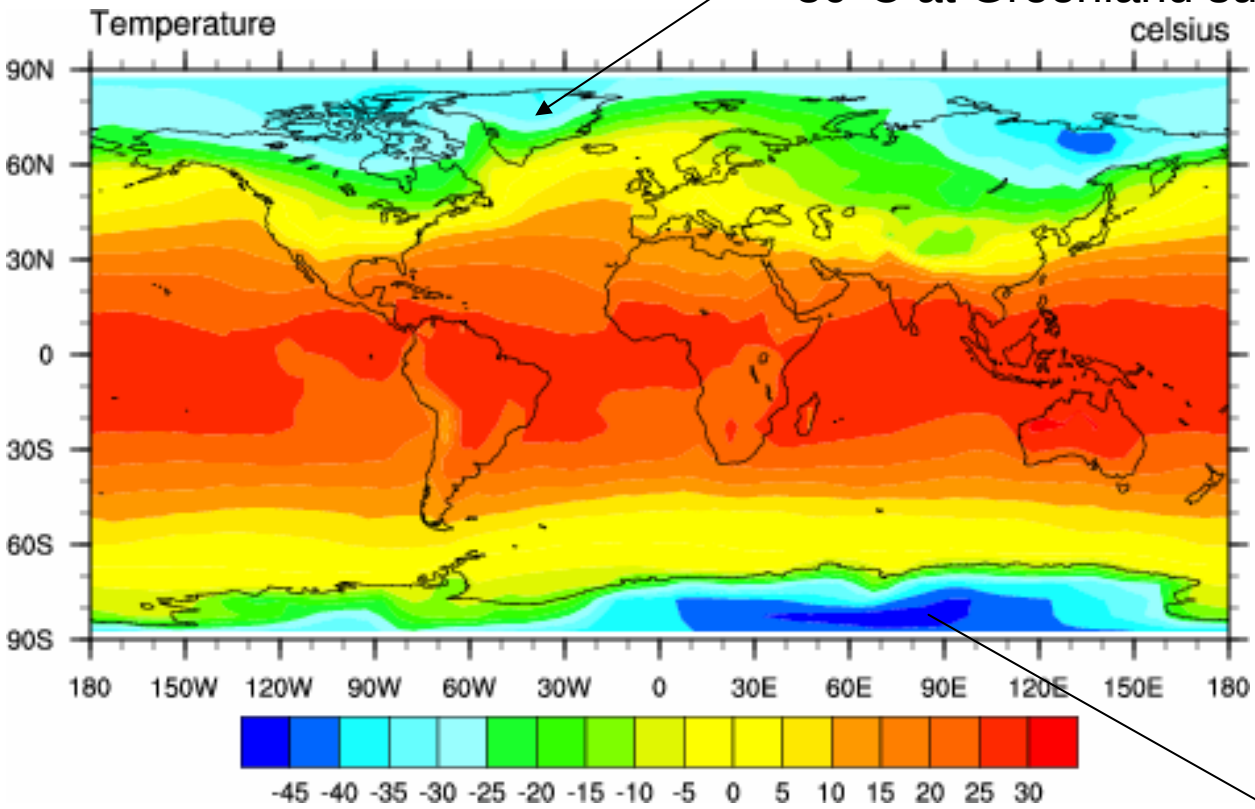
III- Climate reconstructions from deep ice cores
Focus on temperature changes

IV- Perspectives

I- Polar regions in the climate system

Polar regions in the climate machine

Annual mean surface air temperature
- 30°C at Greenland summit



Annual mean surface air temperature
- 55°C in the central Antarctic Plateau

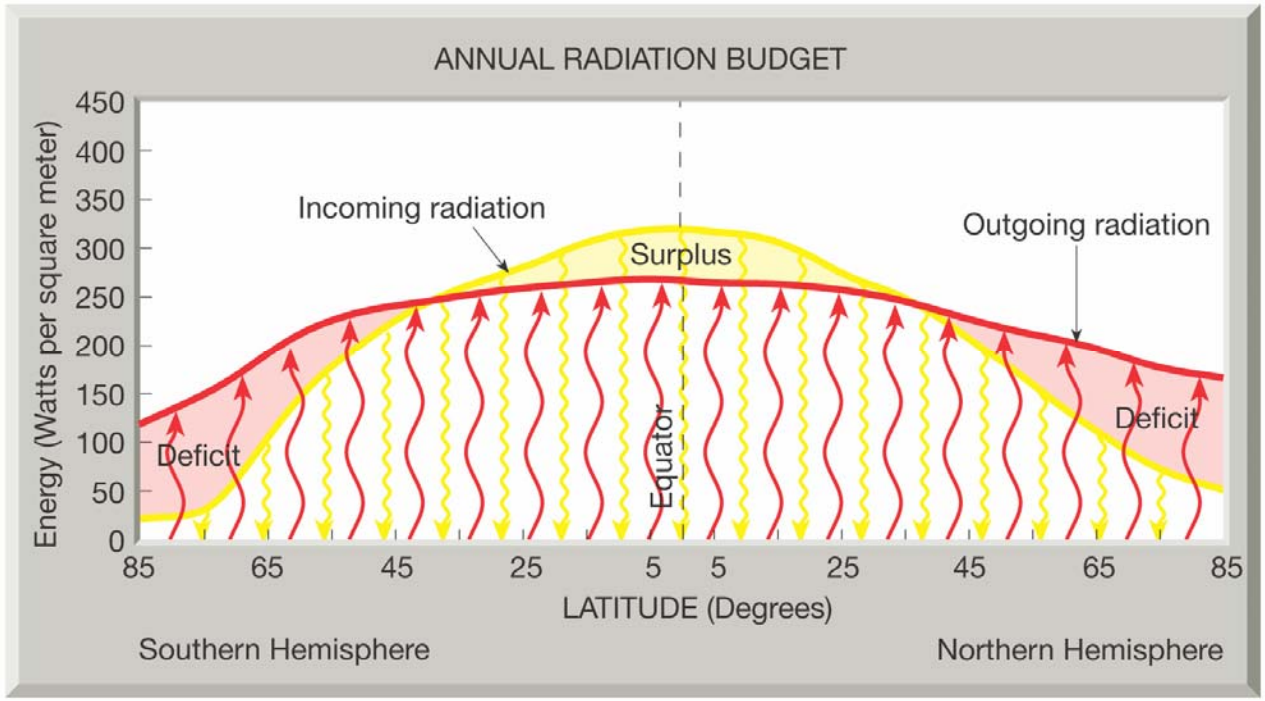
Source : CRU
http://www.ncl.ucar.edu/Applications/cru.shtml

Polar regions in the climate machine

Distribution of solar energy (orbit of the Earth)

Atmosphere (greenhouse gases, aerosols, clouds)

Albedo of the surface

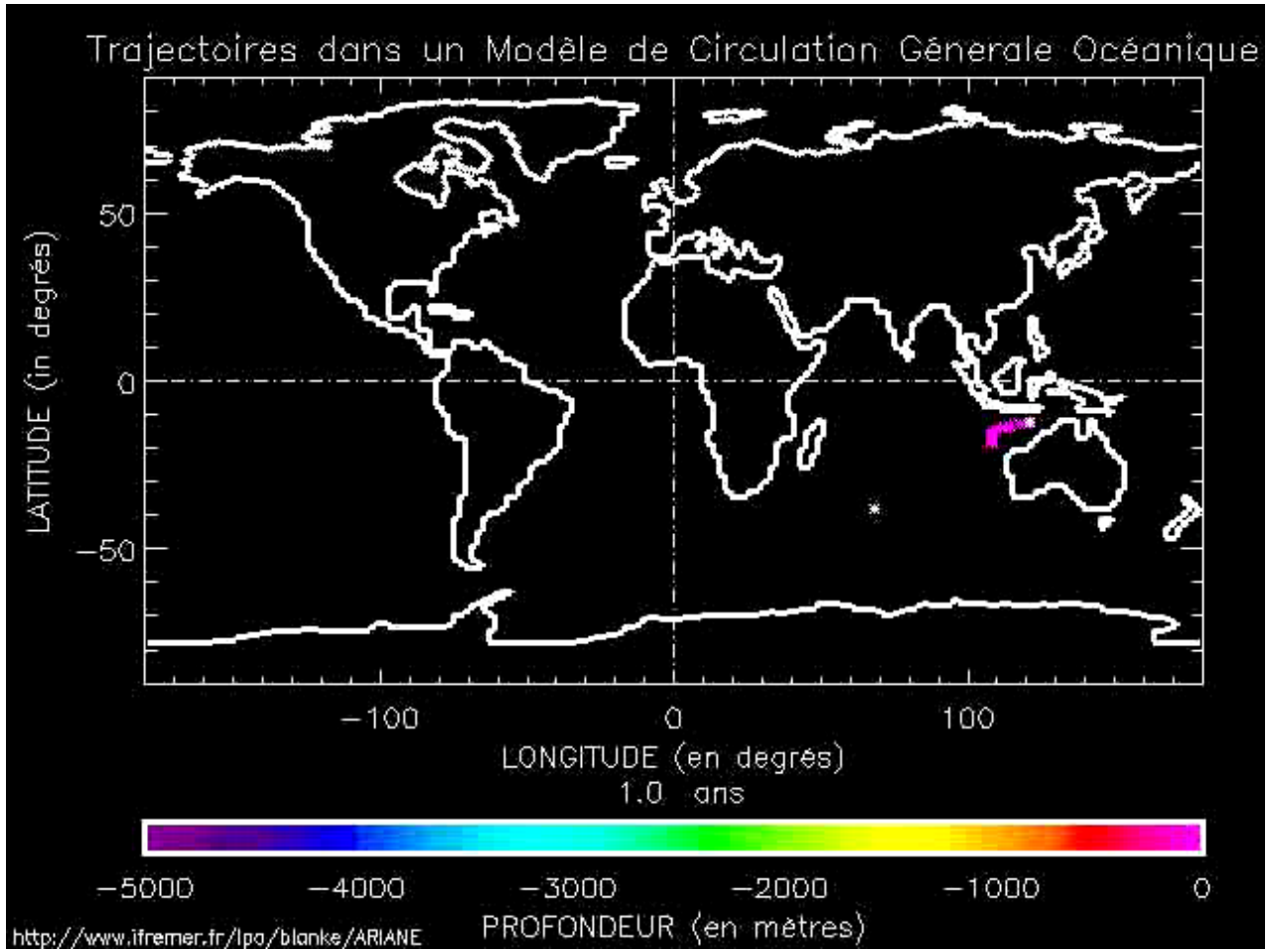


Polar regions

= areas where the Earth is losing energy towards space

= areas where the ocean and the atmosphere transport heat

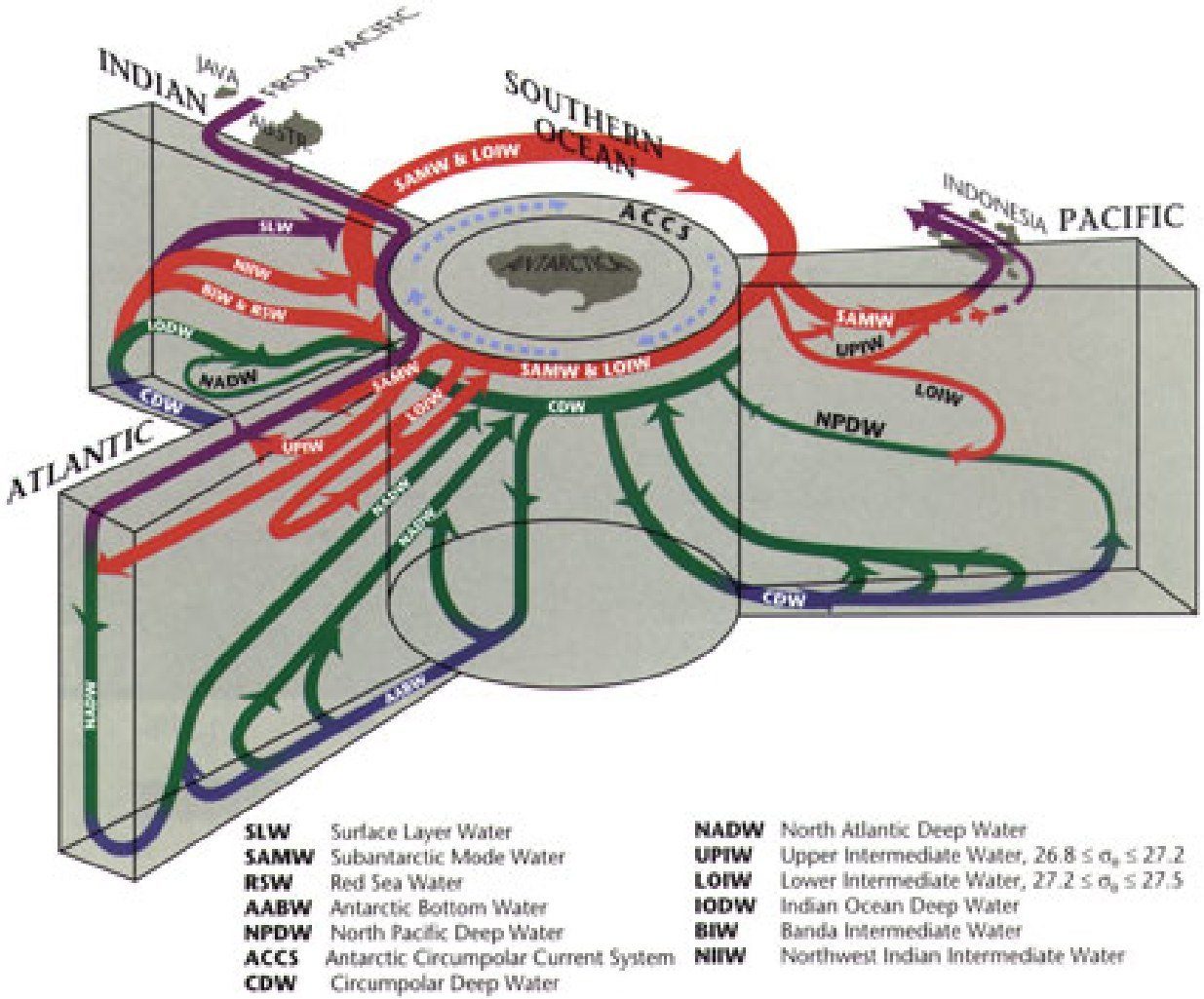
Polar regions in the climate machine



Global ocean circulation

Courtesy of Sabrina Speich (LPO) : http://www.ifremer.fr/lpo/speich/

A view of ocean circulation



SLW	Surface Layer Water	**NADW**	North Atlantic Deep Water
SAMW	Subantarctic Mode Water	**UPIW**	Upper Intermediate Water, $26.8 \le \sigma_\theta \le 27.2$
RSW	Red Sea Water	**LOIW**	Lower Intermediate Water, $27.2 \le \sigma_\theta \le 27.5$
AABW	Antarctic Bottom Water	**IODW**	Indian Ocean Deep Water
NPDW	North Pacific Deep Water	**BIW**	Banda Intermediate Water
ACCS	Antarctic Circumpolar Current System	**NIIW**	Northwest Indian Intermediate Water
CDW	Circumpolar Deep Water		

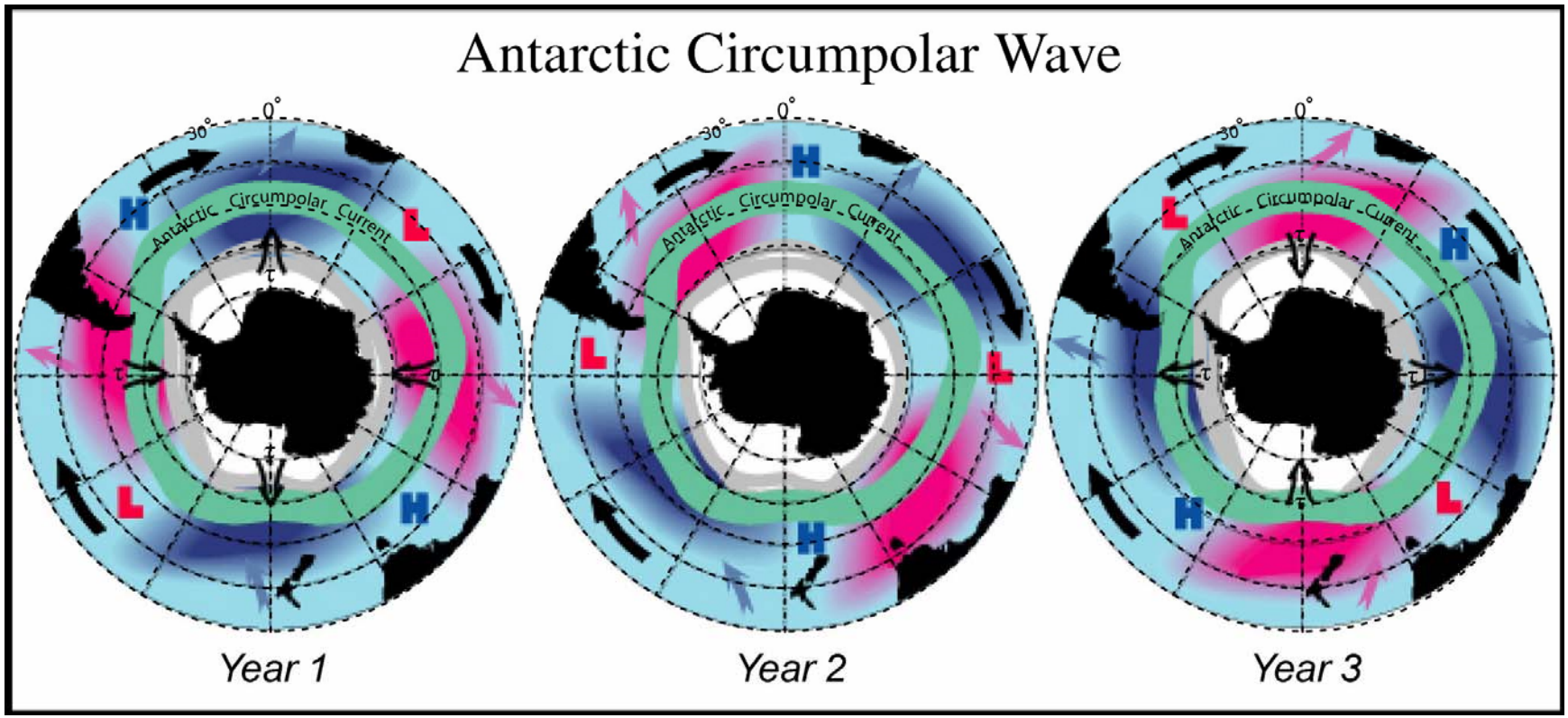
The Arctic Oscillation

Positive Phase

Negative Phase

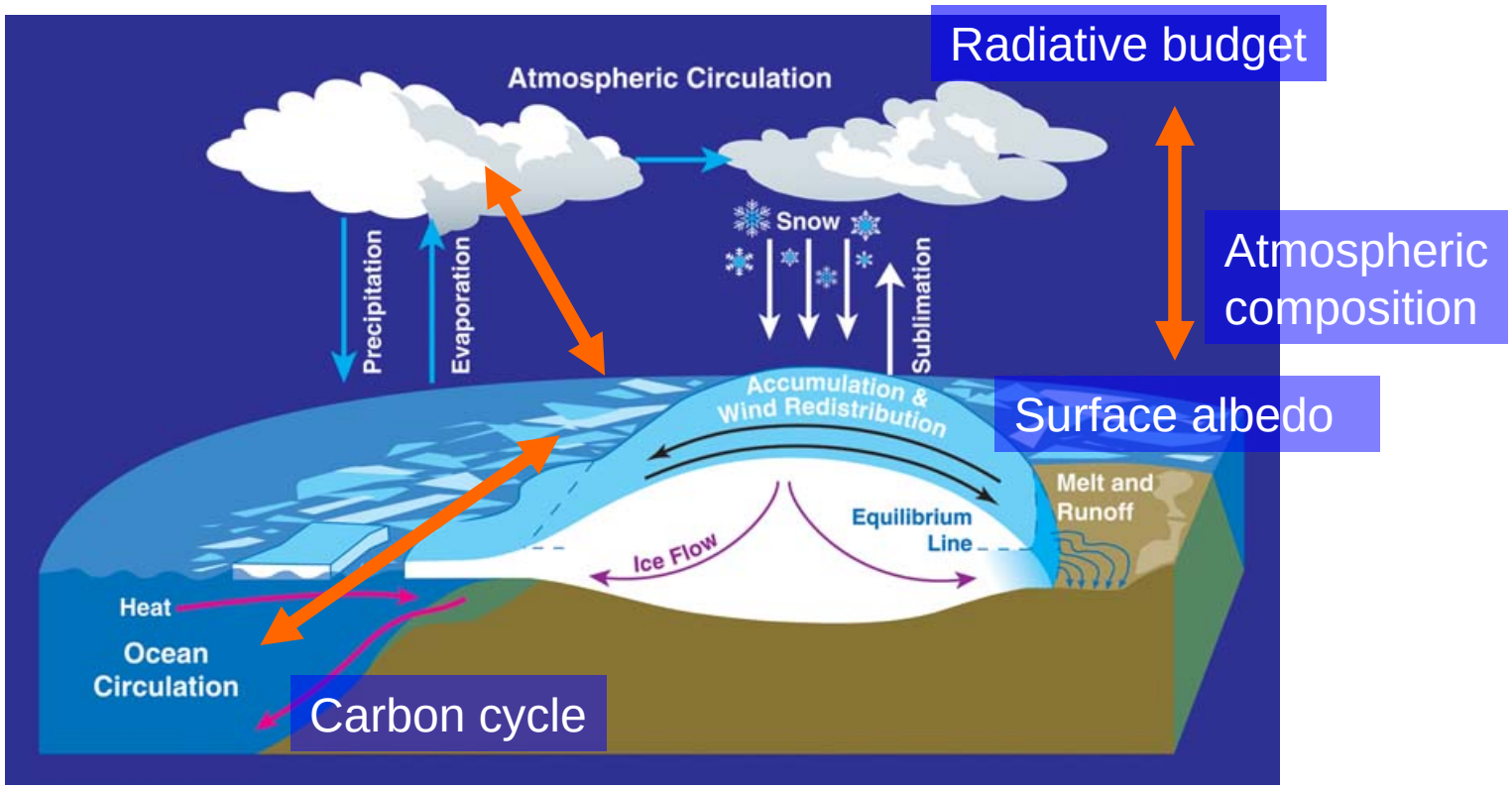
Source : University of Washington

Modes of Antarctic atmospheric circulation variability

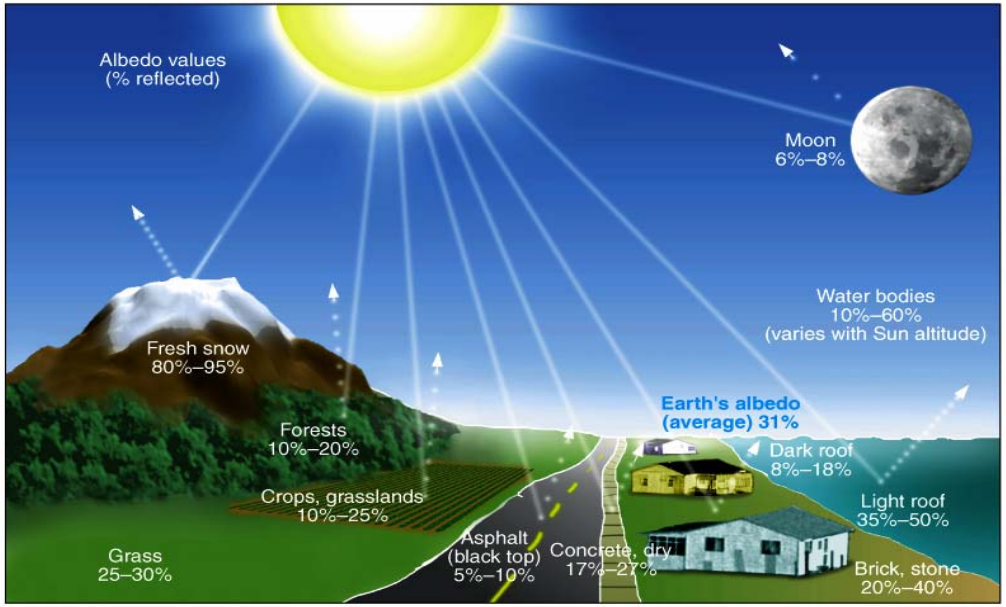


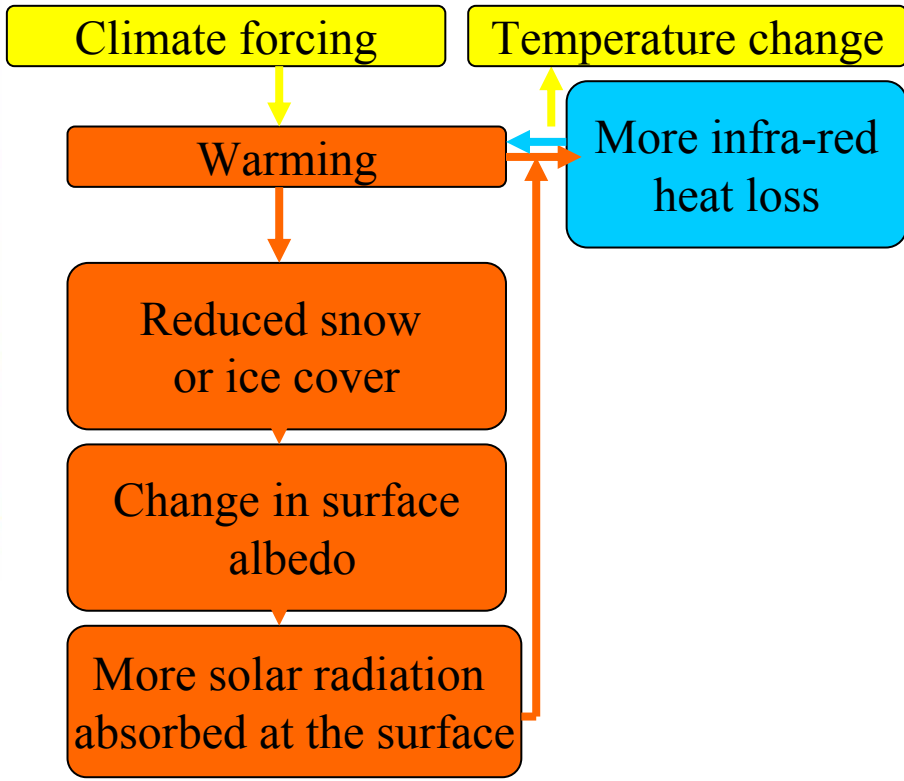
http://jedac.ucsd.edu/ACW/index_description.html

Links between climate change in the polar regions and global changes



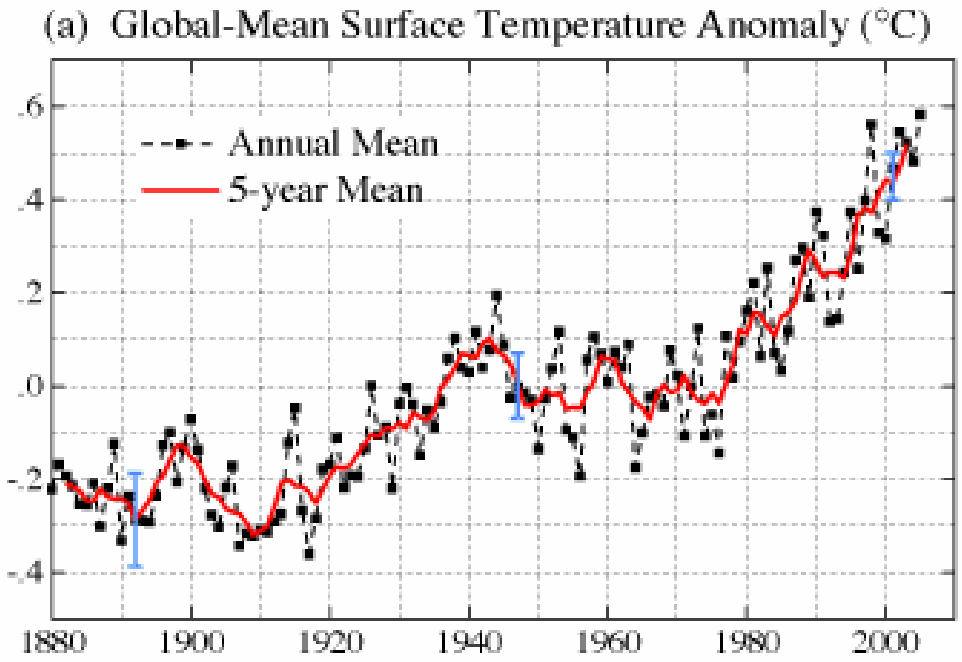
Amplification mechanism : change in surface albedo

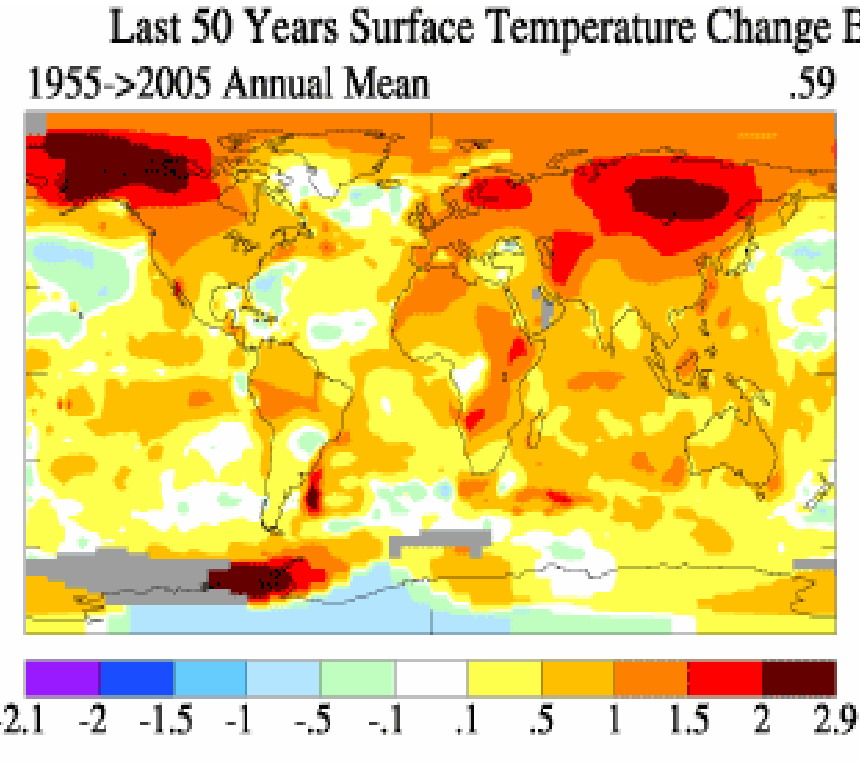




+ effect of water vapour content of the atmosphere
+ effect of the type of clouds formed
…

Climate change now





Source : NASA/GISS http://data.giss.nasa.gov/gistemp/2005/

Take home messages

- Polar regions : key climate areas

⇒ cold point of the climate system

⇒ ongoing large temperature changes

⇒ amplifying mechanisms (Ex: albedo of snow and ice)

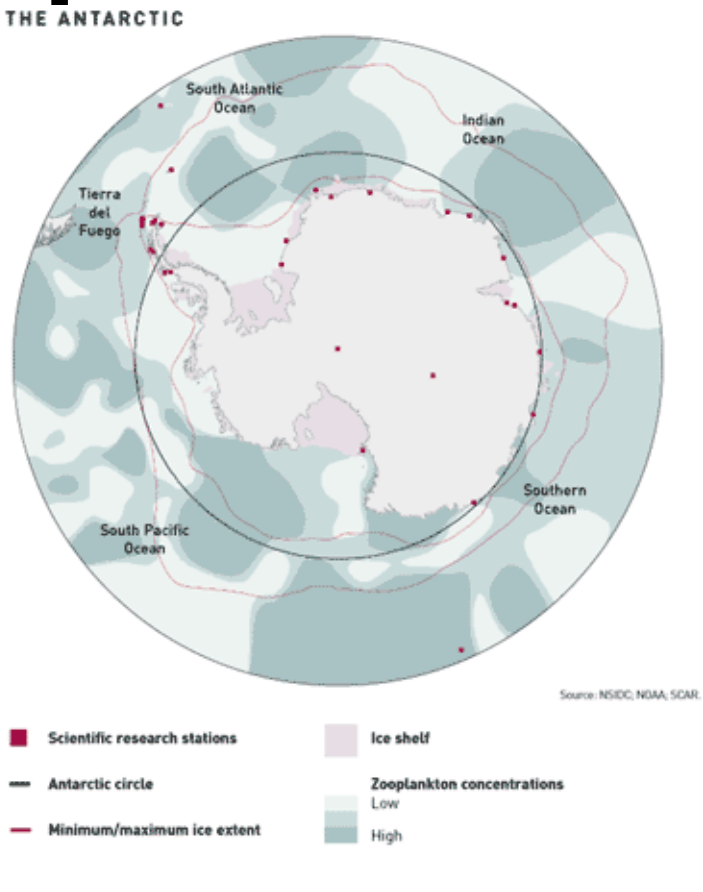
- Global relevance

⇒ ocean and atmosphere circulations (« teleconnections »)

⇒ polar ice caps : risks of sea-level changes

II- Climate archives in ice caps

Polar ice caps



Greenland

~ 2.8 millions of km^3

~ 7 meters of global sea-level

Antarctica

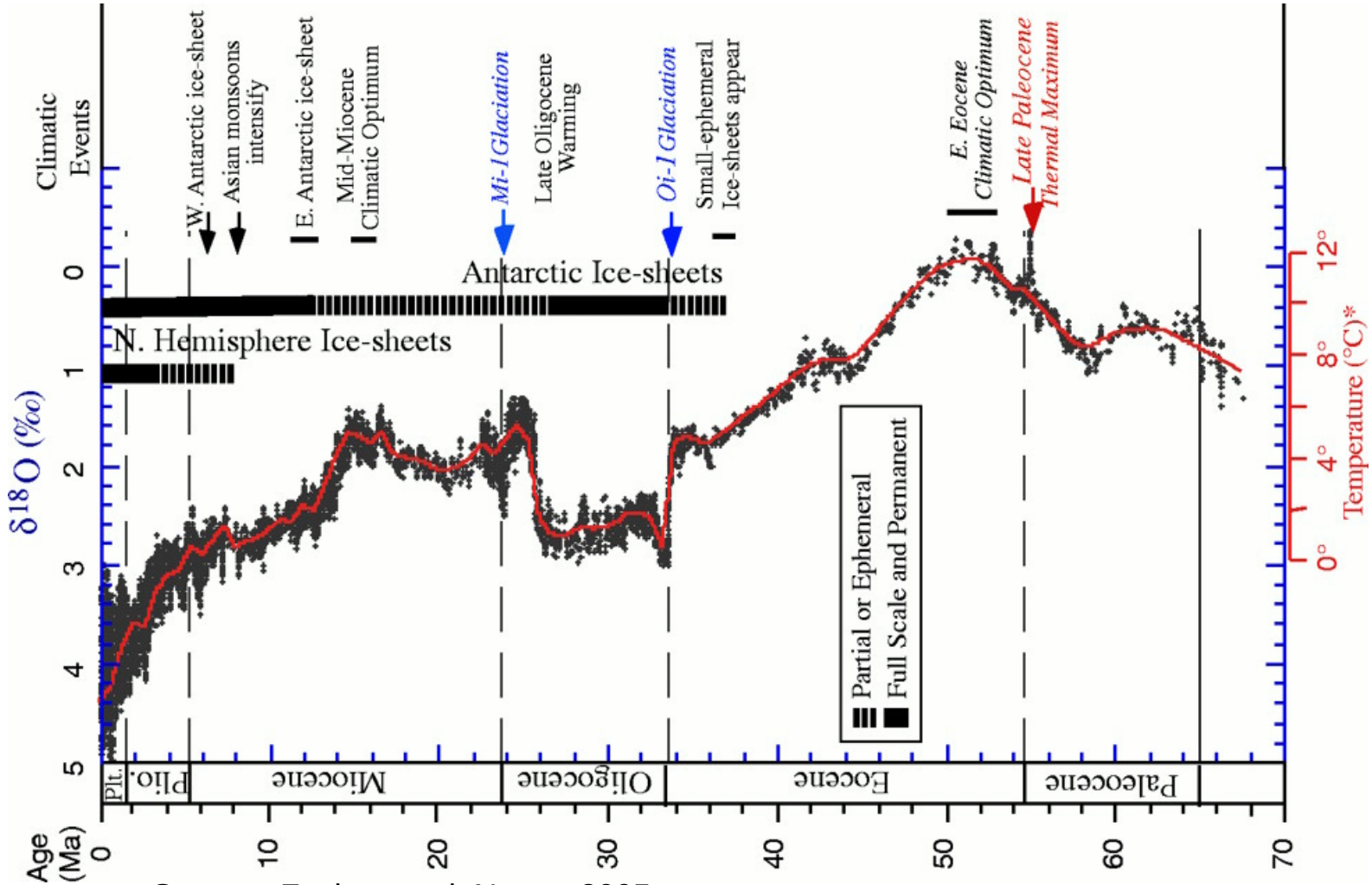
~ 29.3 millions of km3

~ 70 meters of global sea-level

70% of the Earth's freshwater

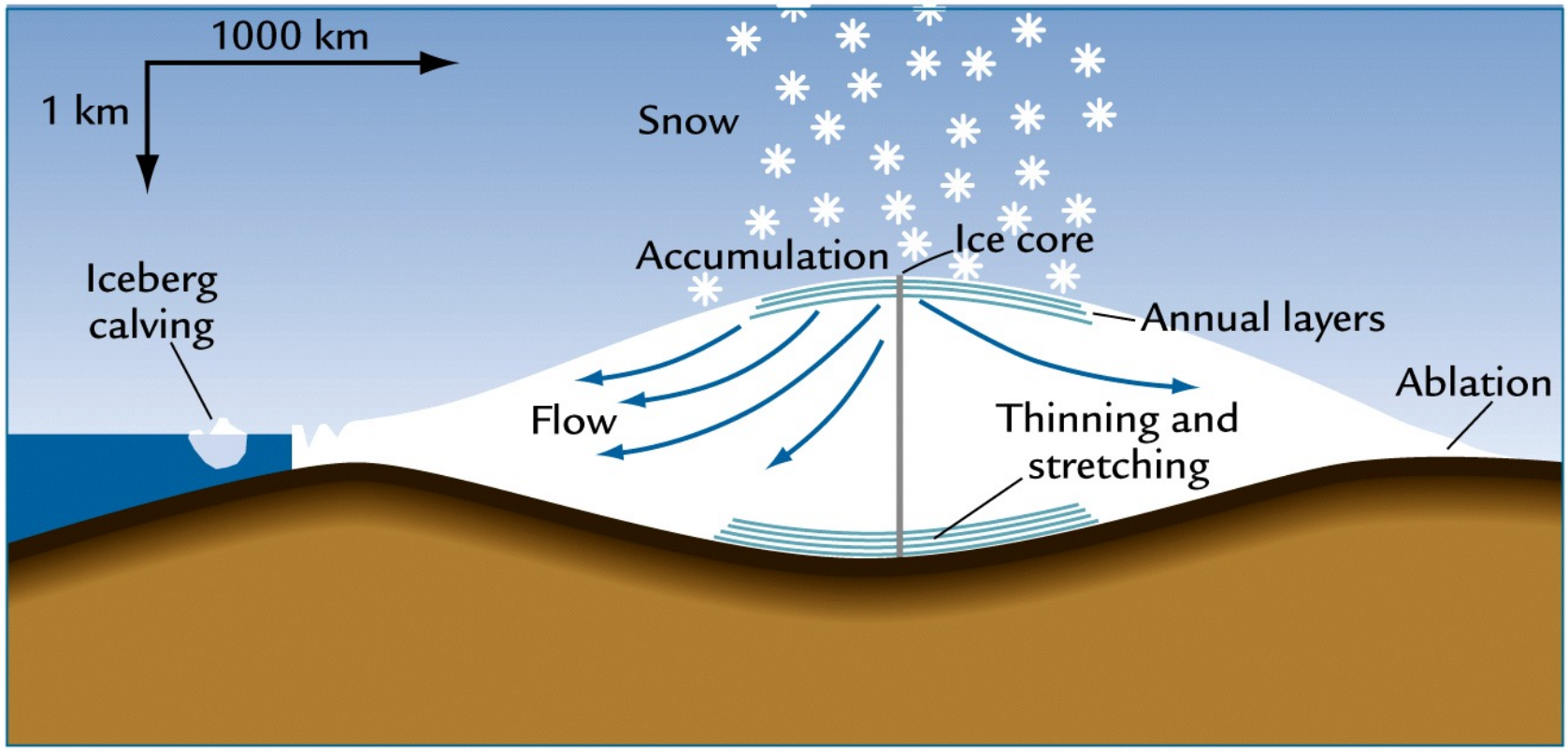
90% of its ice

Antarctic ice sheet : ~12 million years ago
Greenland ice sheet : ~3 million years ago



Source : Zachos et al, Nature 2005

From ice caps to ice cores



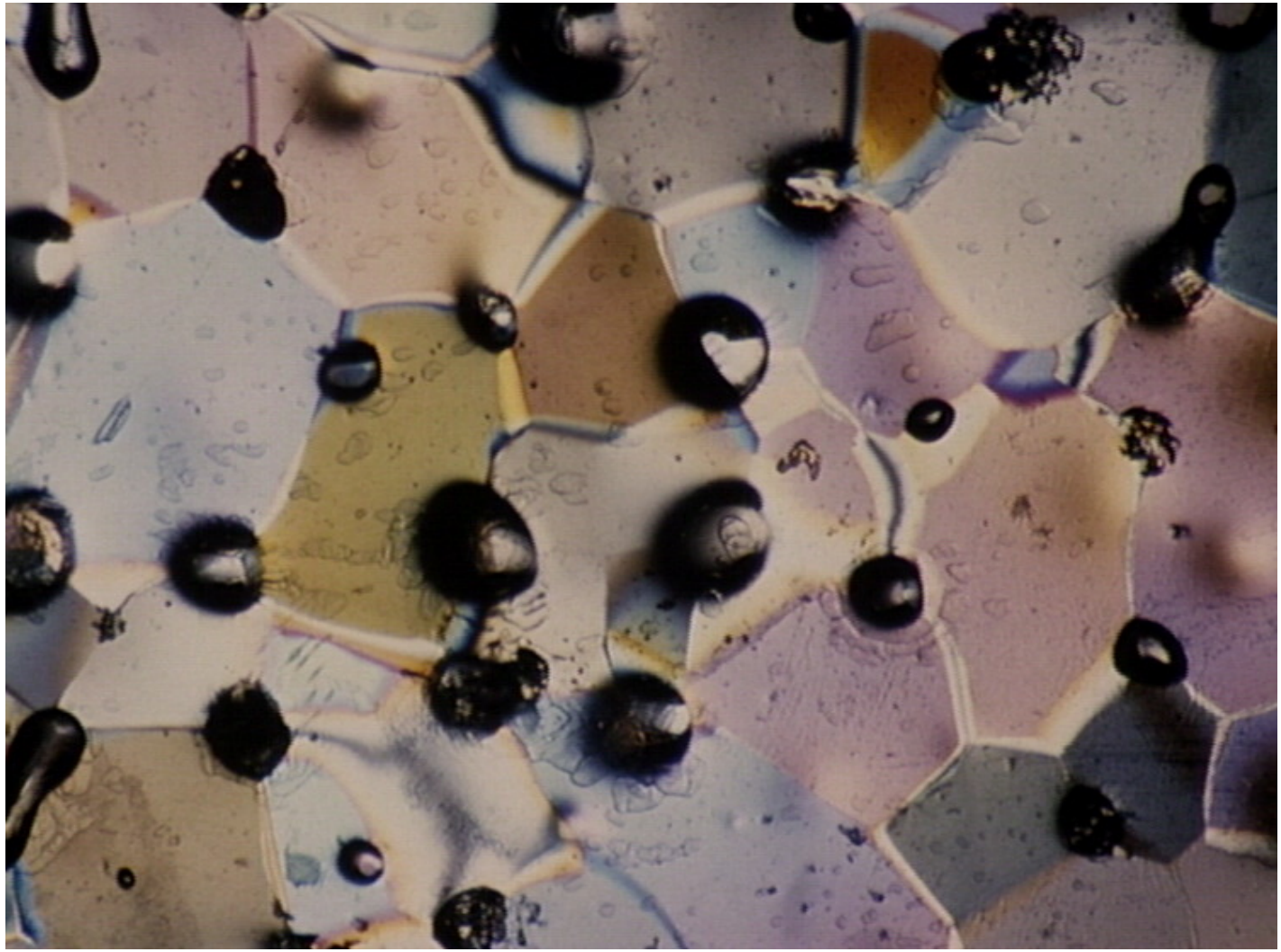
B Continental ice sheets

Accumulation in central Greenland : 30 cm of water equivalent per year
Accumulation in central Antarctica : 3 cm of water equivalent per year

Source : B. Ruddiman

Sampling the cold point of the global climate system

Hidden inside the ice



Water stable isotopes

Main forms of the water molecule :
$H_2{}^{16}O$, $H_2{}^{18}O$, $HD^{16}O$

In ocean water :
$^{18}O/^{16}O \approx 2005$ ppm et $D/H \approx 155$ ppm

Analytical precision ≈ 0.1 ppm

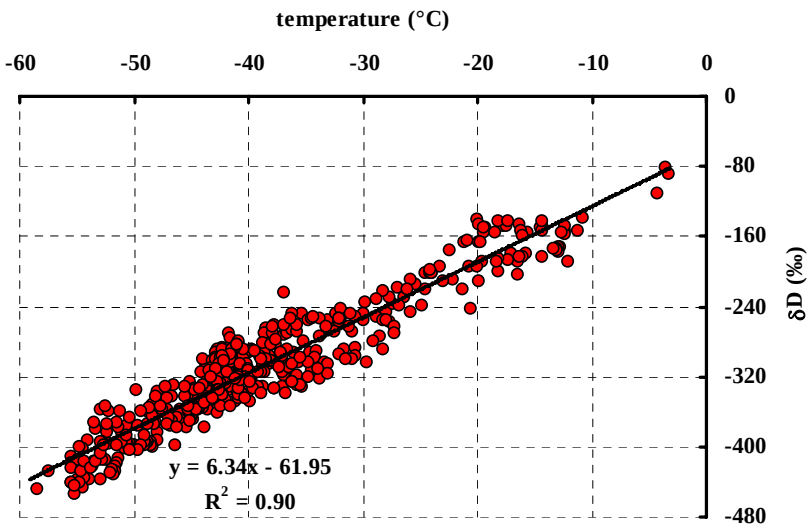
$$\delta^{18}O\ (‰) = \left(\frac{\left[\frac{^{18}O}{^{16}O} \right]_{ech}}{\left[\frac{^{18}O}{^{16}O} \right]_{SMOW}} - 1 \right) * 1000$$

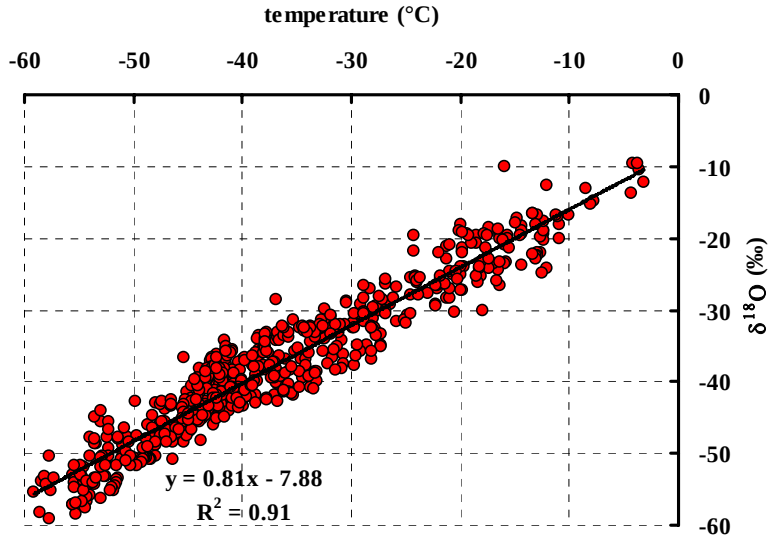
Deuterium excess
$d = \delta^{18}O - 8\ \delta D$

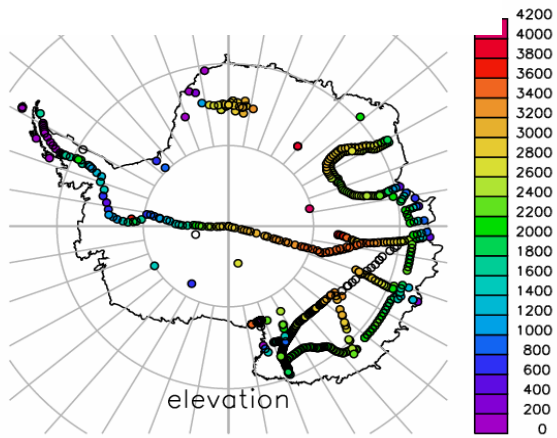
Molecular mass → Saturation vapour pressure → Fractionation during equilibrium phase changes

Molecular symetry → Molecular diffusivity → Fractionation during kinetic processes

Paleothermometry



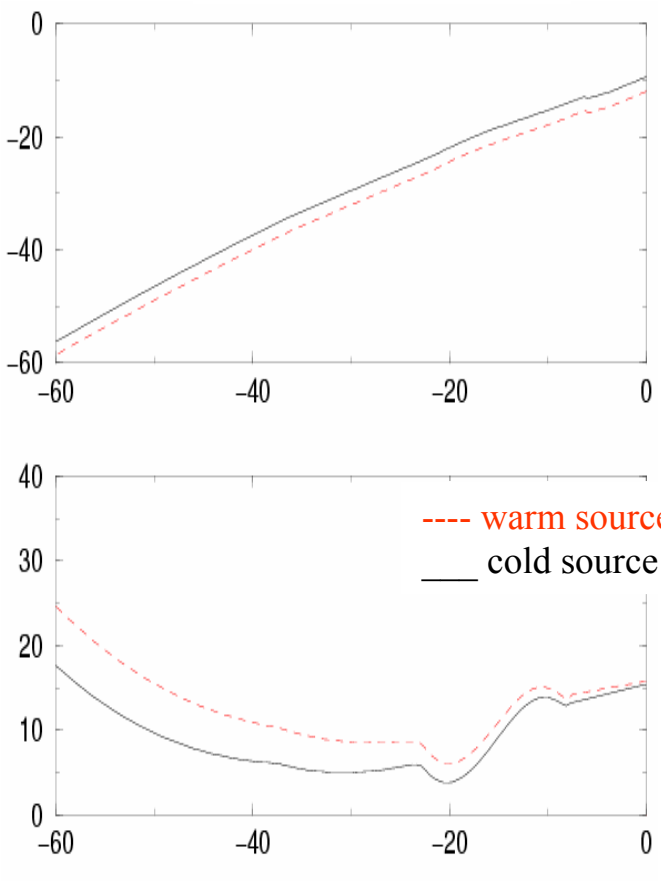


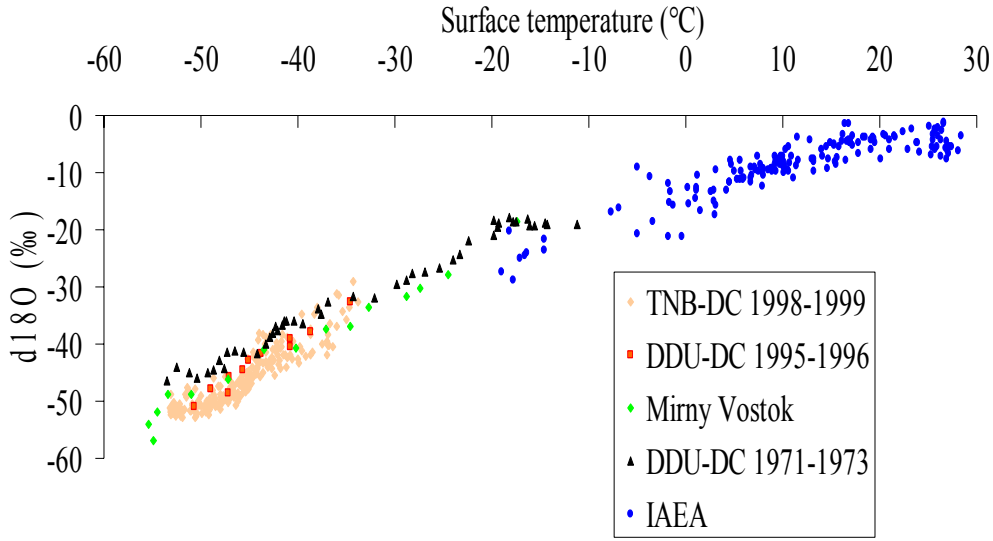


Compilation of Antarctic locations where the isotopic composition of surface snow has been measured

Possibility to quantify site and source temperature changes

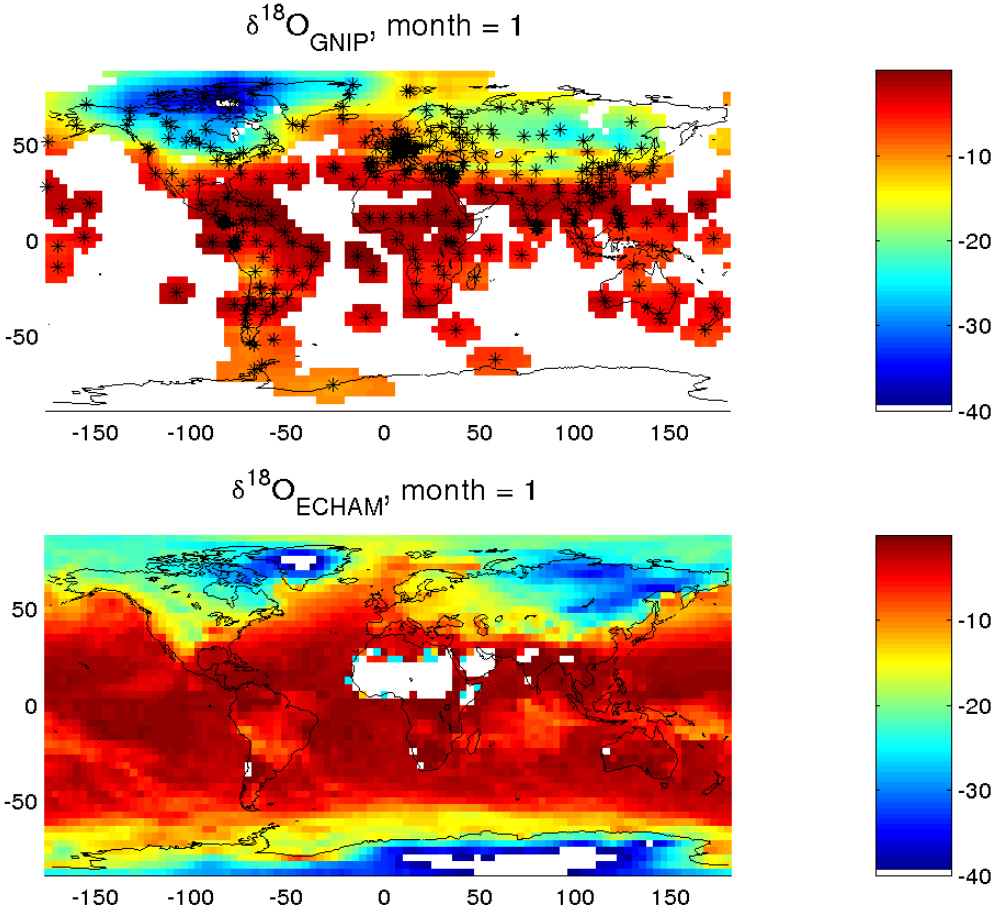
Simple isotopic model





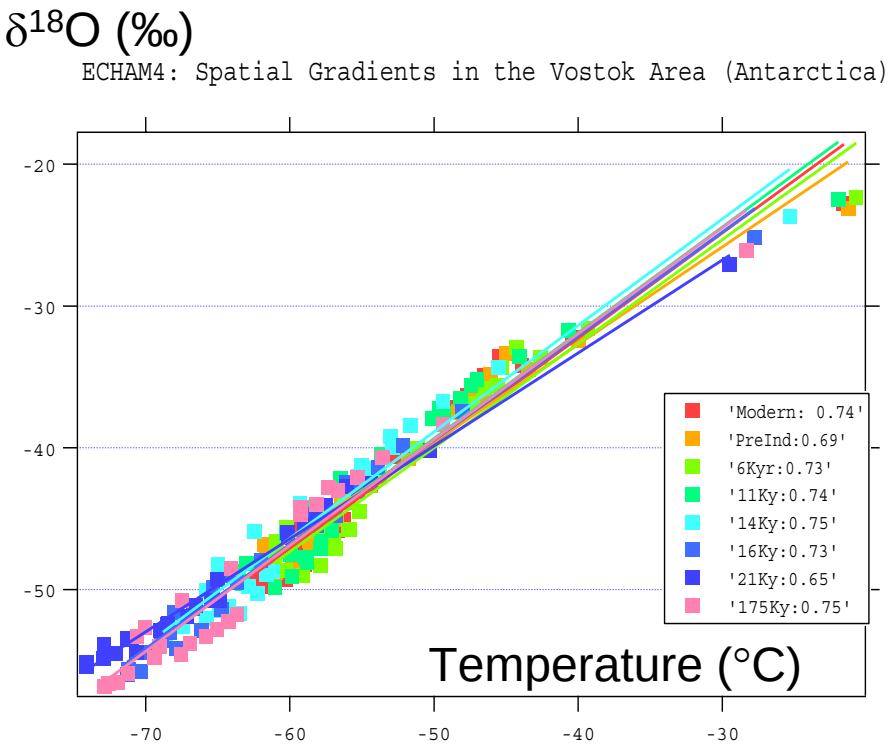
- Physical proxies
- Transfer function : spatial and temporal approach
- Distillation models
- Climate models
- Integrated tracers of the water cycle

Modelling stable isotopes of water in climate models

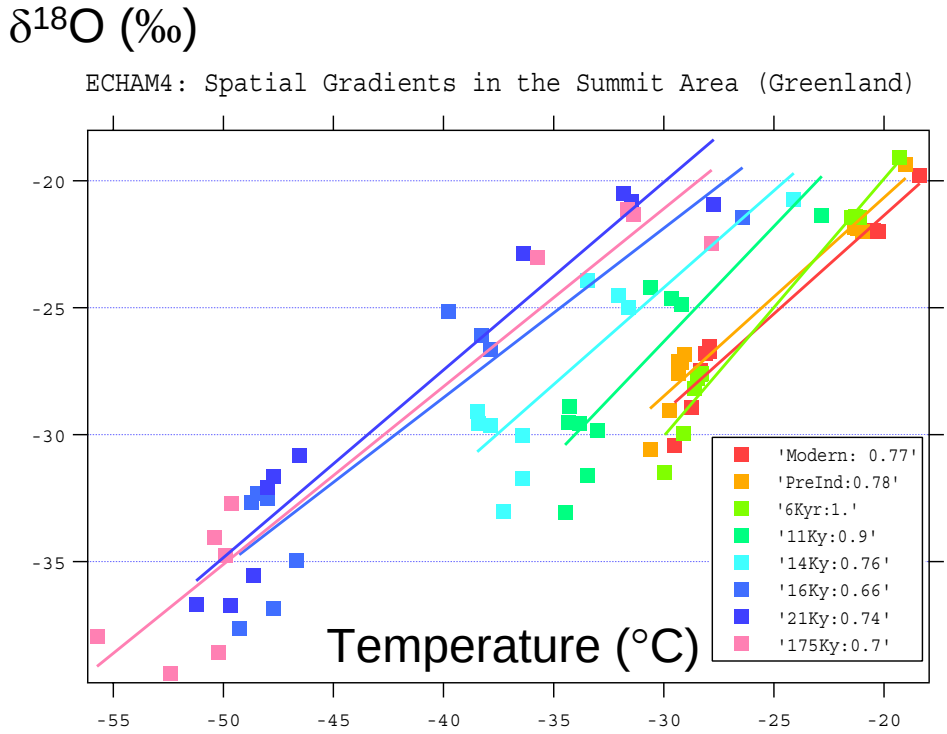


Courtesy of G. Hoffmann (LSCE)

Stability of the isotope-temperature slope for past periods in Antarctica (left) and Greenland (right)

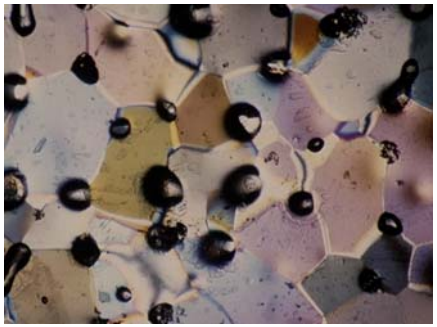


Antarctica : validity of the isotopic thermometer within 20 to 30%



Greenland : underestimation of past temperature changes in stable isotopes due to changing seasonal snowfall

Courtesy of G. Hoffmann (LSCE)



Climatic information preserved in the ice

Water isotopic composition

➡ Past local temperature changes

Antarctic climate change

Ice chemistry

➡ Impurities transported by the atmosphere

Dust, aerosols, pollution…

Volcanism, solar activity (climate forcings)

Air trapped in the ice

➡ Atmospheric composition

Greenhouse gases

Dating of ice cores

- **Layer counting**

⇒ Seasonal cycles of physical or chemical properties of ice layers

⇒ Back to 60 000 years in Greenland with an estimated uncertainty of less than 1200 years

- **Age markers**

⇒ Identification of events dated elsewhere (volcanic signals, magnetic field changes)

⇒ Cross dating of ice cores because atmospheric signals are global (typical uncertainties of 50 to 1000 years)

- **Modelling**

⇒ Ice mechanics

⇒ Requires to estimate past changes of snow accumulation and flow properties

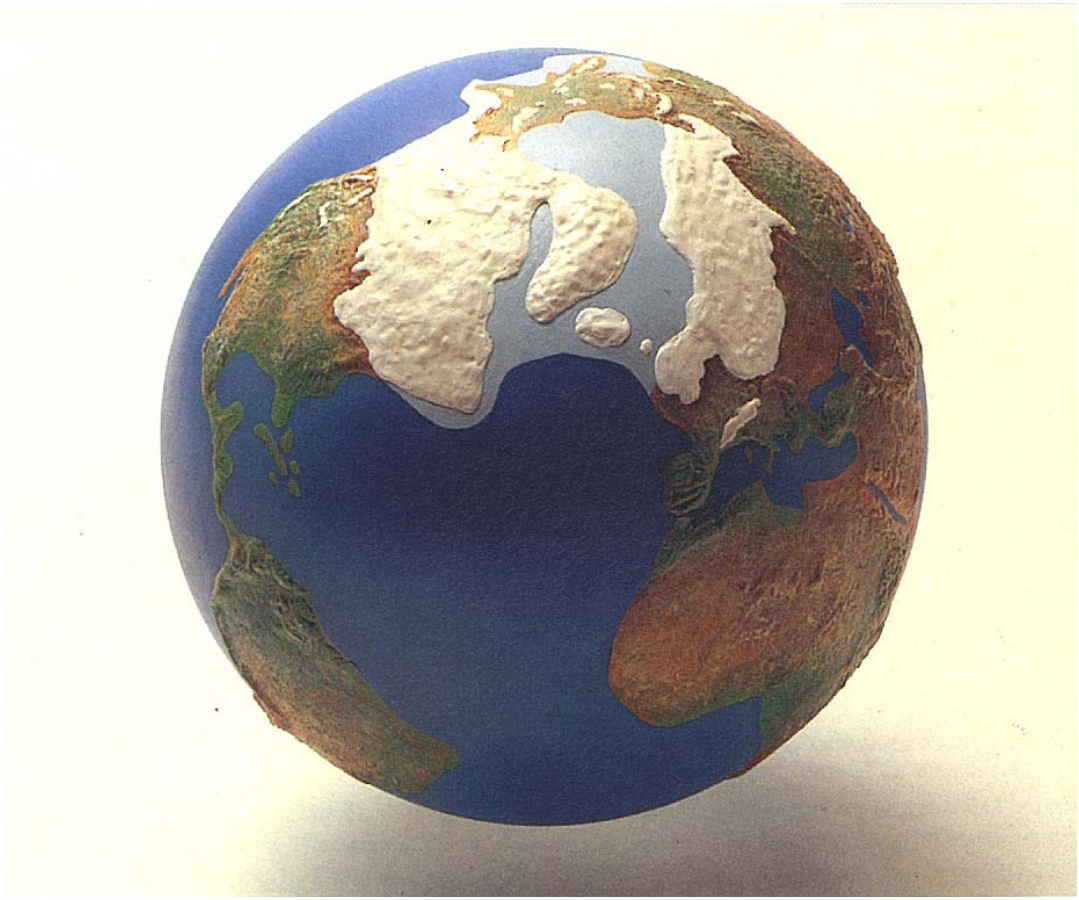
Take home messages

- Chemical, physical analyses of ice cores provide local to global climatic and environmental records

- All ice core records can be placed in a common age scale owing to their records of atmospheric composition

=> Possibility to analyse the sequence of events during climate changes

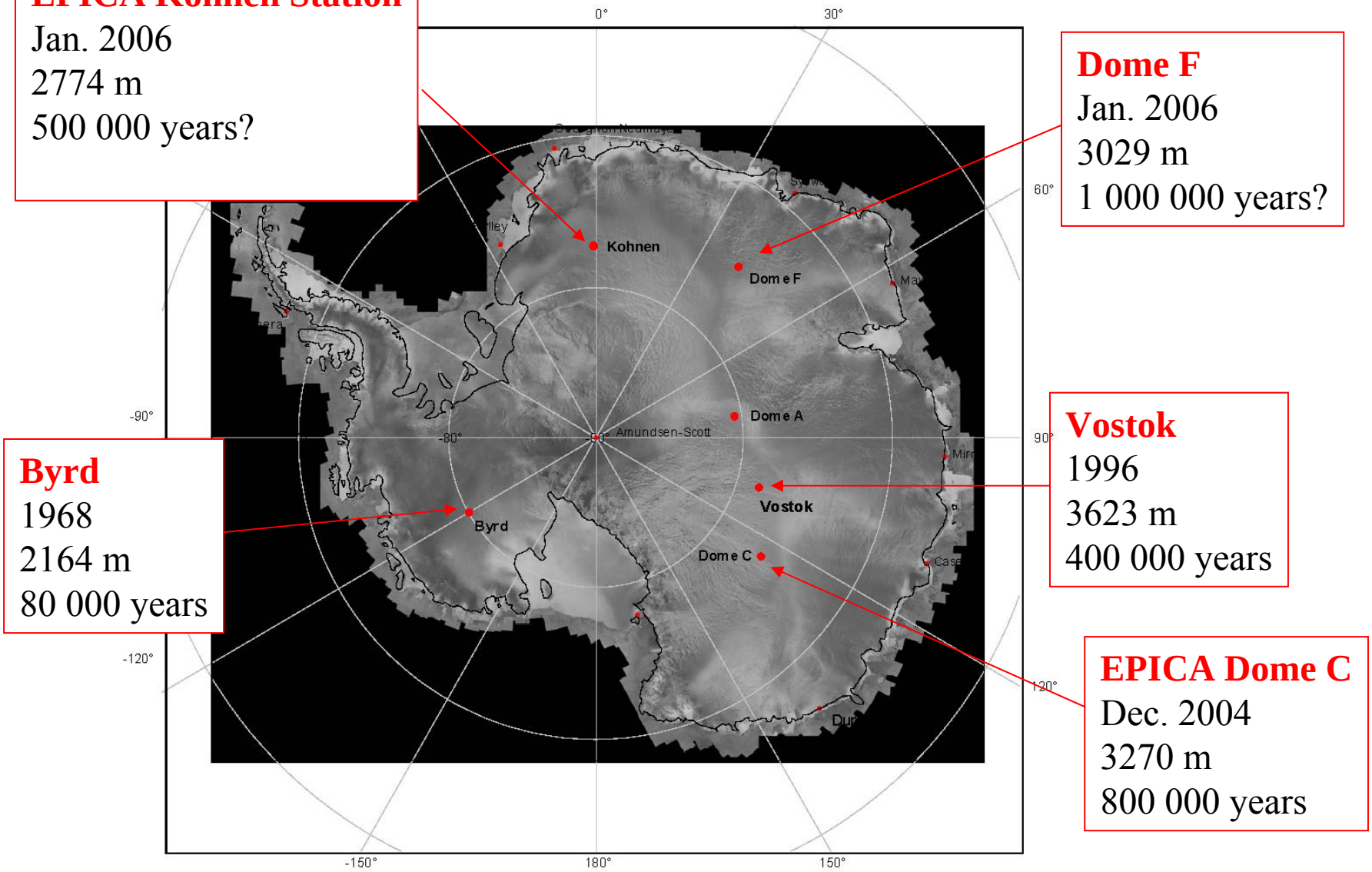
III- Climate reconstructions from deep ice cores



A model of ice caps covering the northern hemisphere at the Last Glacial Maximum, 21 000 years ago (Joussaume, 1995).

Recent completion of drilling projects

EPICA Kohnen Station
Jan. 2006
2774 m
500 000 years?



Dome F
Jan. 2006
3029 m
1 000 000 years?

Byrd
1968
2164 m
80 000 years

Vostok
1996
3623 m
400 000 years

EPICA Dome C
Dec. 2004
3270 m
800 000 years

Deep drilling projects : need for intense operational support

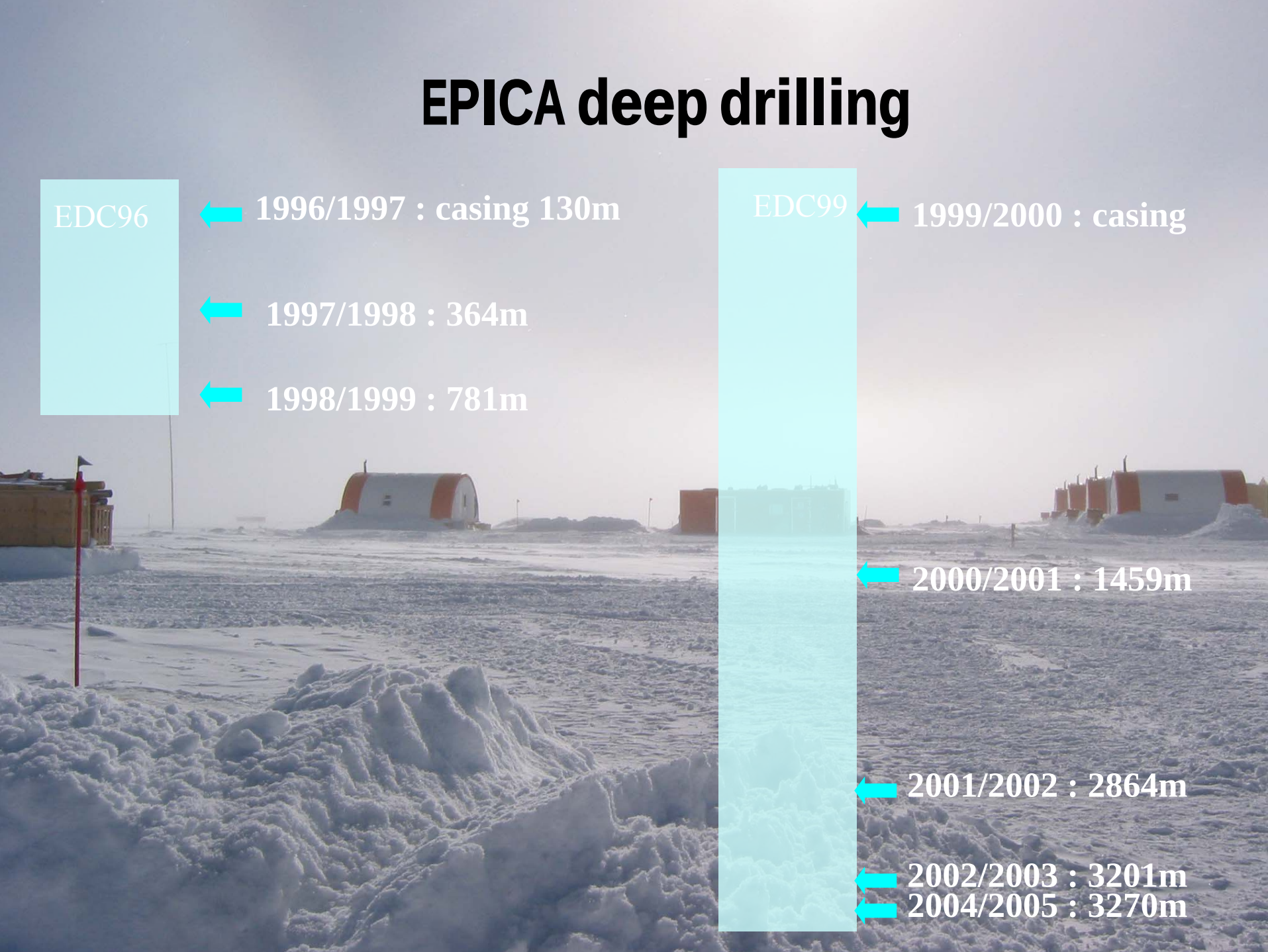
The example of EPICA Dome C

- Climatic and geographic constraints : 3233 m elevation, -54.5°C, 75°S, 123°E
- Transport by traverses : 1200 km from DDU
- Window for summer field work : 8 to 10 weeks
- Drilling capability : 0 to 250 meters per week
- Equipment required : 1000 tons, 7 convoys
- Personnel required : 8 drillers, 20 scientists

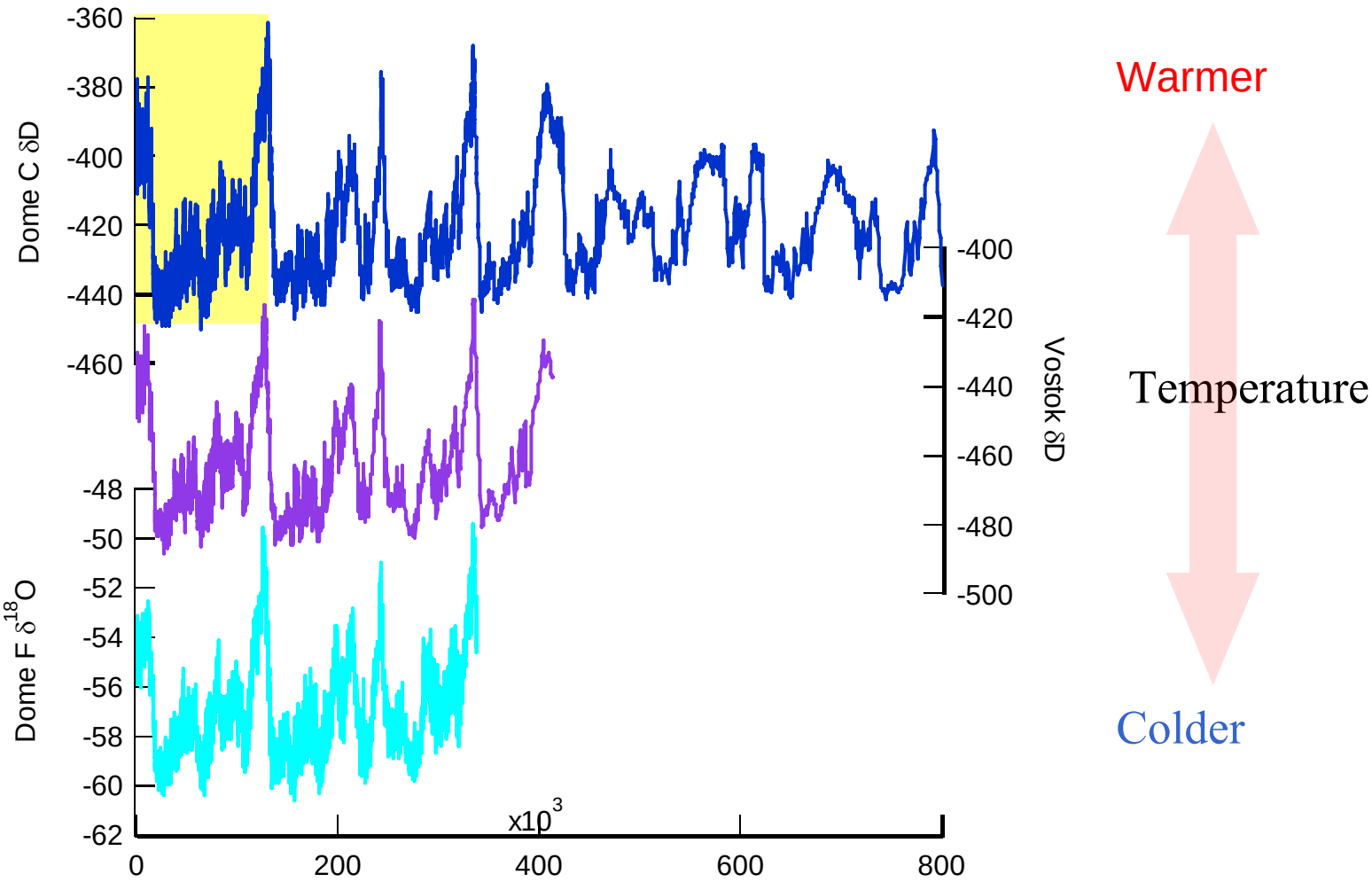
European Project for Ice Coring in Antarctica

Support by 10 national programs (Belgium, Denmark, France, Germany, Italy, The Netherlands, UK, Norway, Sweden, Switzerland), the European Commission (5th and 6th PCRDT) and European Science Foundation

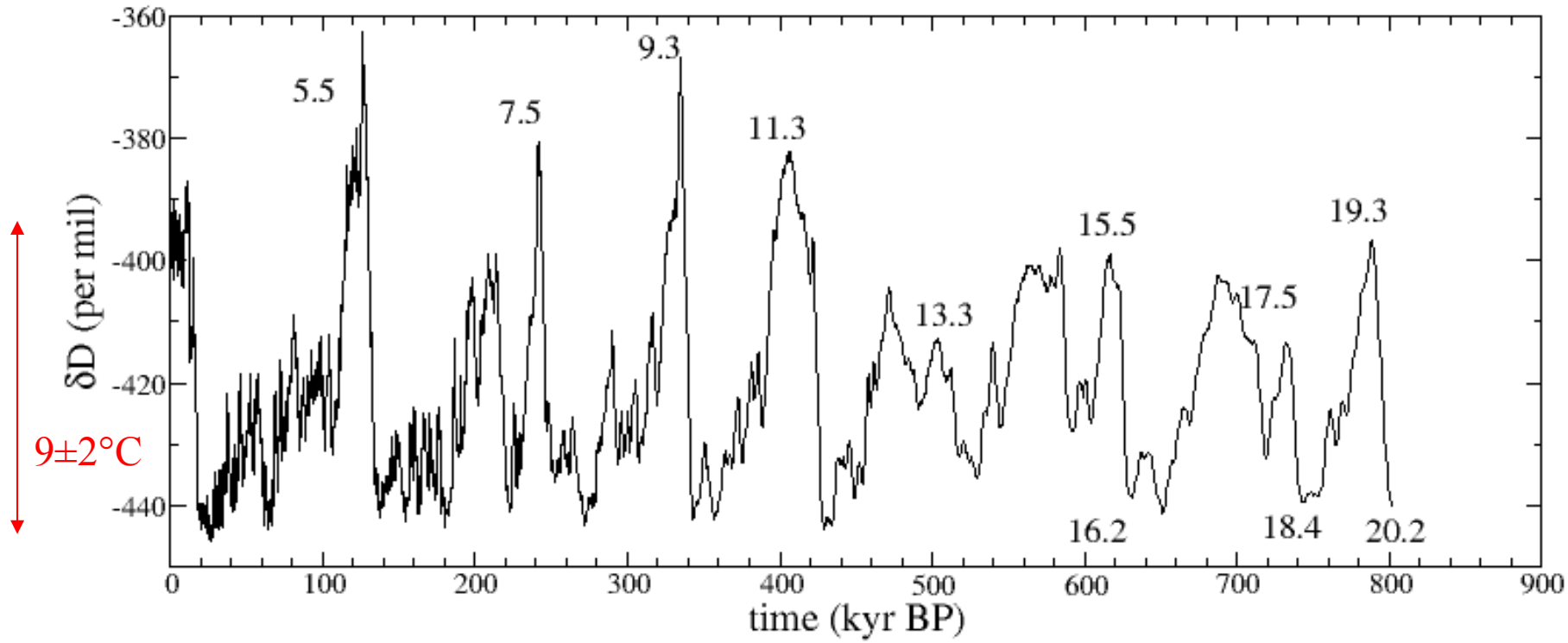
EPICA deep drilling



Climate records in Dome C deep ice



Temperature history at Dome C (as a function of time)

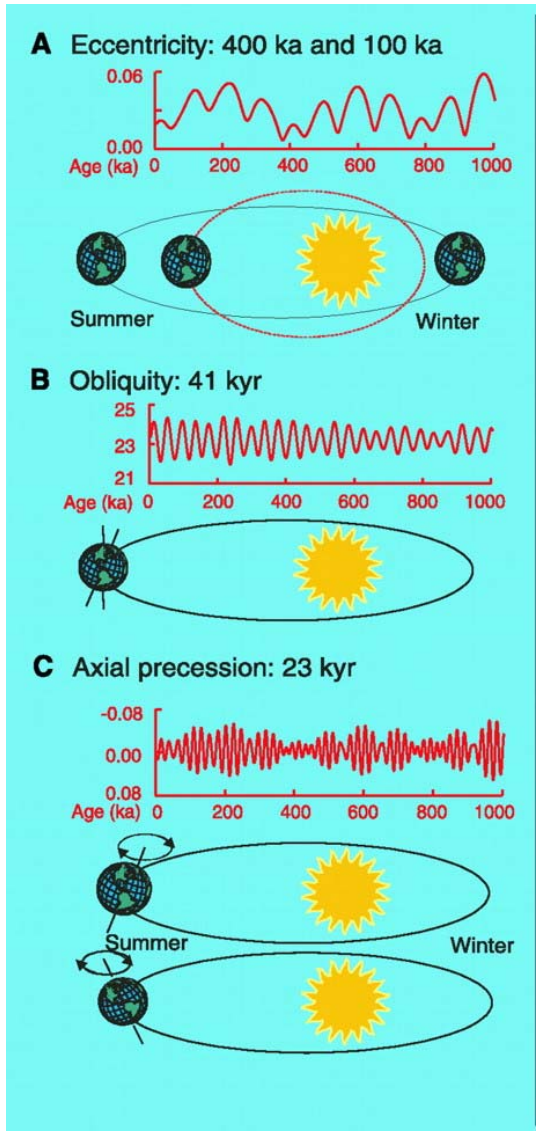


Ice ages each 100 000 years

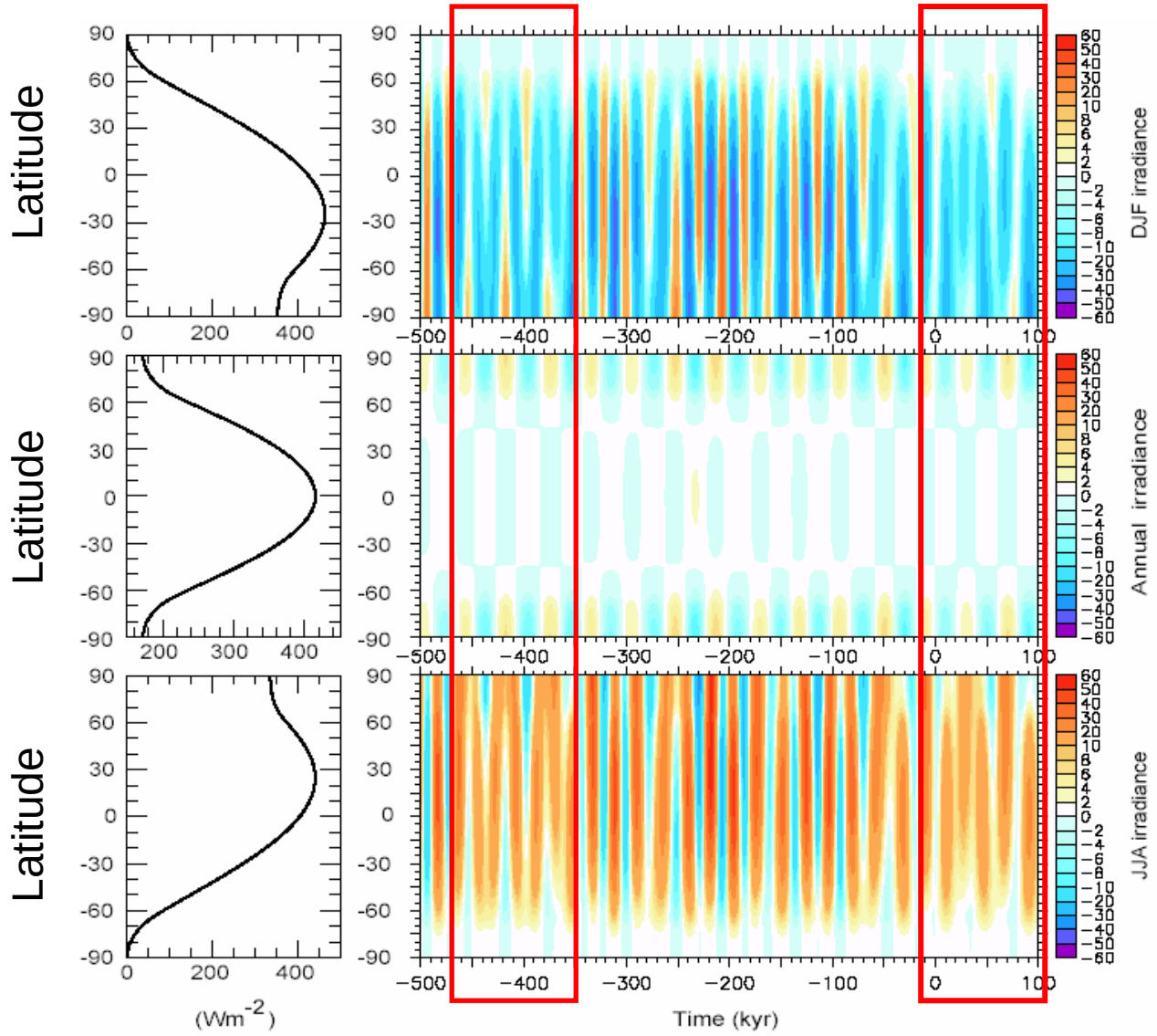
Very long warm period ~400 000 years ago

Changes in the intensity of warm periods : why?

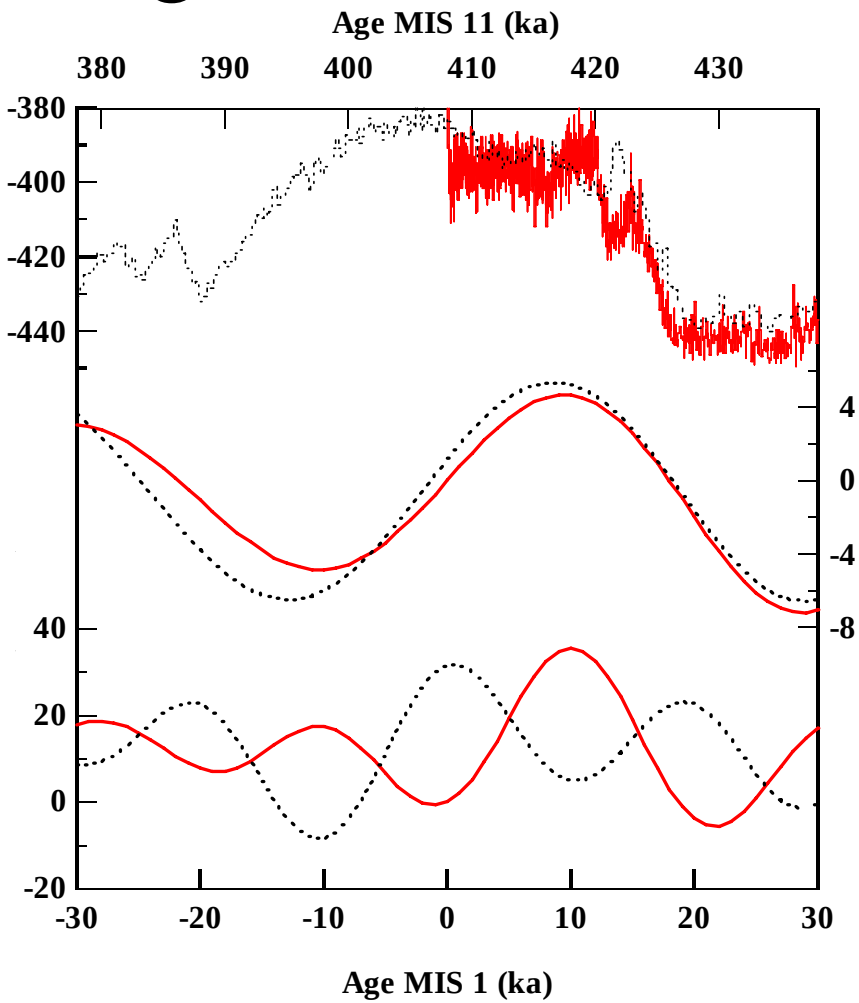
Ice ages : orbital theory



Orbital theory : our past and our future



Insights for the future



Dome C δD (‰)

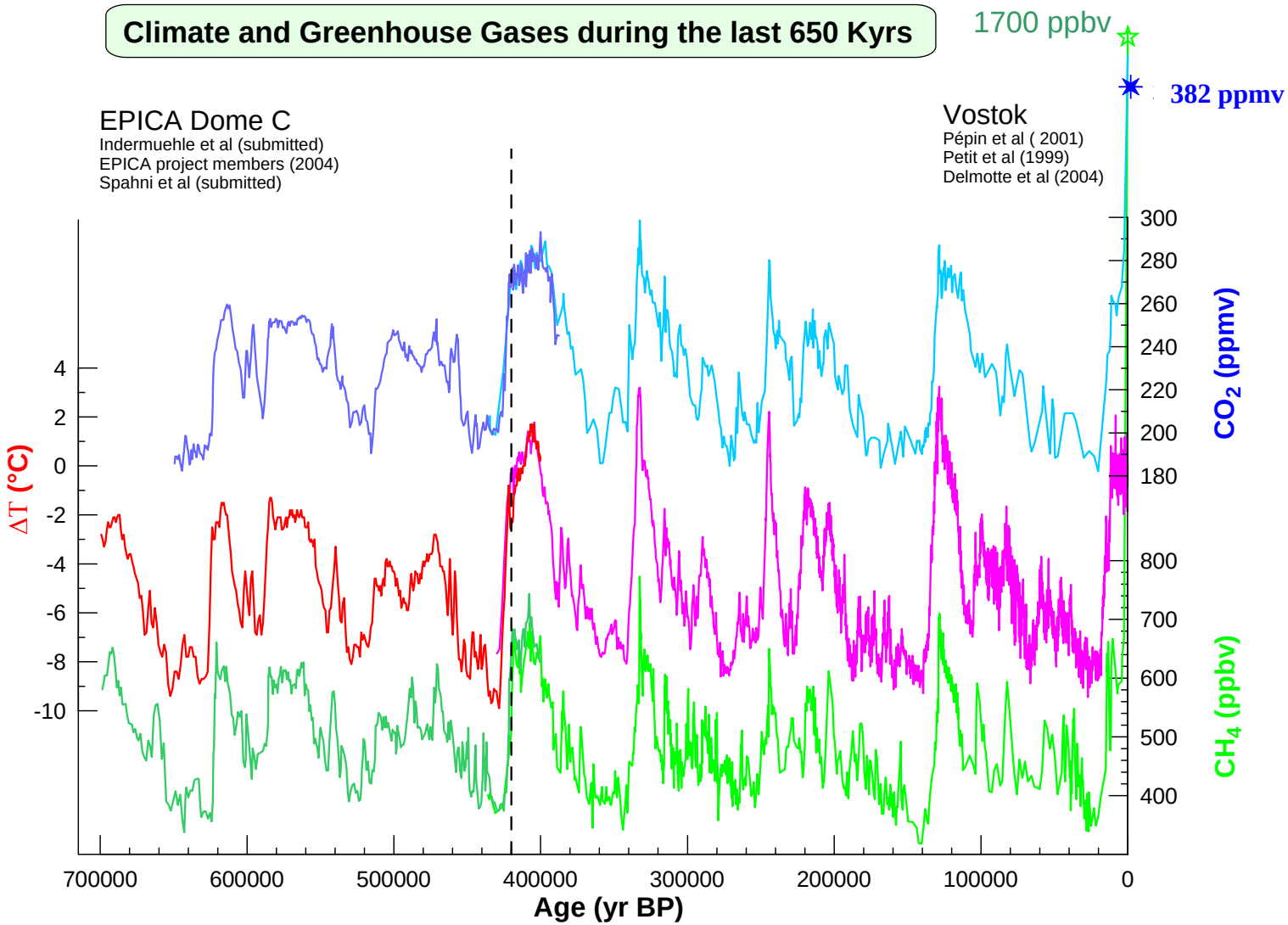
Changes in 75°S annual insolation (W/m²)

Changes in 65°N summer insolation (W/m²)

Future **Present** **Last glacial period**

Our future : a « super-interglacial » period

Evolution of greenhouse gases



http://www.glaciology.gfy.ku.dk/

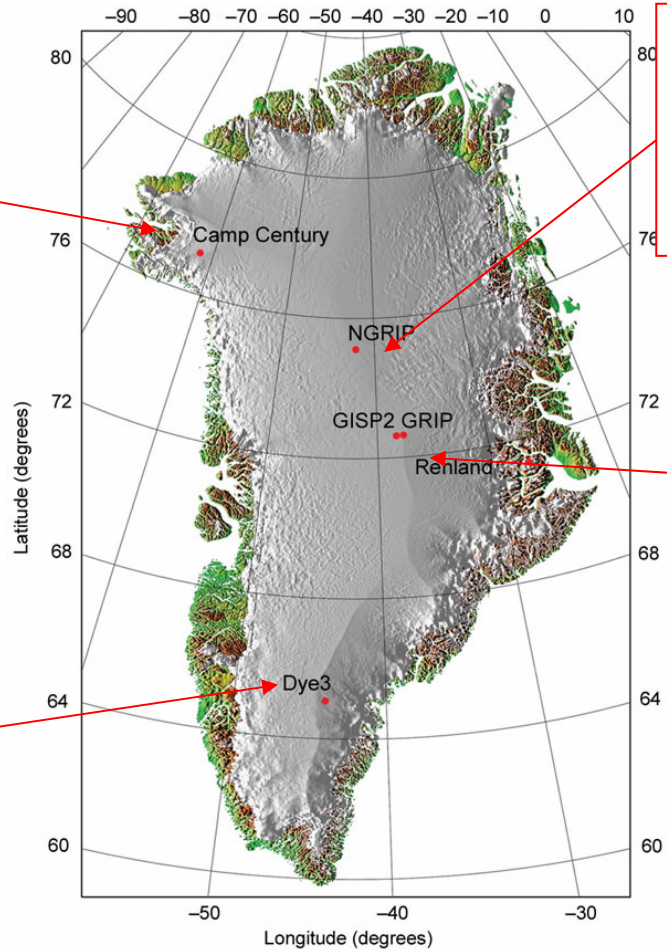
Greenland deep ice cores

Camp Century
1966
1391 m
~ 50 000 years

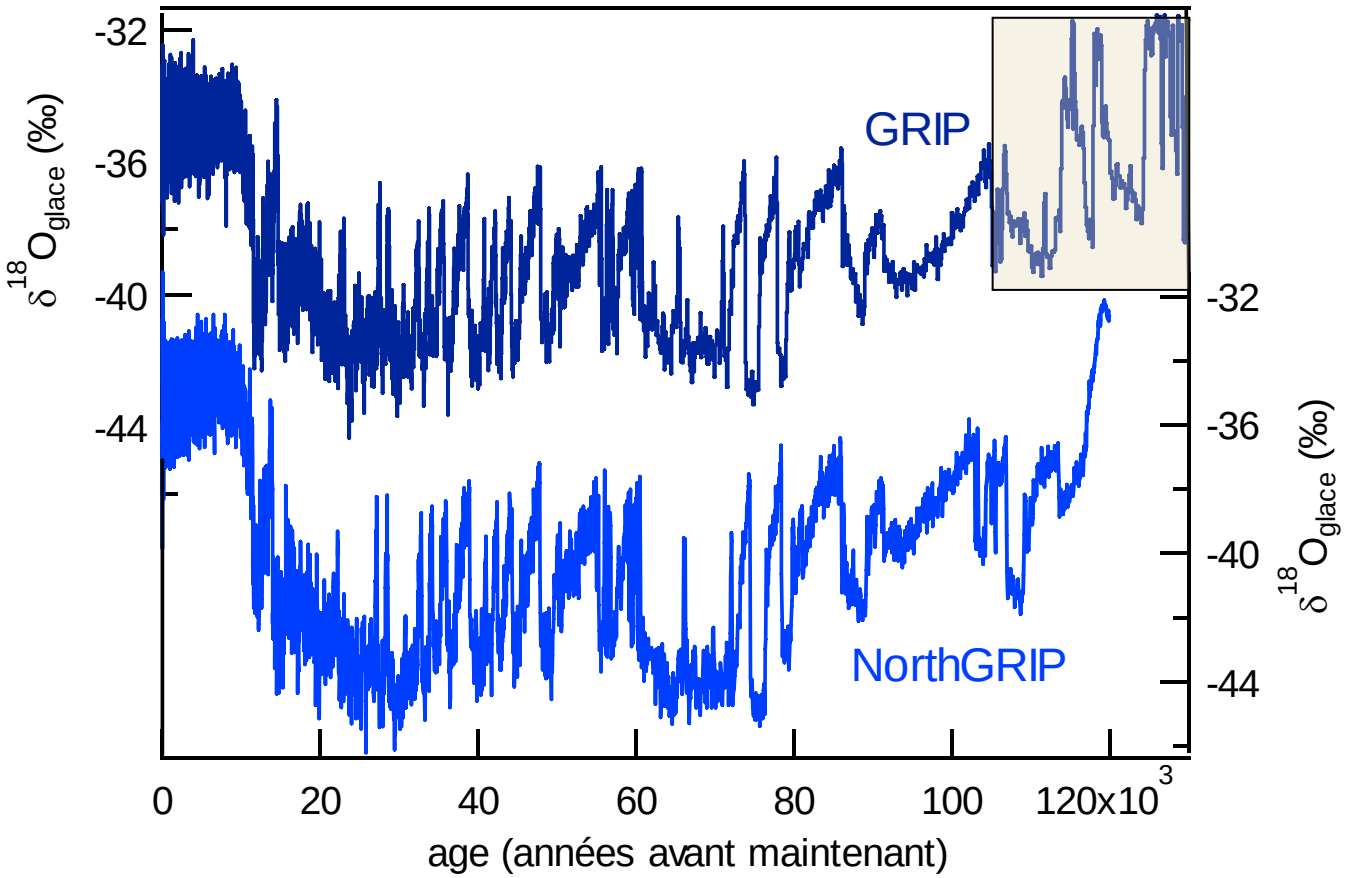
NorthGRIP
2004
3085 m
~125 000 years

Summit (GRIP, GISP2)
1992 and 1993
3029 m
~100 000 years

Dye 3
1981
2037 m
~ 30 000 years

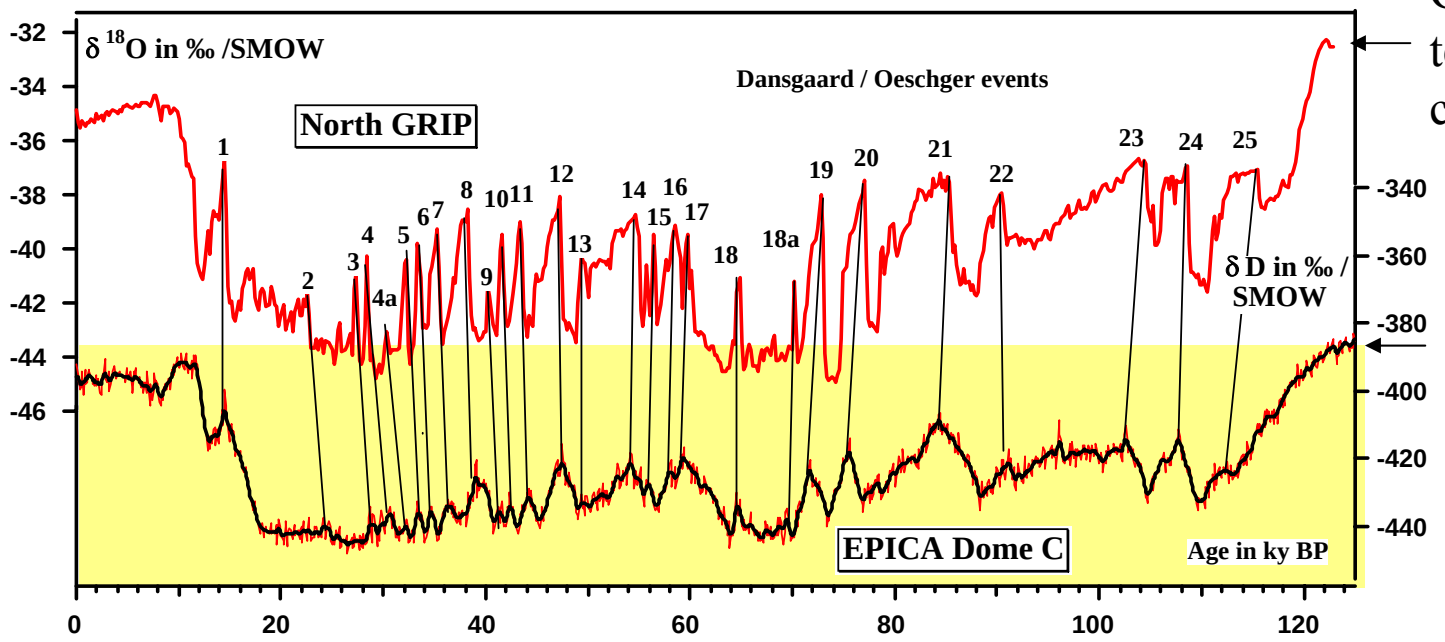


Greenland records : Summit (GRIP) versus NorthGRIP



NorthGRIP community members, Nature, 2004

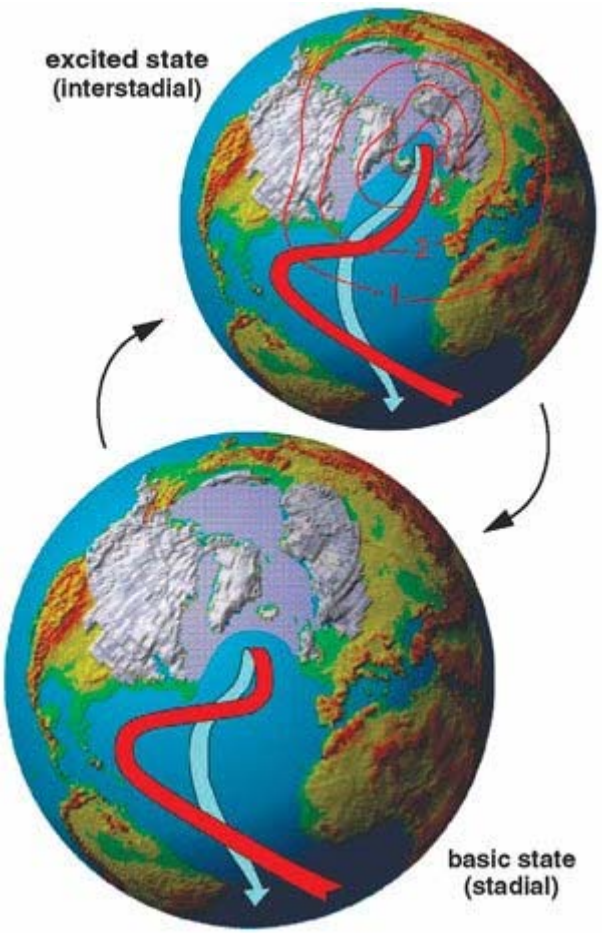
Rapid climate changes in Antarctica

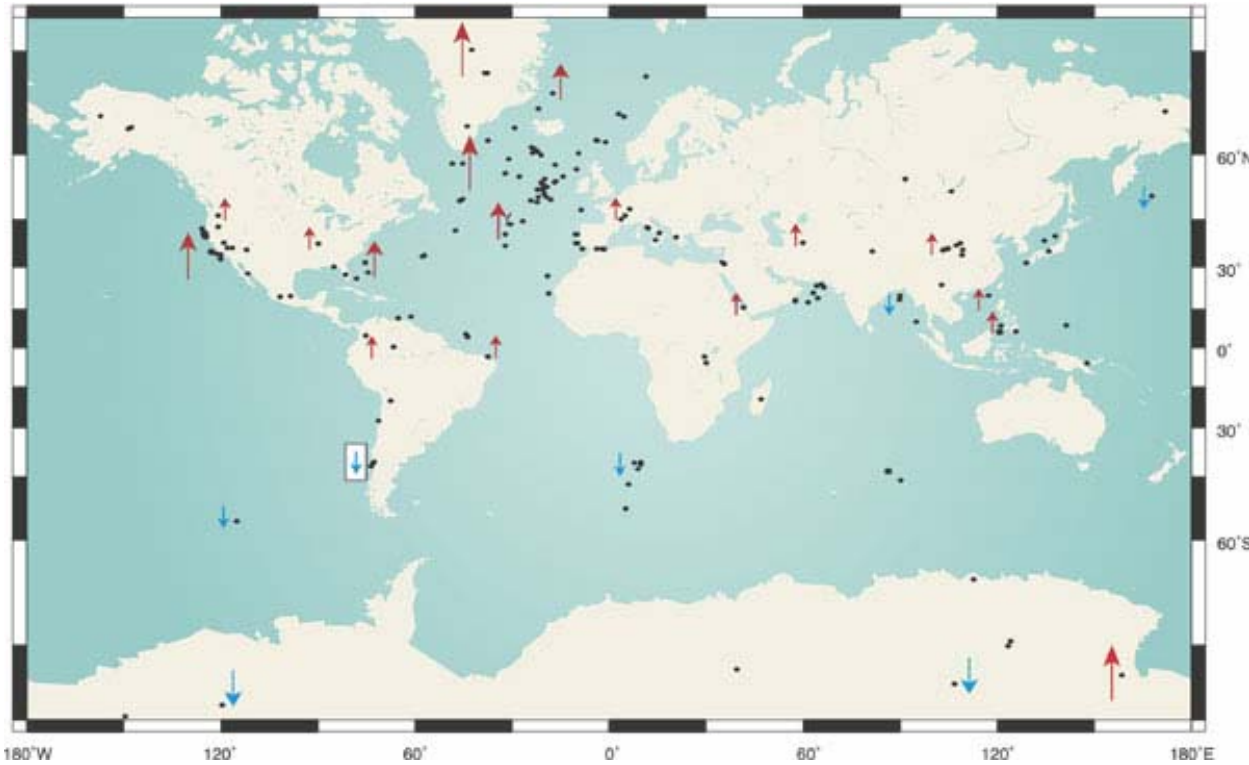


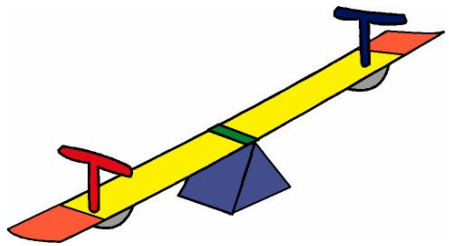
Greenland temperature change

Antarctic temperature change

Age (thousand of years ago)



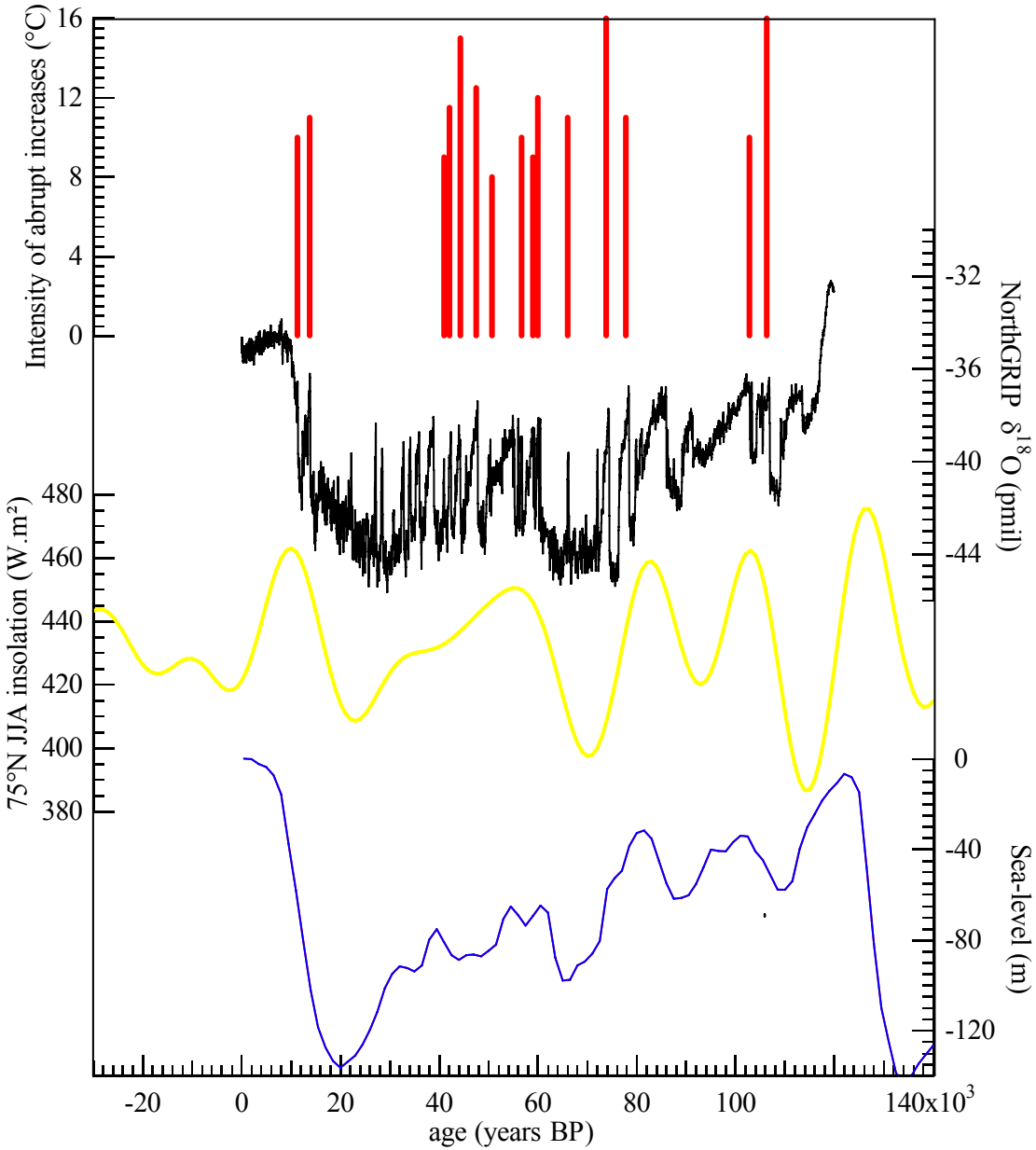




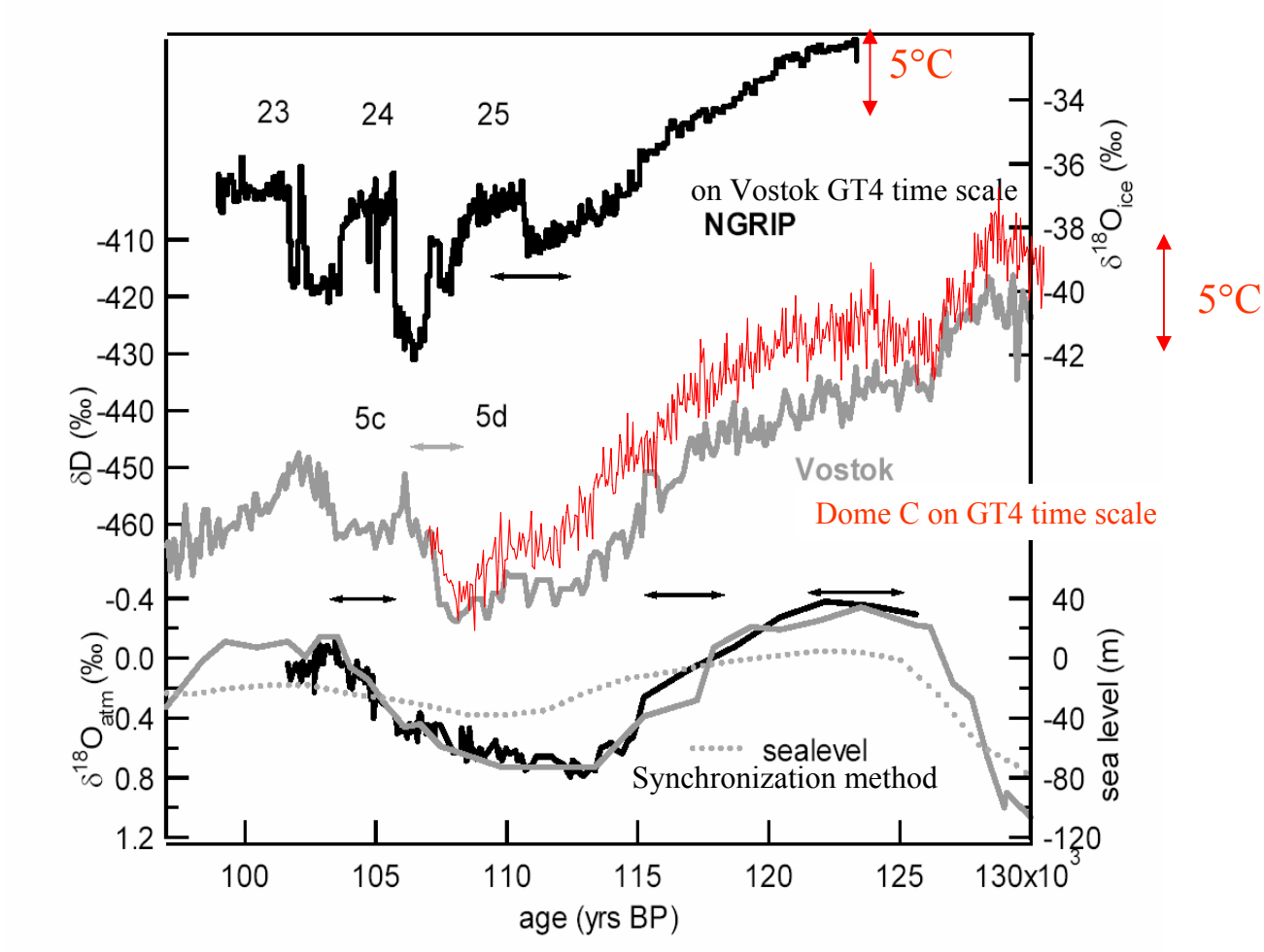
« See-saw effect »

Source : Voelker et al 2002

NorthGRIP ice core record



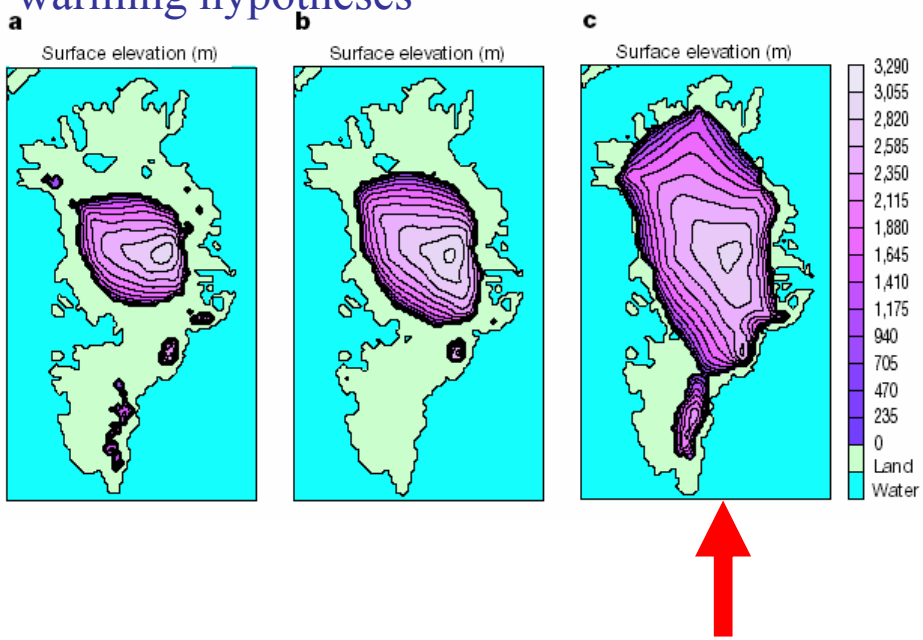
NorthGRIP ice core : a detailed view of the last glacial inception

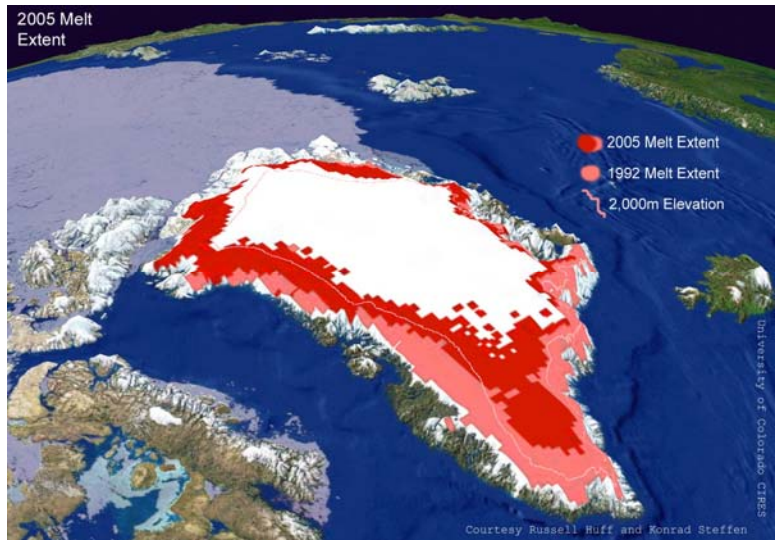


Landais et al Climate Dynamics 2006

Constraints on the Greenland ice sheet reaction to climate change

Modelling the response of the ice sheet to warming hypotheses



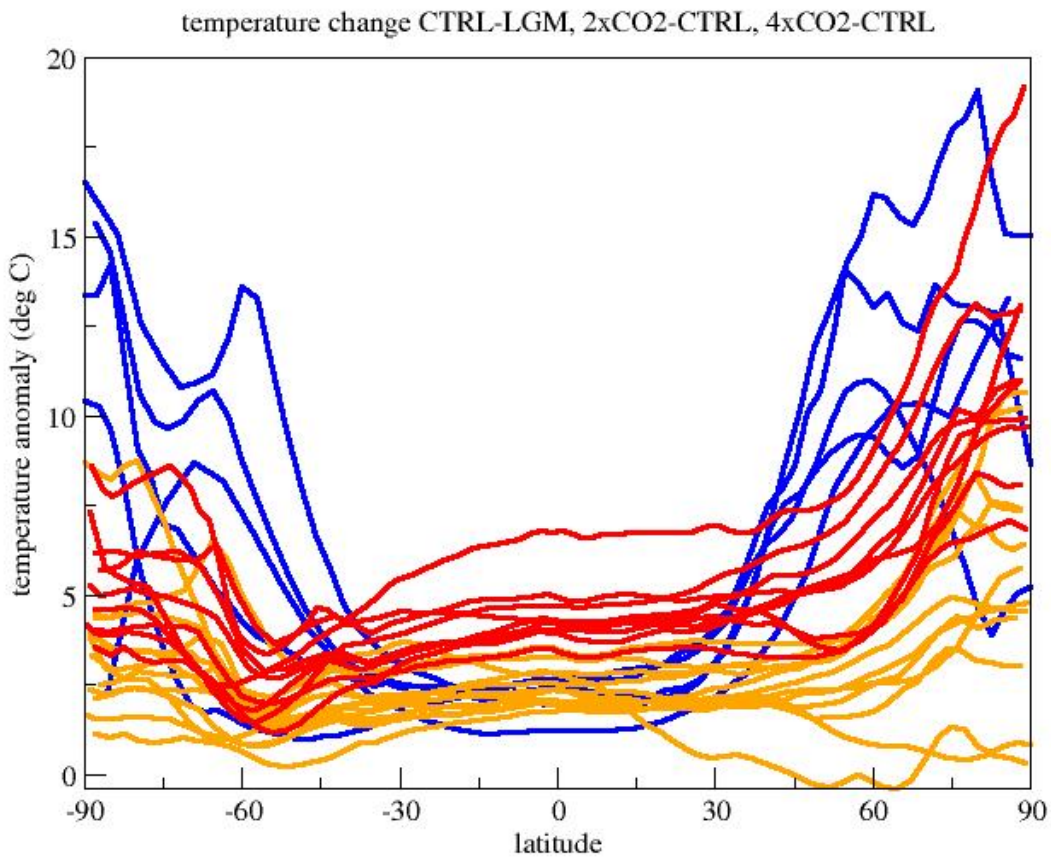


Observed melt area : record extent in september 2005

NorthGRIP : last interglacial period, about 5°C warmer than now at both poles
Greenland responsible for 2 to 3 meters of sea level rise
Antarctica responsible for the rest of the observed 4 to 7 meters

Cuffey and Marshall, 2000; Steffen and Huffs, 2005

Simulated climate change



Ice core range

Ice core range

LGM

$4xCO_2$

$2xCO_2$

Take home messages

- Antarctic ice cores cover the past 800,000 years.
- Greenland longest climate record covers about 123 000 years (not the full last warm period).
- Temperature reconstructions are used to test climate models for their capability to simulate large past climate changes
- Global relevance of temperature changes in polar regions
- Glacial-interglacial temperature changes comparable to those expected in the case of $4xCO_2$

III- Perspectives
International Polar Year and beyond

Past polar climate changes : key uncertainties

- Current and past evolution of ice sheet mass balance
- Climate history in Greenland and West Antarctica during the past interglacial (warm) period
- Evolution of Antarctic climate at time scales of decades
- Regional changes in Greenland and Antarctica
- Antarctic climate change prior to 800 000 years

Perspectives

- 2007-2009 : International Polar Year

Coordinated traverses : surface and bedrock characteristics, recent climate change

- IPICS : International Partnership for Ice Core Science

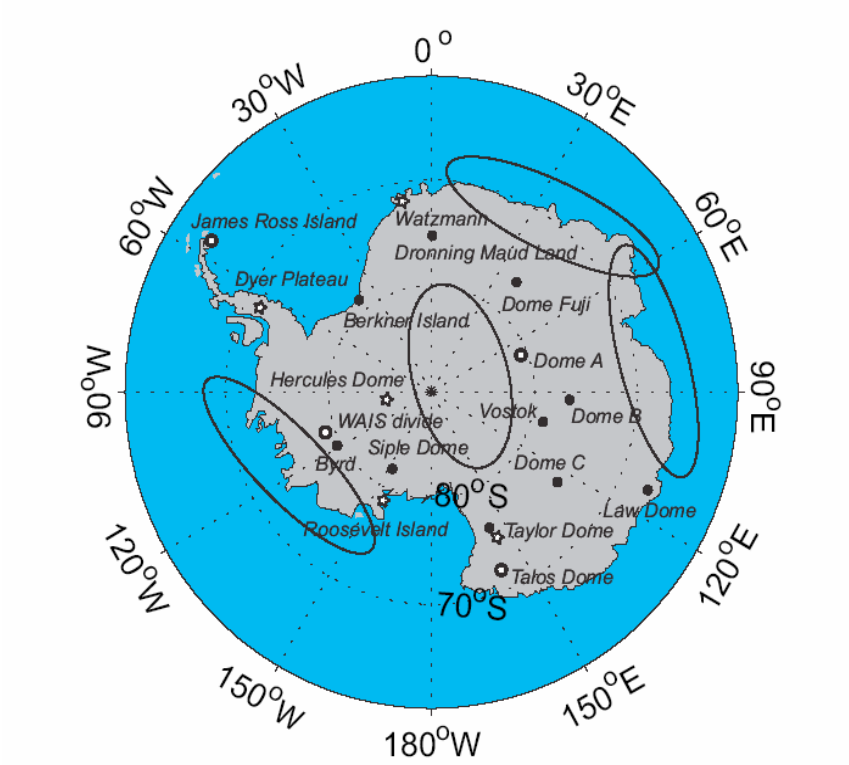
  http://www.nicl-smo.unh.edu/IPICS/

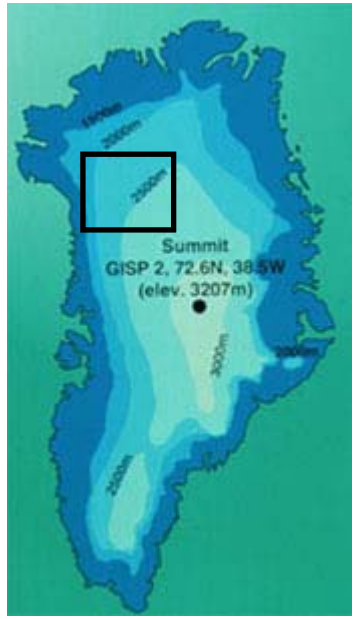
sponsored by NSF/OPP and European Polar Board.

IPICS

- The oldest ice core: A 1.5 million year record of climate and greenhouse gases from Antarctica.
- The last interglacial and beyond: A northwest Greenland deep ice core drilling project.
- The IPICS 40,000 year network: a bipolar record of climate forcing and response.
- The IPICS 2kyr array: a network of ice core climate and climate forcing records for the last two millennia

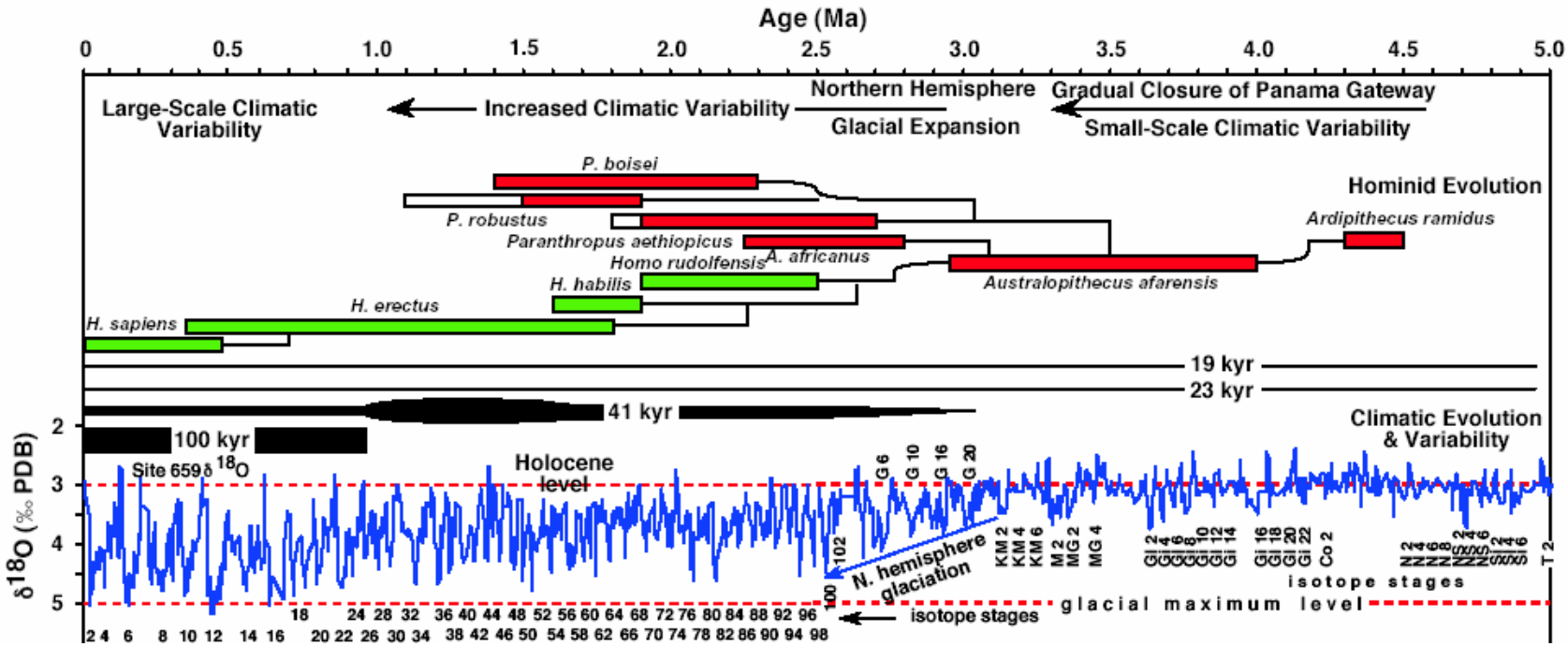
Ongoing and future projects





- ● Existing ice cores
- ○ In preparation
- ✪ Future projects
- ⬭ Lack of information

Why look for climate change prior to 1 million years?



Past climates are essentiel to test and improve the understanding of climate change mechanisms including feedbacks between the global carbon cycle and climate

Need understanding of the shift from small ice ages with periodicities of 40 000 years to large ice ages with periodicities of 100 000 years : natural carbon cycle?