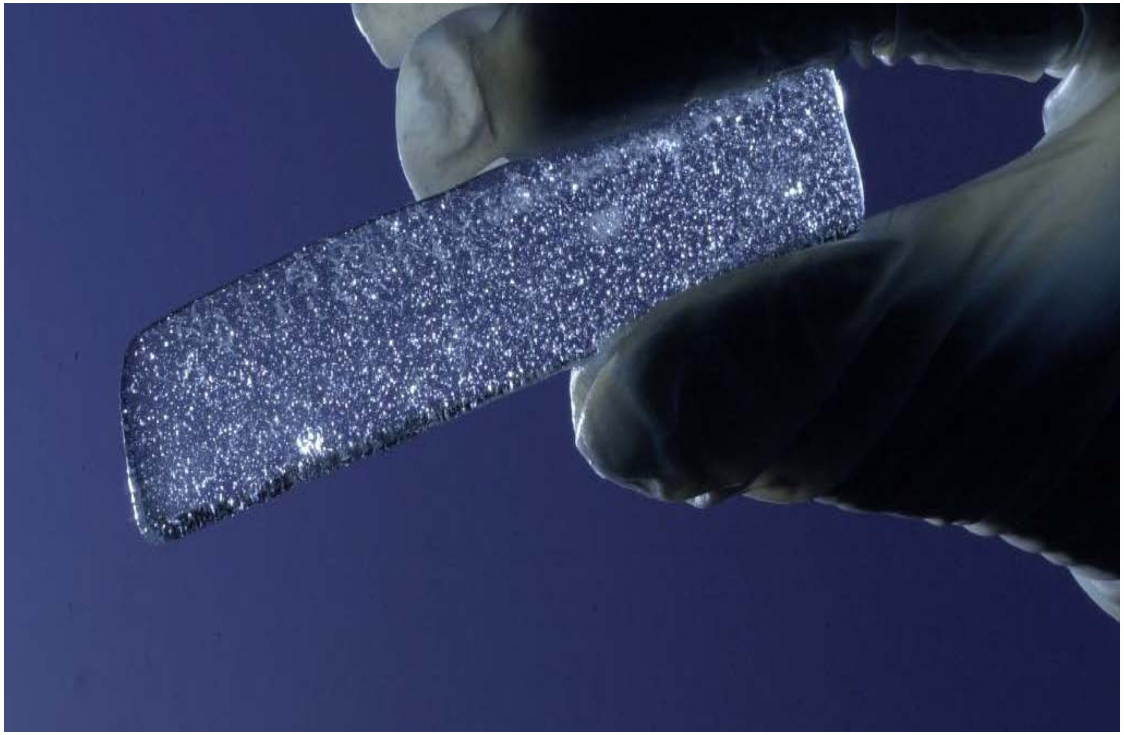
Climate information from ice cores



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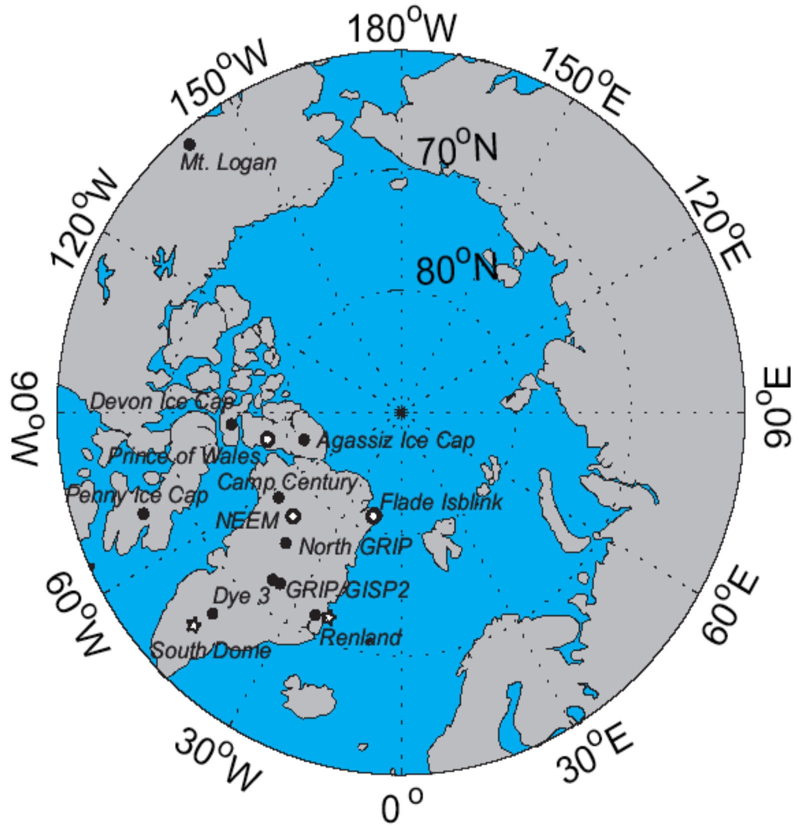
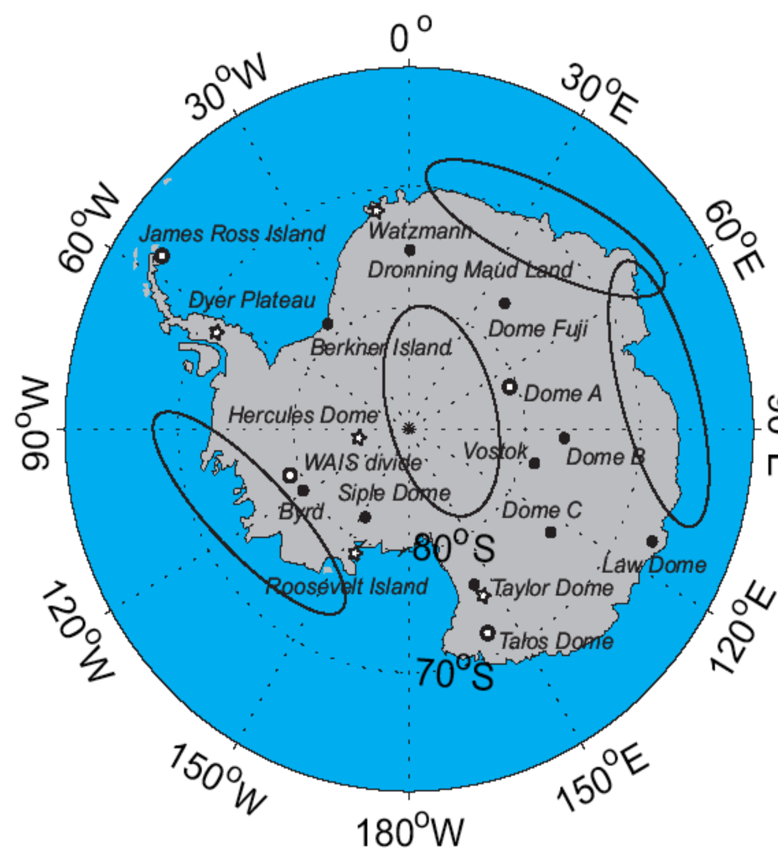
LSCE

European Geosciences Union

GIFT – Geosciences Information For Teachers

50 years of deep drilling efforts



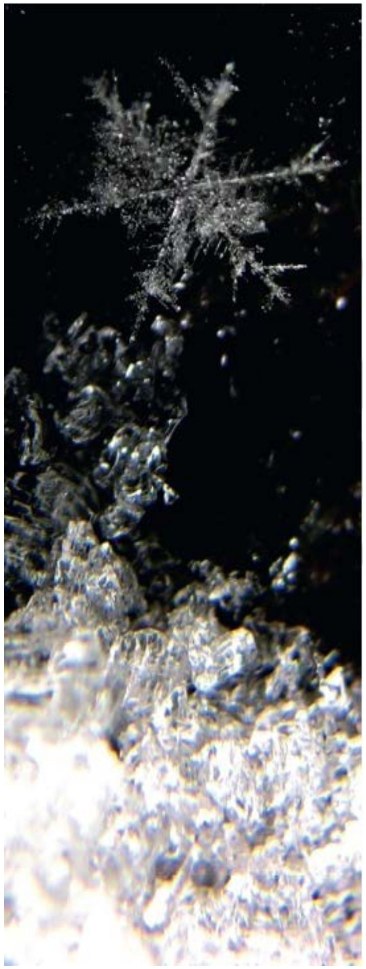


International Partnership for Ice Core Science

For more information on ice core science history : Jouzel et al, Clim. Past, 2013

Outline

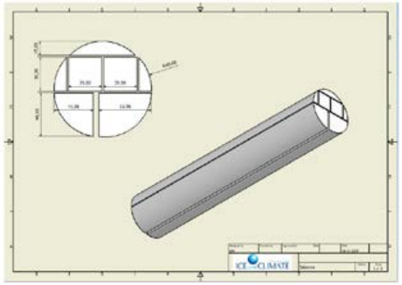
- **Quantifying past climate changes**
  - Polar temperature and accumulation
- **Understanding past climate changes**
  - Last thousand years
  - Present and last interglacial periods
  - Glacial-interglacial variations
  - Abrupt events
- **Relevance for future change**



Methods

Quantifying past climate changes

- **Polar accumulation rate (in water equivalent per year) is important for:**
  - climate (atmospheric water cycle)
  - ice sheet dynamics (surface mass balance) and sea level
  - ice core chronology

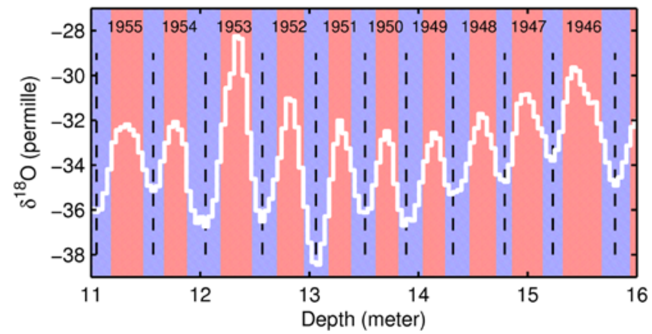


- **Polar temperature is important for climate dynamics:**
  - polar amplification
  - feedbacks in the response of polar climate to forcings
  - variability intrinsic to the climate system at different time scales

- **Precise estimates allow to benchmark climate models**

Methods to estimate past polar temperature

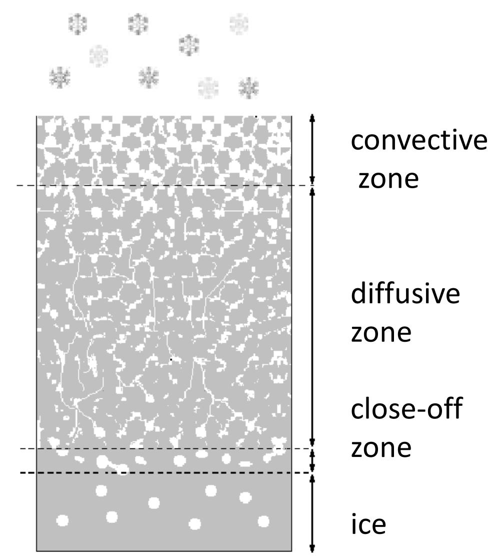
- Water stable isotopes



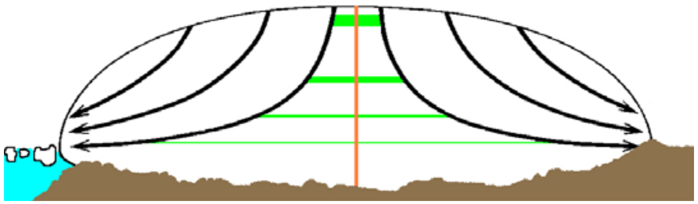
- Inversion of borehole temperature profile

- Changes in firn air thermal and gravitational diffusion during rapid temperature changes

  thanks to measurements of $^{15}N/^{14}N$ or $^{40}Ar/^{36}Ar$ in air



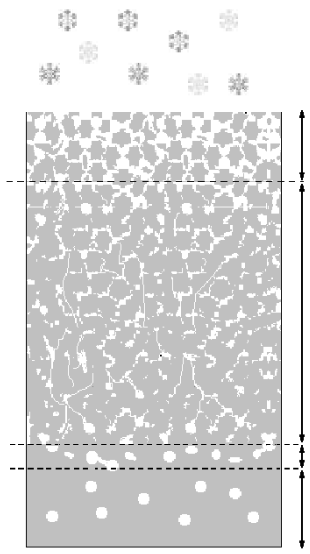
Methods to estimate past accumulation rate



- Identification of annual layer thickness

  Correction for changes in density

  Correction for layer thinning due to ice flow



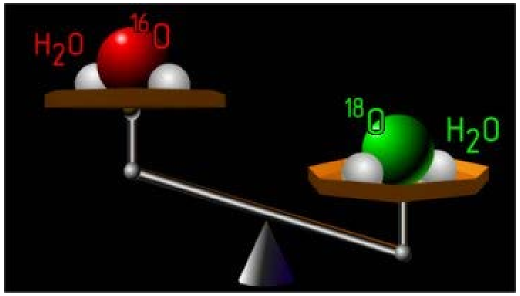
- Assumption of relationships between water stable isotopes, temperature, saturation vapor pressure and accumulation

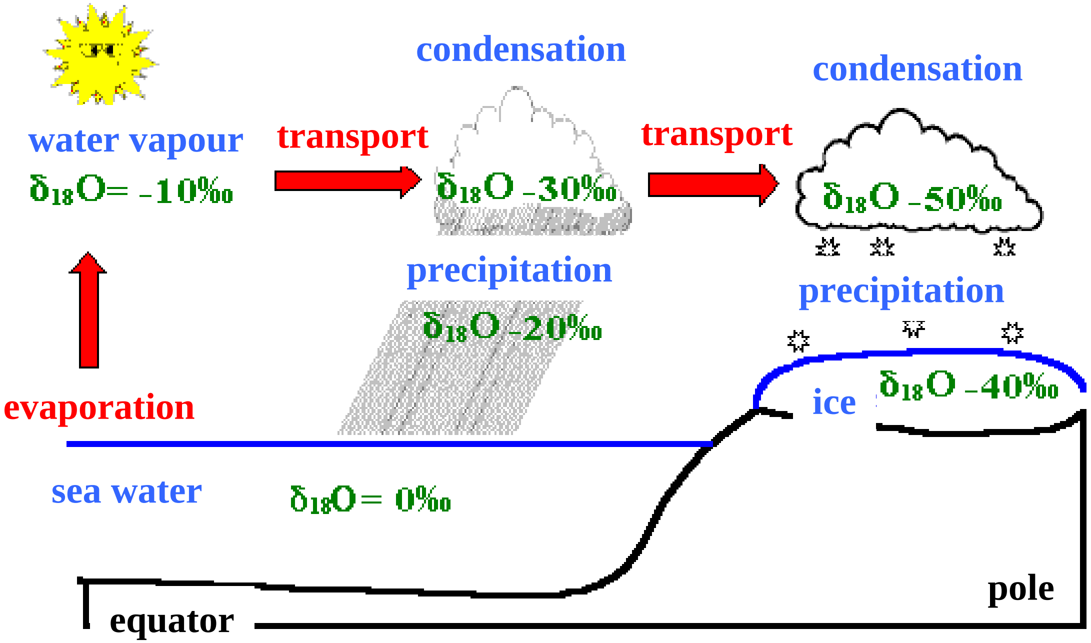
  « Clausius-Clapeyron »

- Changes in firn air thermal and gravitational diffusion

- **NEW** : subproduct of multiple ice core chronologies established from Bayesian models using all available sources of information

Water stable isotopes and climate





Fractionation occurring during each phase change

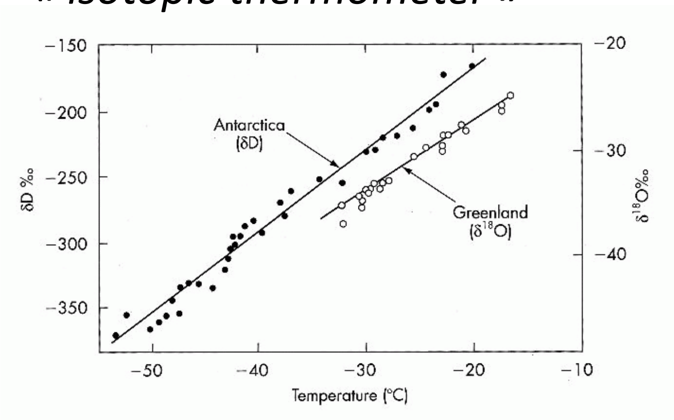
- equilibrium effect due to differences in saturation vapor pressure
- kinetic effect due to difference in molecular diffusivities

Water stable isotopes and climate

Since the 1950s

Precipitation and surface snow measurements

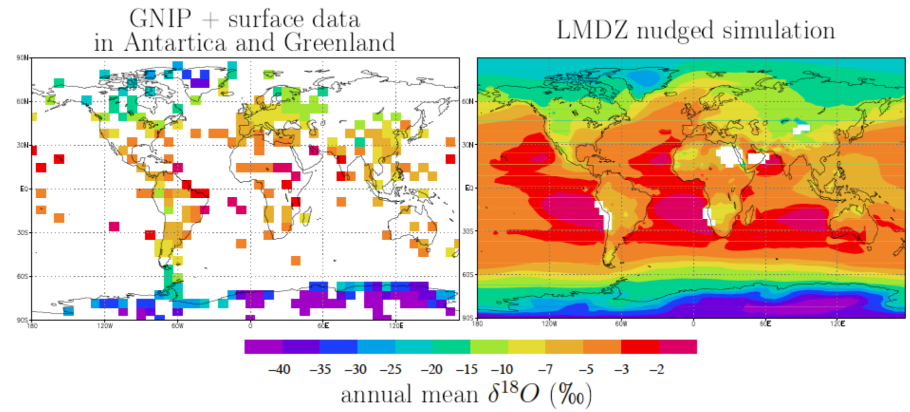
« isotopic thermometer »



Since the 1980s

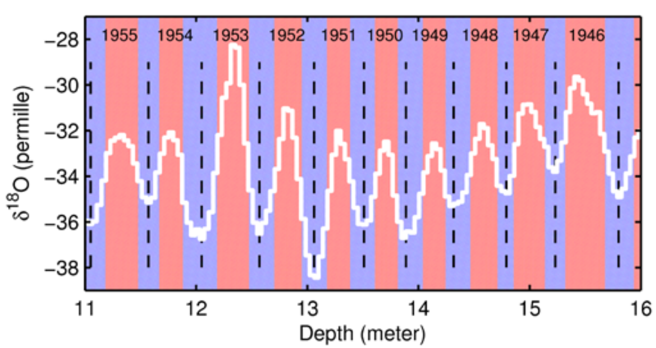
Atmospheric modelling

Climate-isotope relationships



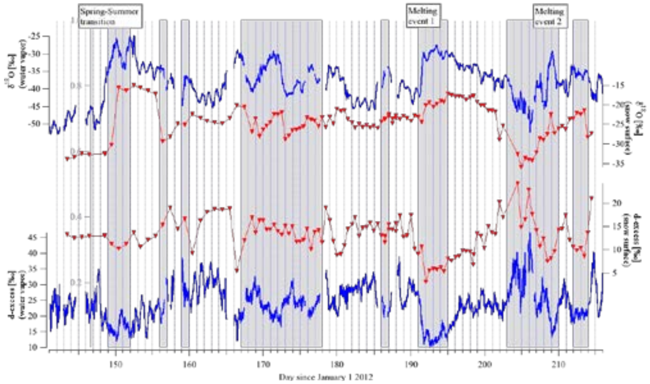
Measurements in ice cores:

Past climate, chronology



Since the 2010s

Water vapour in situ monitoring



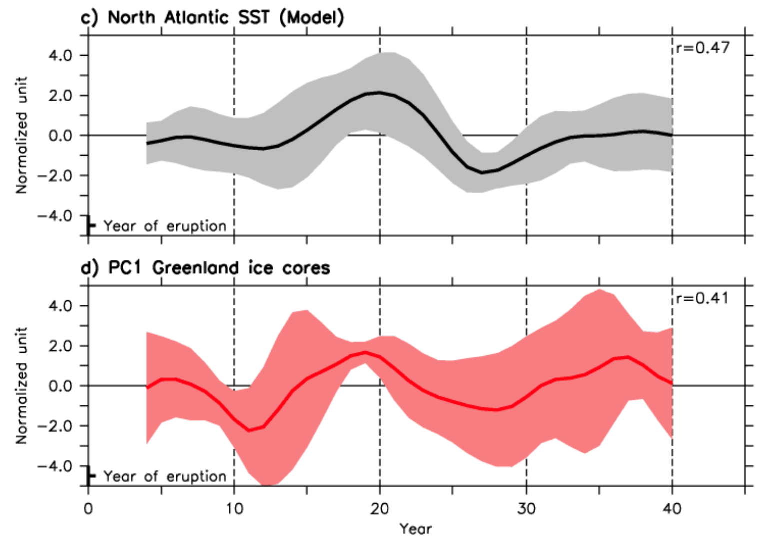
Results

Climate variability during the last thousand years

- Key drivers : volcanic and solar forcing + human activites
- Importance of internal climate variability
- Large uncertainties for Antarctica (signal to noise low)
- Mechanisms relatively well understood for Greenland

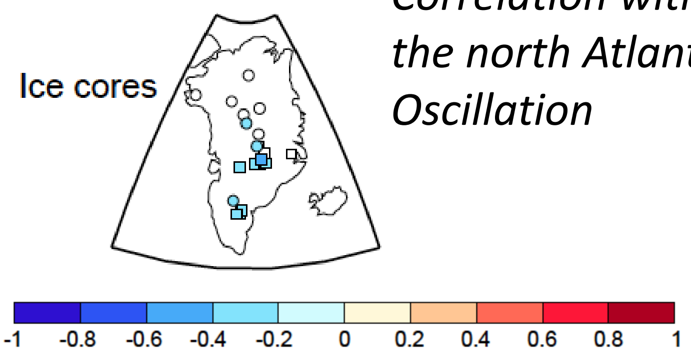
Greenland climate is affected by

Changes in North Atlantic ocean surface temperature

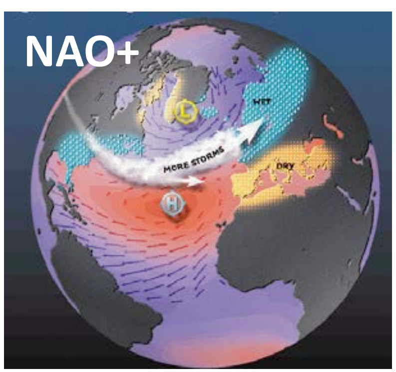


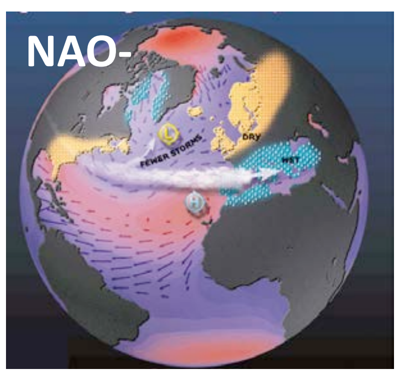
Response to large volcanic eruptions

Changes in atmospheric circulation



Correlation with the north Atlantic Oscillation

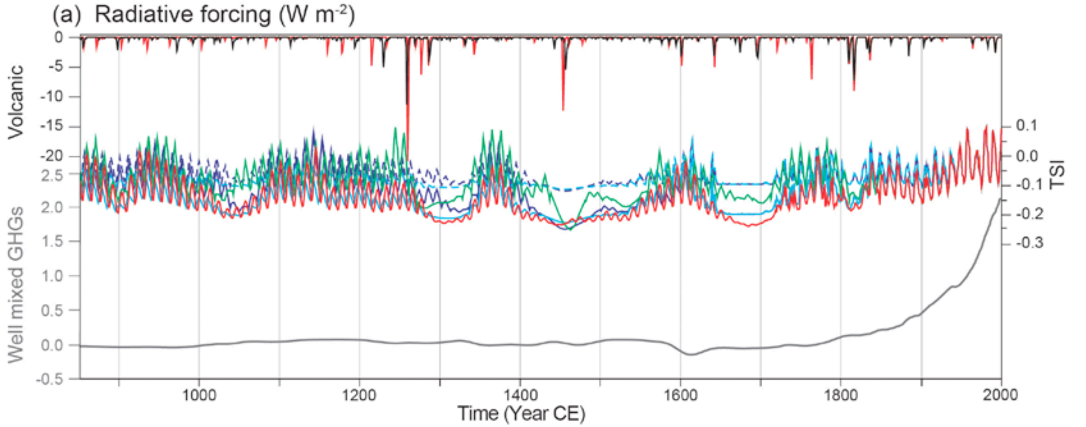




Volcanic forcing

Solar forcing

Greenhouse gas forcing



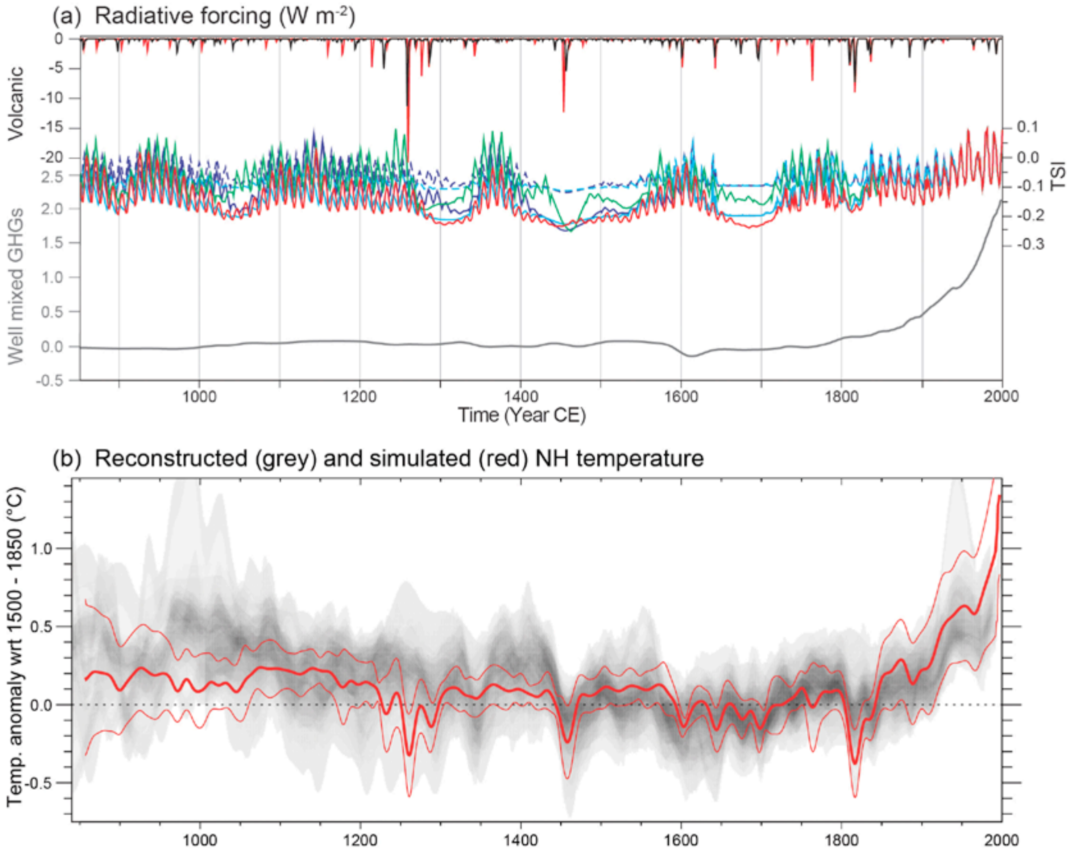
IPCC AR5 WG1, Box TS.5, Fig.1 and Chapter 5 Fig. 5.12

Volcanic forcing

Solar forcing

Greenhouse gas forcing

Northern Hemisphere temperature



simulations

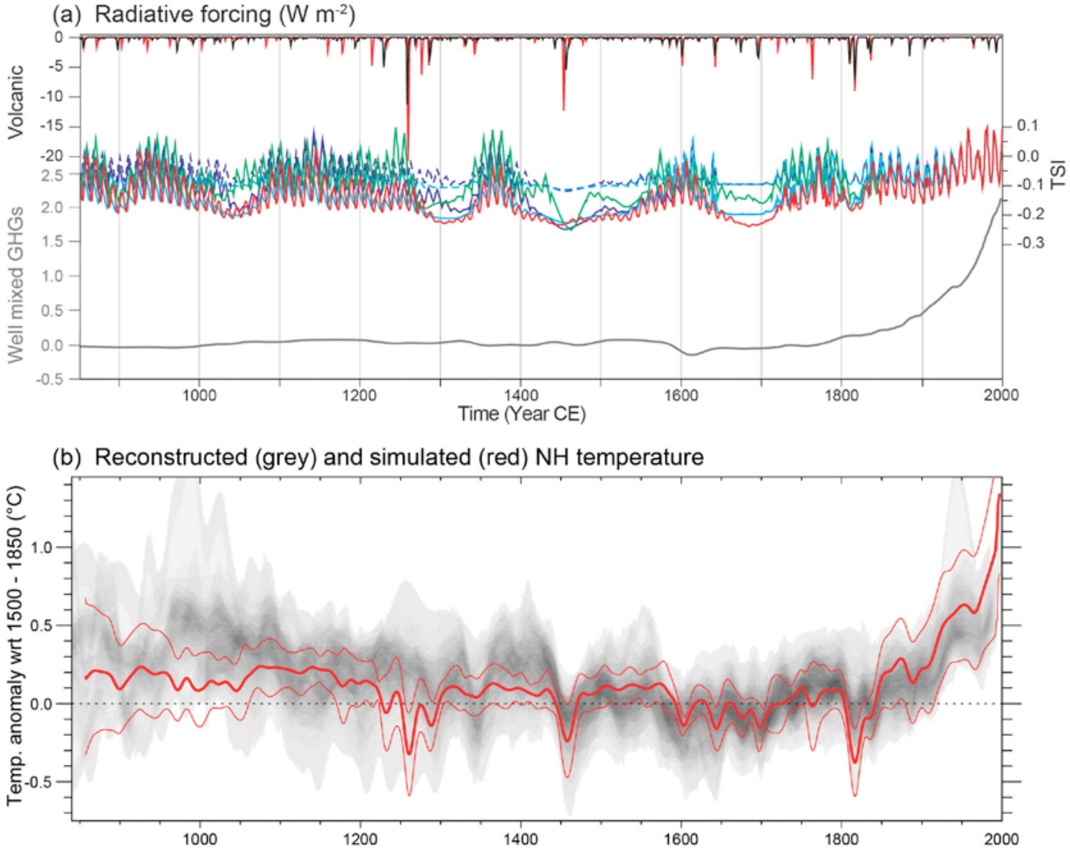
IPCC AR5 WG1, Box TS.5, Fig.1 and Chapter 5 Fig. 5.12

Volcanic forcing

Solar forcing

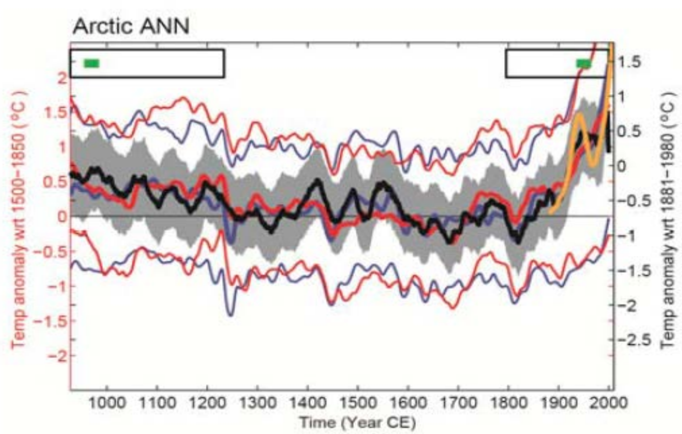
Greenhouse gas forcing

Northern Hemisphere temperature

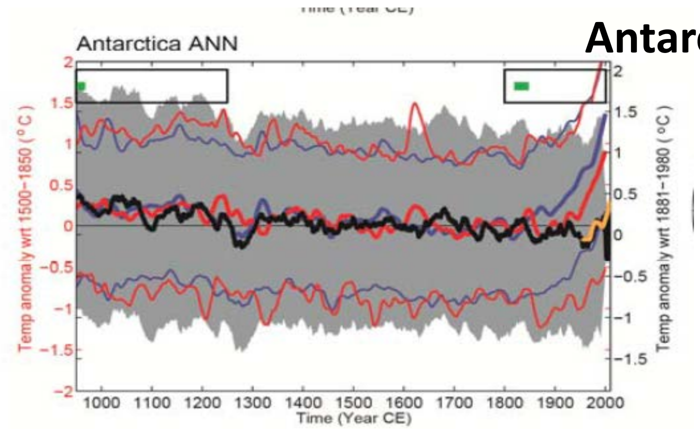


simulations

Arctic



Antarctica

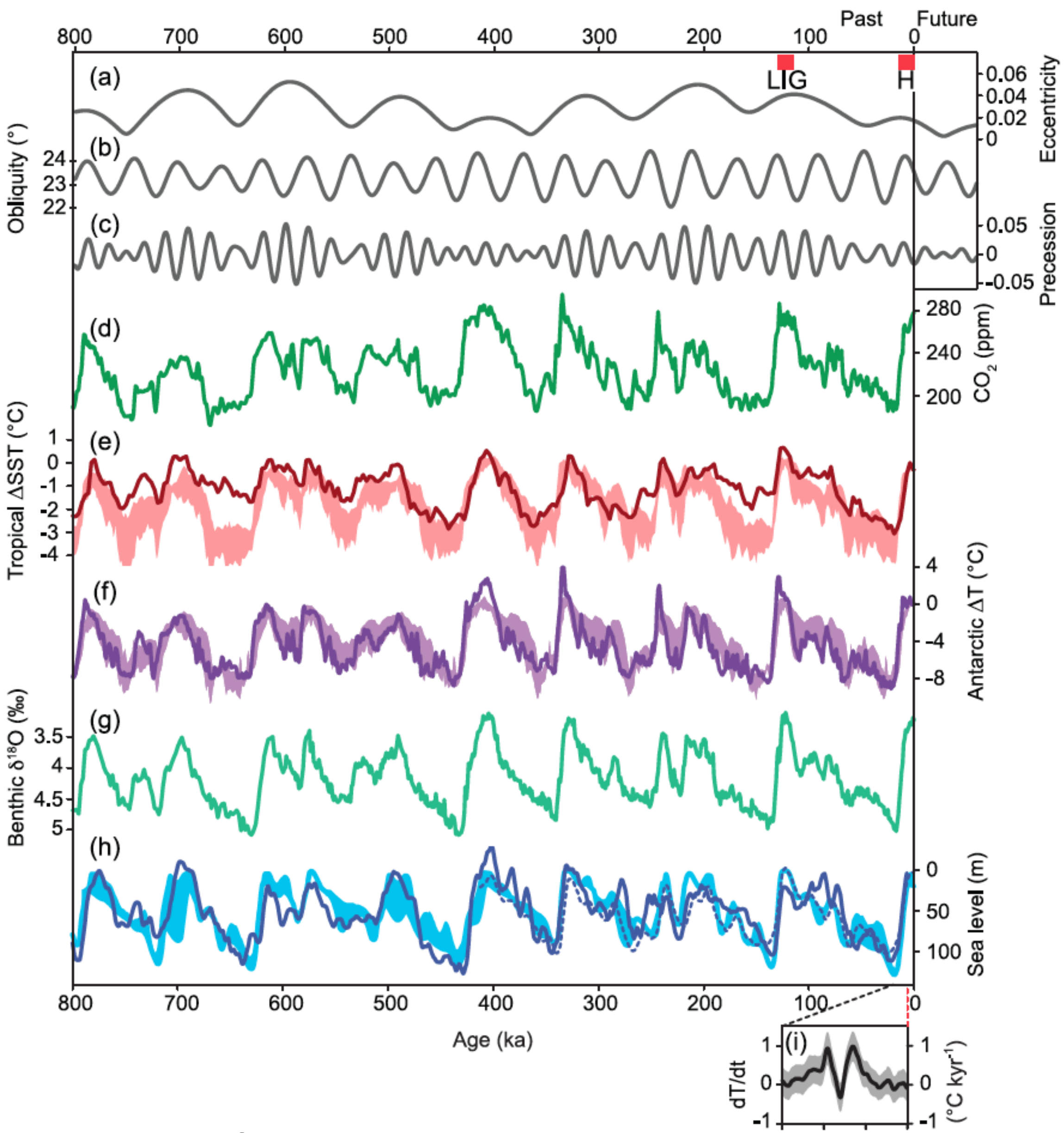


IPCC AR5 WG1, Box TS.5, Fig.1 and Chapter 5 Fig. 5.12

Glacial-interglacial variations

- Key driver : orbital forcing
- Key « slow » feedbacks : response of ice sheets (albedo) and carbon cycle (greenhouse effect)

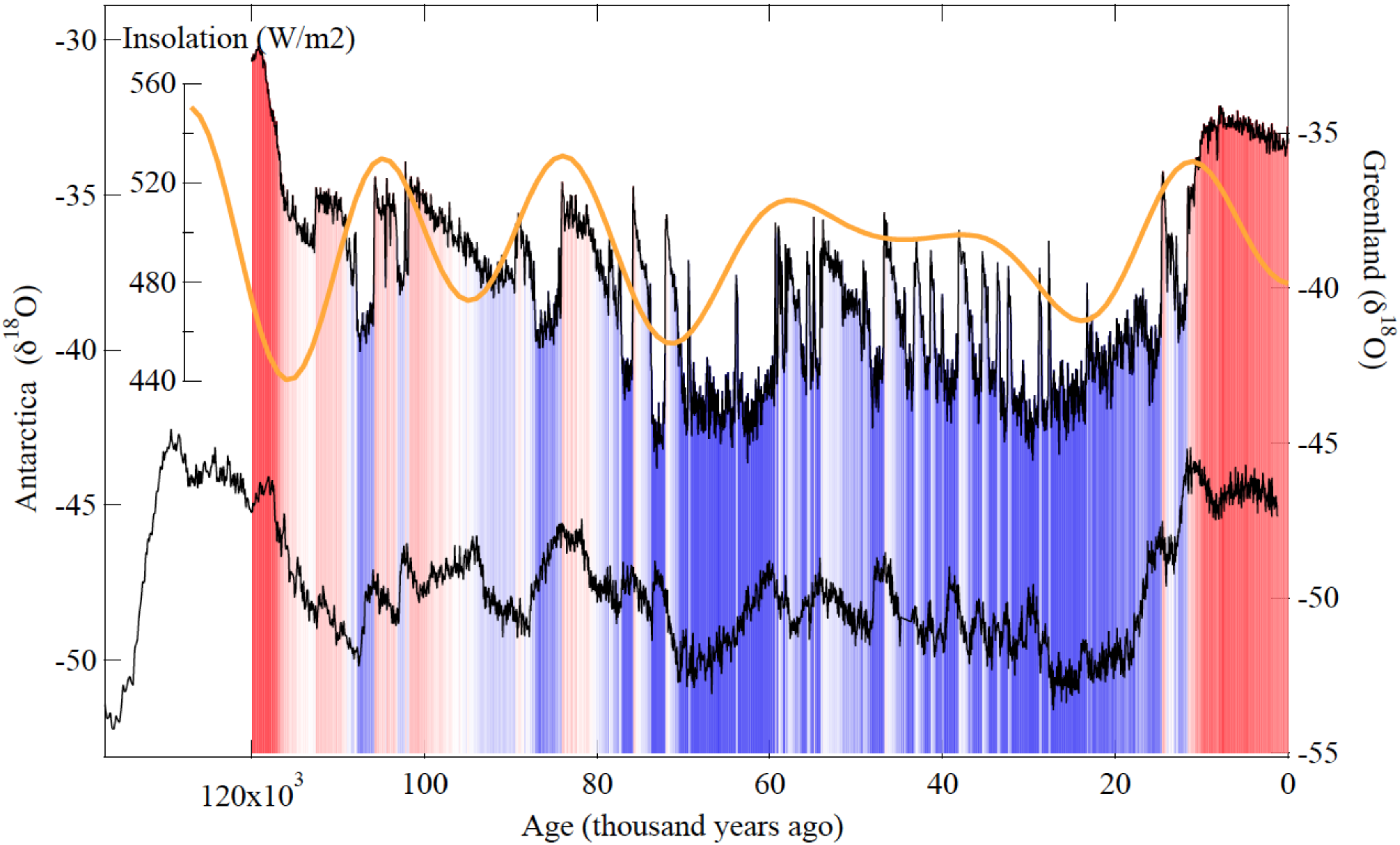
Glacial-interglacial variations



- Close coupling between changes in NH ice sheets, CO_2 concentration and Antarctic climate
- Last deglaciation: Antarctic T // CO_2

IPCC AR5 WG1, Chapter 5 Fig. 5.3

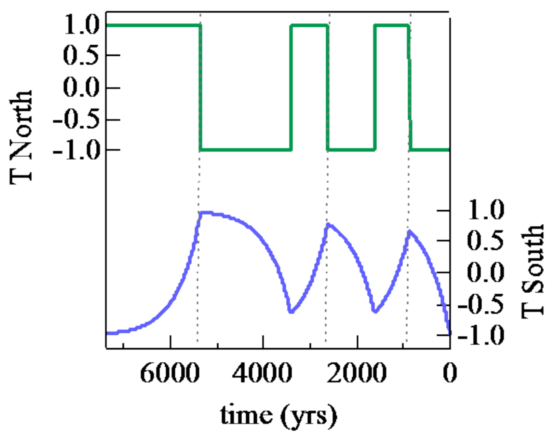
Greenland vs Antarctica during the last glacial-interglacial cycle

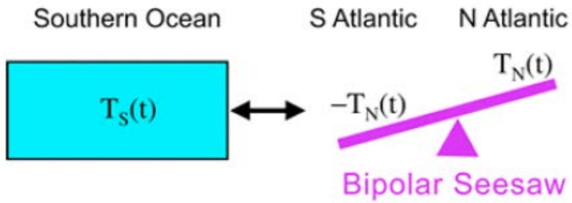


NGRIP vs EDLM ice cores, AICC 2012 chronology (Bazin et al, Clim. Past, 2013)

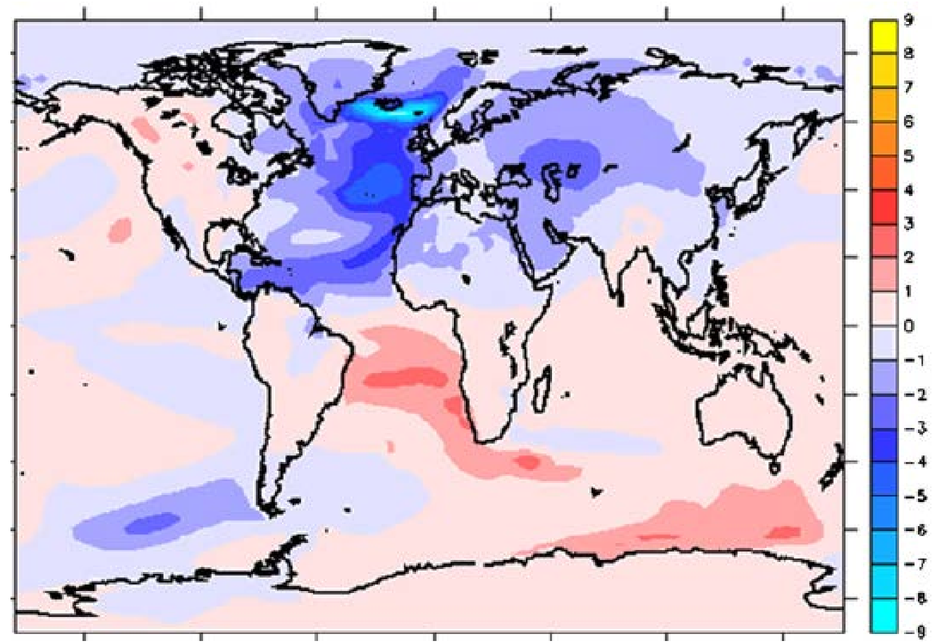
Bipolar seesaw

Conceptual model



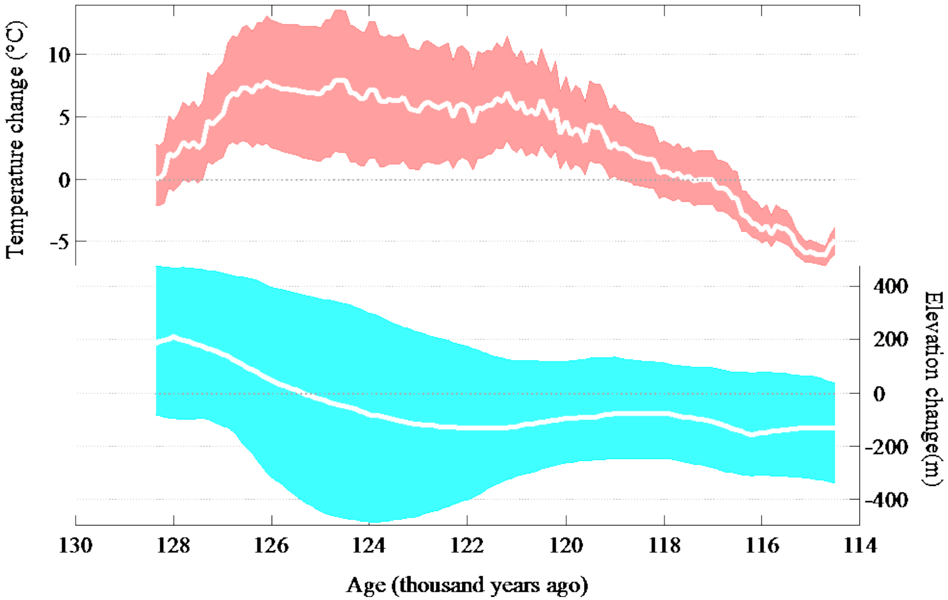


Coupled ocean-atmosphere model



Stocker and Johnsen, 2001; Buiron et al, 2012

The Greenland ice sheet during the last interglacial period (125 000 years ago)



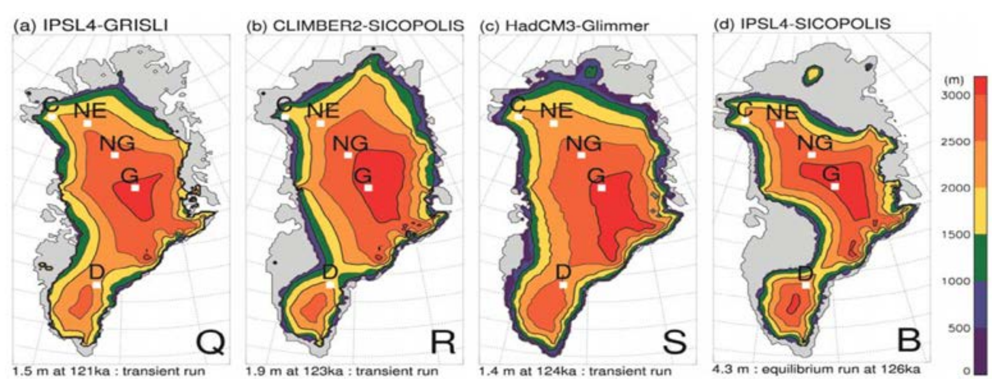
NEEM ice core :

Estimate of changes in temperature and elevation (ice thickness)

Compatible with ice sheet simulations producing 1.5 to 4.3 m sea level rise

Estimations : 5 to 10 m
(best guess : 6 m)

-> contribution from Antarctica



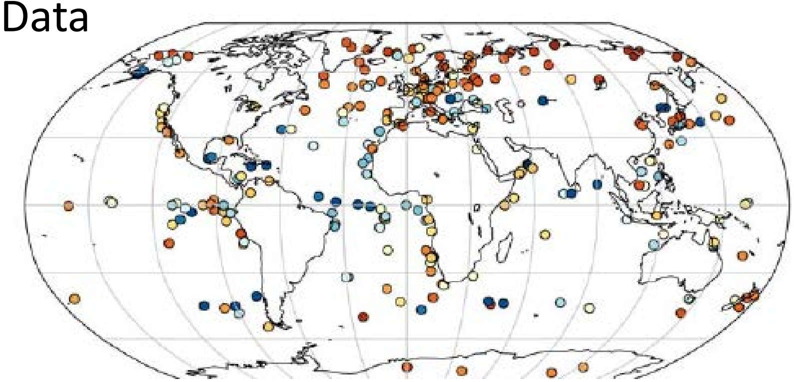
NEEM, 2013; IPCC AR5, WG1, chapter 5, fig. 5.16

Range of temperature changes during the last million years

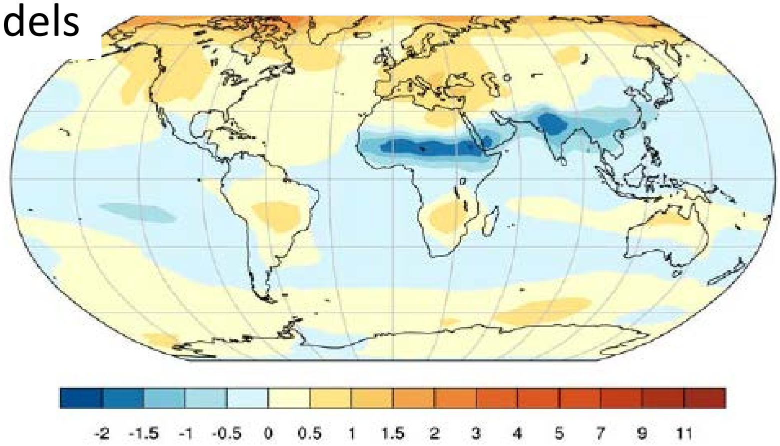
Last interglacial period (125 000 years ago)

<2°C globally

Data



Models

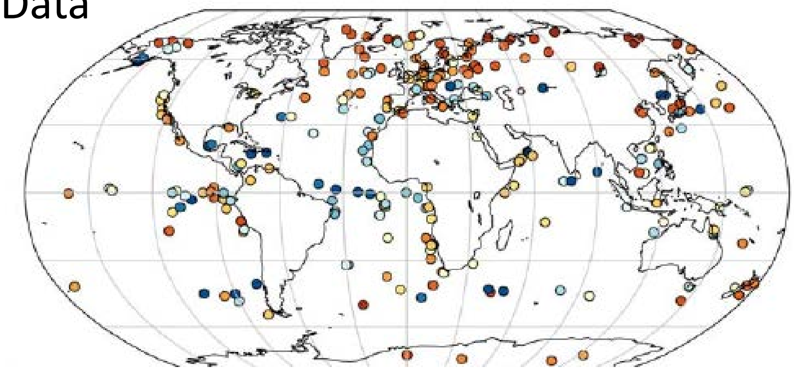


IPCC AR5, Chap 5, Box 5.1

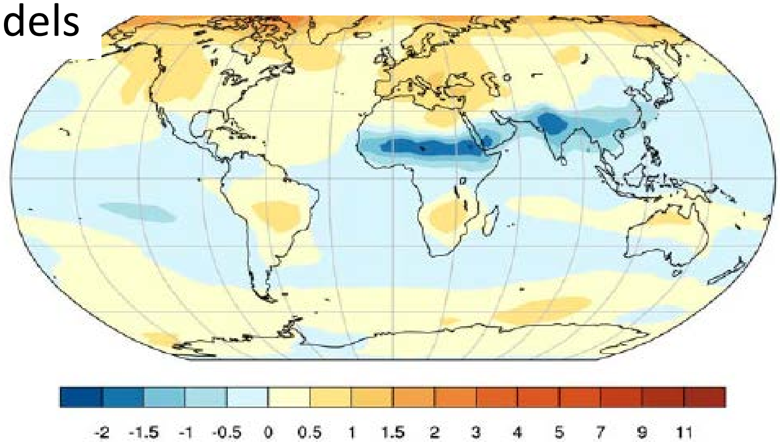
Range of temperature changes during the last million years

Last interglacial period (125 000 years ago) <2°C

Data



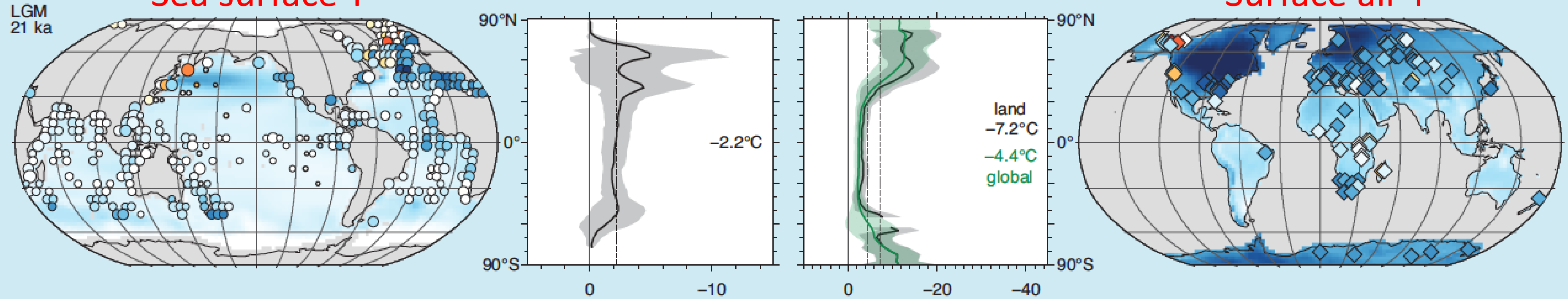
Models



Last glacial maximum (21 000 years ago) -4.5±1.5°C

Sea surface T

Surface air T



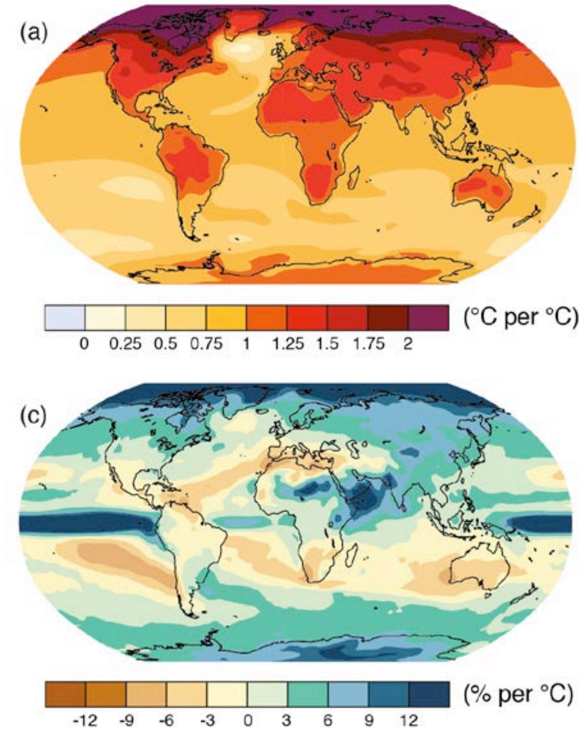
Relevance for future change

- **Past climates = « natural experiments » on the climate system**
  Climate sensitivity
  Polar amplification
  Abrupt change

- **Constrain the response of polar ice sheets**
  Contributions to sea level rise

- **Compare magnitudes and rates of projected future changes with past ones**
  2°C warming : above ranges of recent interglacial periods
  4°C warming : abrupt

Projected temperature and precipitation change per °C global warming



IPCC AR5 WG1 Ch12

Summary

- **Ice cores :** wealth of climate and environmental information, precise age scales

- **Integration with other archives, comparisons with climate models (explicitely simulating tracers such as water stable isotopes)**

- **Work under progress :**
- High resolution records of the recent past
- Origin of moisture, aerosols, gases
- Oldest ice challenge