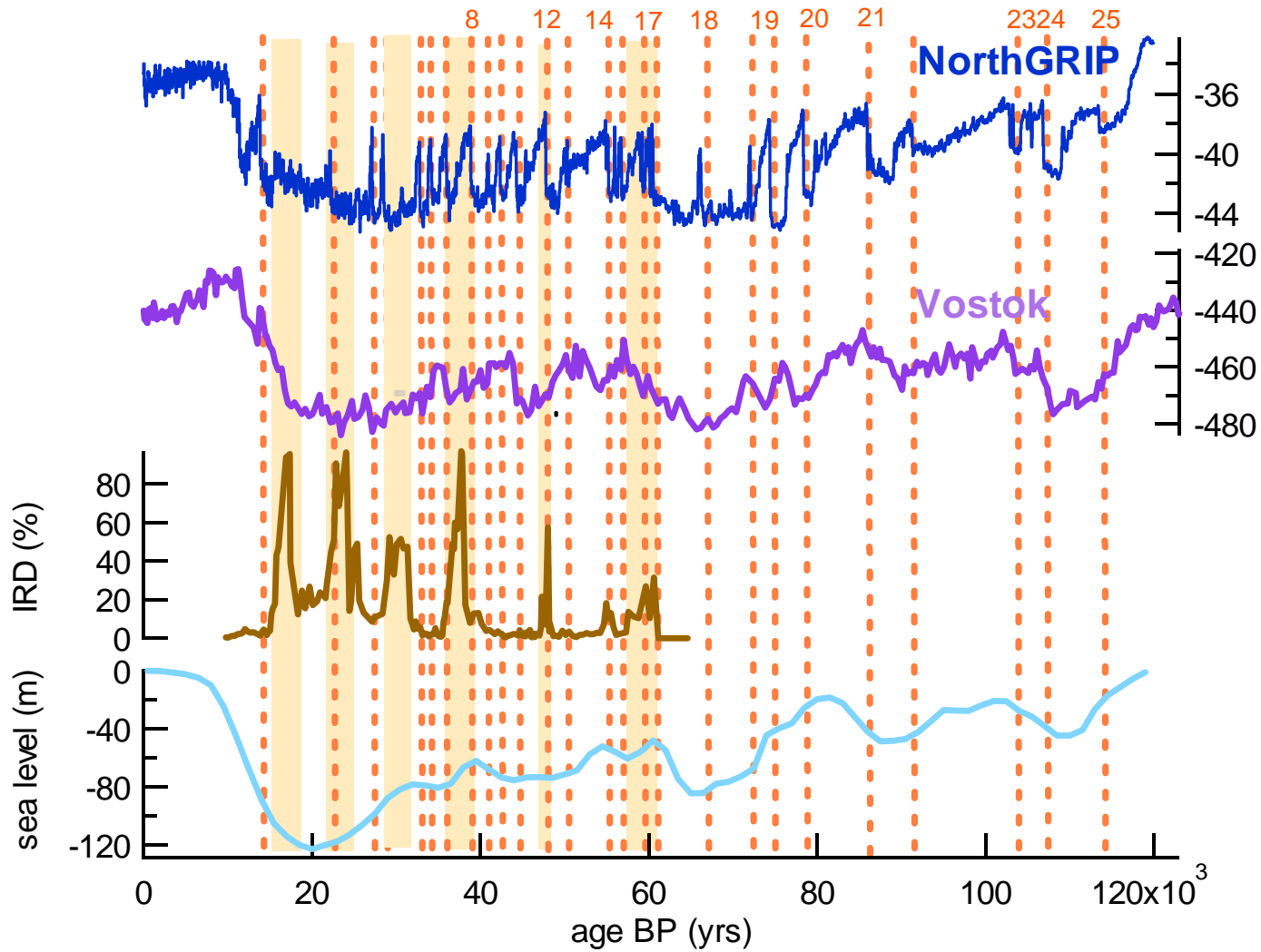


Rapid climate variability during cold and warm periods in North-Atlantic as inferred from Greenland ice cores

- Air isotopic measurements
- NorthGRIP ice core

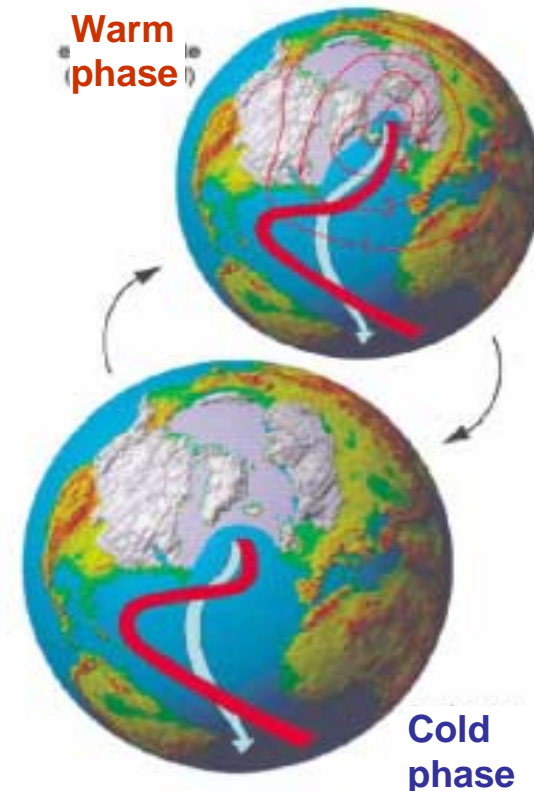
A. Landais, V. Masson-Delmotte, J. Jouzel, J.M. Barnola, J. Chappellaz, S. Johnsen, D. Dahl-Jensen, and M. Leuenberger

The rapid climatic variability



Characteristics and mechanism of a Dansgaard-Oeschger event

- Rapid temperature increase in the mid and high latitudes of the northern hemisphere
- Mediterranean vegetation changes from semi-desert (cold phase of a DO) to temperate (warm phase of a DO)
- Southward displacement of the ITCZ during cold phase of a DO
- Increase in Greenhouse gases concentration during warm phase of a DO
- Reorganization of the deep water circulation: induced by huge icebergs discharges ?



*e.g. Broecker et al., 1985
Figure from
Ganopolski and Rahmstorf, 2002*

Still numerous questions on the Dansgaard-Oeschger events sequence

- Rapid temperature increase in the mid and high latitudes of the northern hemisphere



1-Amplitude ??

- Mediterranean vegetation changes from semi-desert (cold phase of a DO) to temperate (warm phase of a DO)

- Southward displacement of the ITCZ during cold phase of a DO



2-Sequence ??

- Increase in Greenhouse gases concentration during warm phase of a DO

- Reorganization of the deep water circulation: induced by huge icebergs discharges ?



3-Impossible in interglacial period ?

1- Amplitude of the temperature change

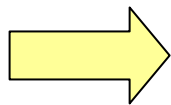
Temperature reconstruction in Greenland ice cores : methods

- $\Delta\delta^{18}\text{O}_{\text{ice}}/\Delta T = 0.67 = \text{spatial relationship (Dansgaard et al., 1964)}$

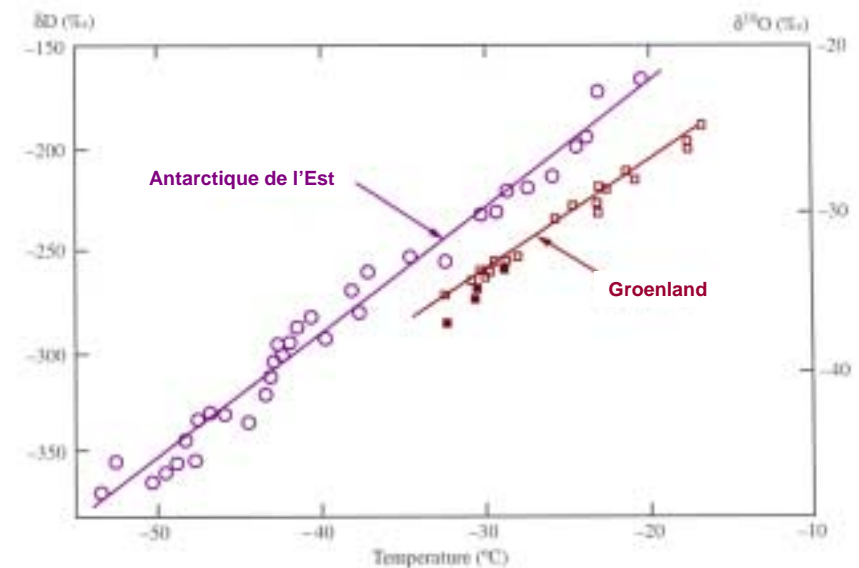
Pb: 1- source influence

2- seasonality of the precipitations

3- ice sheet elevation



Bias up to a factor of two for the temperature reconstruction during the glacial period in Greenland.

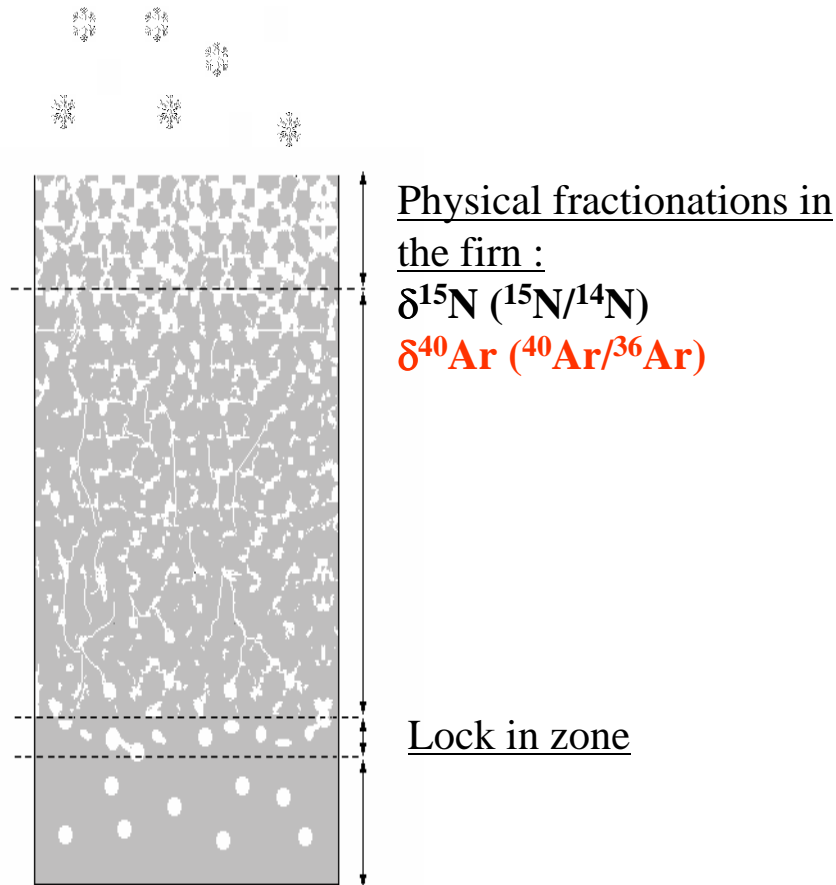


- Borehole temperature inversion (Cuffey et al., 1995; Johnsen et al., 1995; Dahl-Jensen et al., 1998) : does not apply to DO
- Isotopes of the air trapped in the ice. (Severinghaus et al., 1998)

1- Amplitude of the temperature change

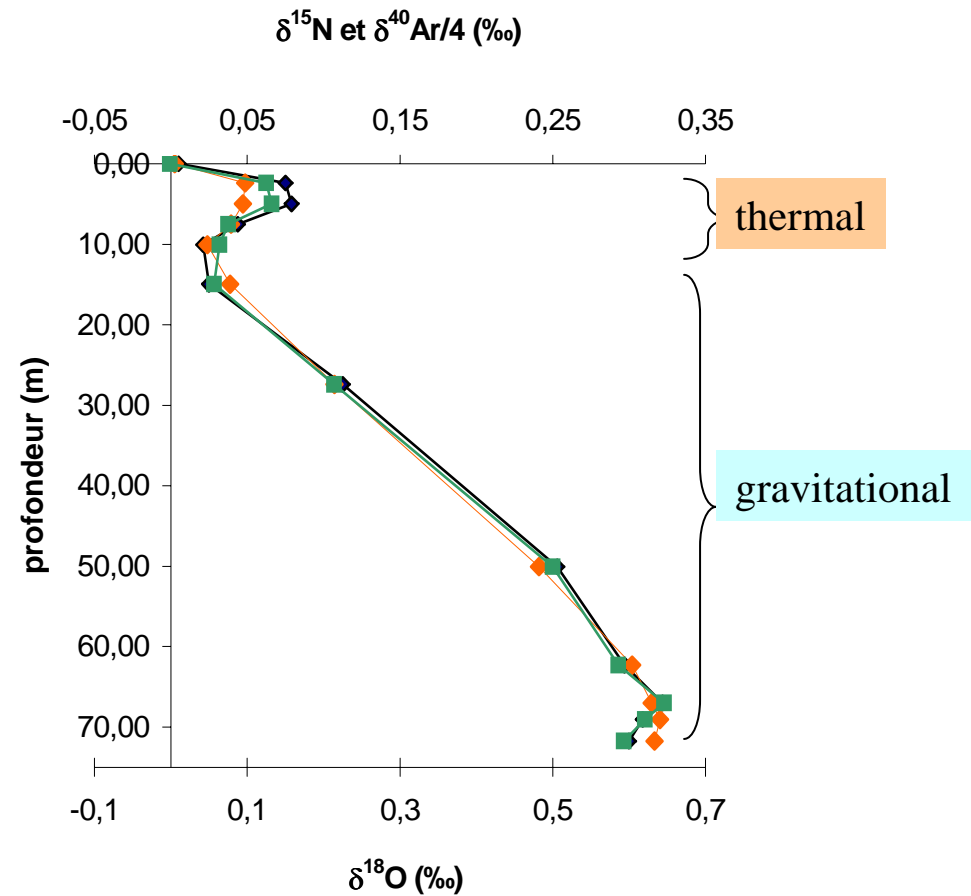
1-Isotopes of the air trapped in ice core

$\delta^{15}\text{N}$ constant
 $\delta^{40}\text{Ar}$ constant



Gravitational fractionation : $\delta = \Delta mgz/RT$

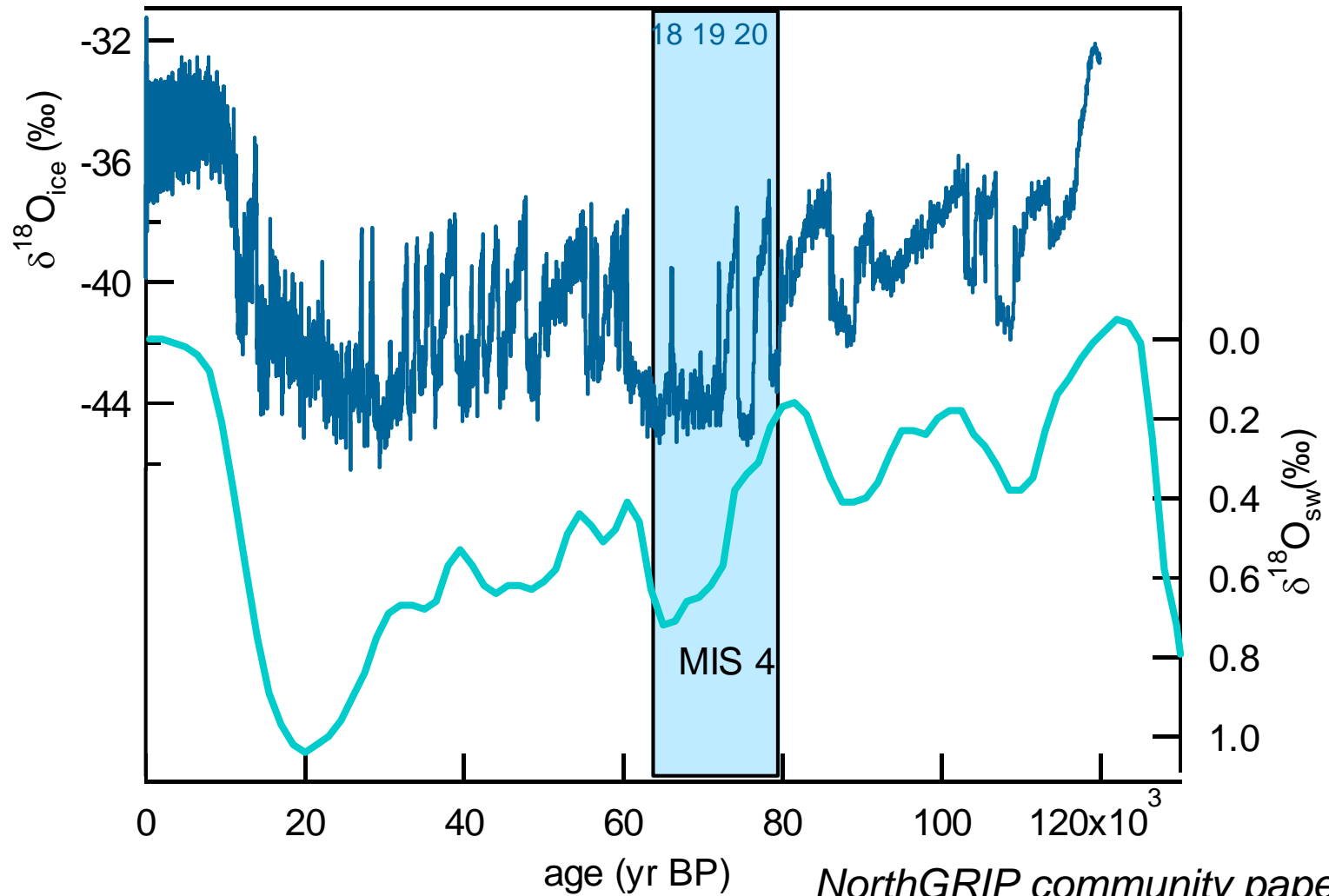
Thermal fractionation : $\delta = \Omega \Delta T$



Extraction of the thermal signal alone : $\delta^{15}\text{N}_{\text{excess}} = \delta^{15}\text{N} - \delta^{40}\text{Ar}/4 = (\Omega_{\text{N}} - \Omega_{\text{Ar}}/4) \Delta T$

1- Amplitude of the temperature change

Temperature reconstruction over a sequence of three DO



NorthGRIP community paper, 2004

1- Amplitude of the temperature change

Temperature reconstruction over a sequence of three DO

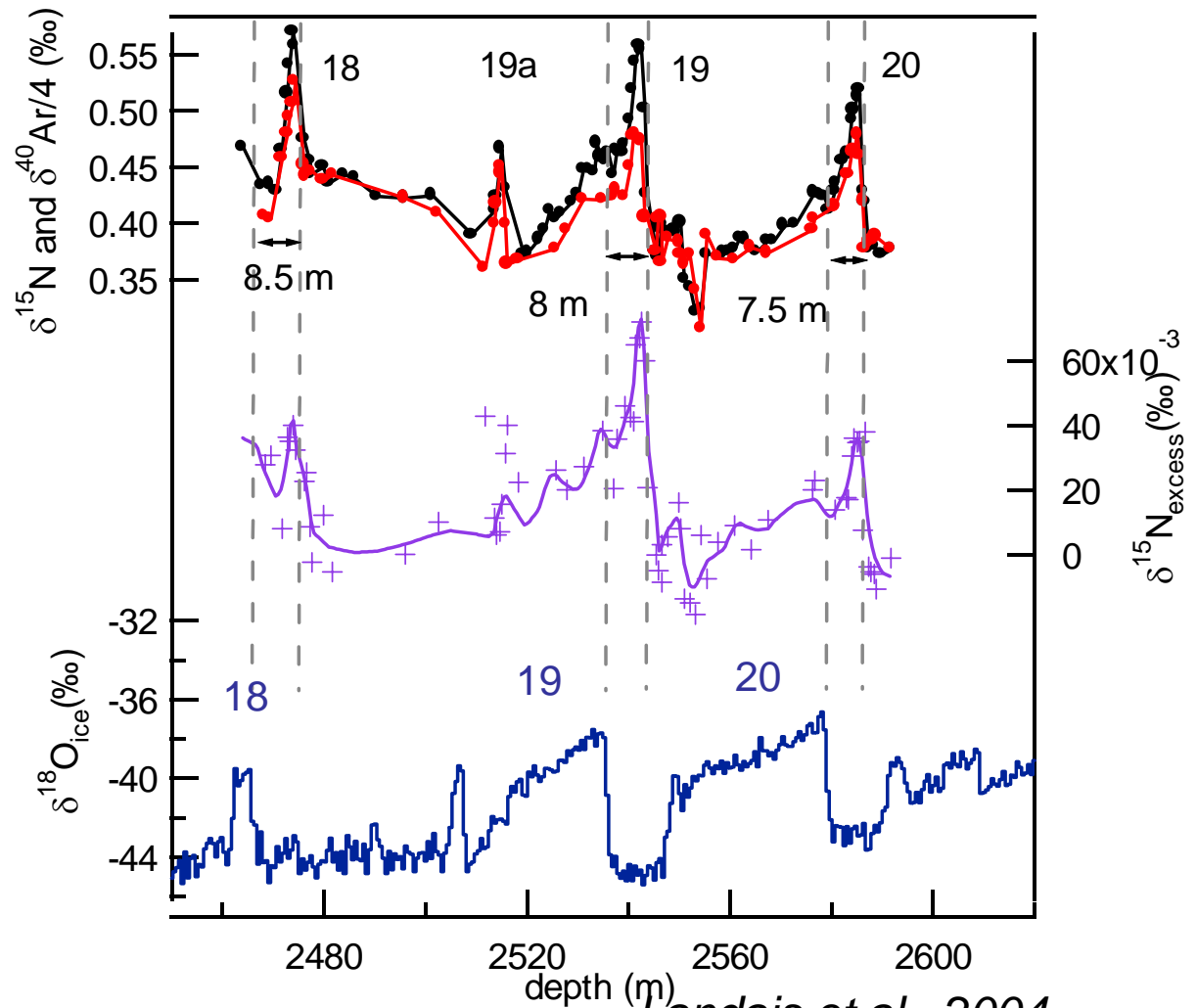
$$\delta^{15}\text{N}_{\text{excess}} = \delta^{15}\text{N} - \delta^{40}\text{Ar}/4$$

$$\Delta\delta^{15}\text{N}_{\text{excess}} = (\Omega_{\text{N}} - \Omega_{\text{Ar}}/4)\Delta T$$

Temperature gradient in the firn

Model
(Goujon et al., 2003)

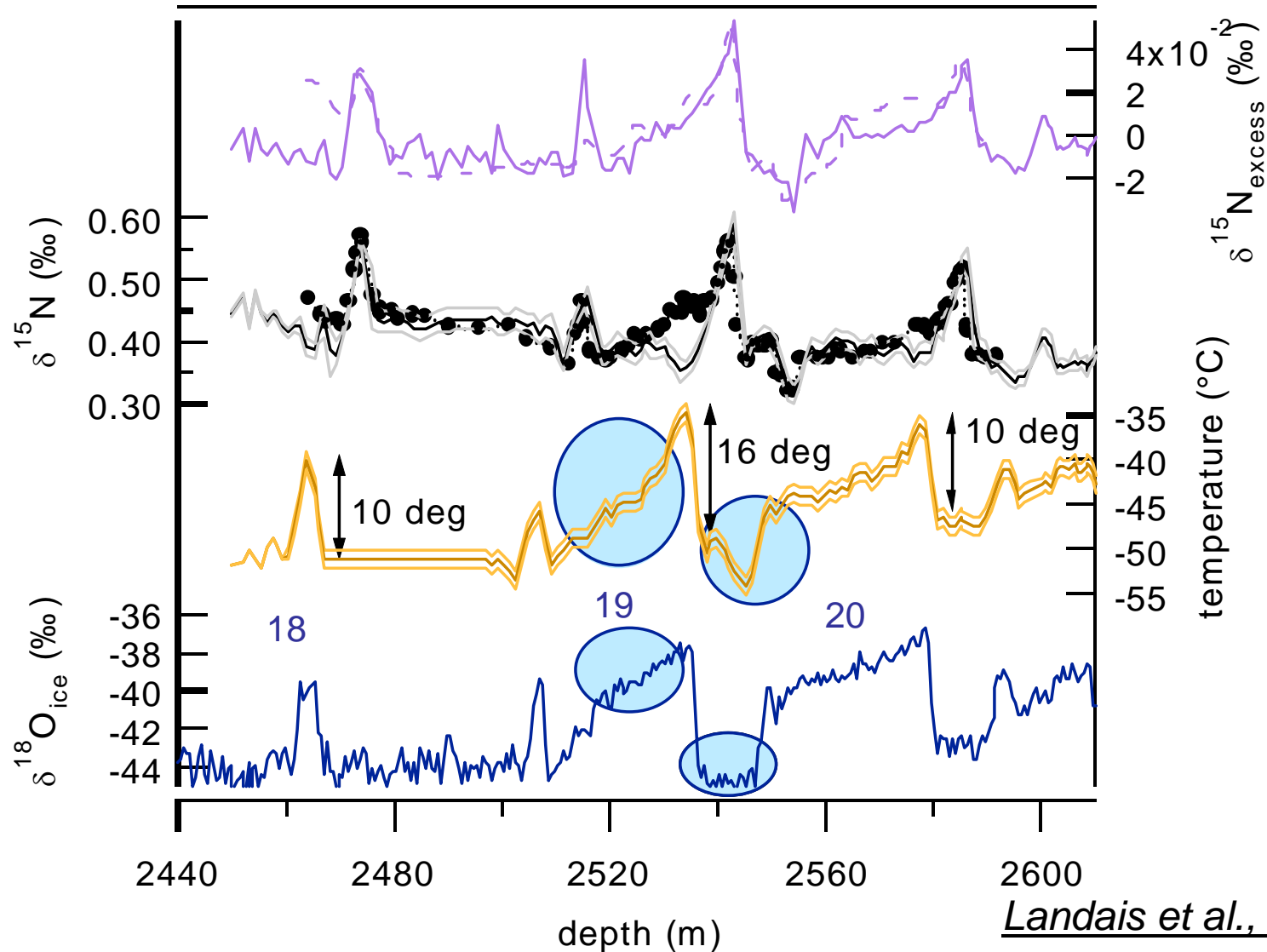
Surface temperature change



Landais et al., 2004

1- Amplitude of the temperature change

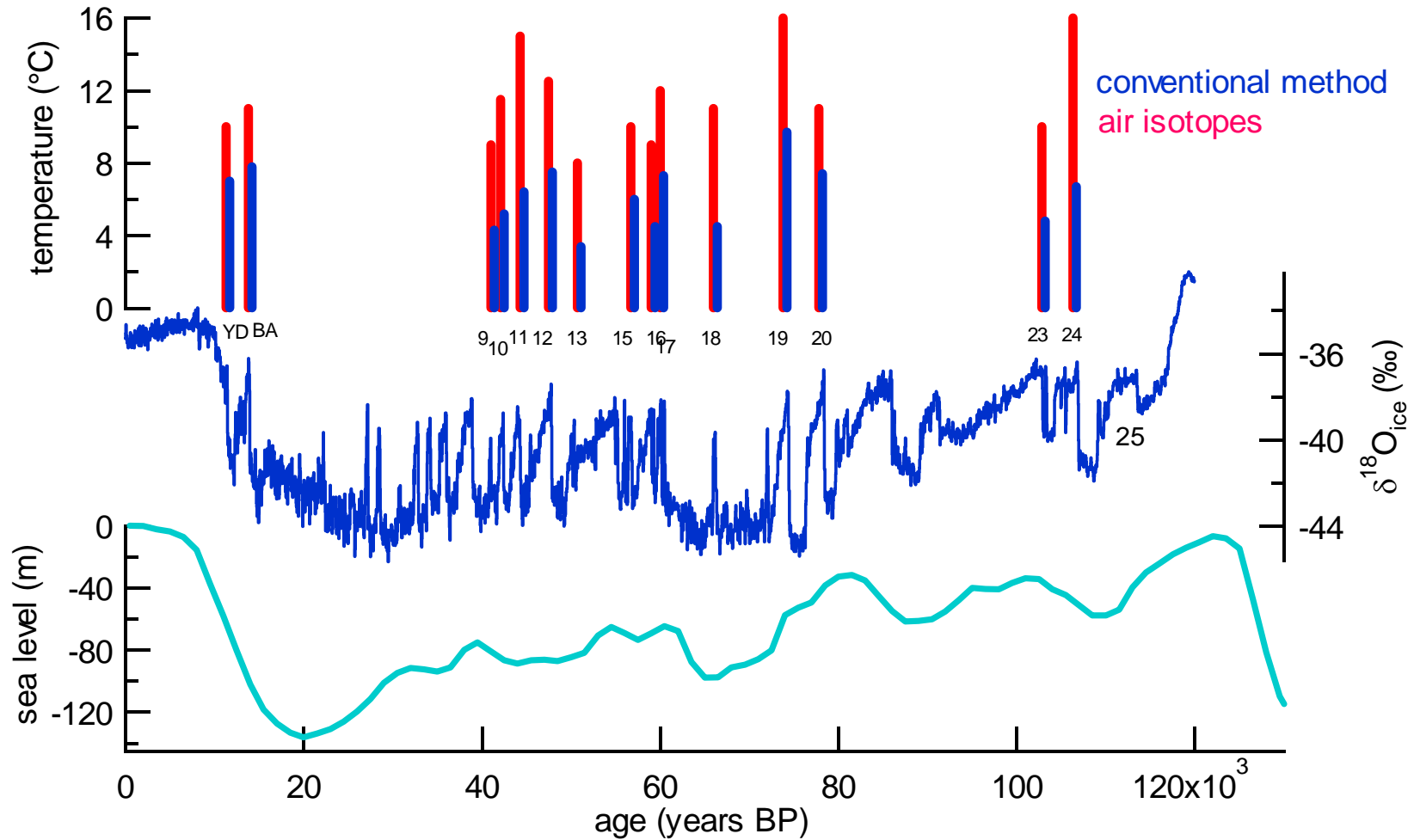
Temperature reconstruction over a sequence of three DO



Landais et al., GRL 2004

1- Amplitude of the temperature change

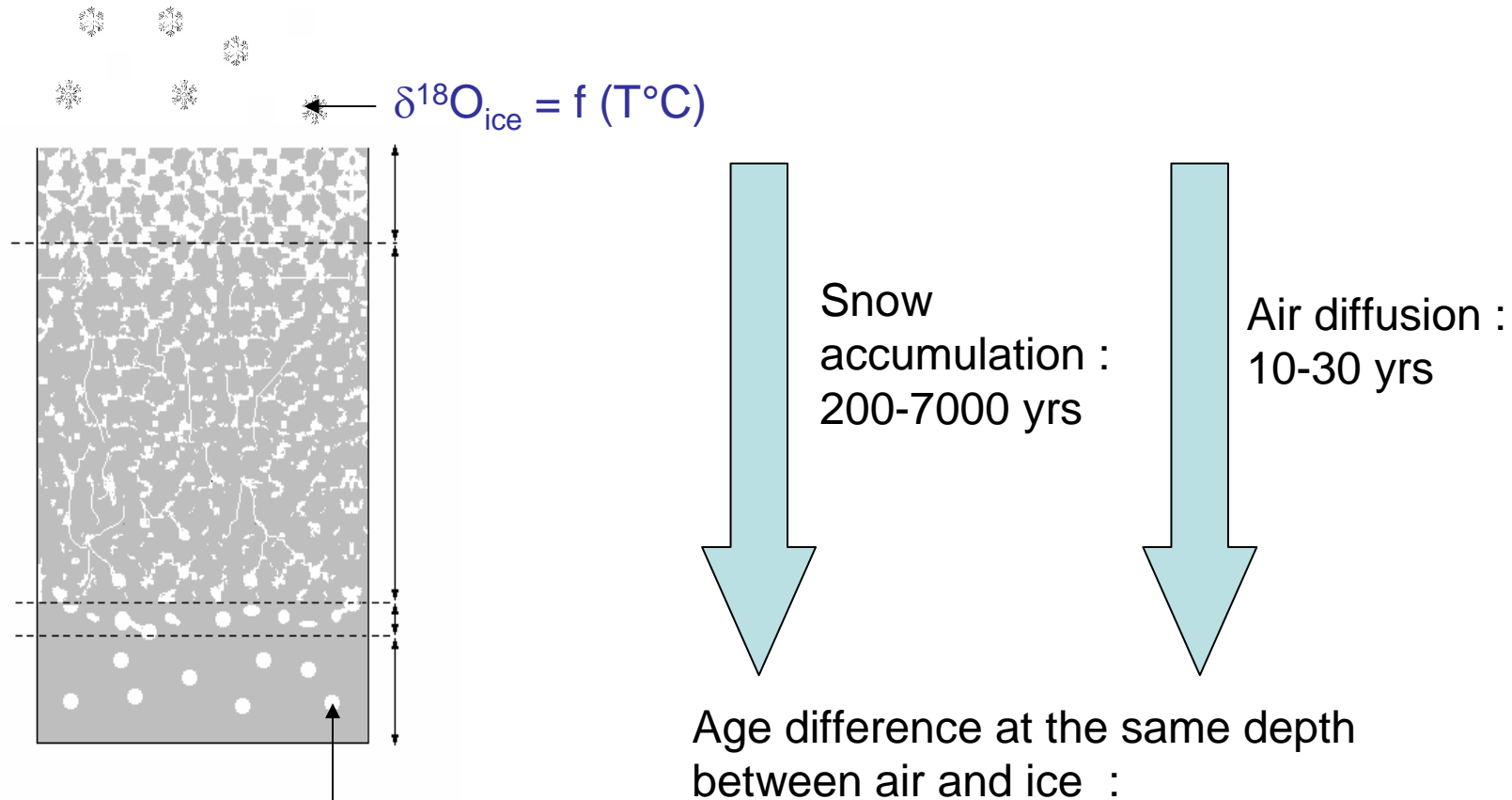
Amplitudes of DO



Severinghaus et al., 1999; 2003; Grachev and Severinghaus, 2005; Huber et al., in revision; Landais et al., EPSL, 2004; Landais et al., GRL, 2004; Landais et al., CD, in rev.; Landais et al., CRAS, 2004; Landais et al., CRAS, 2005;

2- Sequence temperature / atmospheric composition

Atmospheric composition / temperature



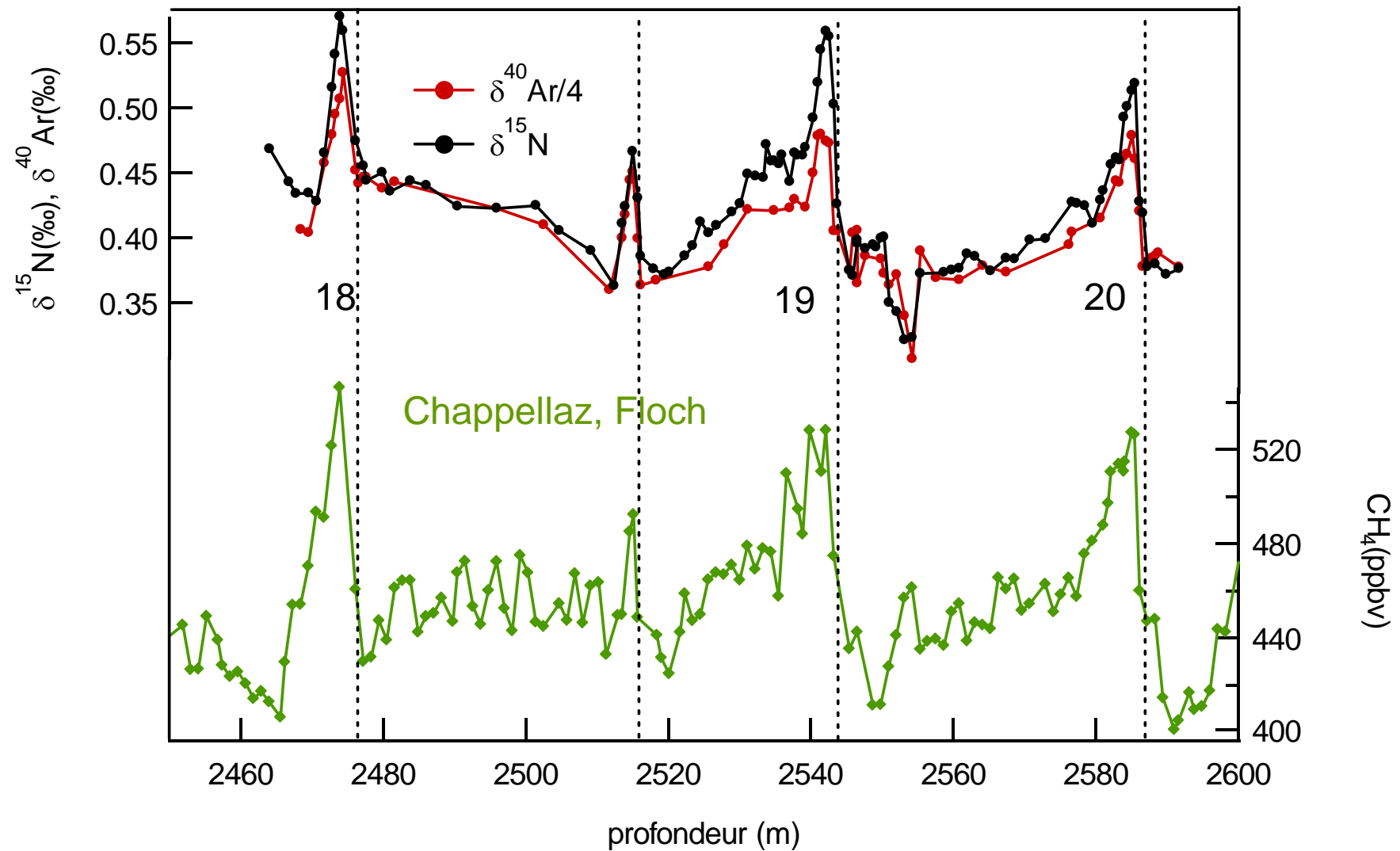
Atmospheric composition
(CH_4 , CO_2 , N_2O , ...)

Δage

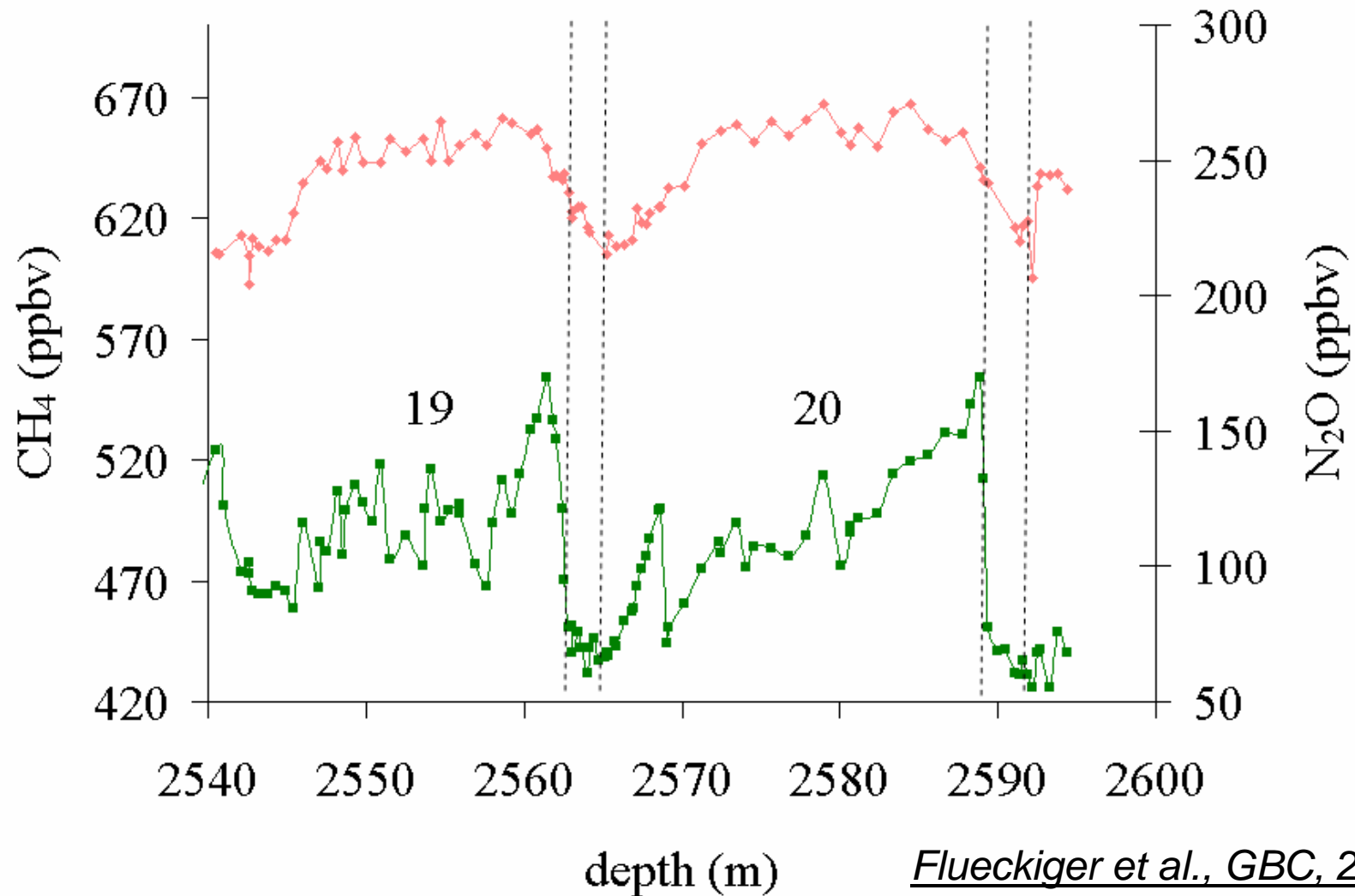
Temperature measured directly in the air bubbles
($\delta^{15}\text{N}$, $\delta^{40}\text{Ar}$)

2- Sequence temperature / atmospheric composition

Methane / temperature

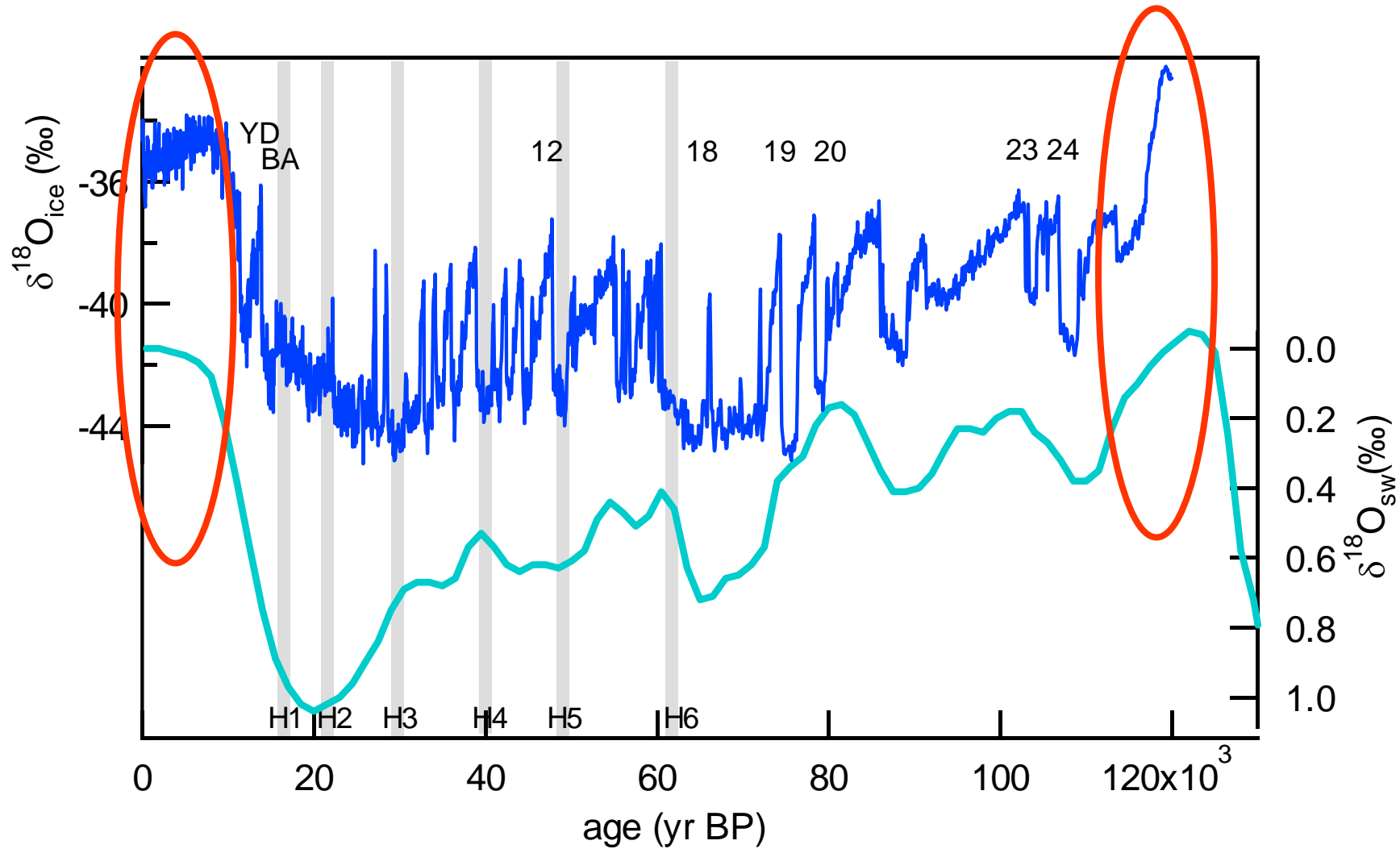


Nitrous oxide / methane (=temperature)



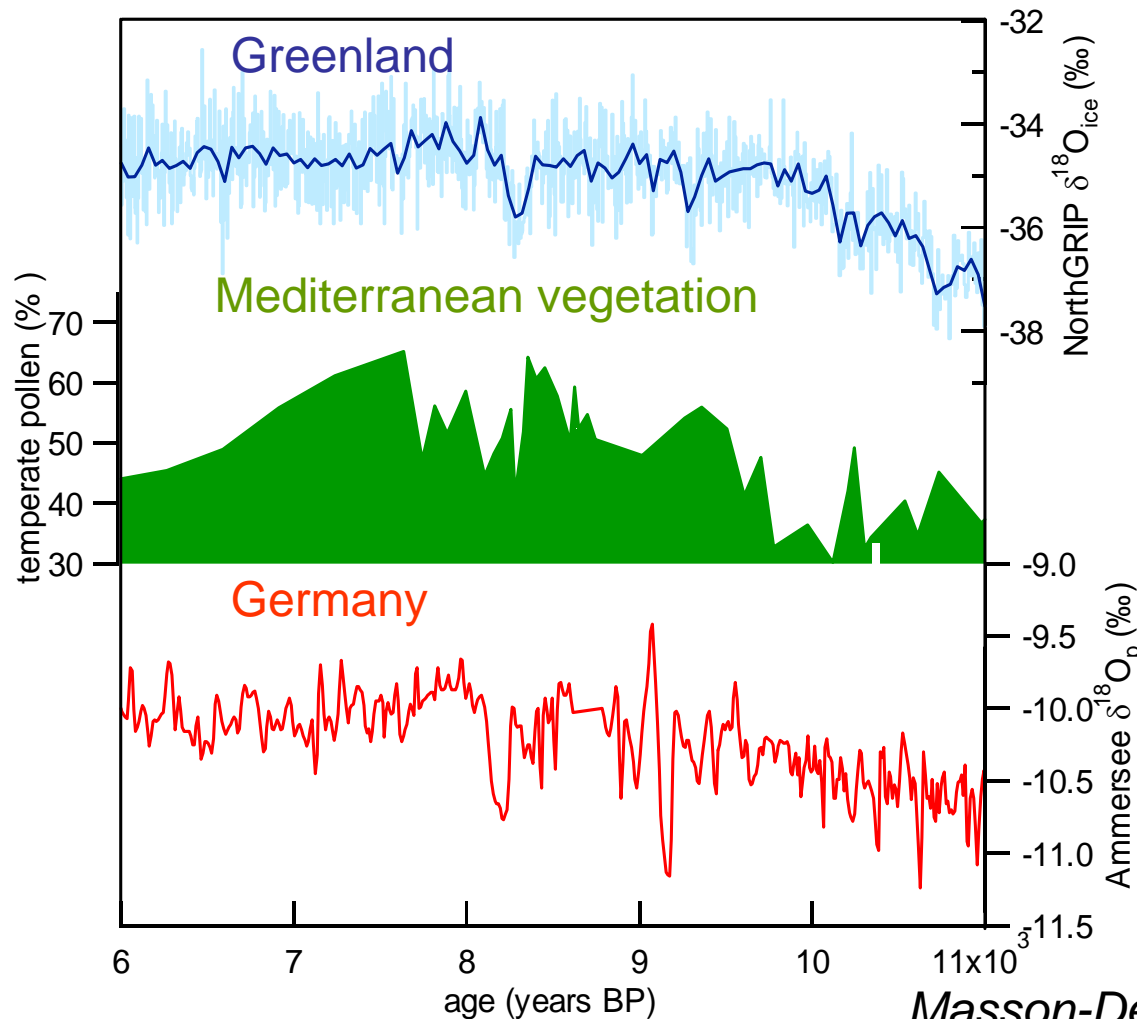
3- Rapid events in interglacial time

Rapid events in interglacial time ?



3- Rapid events in interglacial time

During the Holocene : 8.2 kyr BP



-Duration in Greenland :
200 yrs.

- Temperature change in
Greenland : ~ -5 deg

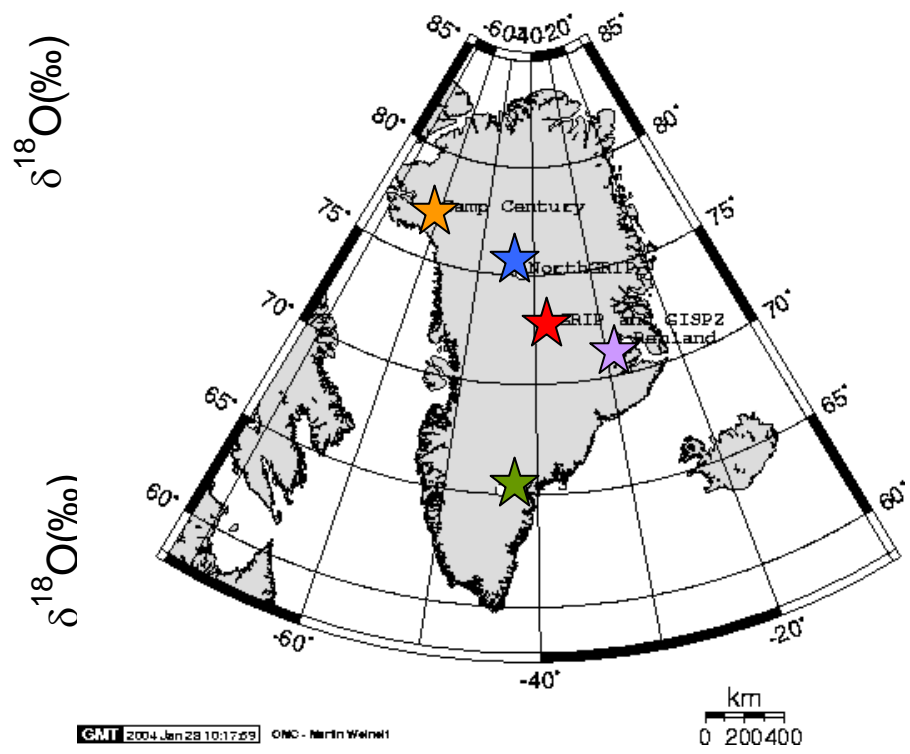
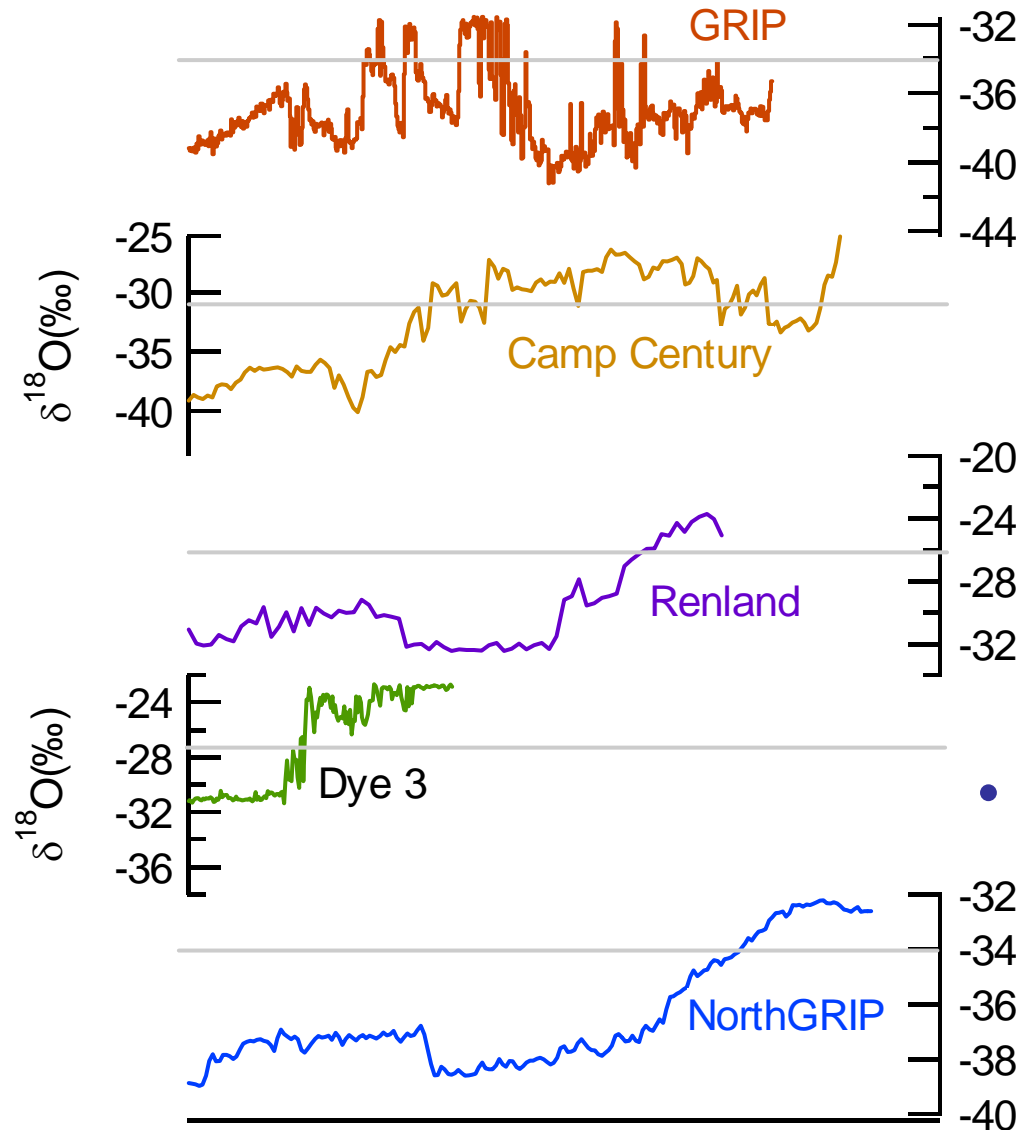
- Long term modification
of the mediterranean
vegetation

- Temperature change in
Europe : ~ -2 deg

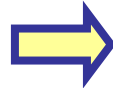
Masson-Delmotte et al., 2005

3- Rapid events in interglacial time

During the previous interglacial (warmer)



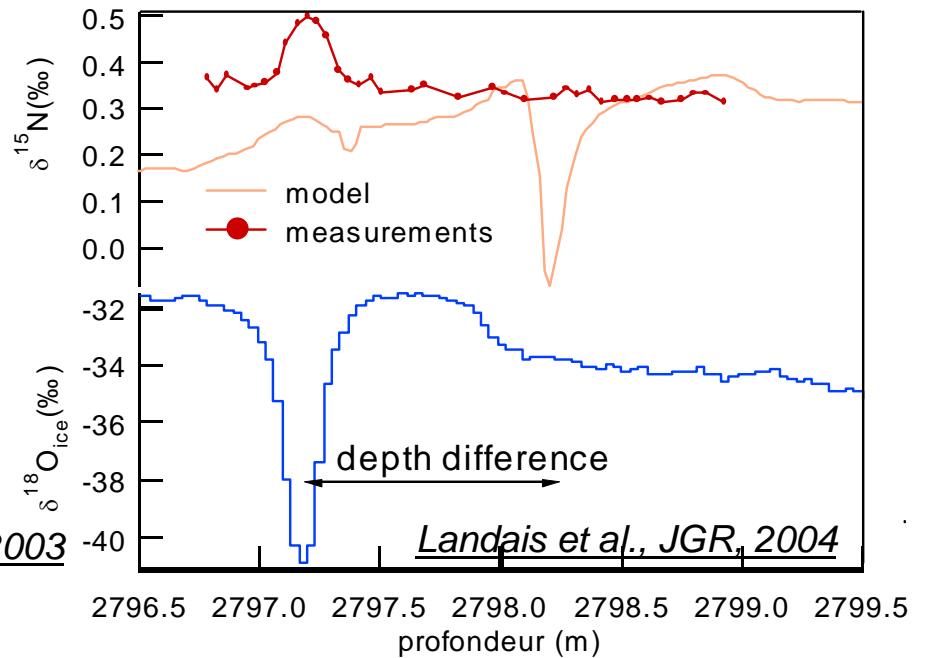
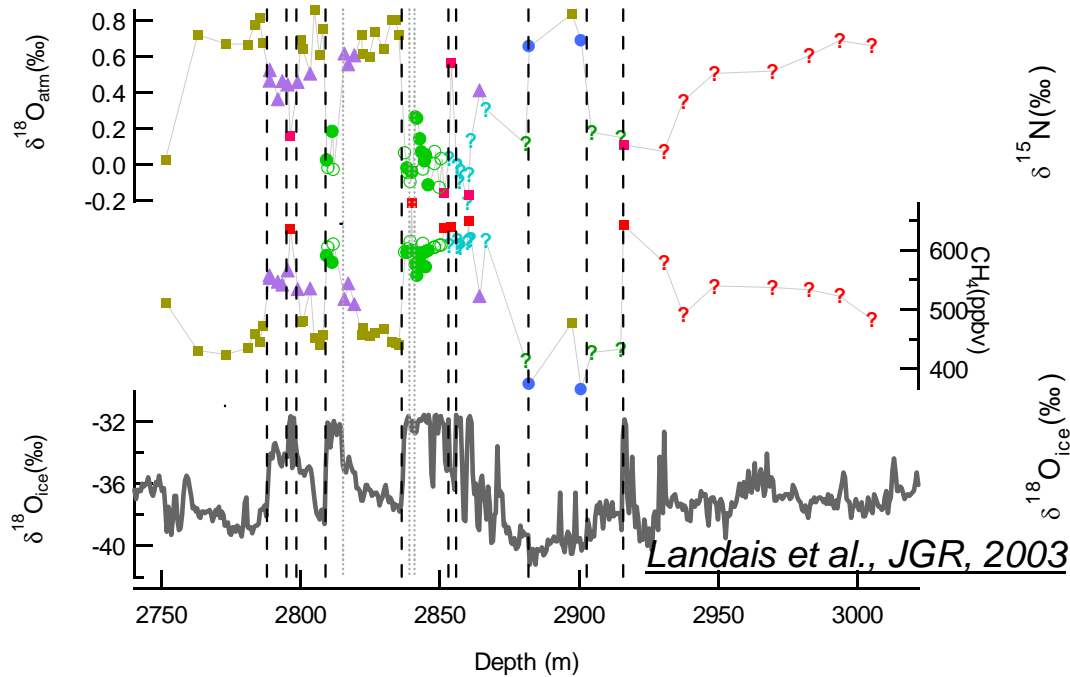
• Last interglacial : 5 deg warmer than today in Greenland



Rapid climatic variability in a warmer world ?

3- Rapid events in interglacial time

Climate was not as unstable as suggested by the GRIP ice core



Variations of $\delta^{18}\text{O}$ of O_2 : 1‰ in 100 yrs
Residence time of O_2 = 1200 yrs



IMPOSSIBLE

No $\delta^{15}\text{N}$ decrease associated to the $\delta^{18}\text{O}_{\text{ice}}$ decrease

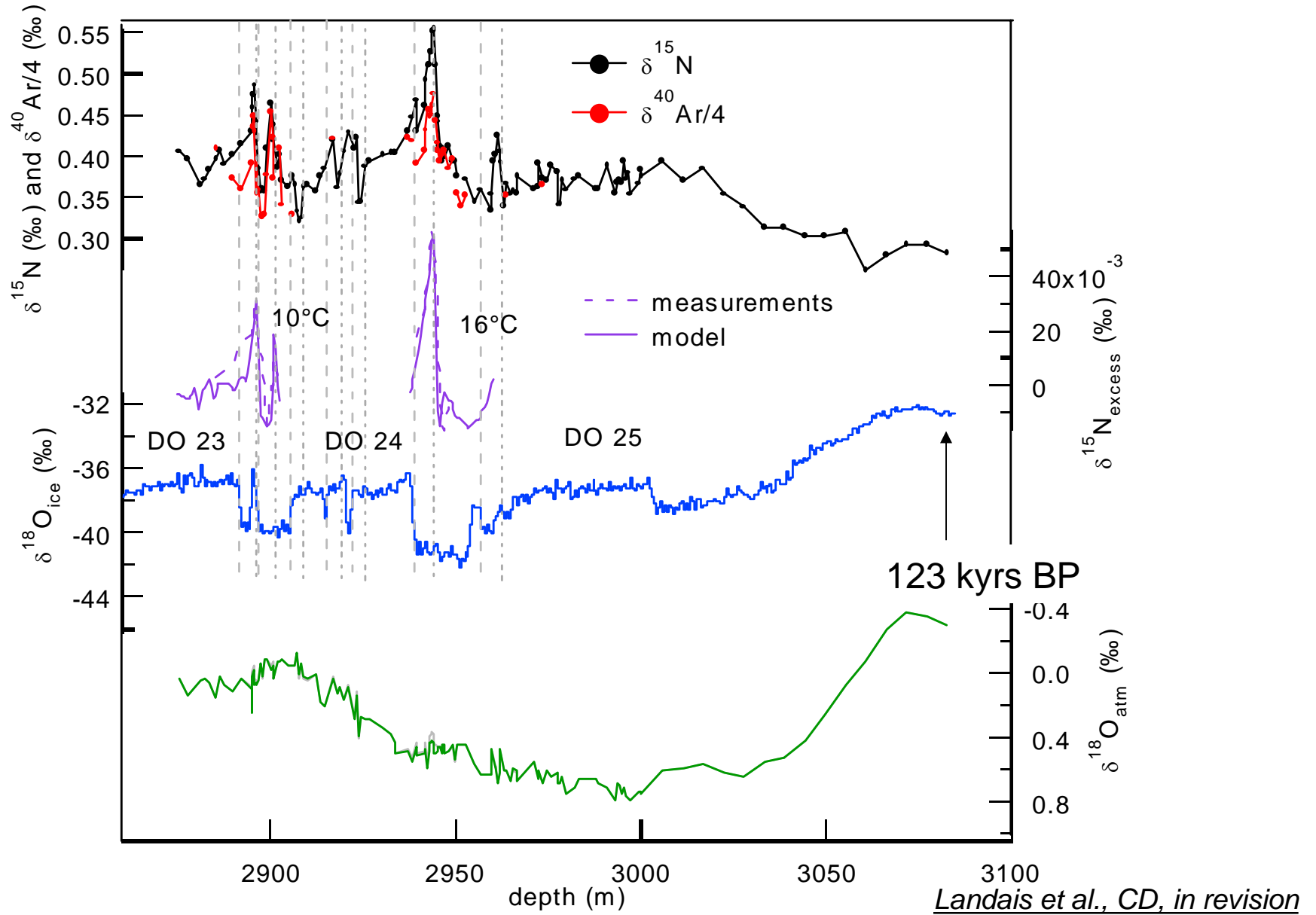


NOT A CLIMATIC EVENT

GRIP ice core = ice mixing before 105 kyrs BP

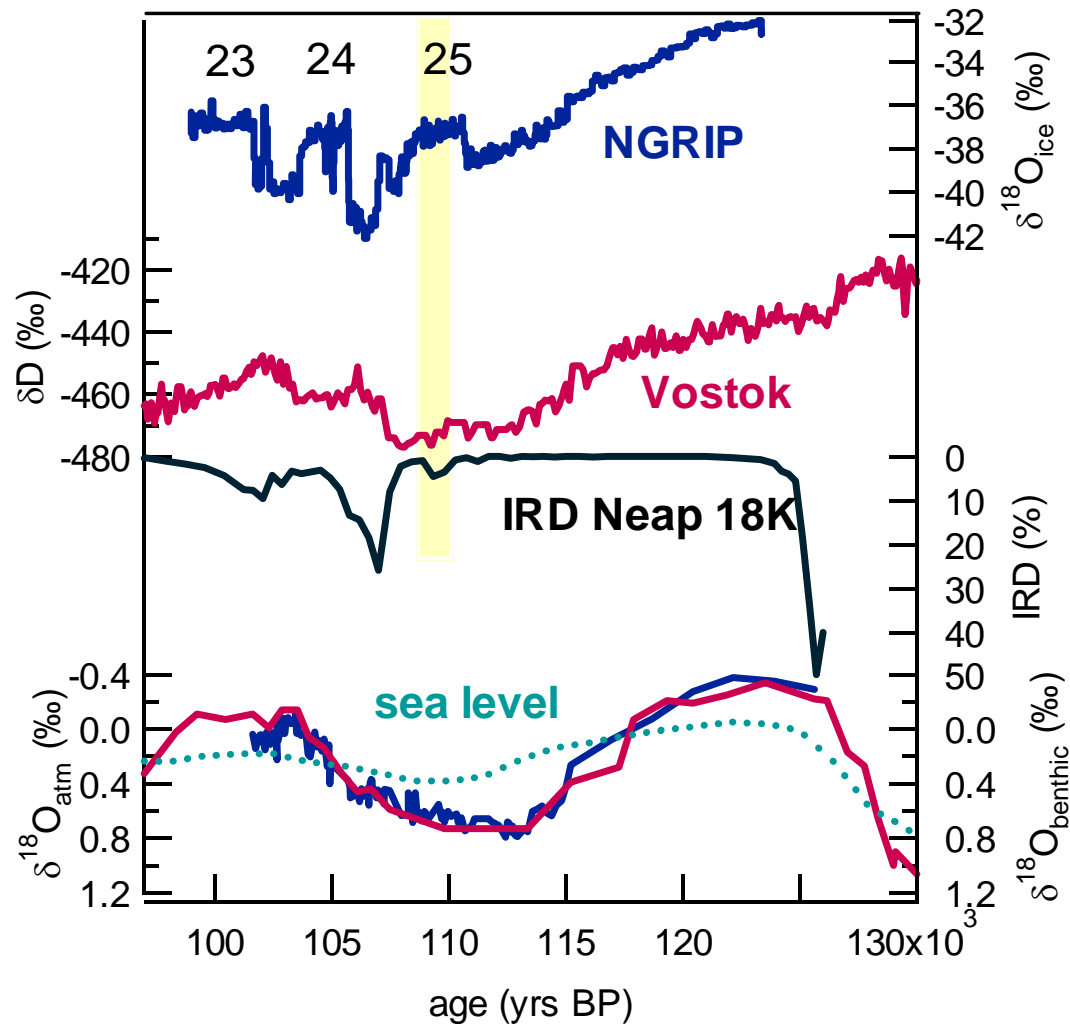
3- Rapid events in interglacial time

NorthGRIP = new reference



3- Rapid events in interglacial time

Specificity of the first Dansgaard-Oeschger

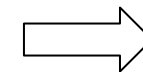


-DO 24, 23 :

- high amplitude for the temperature changes (up to 16 deg)
- Associated Antarctic events
- IRD

- DO 25 :

- Small amplitude for the temperature change ?
- No Antarctic event
- No IRD



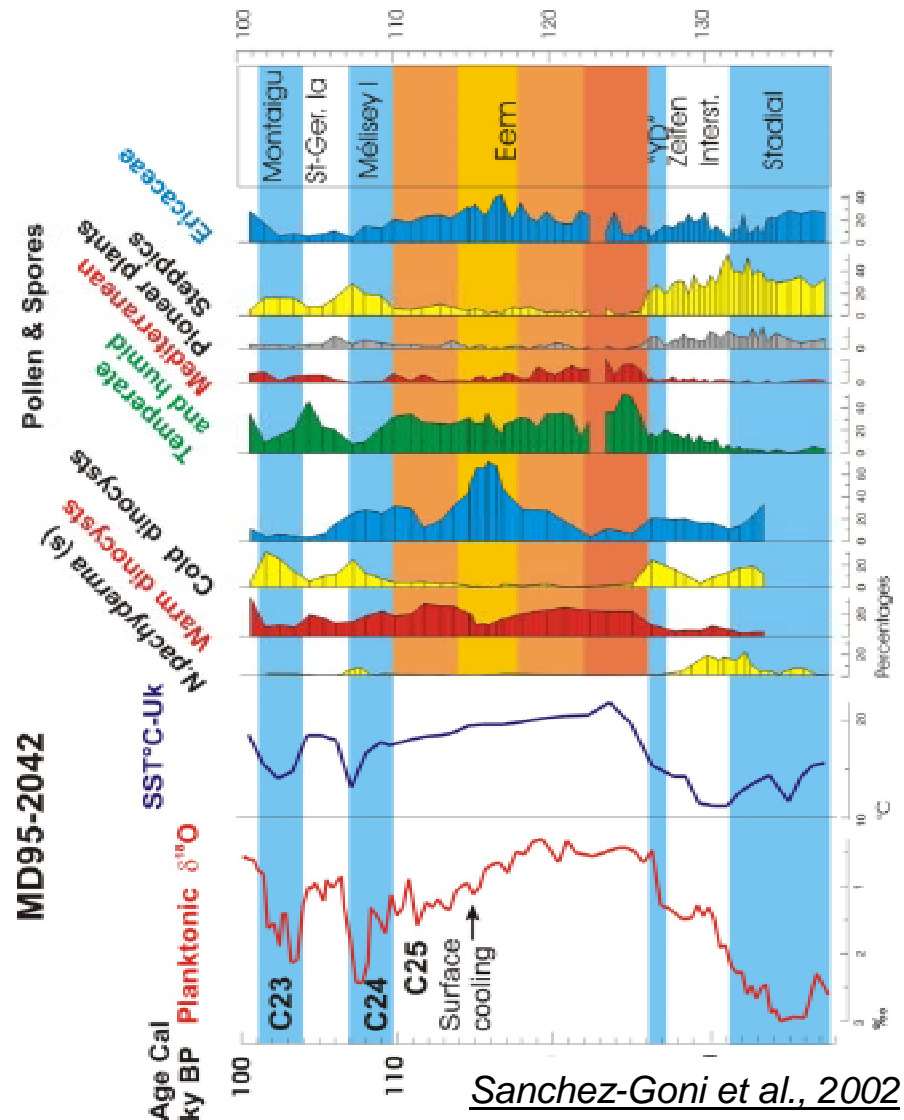
Mechanism ?
Role of the water cycle

Conclusions

- DO events description from $\delta^{18}\text{O}_{\text{ice}}$ is not quantitative
 - Amplitude : up to 16°C (~ 8°C from $\delta^{18}\text{O}_{\text{ice}}$)
 - Shape
- Methane and northern temperature increase together
- N₂O suggests “precursors” for the DO ?
- 2 types of rapid events during “interglacial” conditions
 - DO 25 : initiates the rapid climatic variability of the last glacial
 - How was it triggered ?
 - 8.2 kyrs BP : Earth system response to North Atlantic freshening.

3- Rapid events in interglacial time

The first event of the glacial inception: geographic extend

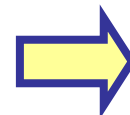


-DO 24, 23 :

- SST variations Portugal : 5 deg
- Methane signal
- Huge changes in mediterranean vegetation

-DO 25 :

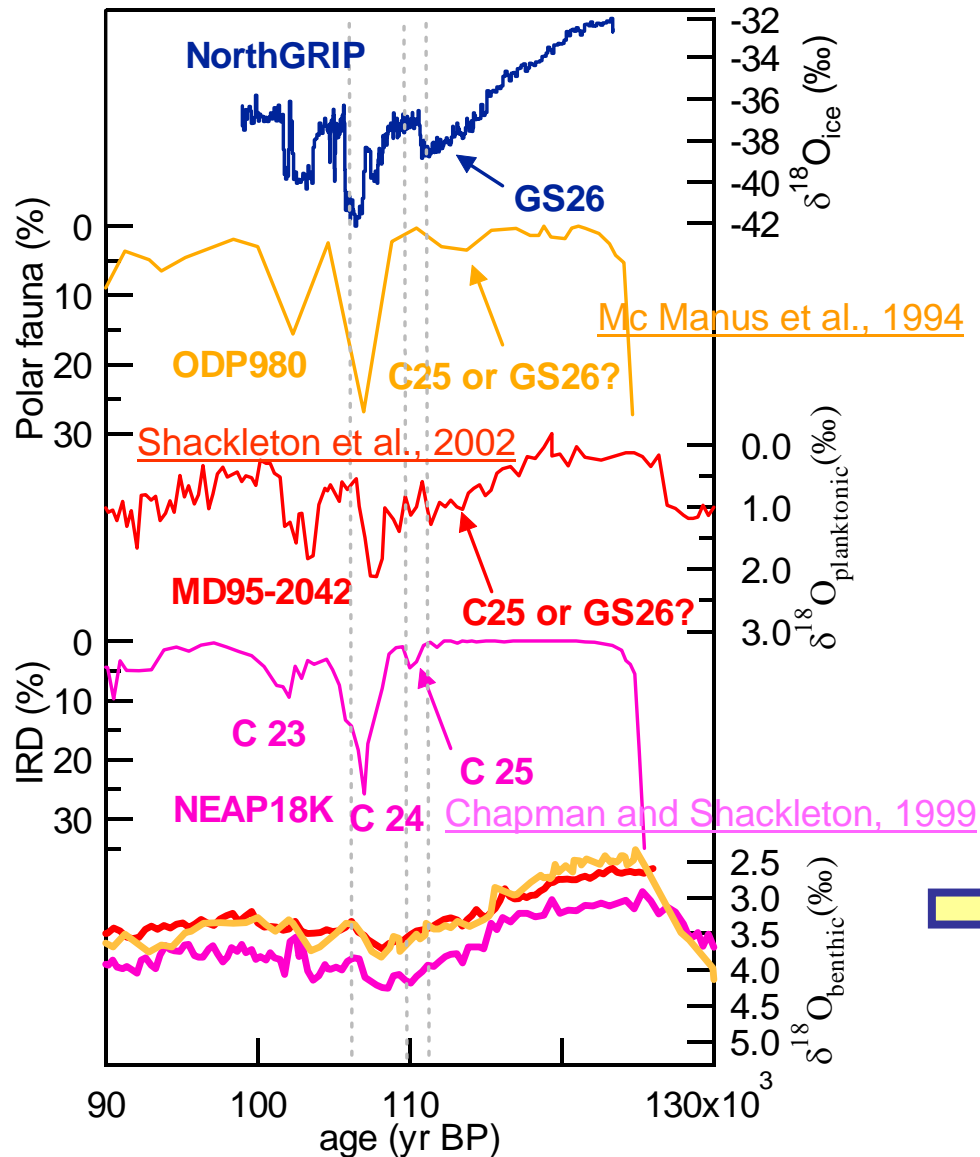
- SST variations Portugal : 1-2 deg
- Methane signal
- No change in mediterranean vegetation



Sampling resolution over DO 25 ?

3- Rapid events in interglacial time

The first event of the glacial inception: mechanism

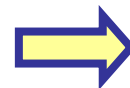


-DO 24, 23 :

- "Large" ice sheets (-40 m sea level)
- IRD signal
- Iceberg discharges

-DO 25 :

- Small ice sheets
- No IRD signal
- No iceberg discharges



What triggers DO 25 ??
Role of hydrological cycle.

