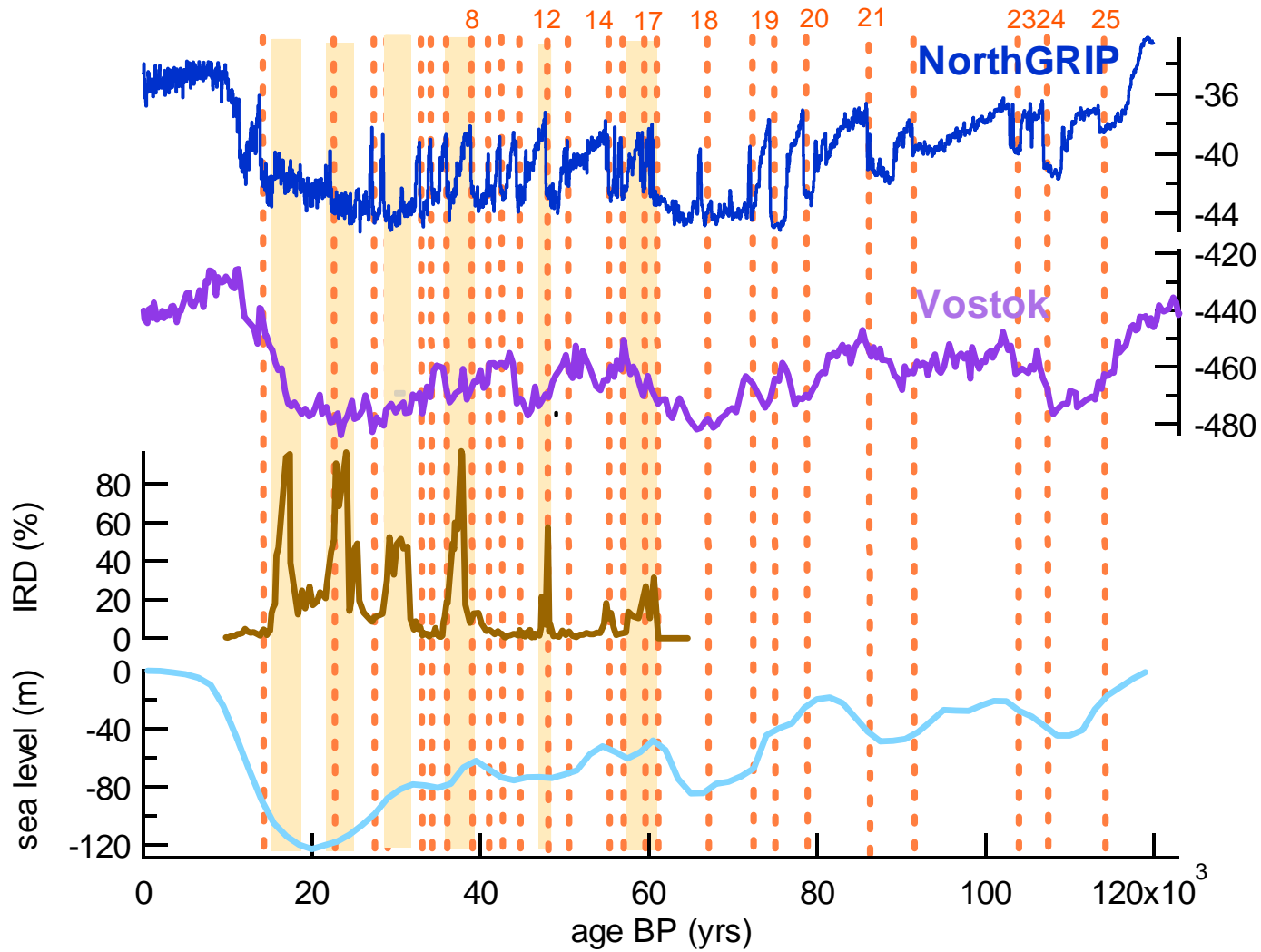


# Rapid climate variability during cold and warm periods in North-Atlantic as inferred from Greenland ice cores

- Air isotopic measurements
- NorthGRIP ice core

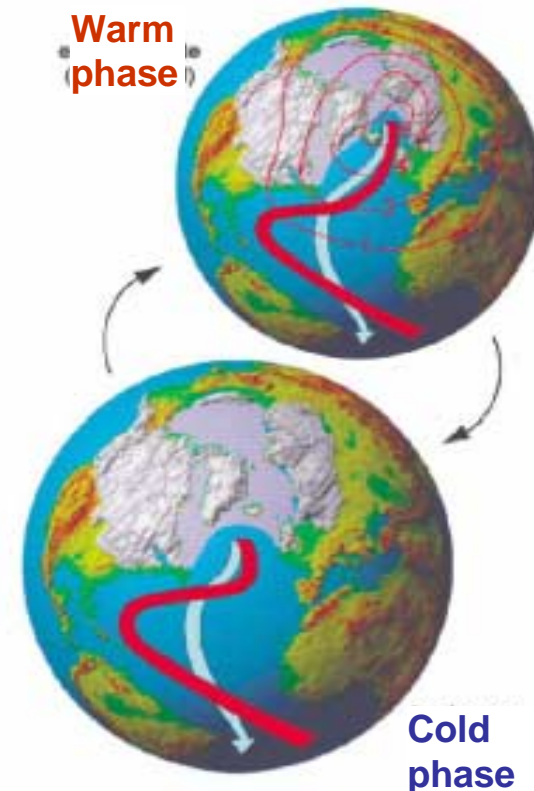
**A. Landais**, V. Masson-Delmotte, J. Jouzel, J.M. Barnola, J. Chappellaz, S. Johnsen, D. Dahl-Jensen, and M. Leuenberger

# 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

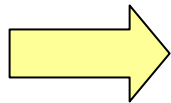
# Temperature reconstruction in Greenland ice cores : methods

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

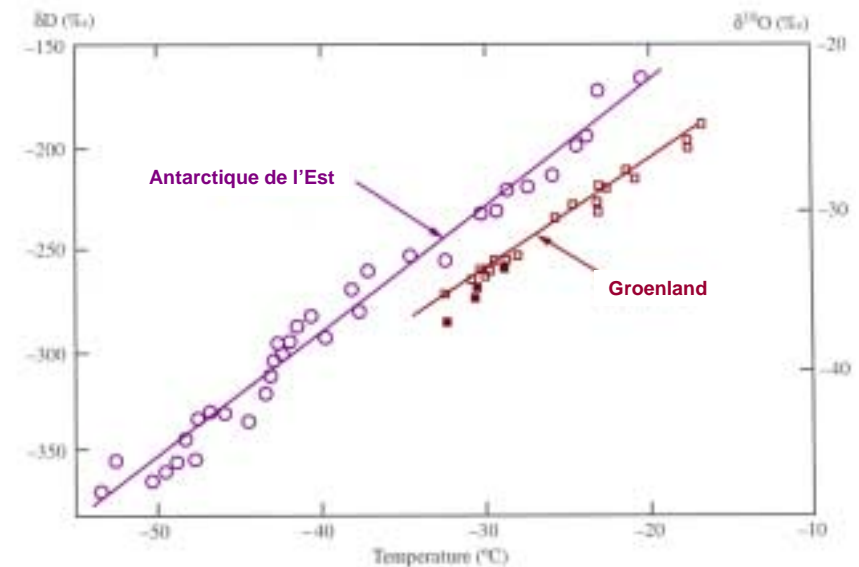
Pb: 1- source influence

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.*



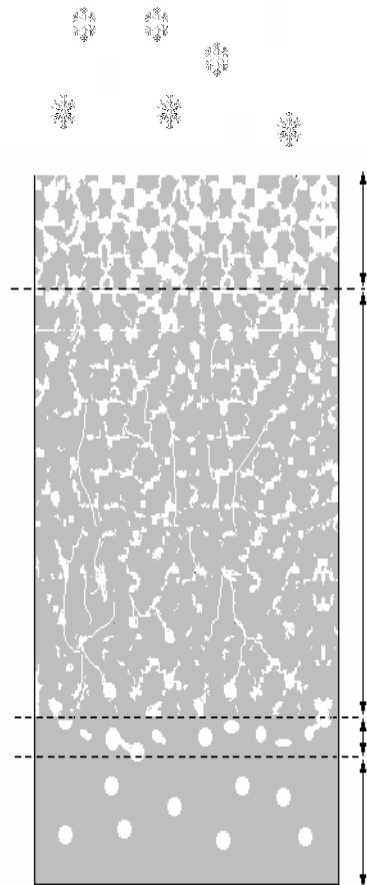
- Borehole temperature inversion (Cuffey et al., 1995; Johnsen et al., 1995; Dahl-Jensen et al., 1998) : does not apply to DO
- Isotopes of the air trapped in the ice. (Severinghaus et al., 1998)

# 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



Physical fractionations in the firn :

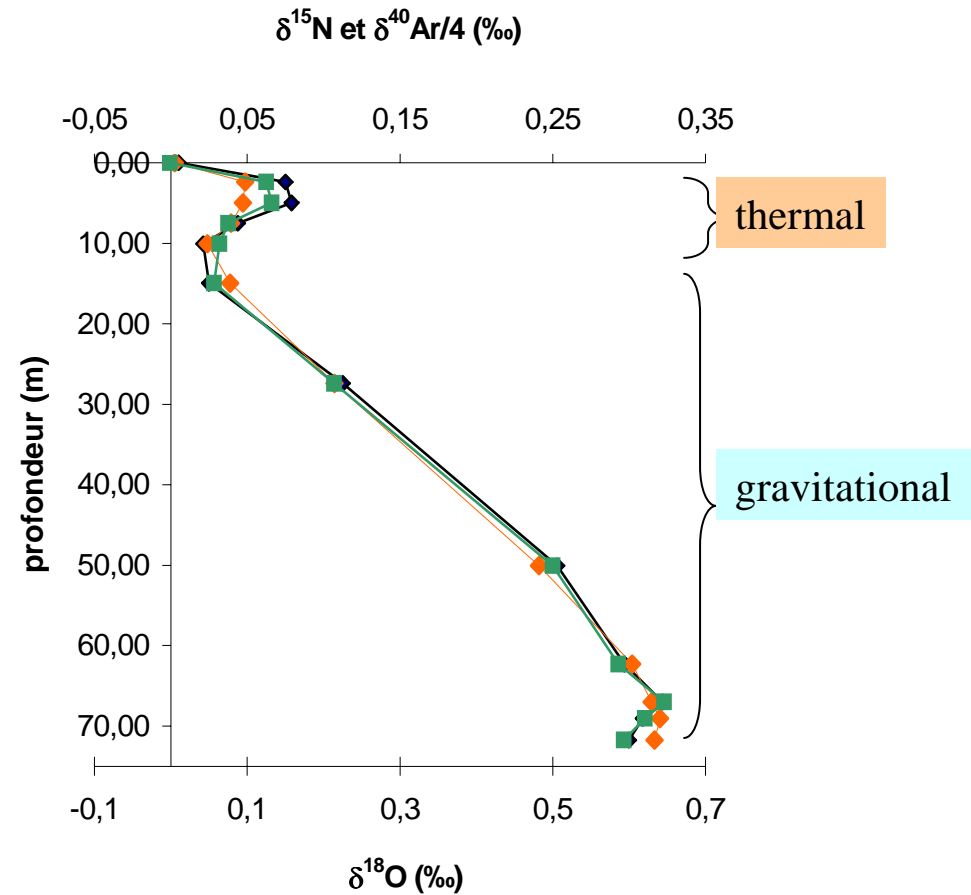
$\delta^{15}\text{N}$  ( $^{15}\text{N}/^{14}\text{N}$ )

$\delta^{40}\text{Ar}$  ( $^{40}\text{Ar}/^{36}\text{Ar}$ )

Lock in zone

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

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



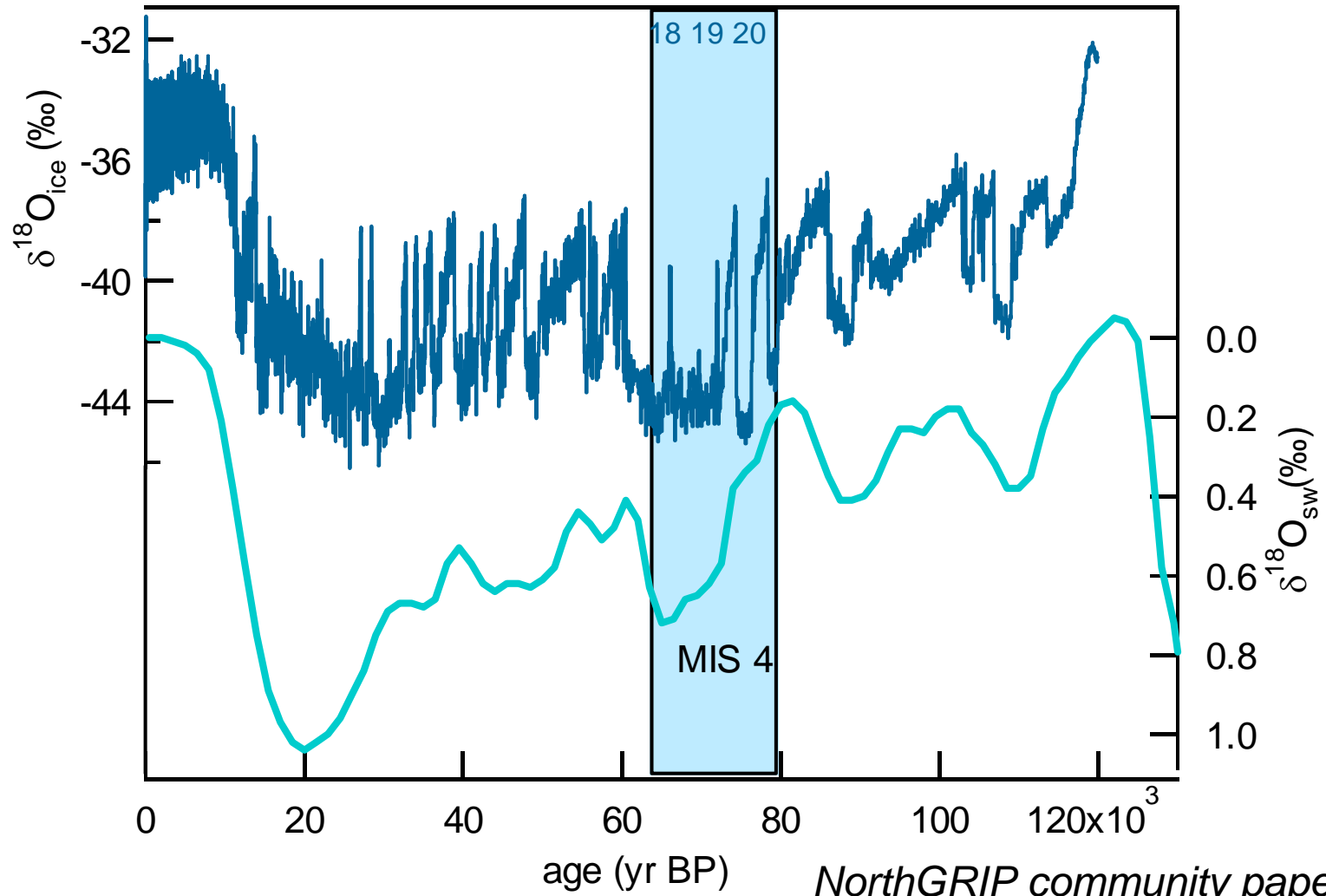
thermal

gravitational

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*

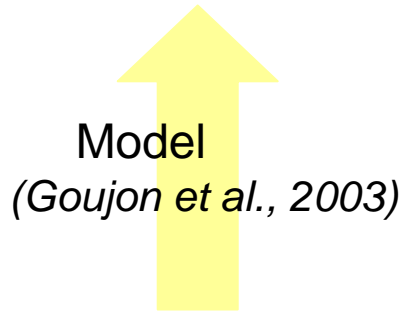
1- Amplitude of the temperature change

# Temperature reconstruction over a sequence of three DO

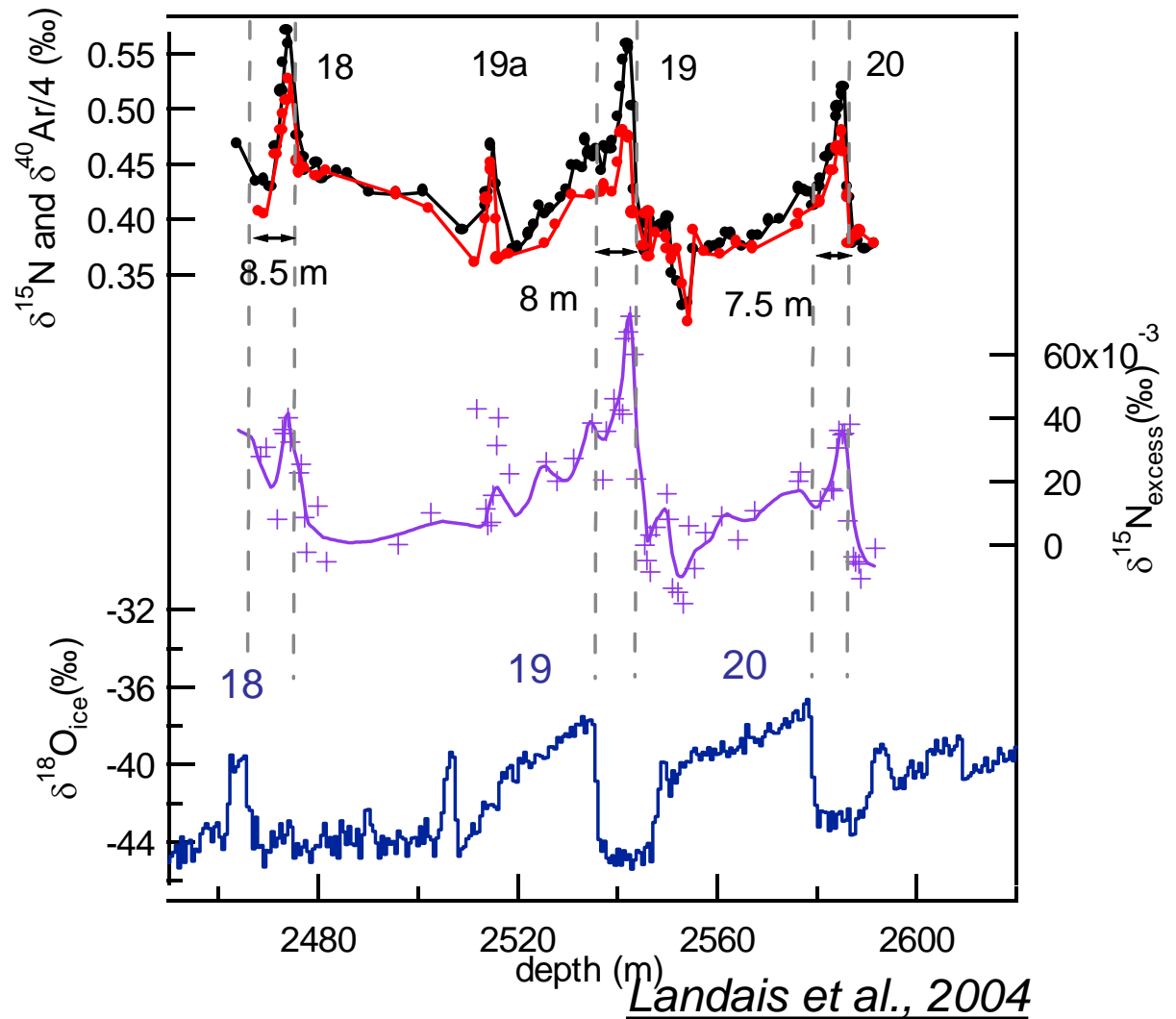
$$\delta^{15}\text{N}_{\text{excess}} = \delta^{15}\text{N} - \delta^{40}\text{Ar}/4$$

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

Temperature gradient in the firn



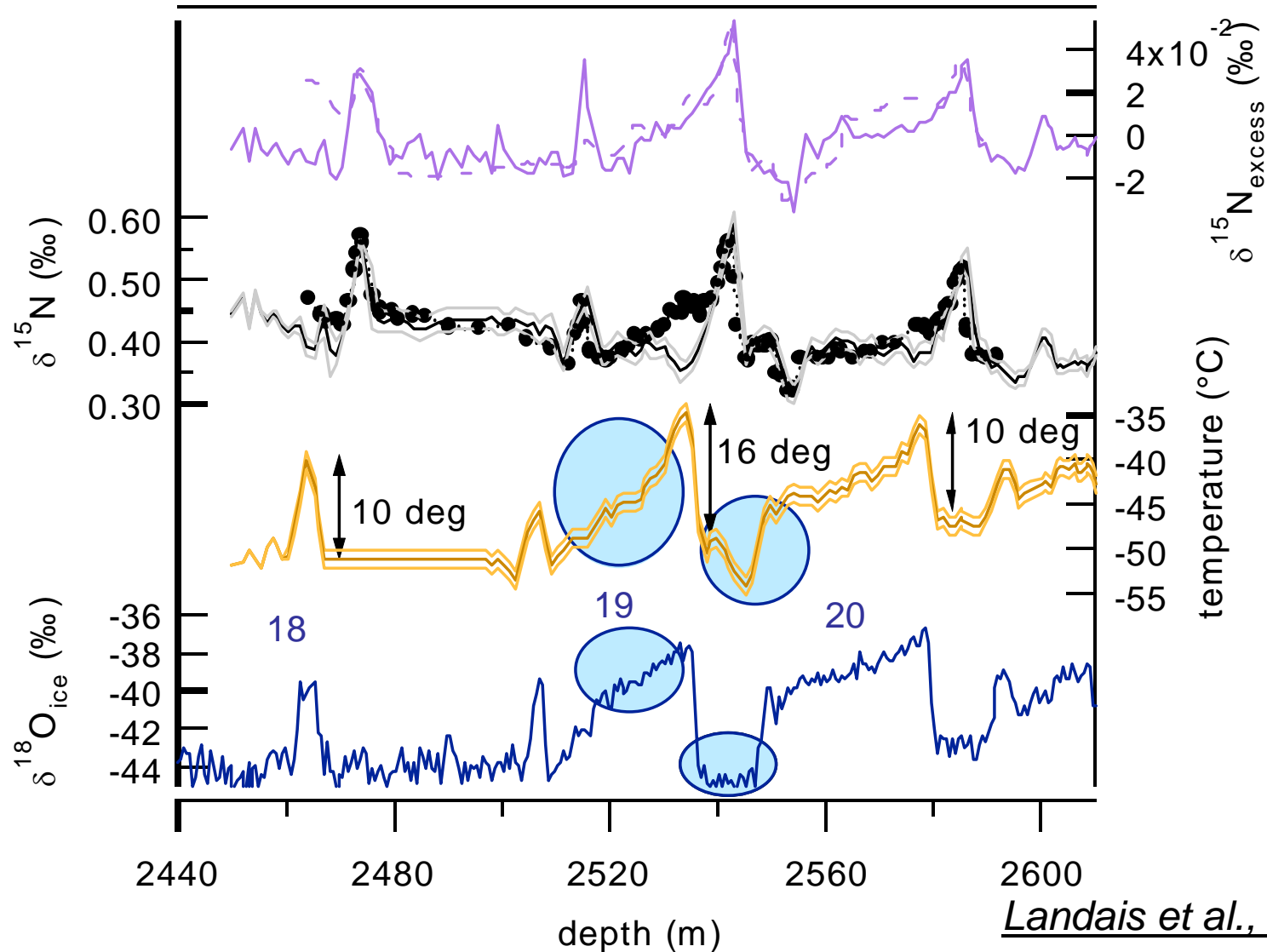
Surface temperature change





1- Amplitude of the temperature change

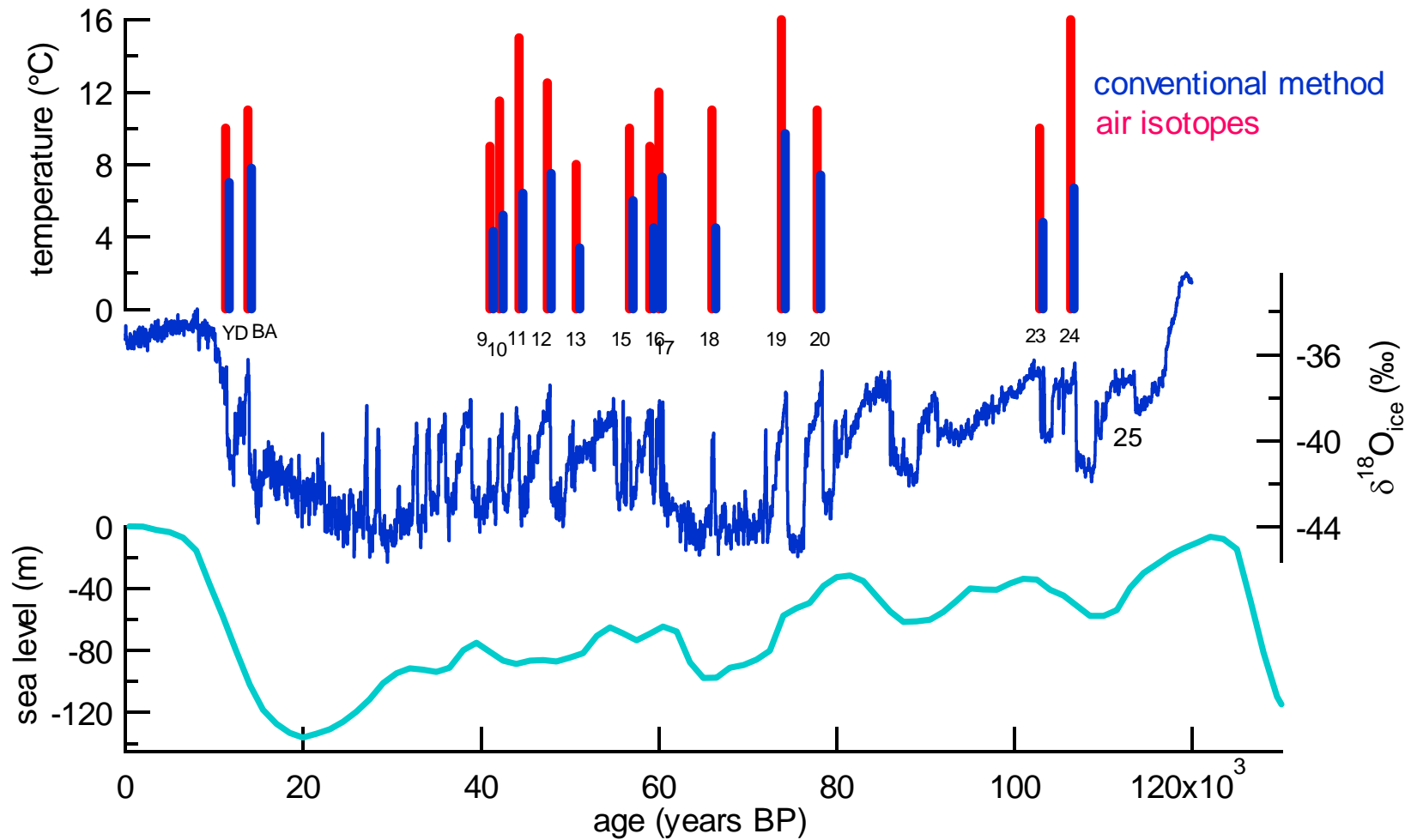
# Temperature reconstruction over a sequence of three DO



*Landais et al., GRL 2004*

# 1- Amplitude of the temperature change

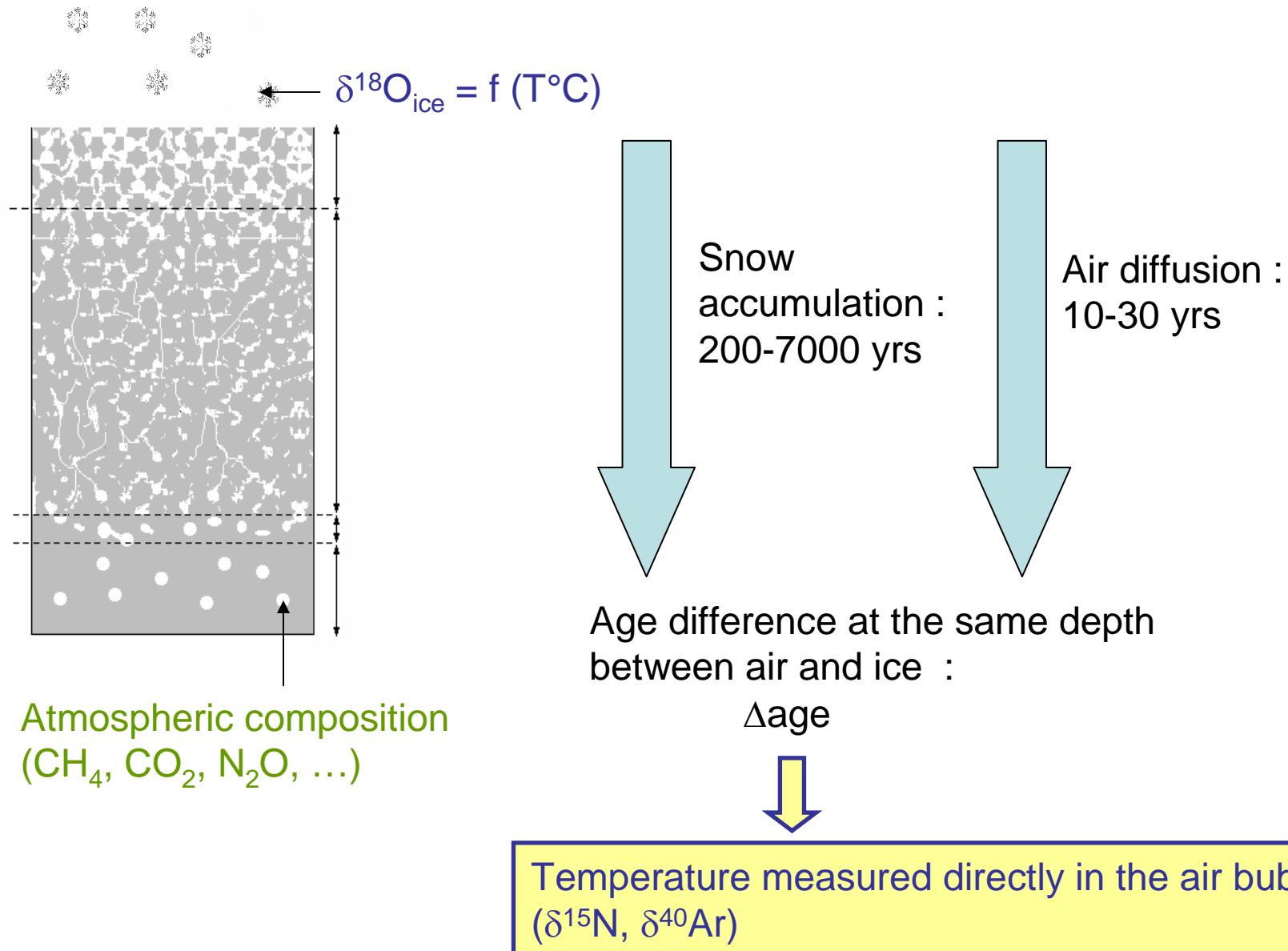
## Amplitudes of DO



*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;*

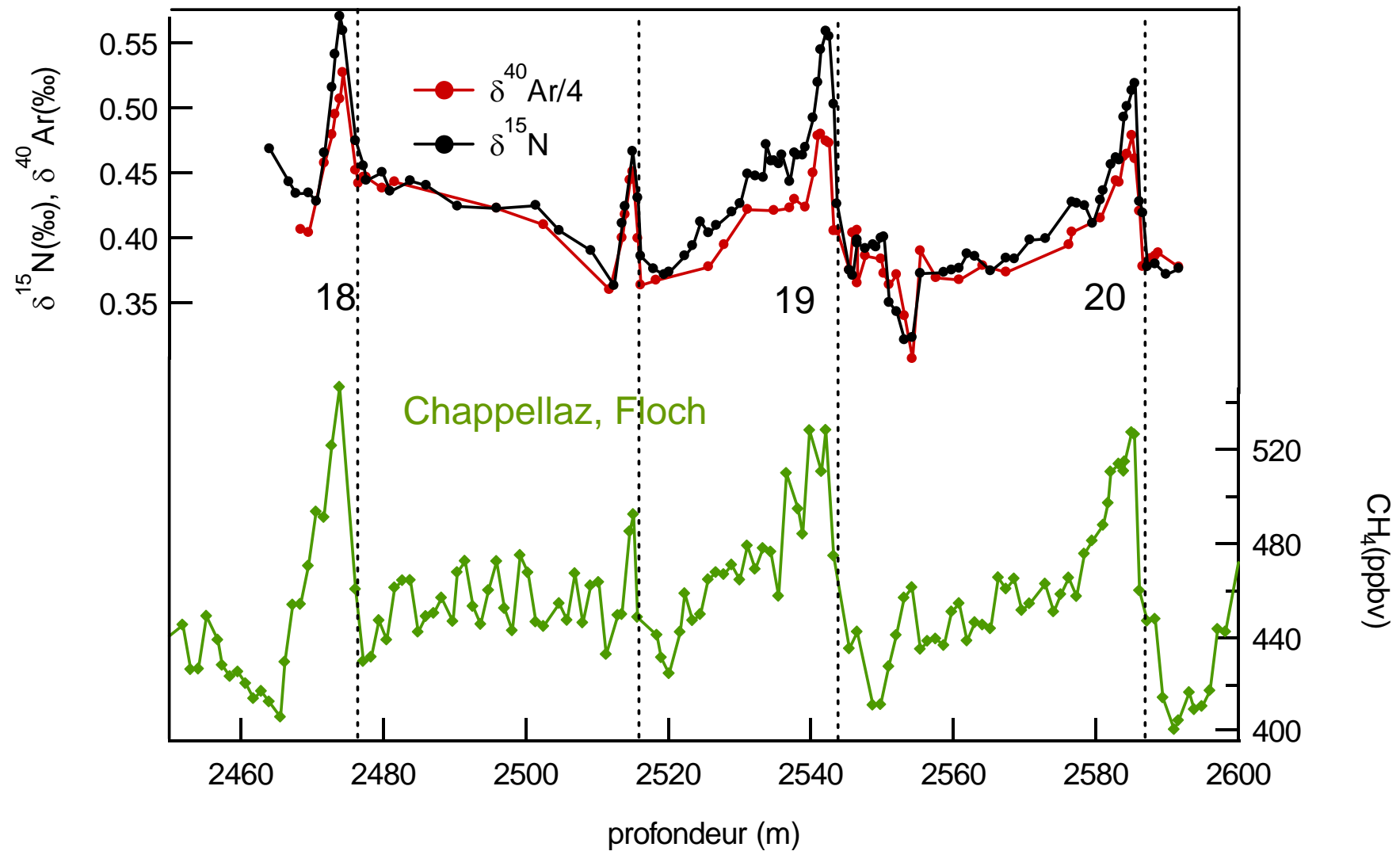
## 2- Sequence temperature / atmospheric composition

# Atmospheric composition / temperature

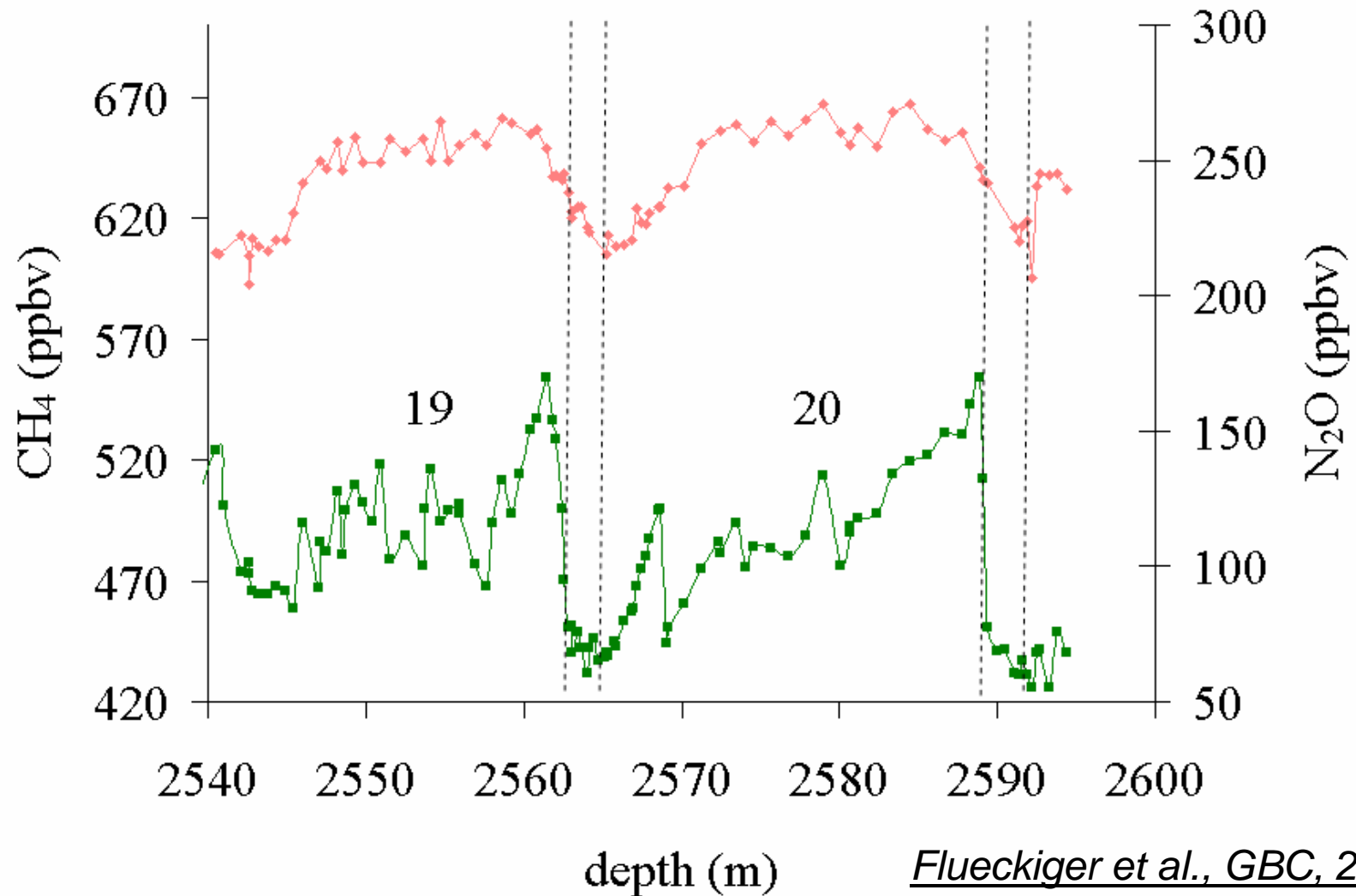


## 2- Sequence temperature / atmospheric composition

# Methane / temperature

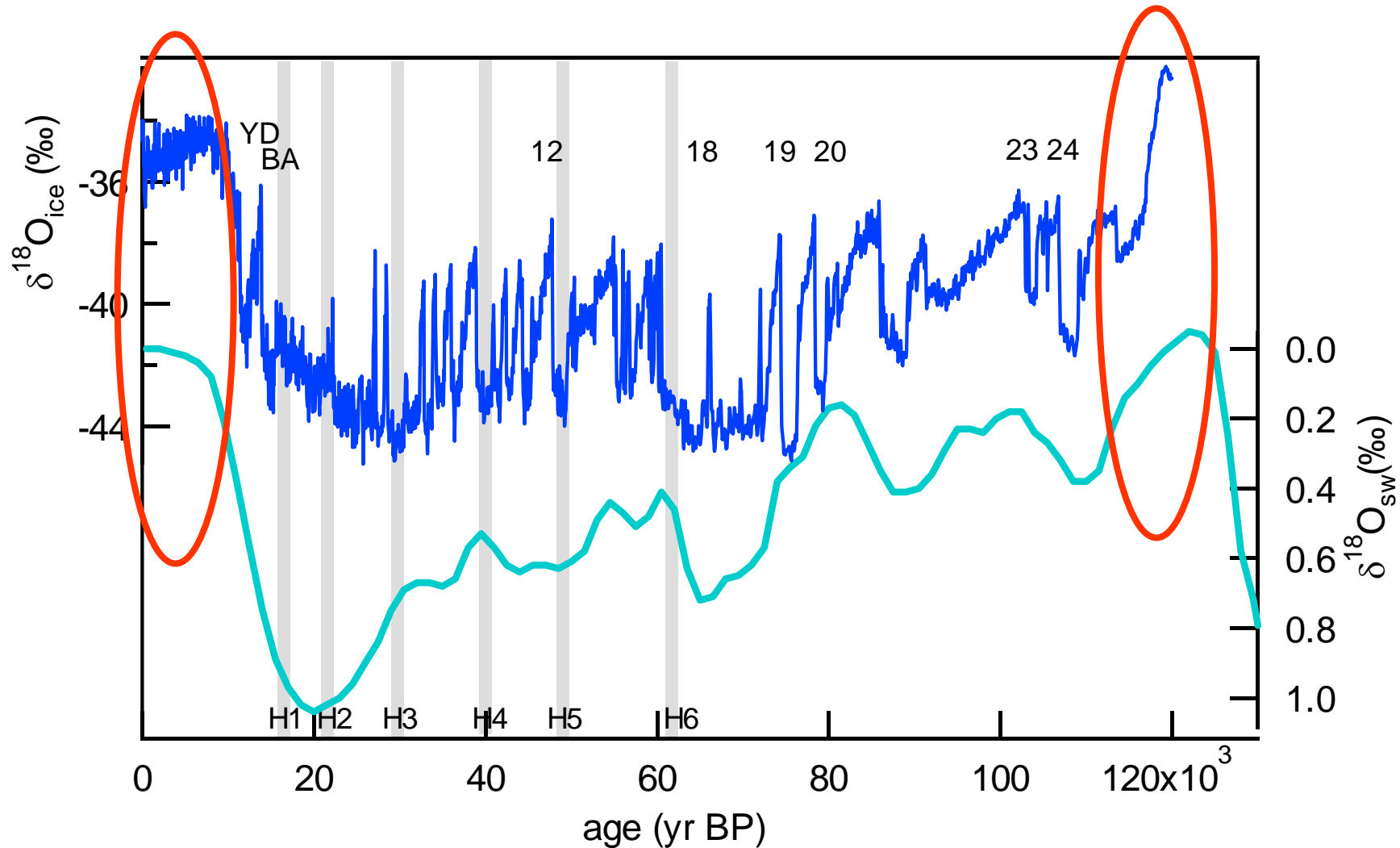


# Nitrous oxide / methane (=temperature)



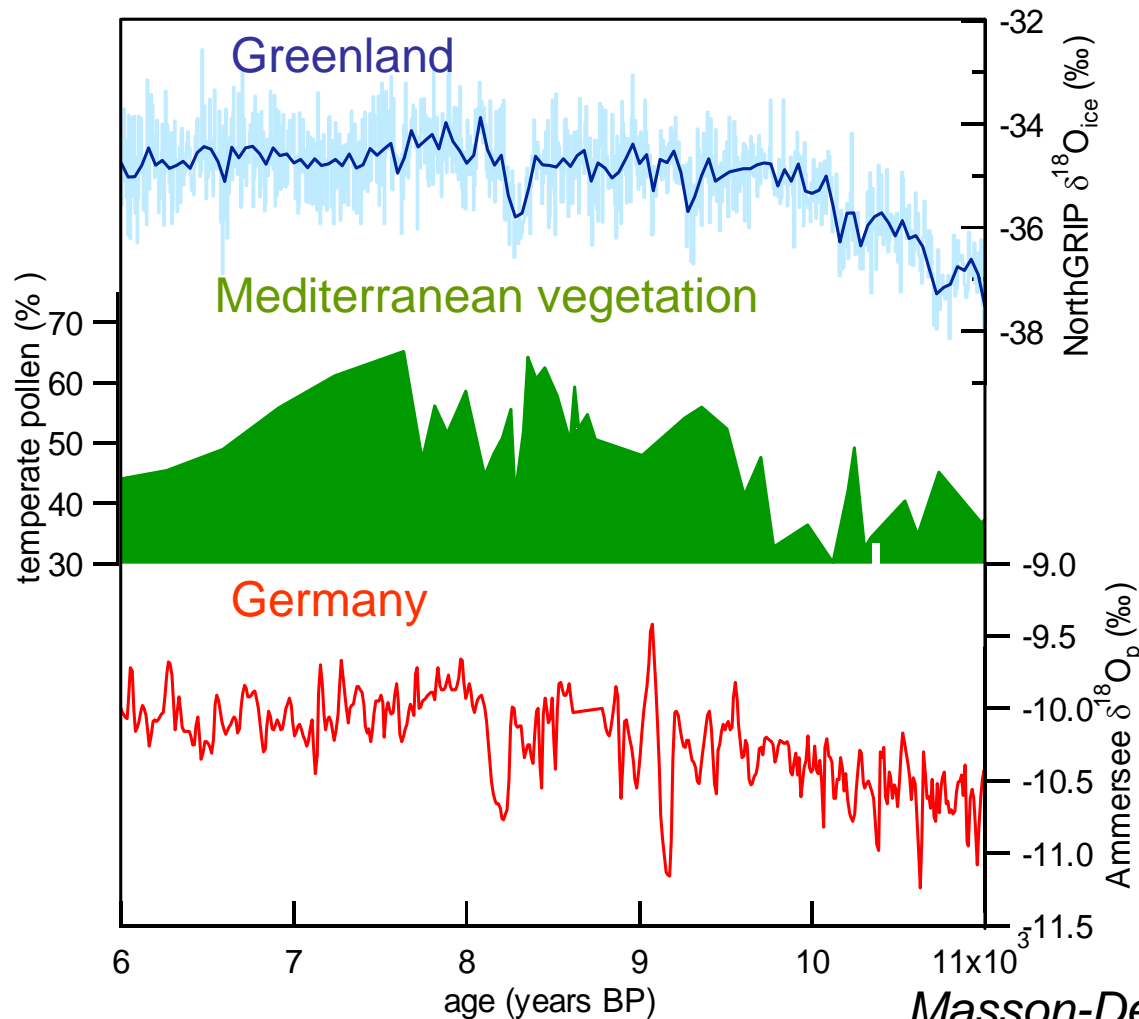
### 3- Rapid events in interglacial time

# 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

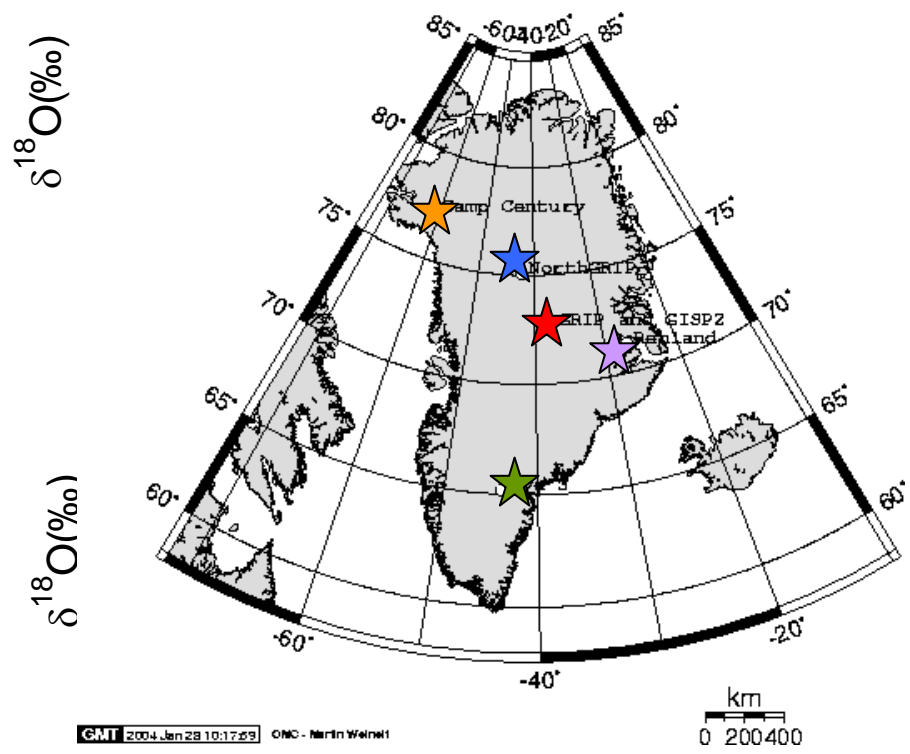
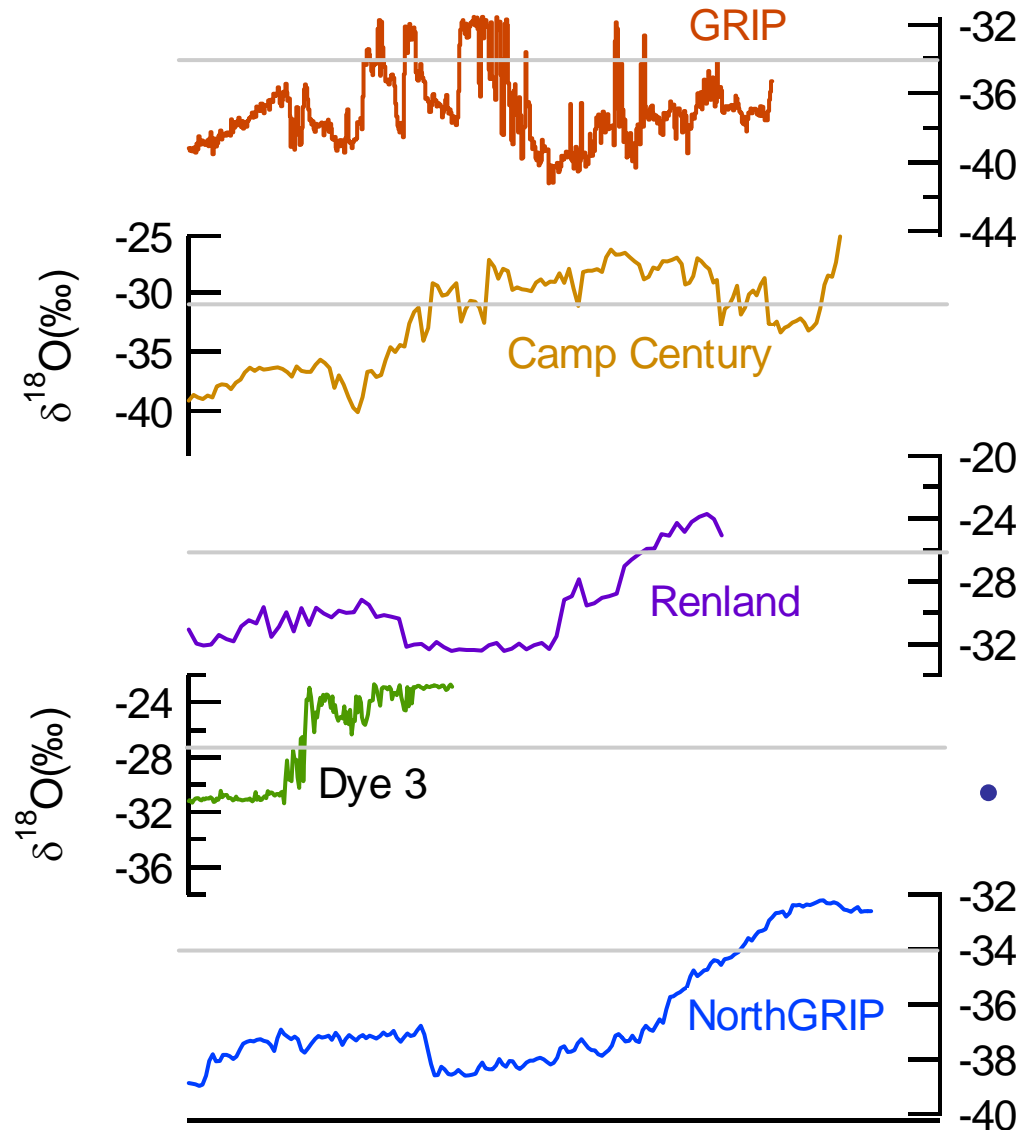
- Long term modification  
of the mediterranean  
vegetation

- Temperature change in  
Europe : ~ -2 deg

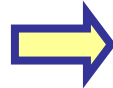
*Masson-Delmotte et al., 2005*

### 3- Rapid events in interglacial time

# During the previous interglacial (warmer)



• Last interglacial : 5 deg warmer than today in Greenland

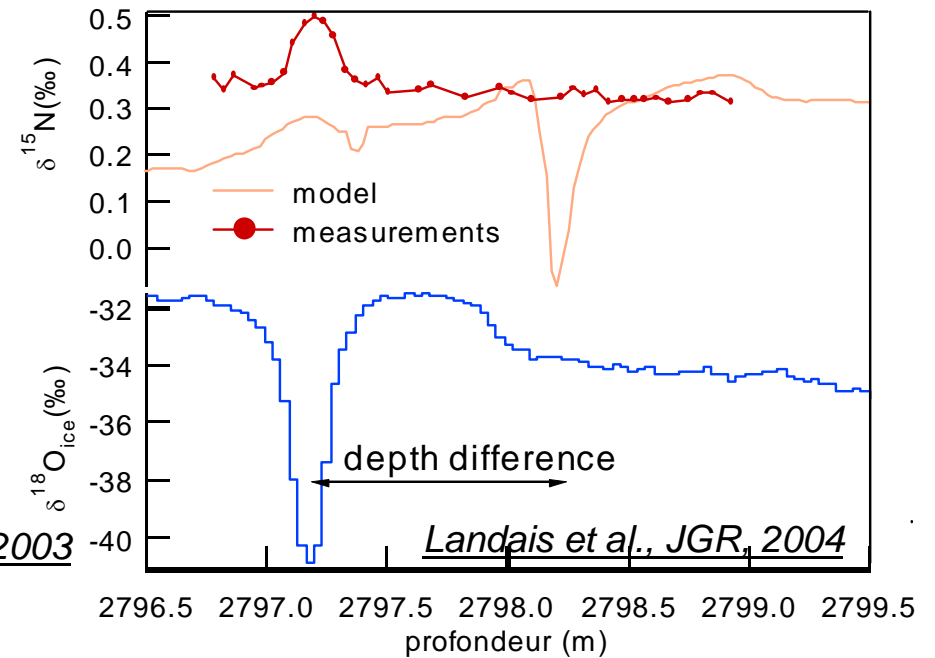
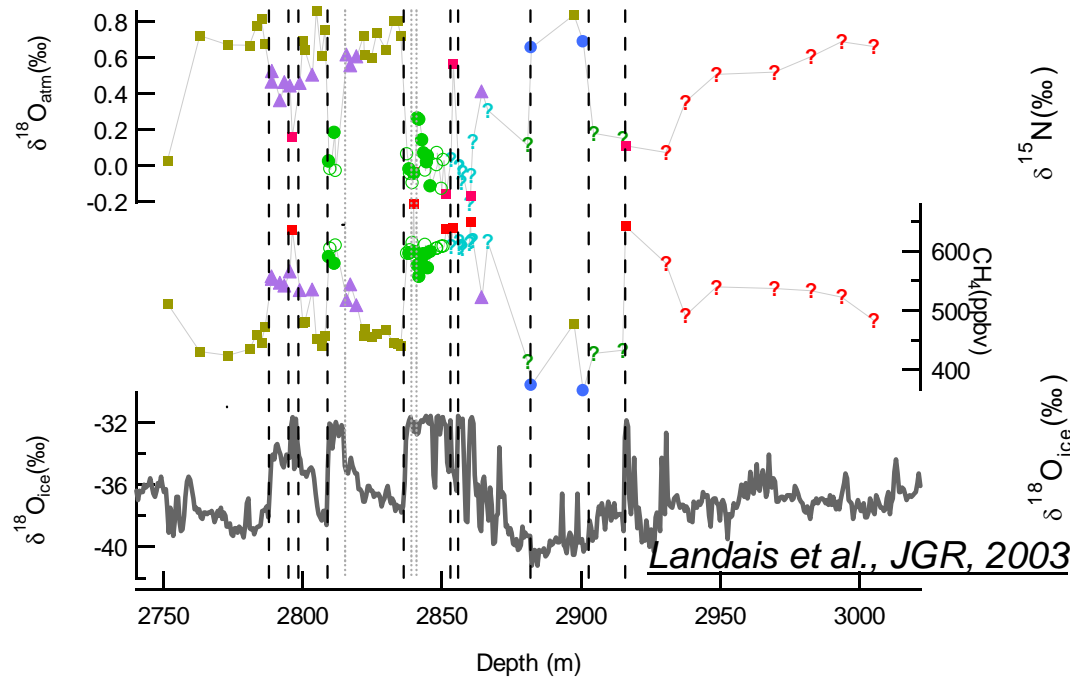


Rapid climatic variability in a warmer world ?



### 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  $\text{O}_2$ : 1‰ in 100 yrs  
Residence time of  $\text{O}_2 = 1200$  yrs



IMPOSSIBLE

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

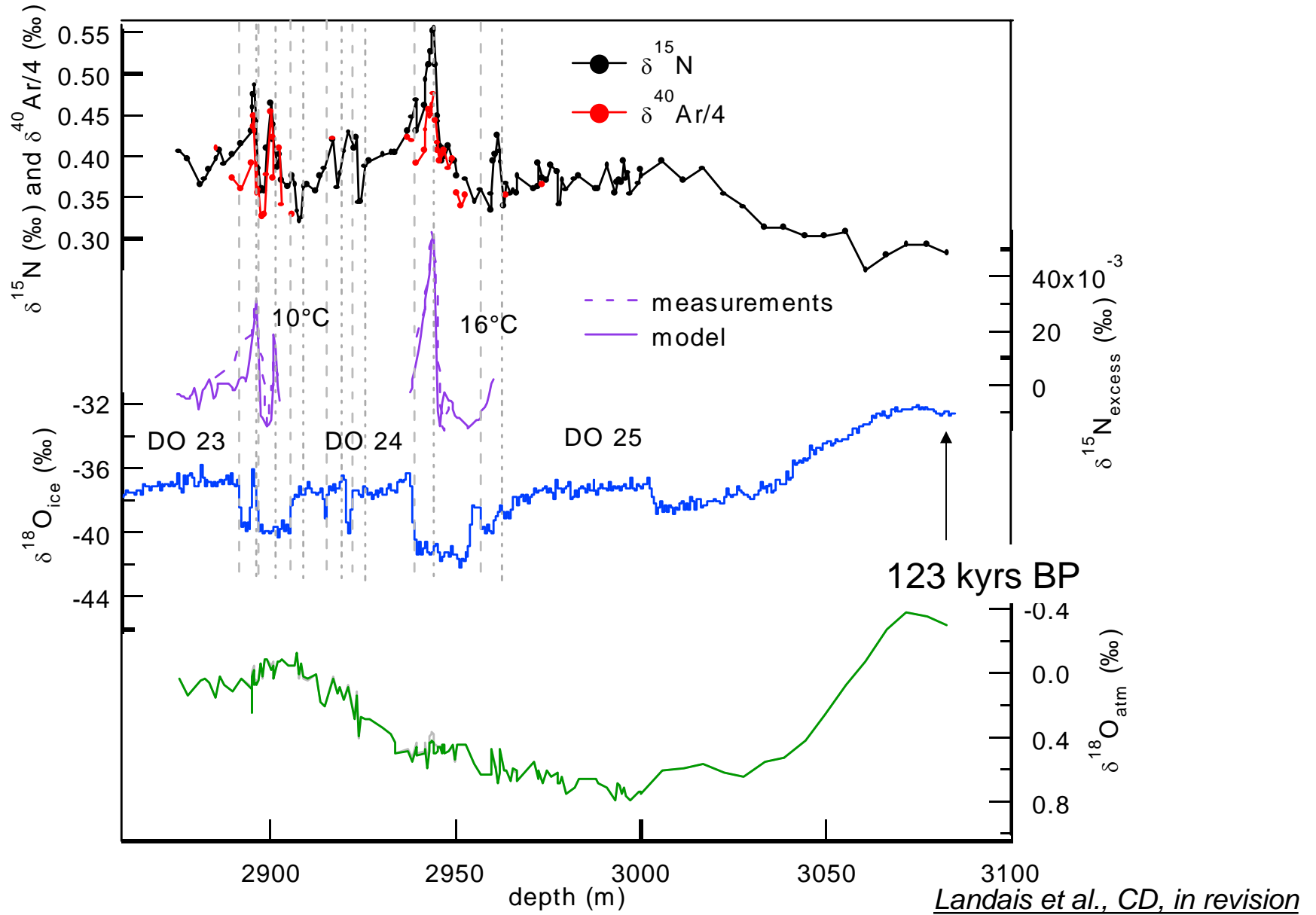


NOT A CLIMATIC EVENT

**GRIP ice core = ice mixing before 105 kyrs BP**

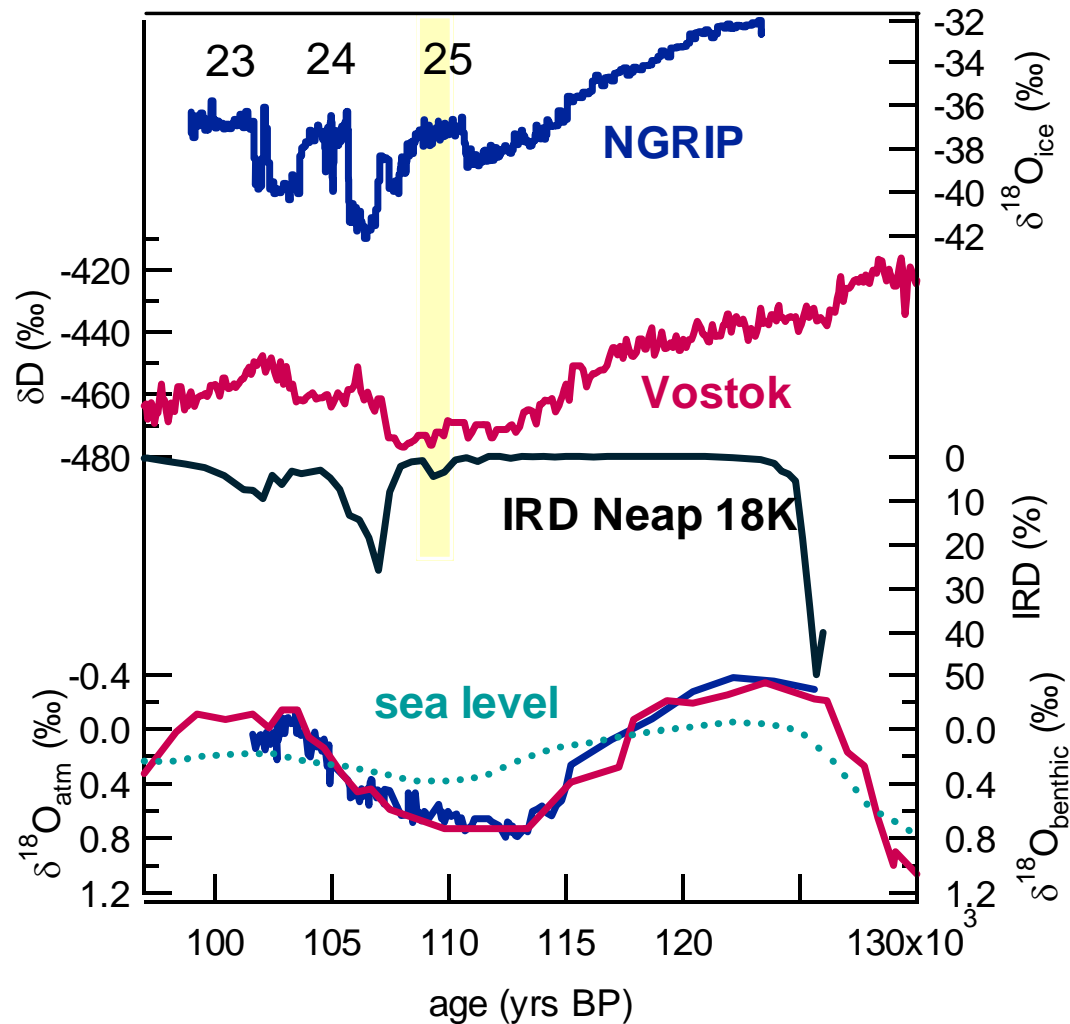
### 3- Rapid events in interglacial time

NorthGRIP = new reference



### 3- Rapid events in interglacial time

# Specificity of the first Dansgaard-Oeschger

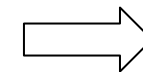


#### -DO 24, 23 :

- 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



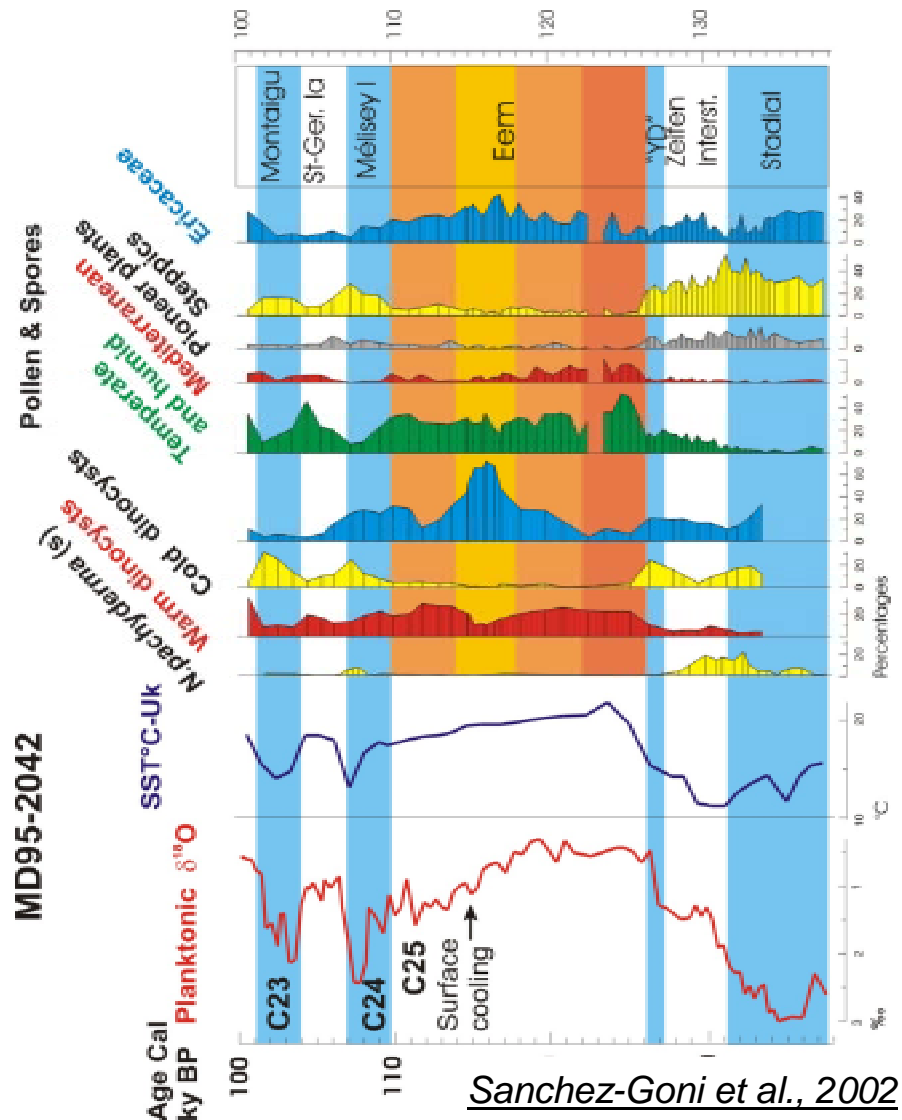
Mechanism ?  
Role of the water cycle

# 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
- N<sub>2</sub>O 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

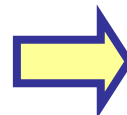


#### -DO 24, 23 :

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

#### -DO 25 :

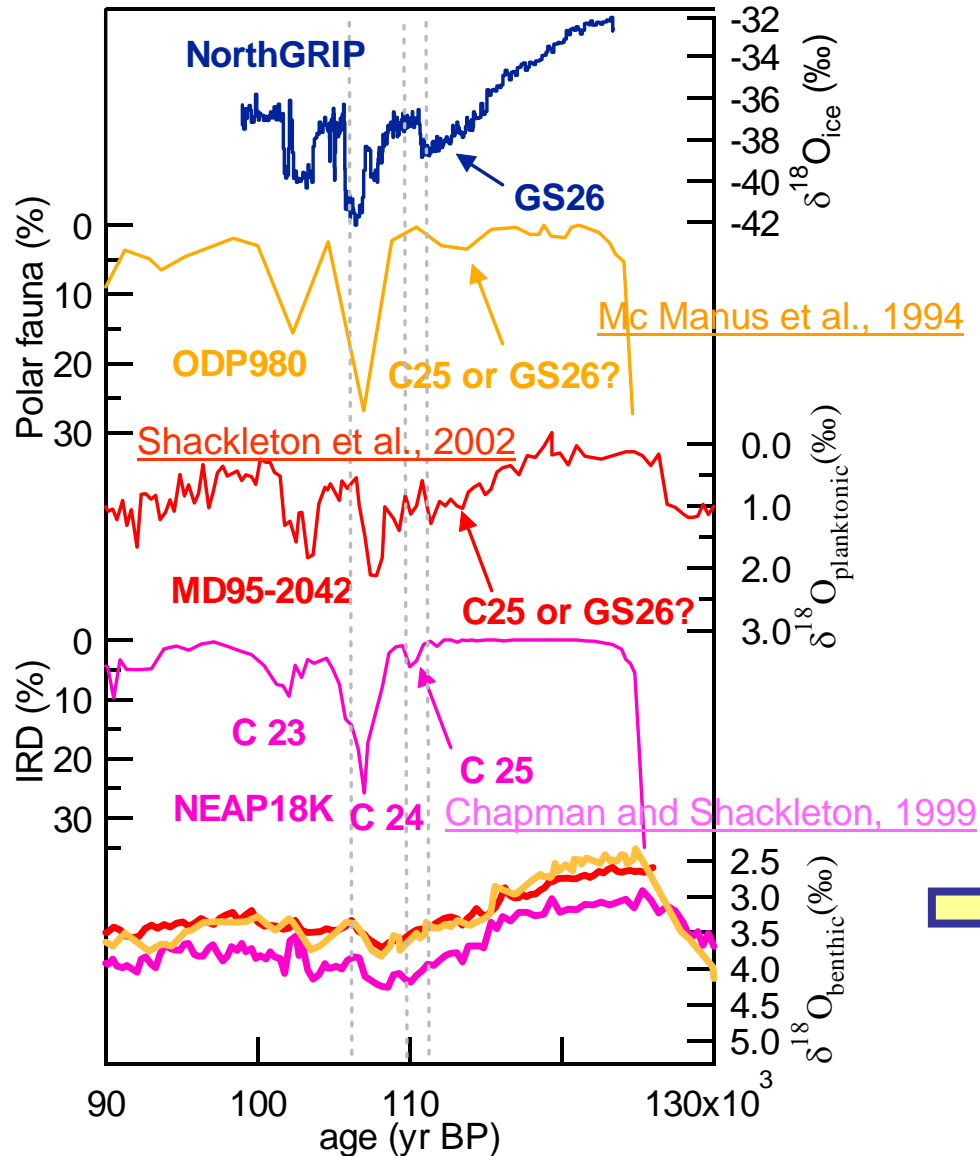
- SST variations Portugal : 1-2 deg
- Methane signal
- No change in mediterranean vegetation



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.

