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Ice core-based climate research in Denmark

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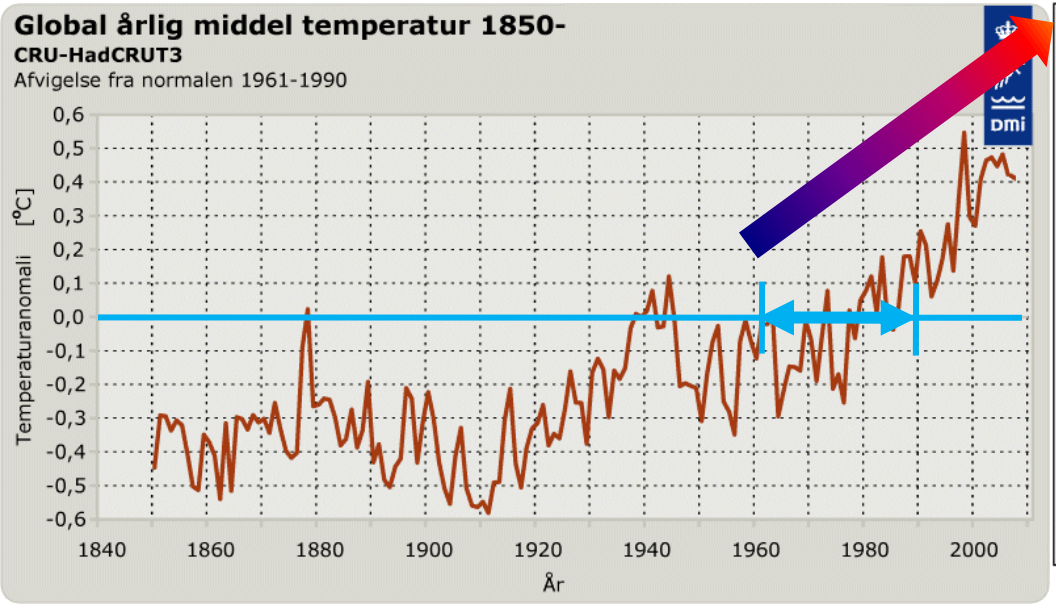
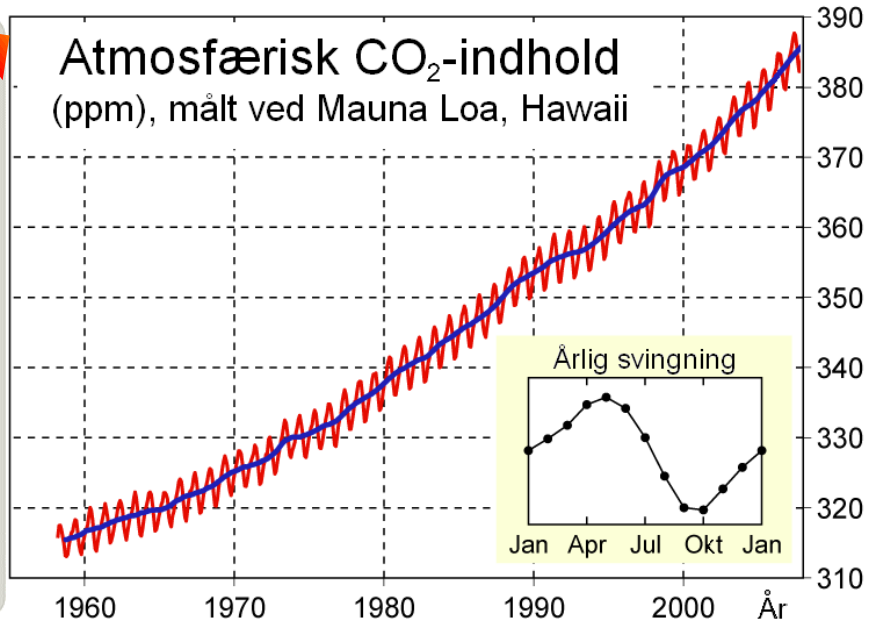
University of Copenhagen

Temperature and CO_2 observations

- Temperature: global values since approx. 1850 (left), spotwise regional values since approx. 1750
- CO_2 measurements since 1958 (right)





Covariation og correlation

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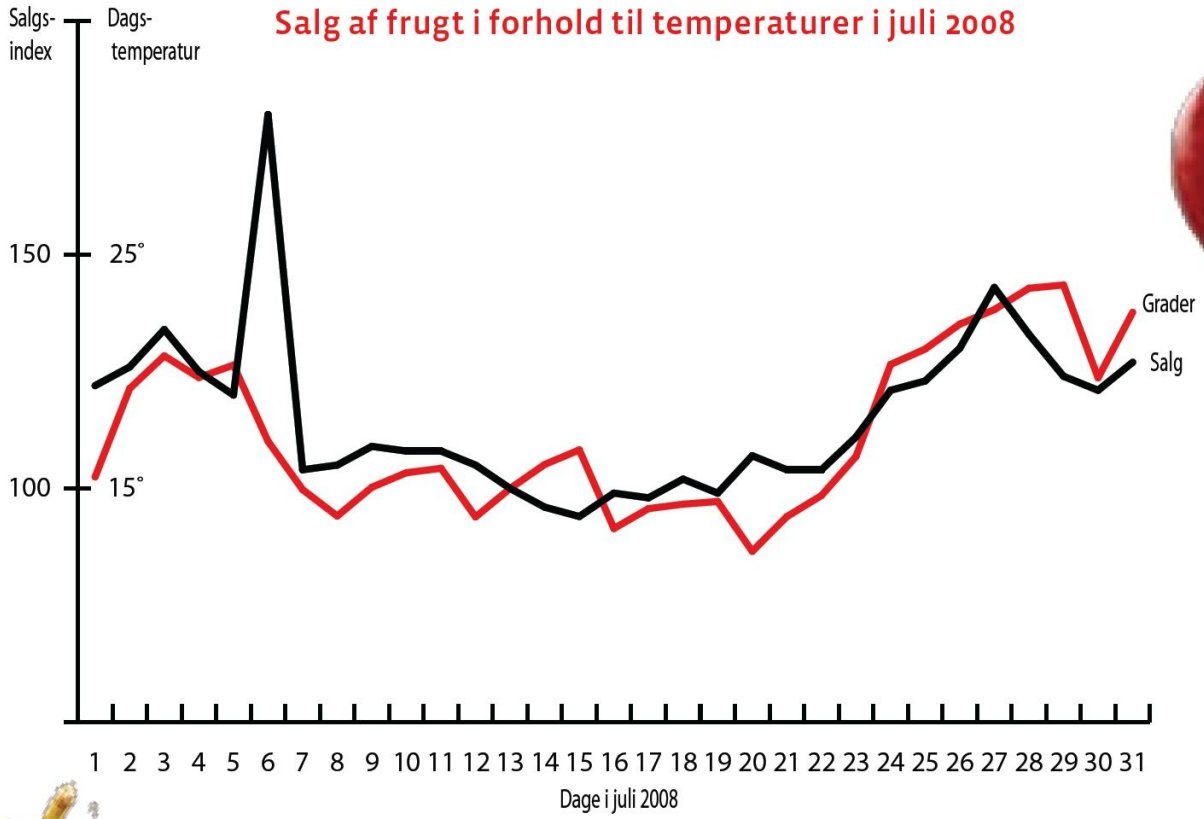

Salget af frugt i Coops butikker følger temperaturen nøje. Det høje udsving en enkelt dag i begyndelsen af måneden skyldes, at der var ekstraordinært søndagsåbent.

Kilde: DMI og Coop

Samvirke
November • 11 • 2008

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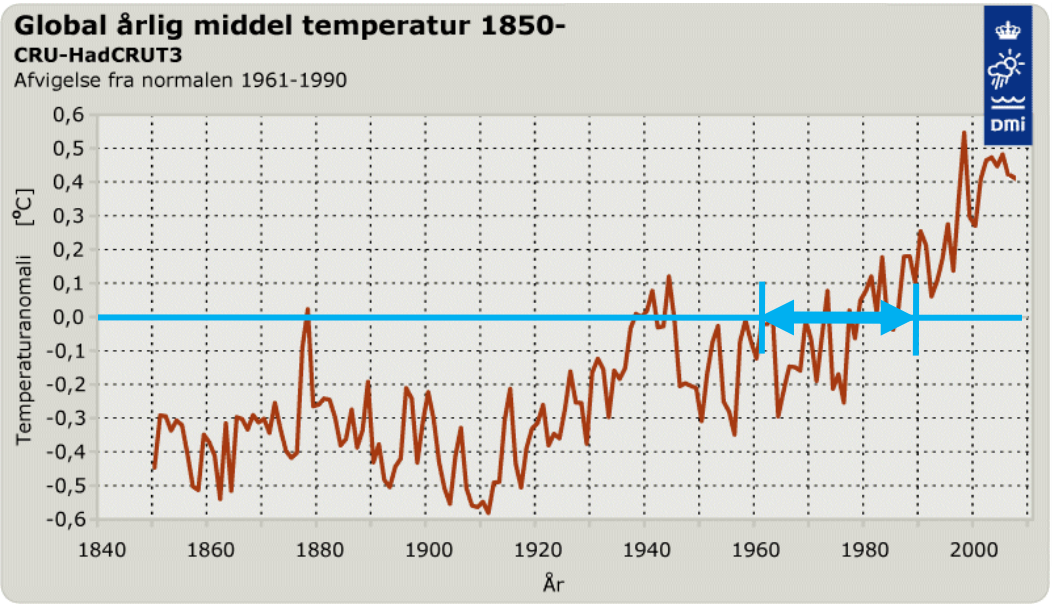

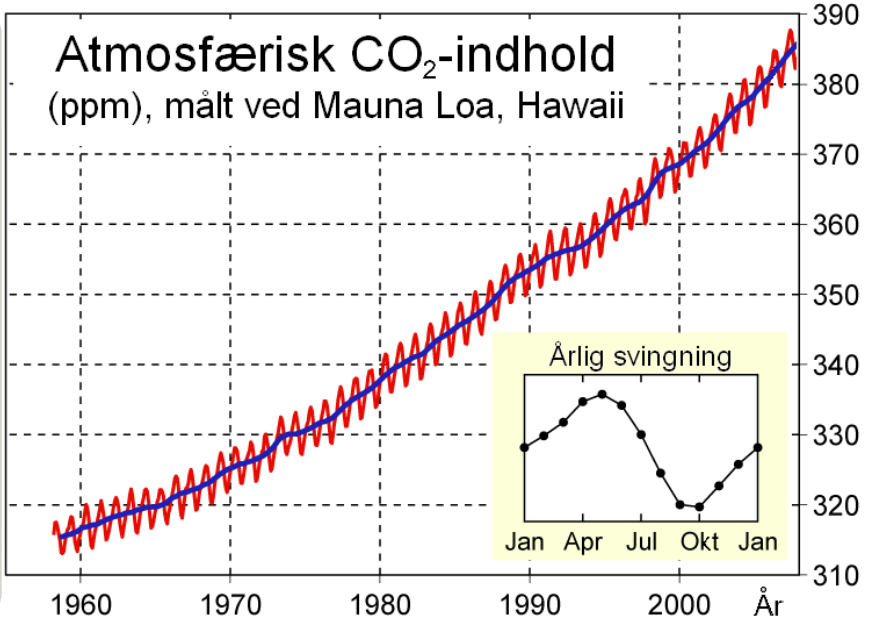

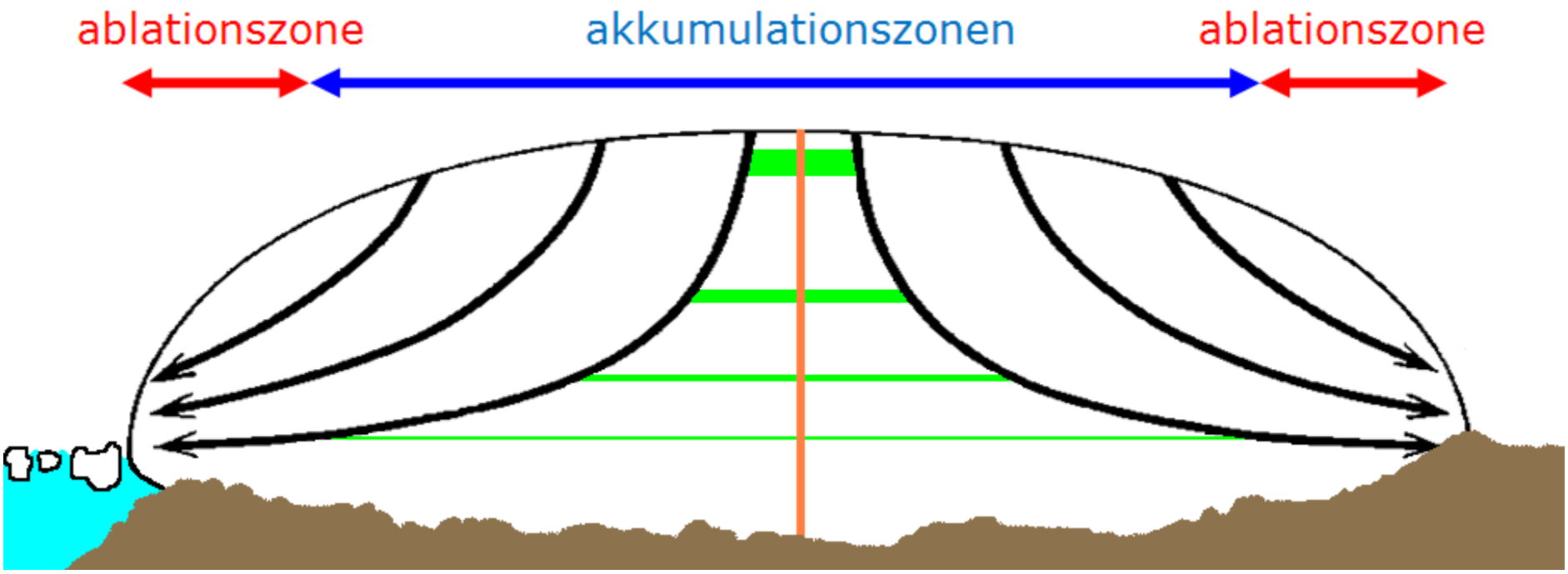
ablationszone
akkumulationszonen
ablationszone

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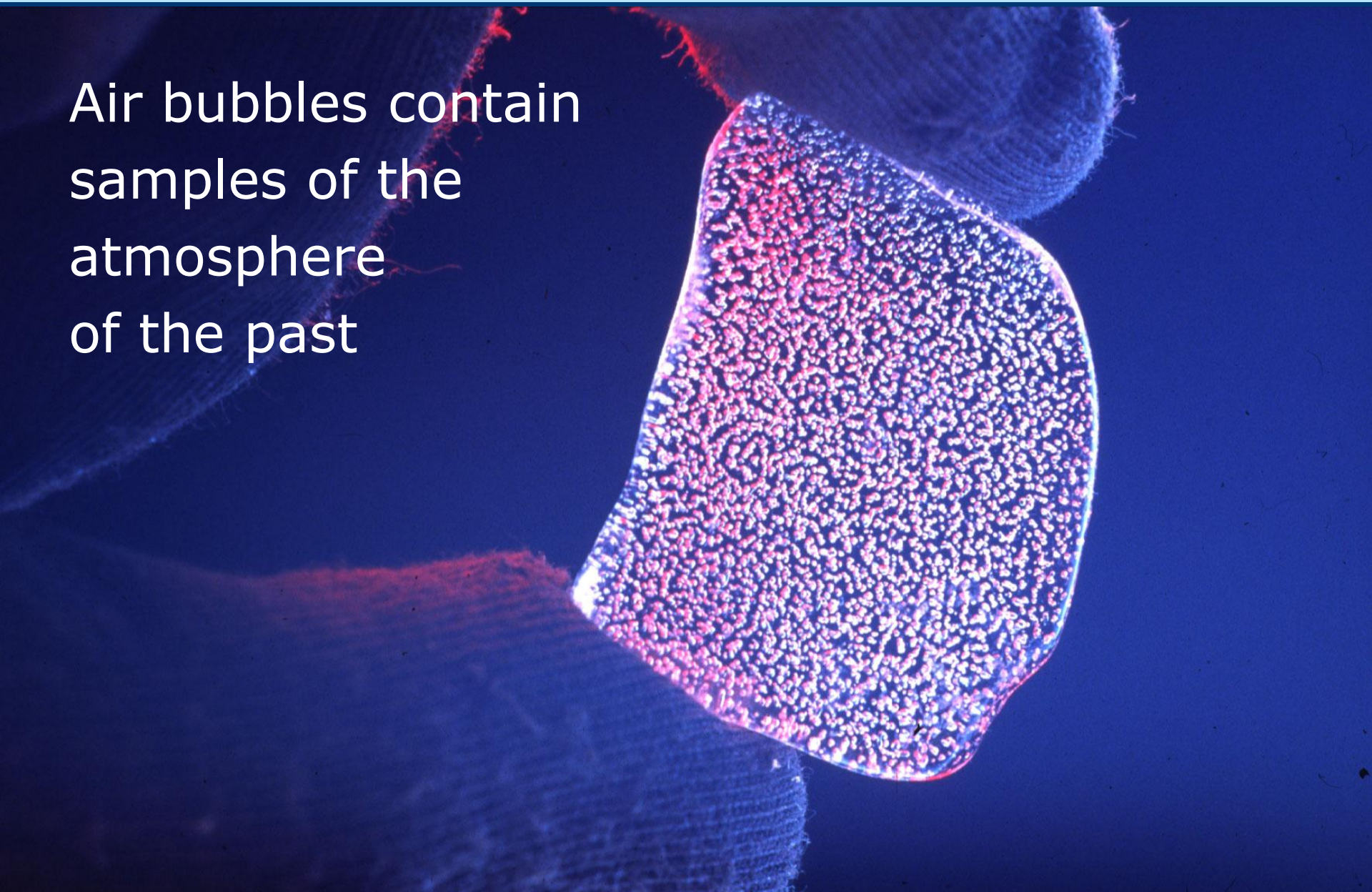
Air bubbles contain samples of the atmosphere of the past



What ice cores show

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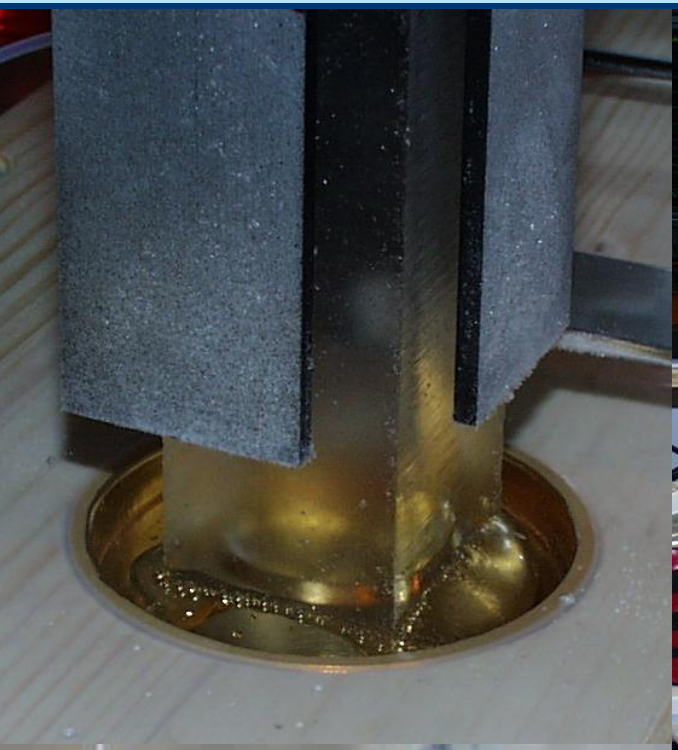
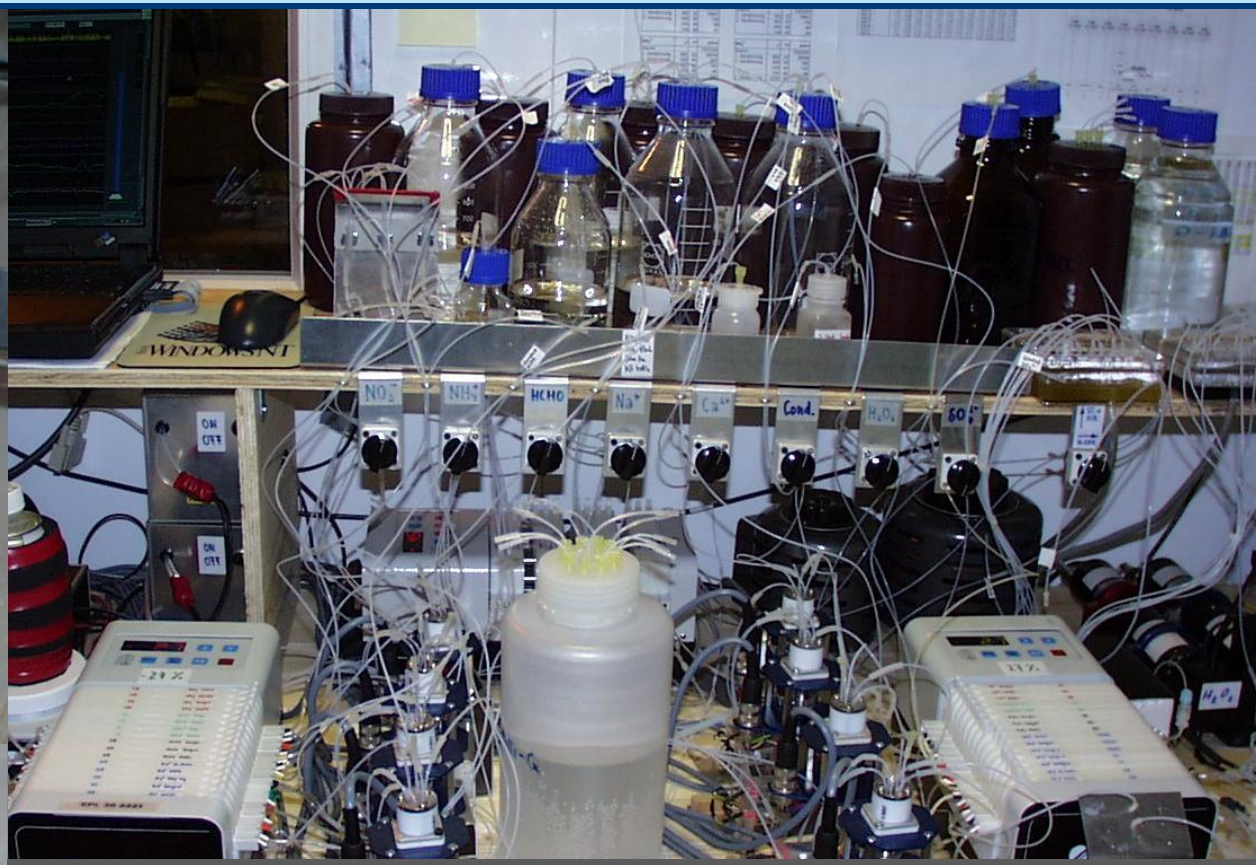
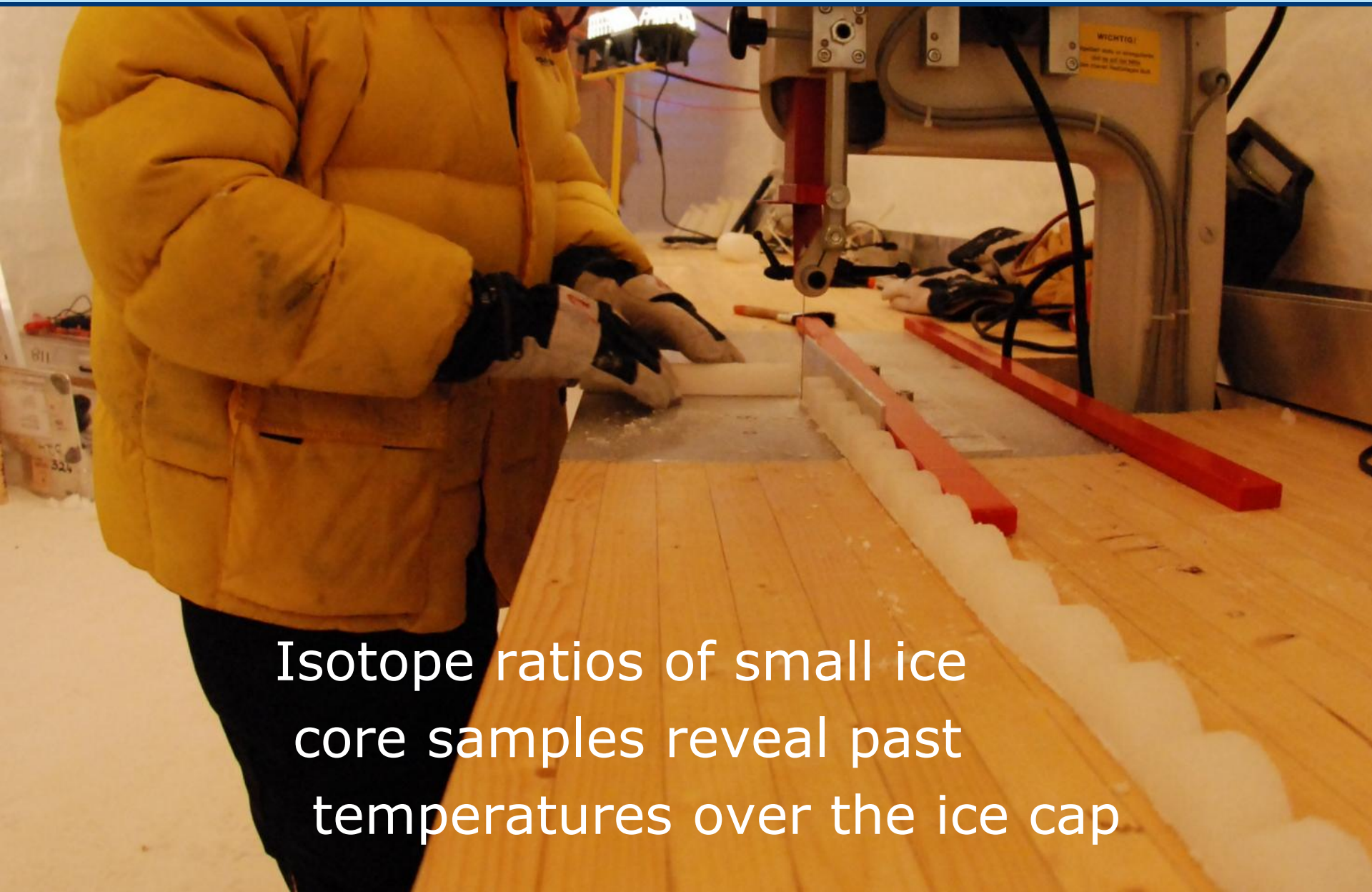




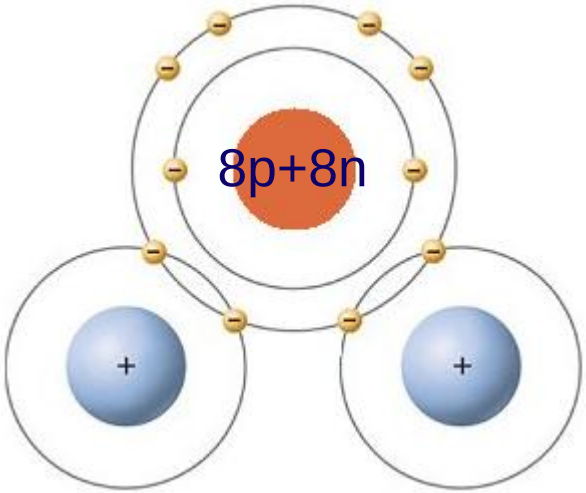
Impurities in the ice contain information about e.g. atmospheric dust load, volcanic eruptions, forrest fires, etc.

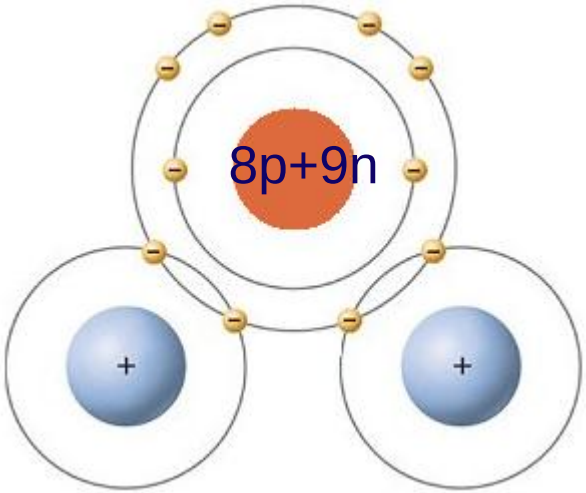
What ice cores show

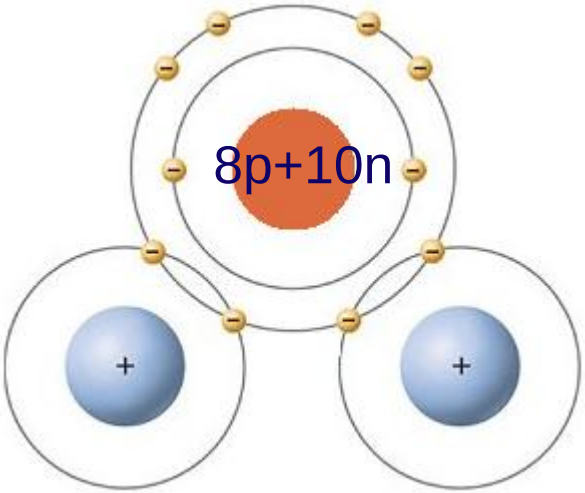


Isotope ratios of small ice core samples reveal past temperatures over the ice cap

Isotope ratios used as a thermometer







^{16}O		^{17}O		^{18}O
9977	:	3	:	20

$H_2{}^{18}O$ evaporates less easily and condenses more easily than $H_2{}^{16}O$

$\Rightarrow$ $H_2{}^{18}O$ is lost during distillation

$\delta^{18}O$ is the $^{18}O/^{16}O$ ratio's relative deviation in permille from *Standard Mean Ocean Water*.

Formal definition:

$$R = \frac{[^{18}\mathrm{O}]}{[^{16}\mathrm{O}]}$$

$$\delta^{18}\mathrm{O} = \frac{R_{prøve} - R_{standard}}{R_{standard}} \cdot 1000\,‰$$

For precipitation, $\delta^{18}O$ range from -80‰ to 0 ‰.

Colder conditions $\Rightarrow$ lower $\delta^{18}O$ (more negative):

1‰ ~ 1,5°C - 3°C

Isotope ratios as palaeo-thermometer and as a dating tool

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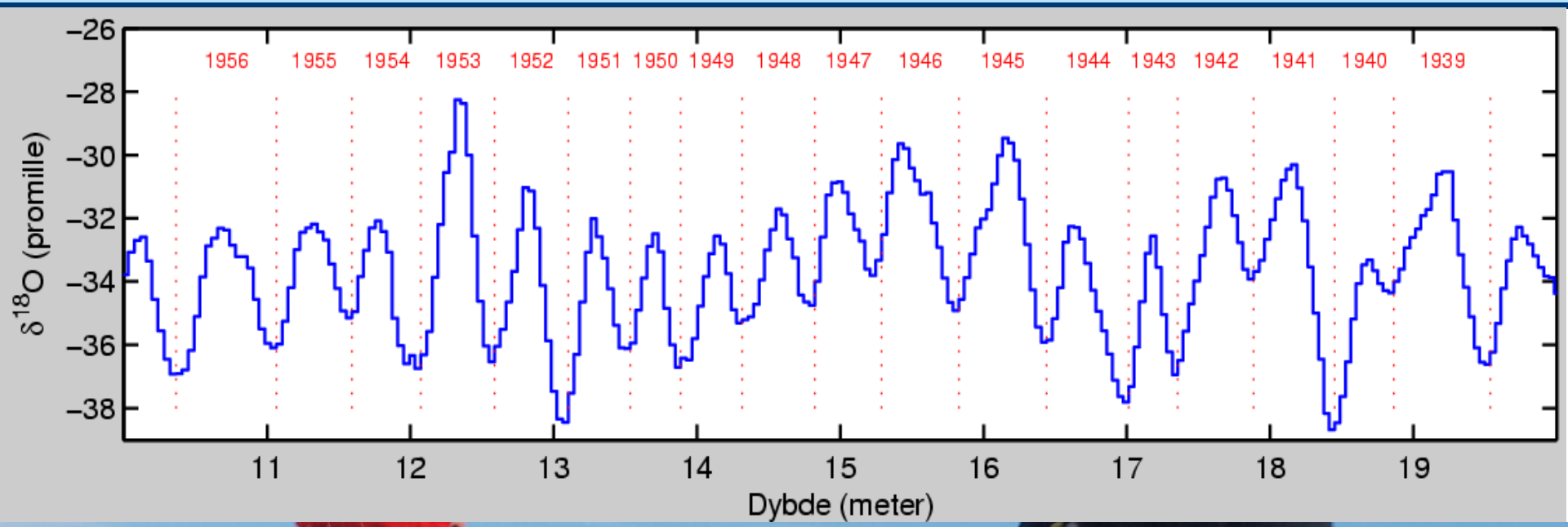
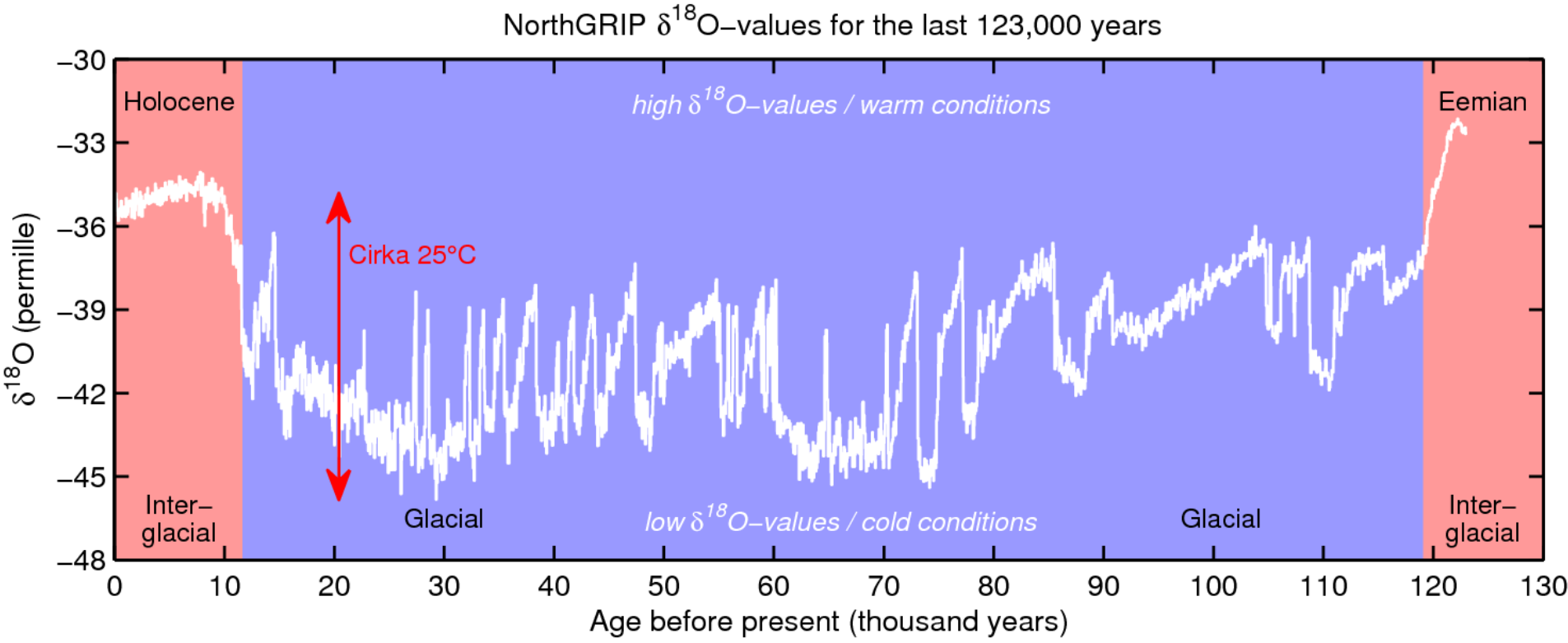
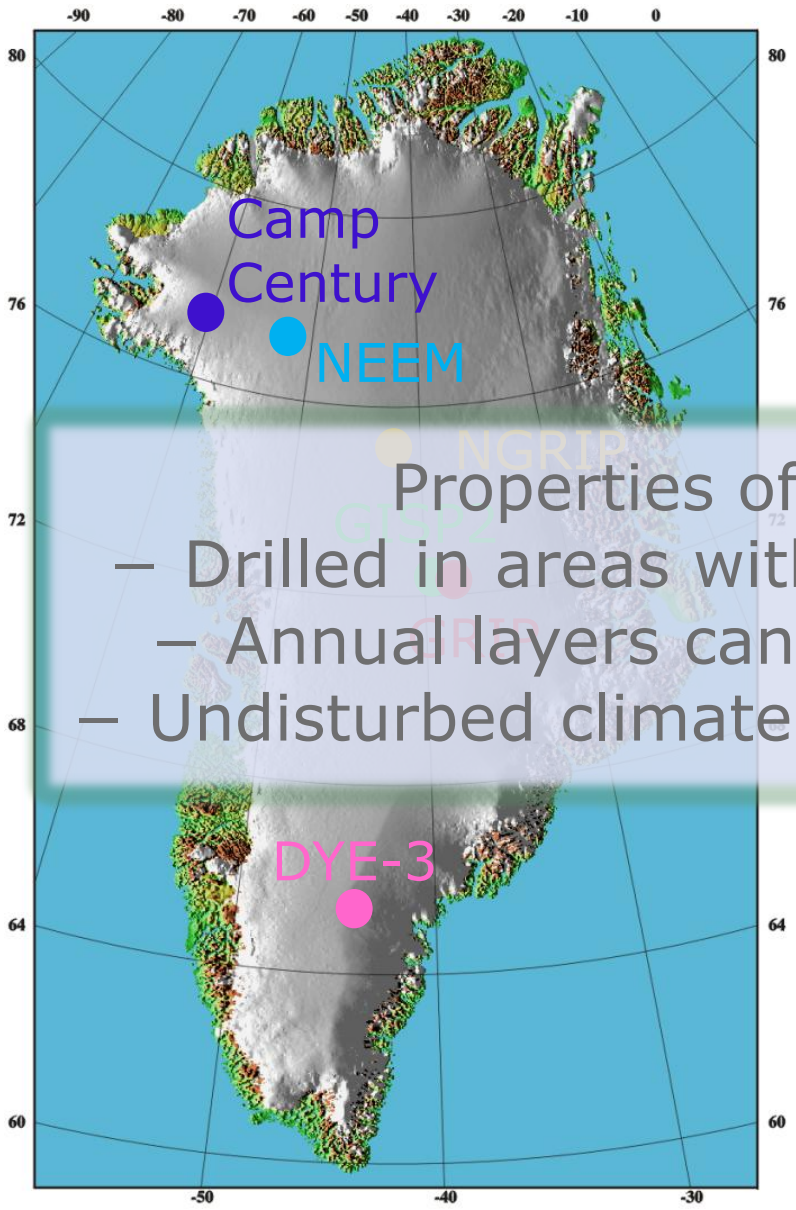


NorthGRIP stable isotope ratios



Ice cores drilled in Greenland



Camp Century (1391 m)
CRREL, US Army, 1966

DYE-3 (2037 m)
Denmark, US, and Switzerland, 1981

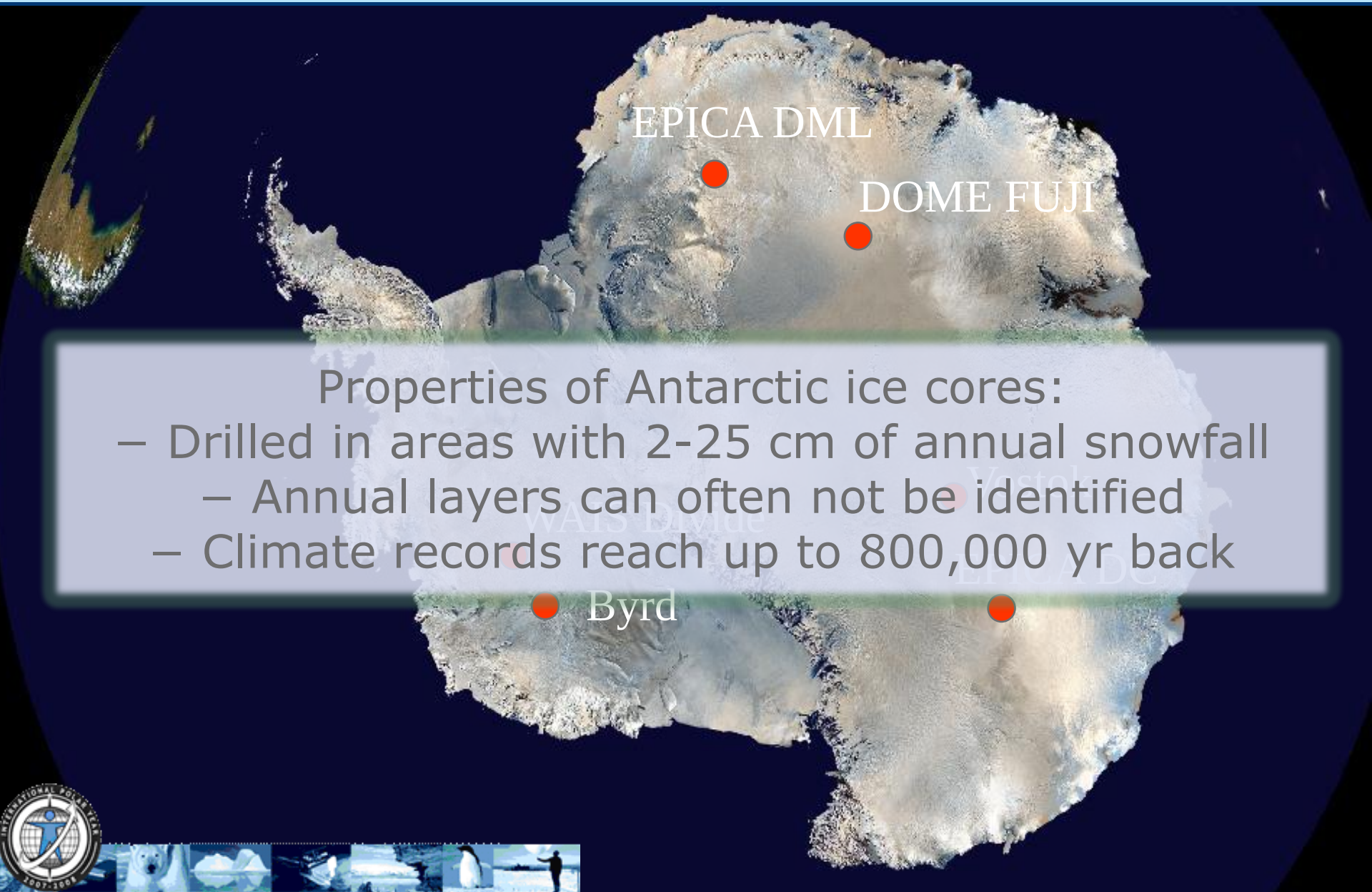
GRIP (3029 m)
International (mostly European), 1992

NGRIP (3090 m)
International, 2003

NEEM (~2540 m)
International, 2007-2012

Properties of Greenland ice cores:
- Drilled in areas with 19-50 cm of annual snowfall
- Annual layers can be identified 60,000 yr back
- Undisturbed climate records reach 123,000 yr back

Selected Antarctic ice cores



Properties of Antarctic ice cores:

- Drilled in areas with 2-25 cm of annual snowfall
- Annual layers can often not be identified
- Climate records reach up to 800,000 yr back

Taking the bus to work

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How to drill an ice core …
Working under cold and extreme conditions

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Building labs under the surface

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The NEEM drilling camp

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NorthGRIP drill trench

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The EPICA ice core drill

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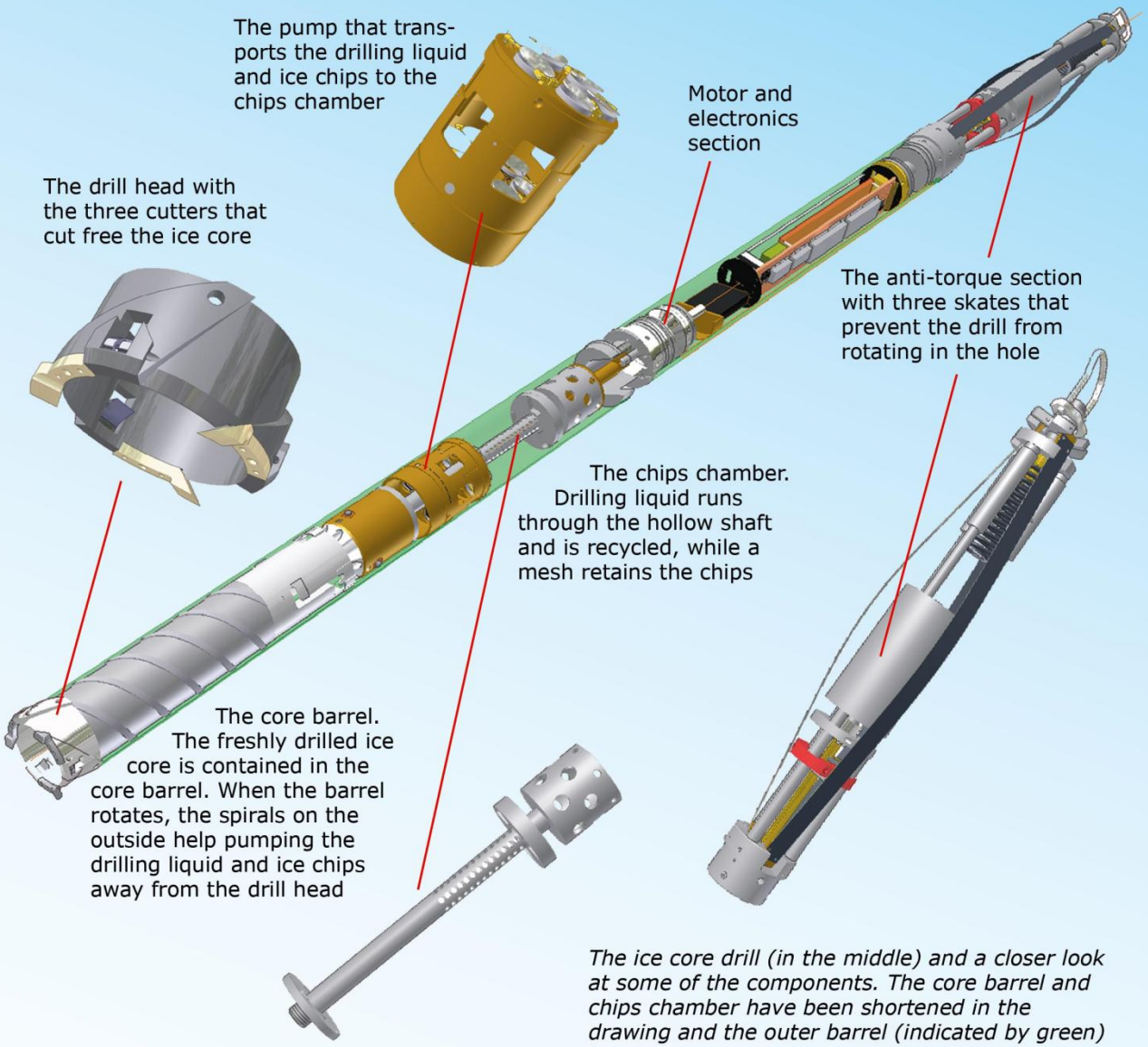
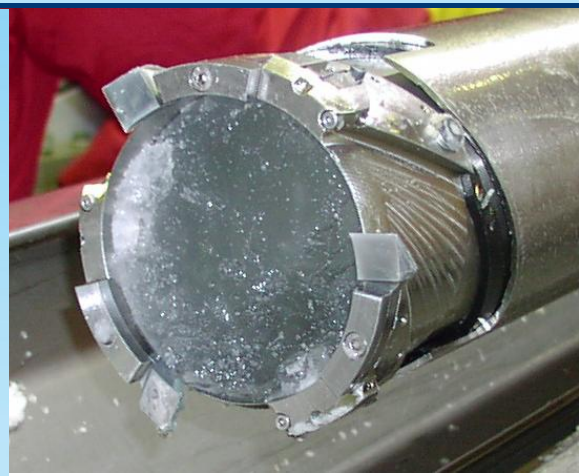


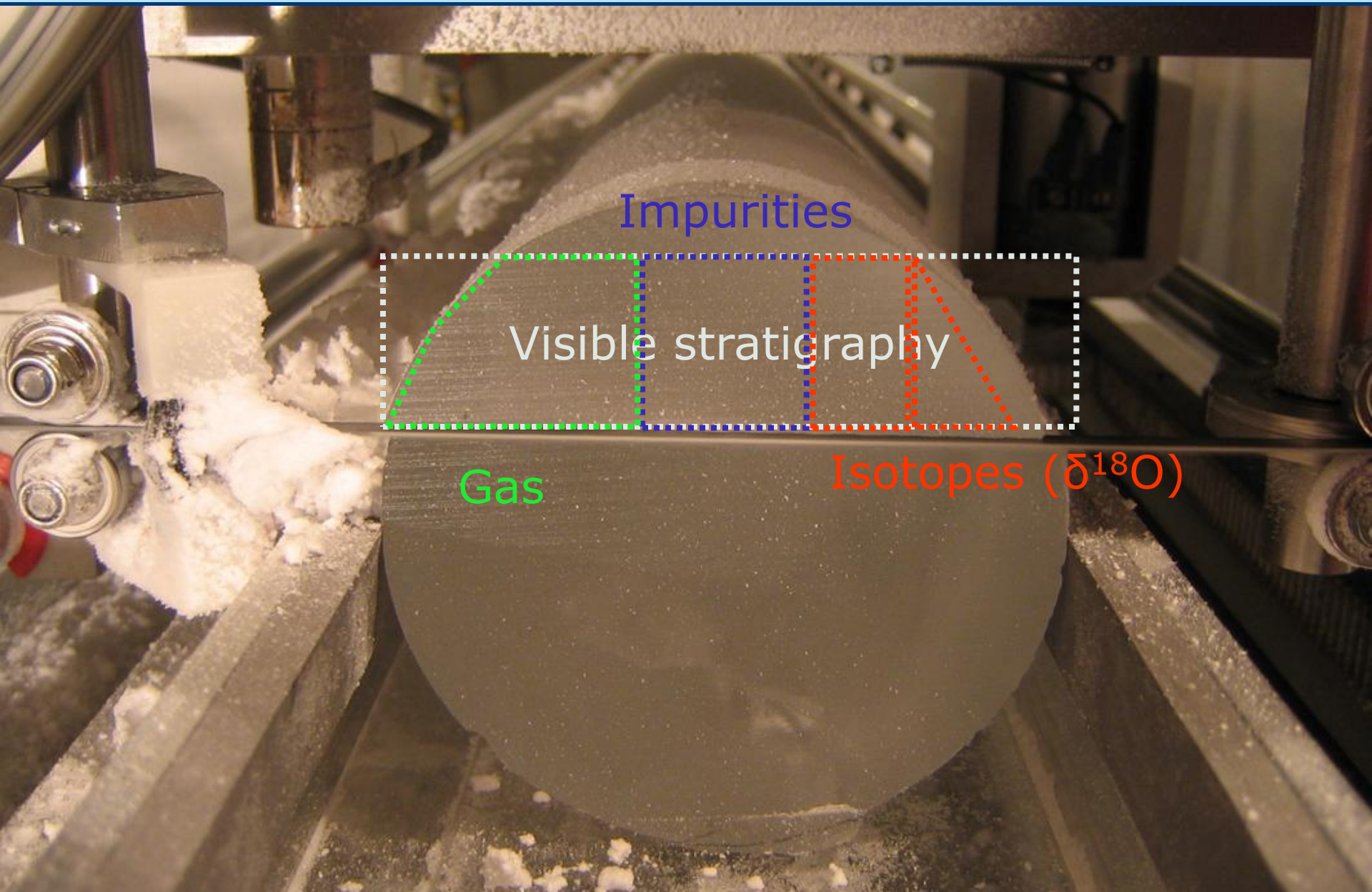
The ice core drill (in the middle) and a closer look at some of the components. The core barrel and chips chamber have been shortened in the drawing and the outer barrel (indicated by green) has been removed to reveal the parts inside



[play movie]

Ice core handling

Cutting samples



The strengths of ice cores

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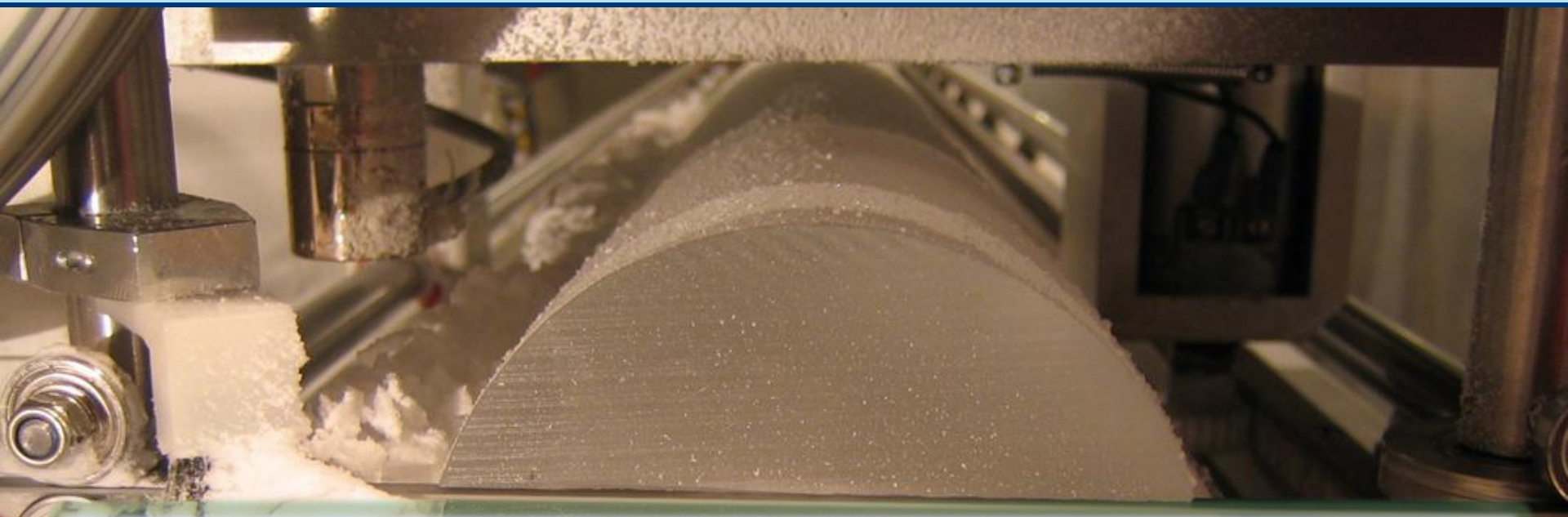

Data on climate **evolution** and **forcing** from the same record

Data reach **far back in time** at **high temporal resolution**, with **good dating precision** obtainable

Many different types of information on the different components of the climate system

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CO_2, CH_4, and temperature
800,000 years back in time

Temperatures and greenhouse gas concentrations from Antarctic ice cores

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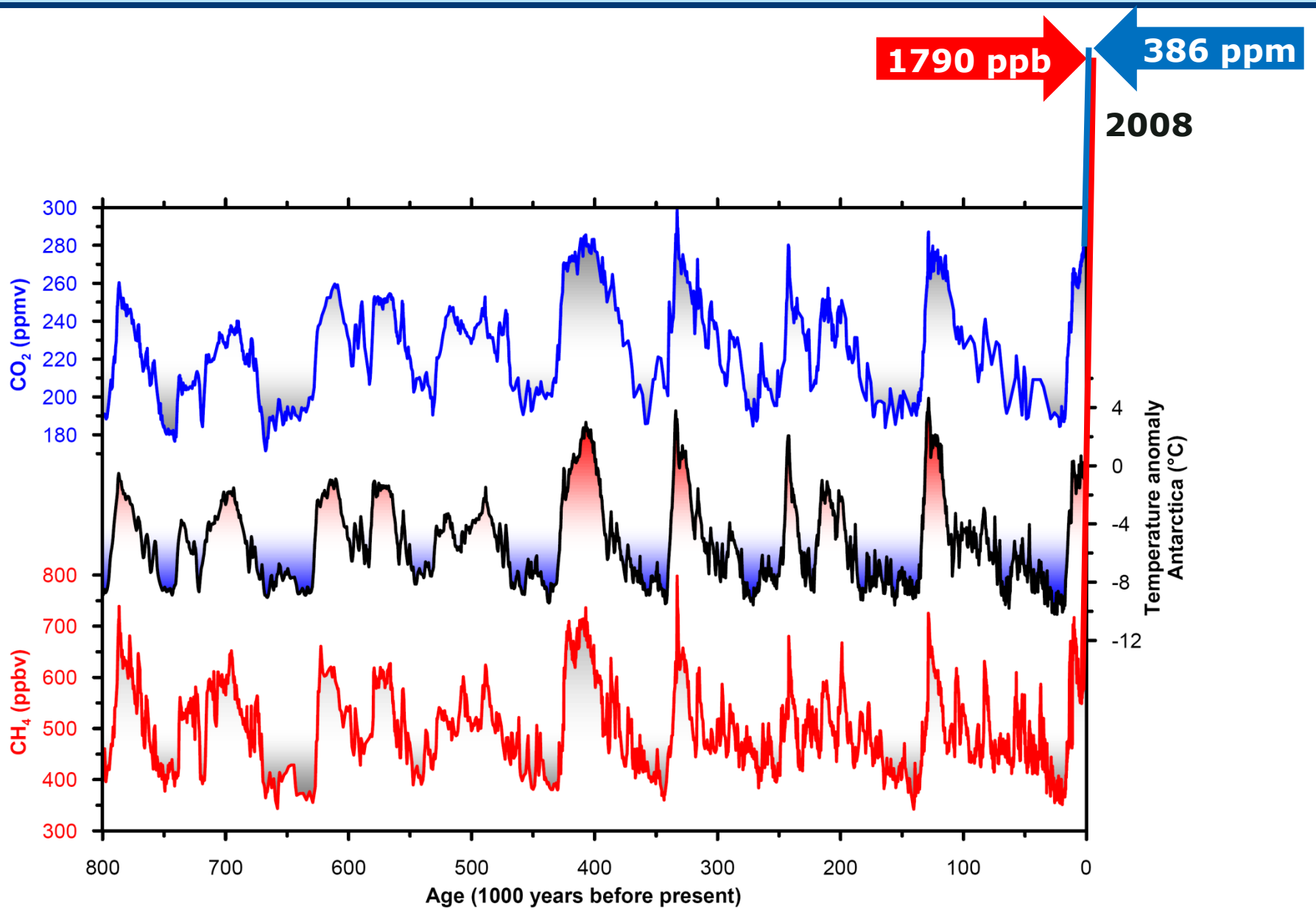
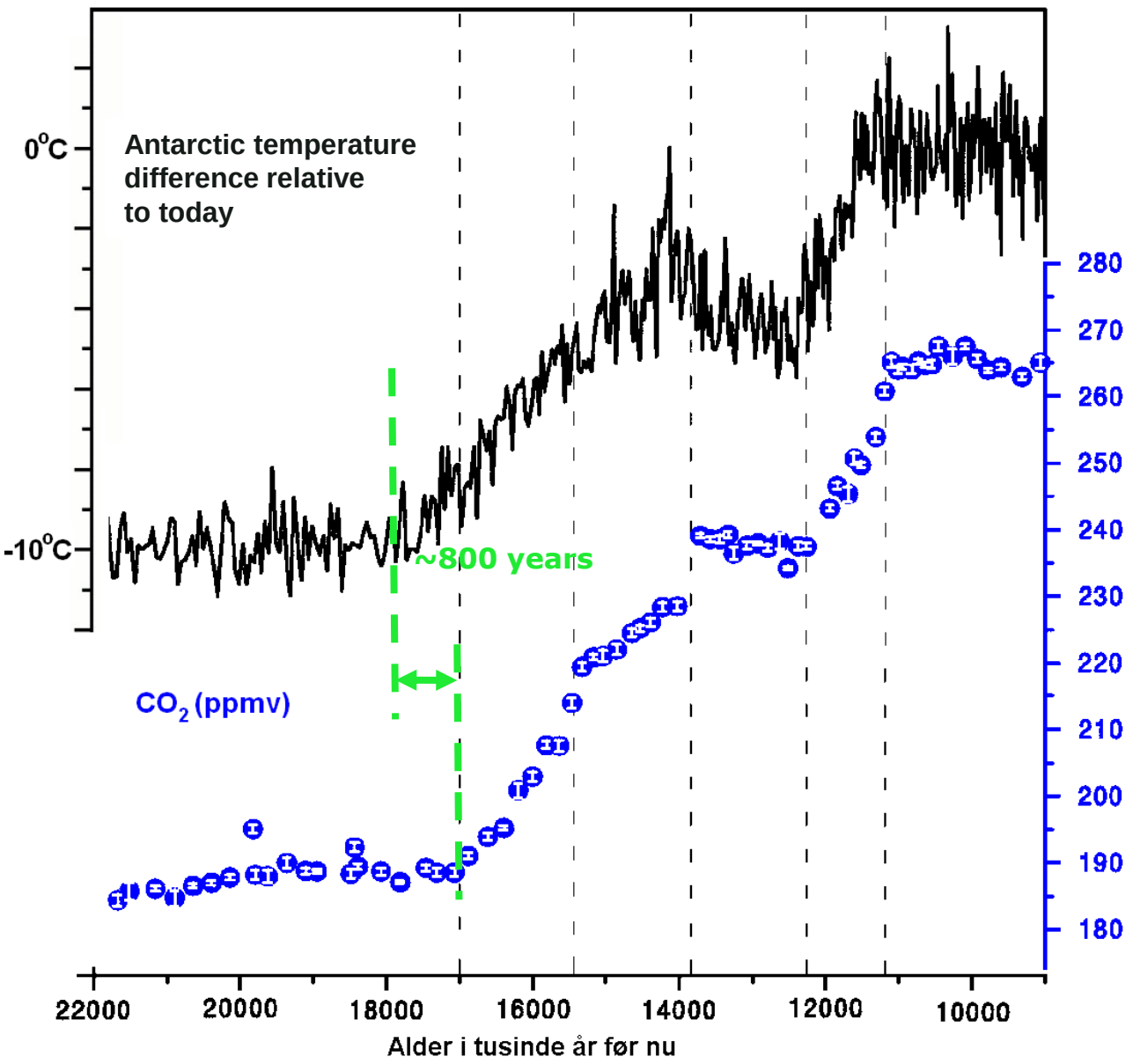
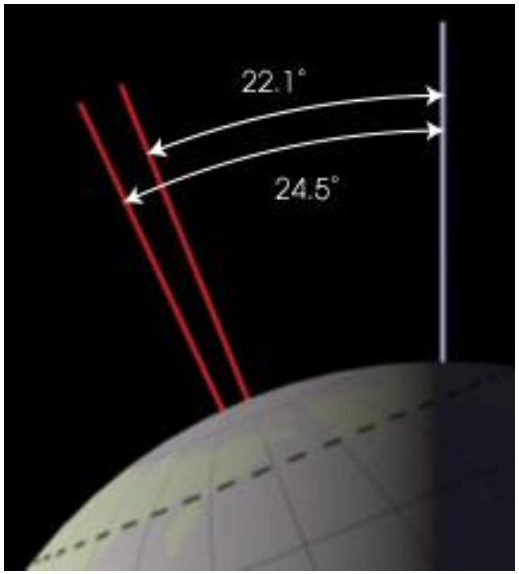
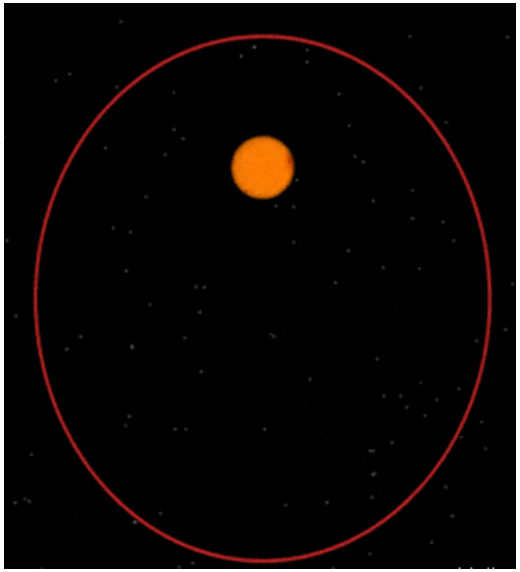


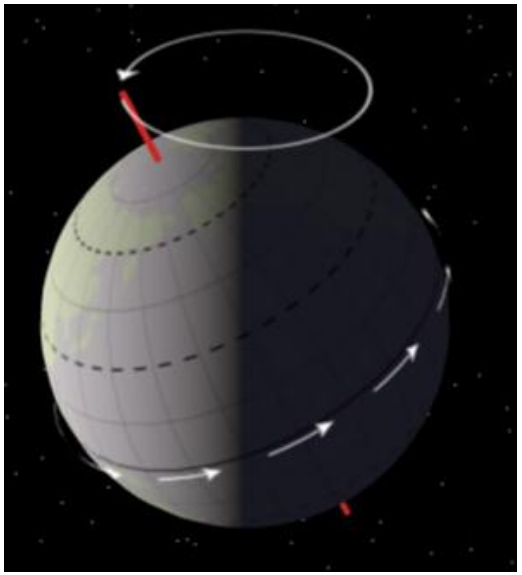
The termination of the glacial: temperature – CO_2 phasing



Glacial-interglacial oscillations: Milankovitch forcing





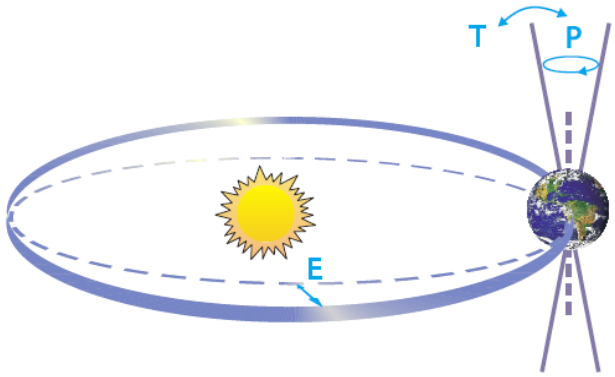


Earth axis tilt : 21,8º – 24,4º. Period ~ 40.000 years

Earth orbit eccentricity: Radiation difference between perihelium and apheilum varies between 7% and 30%. Period ~ 100.000 years

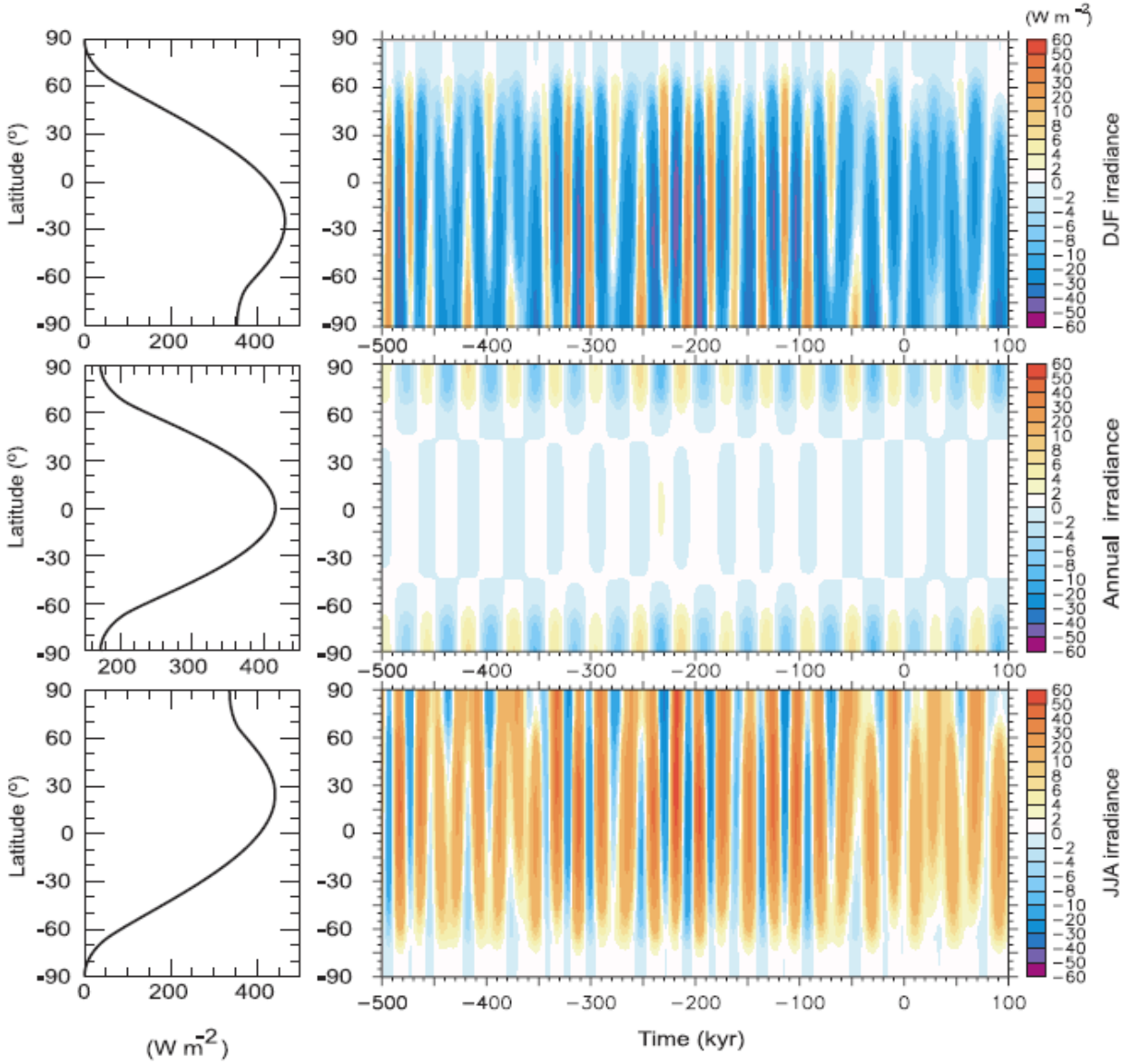
Orientation of axis / Season at perihelium. Period ~ 21.000 years

Milankovitch variations in the amount of energy received

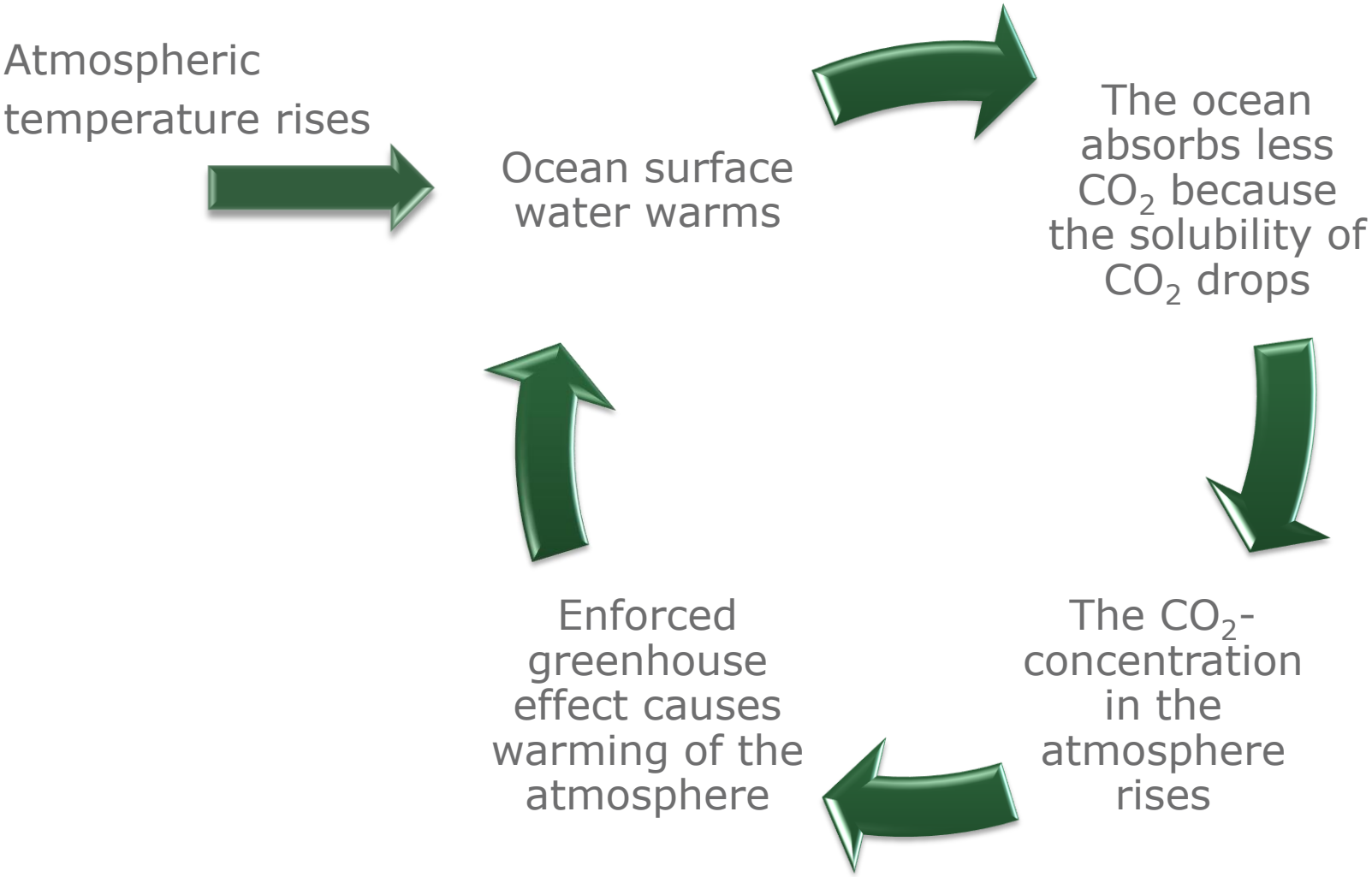


These variations are not in themselves large enough to start a glacial ...

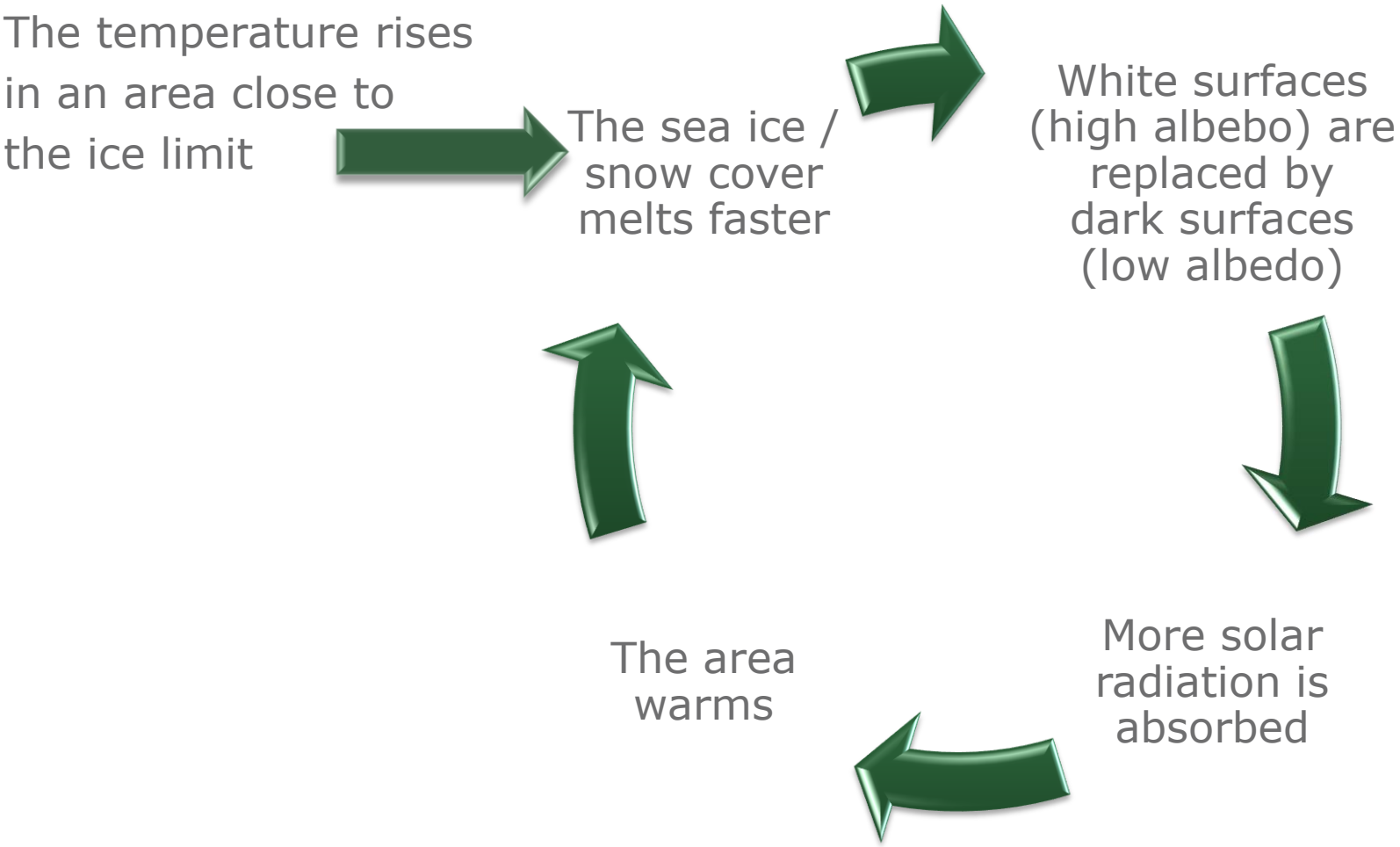
but the climate system contains feedbacks that amplify the effect



CO_2-ocean feedback:

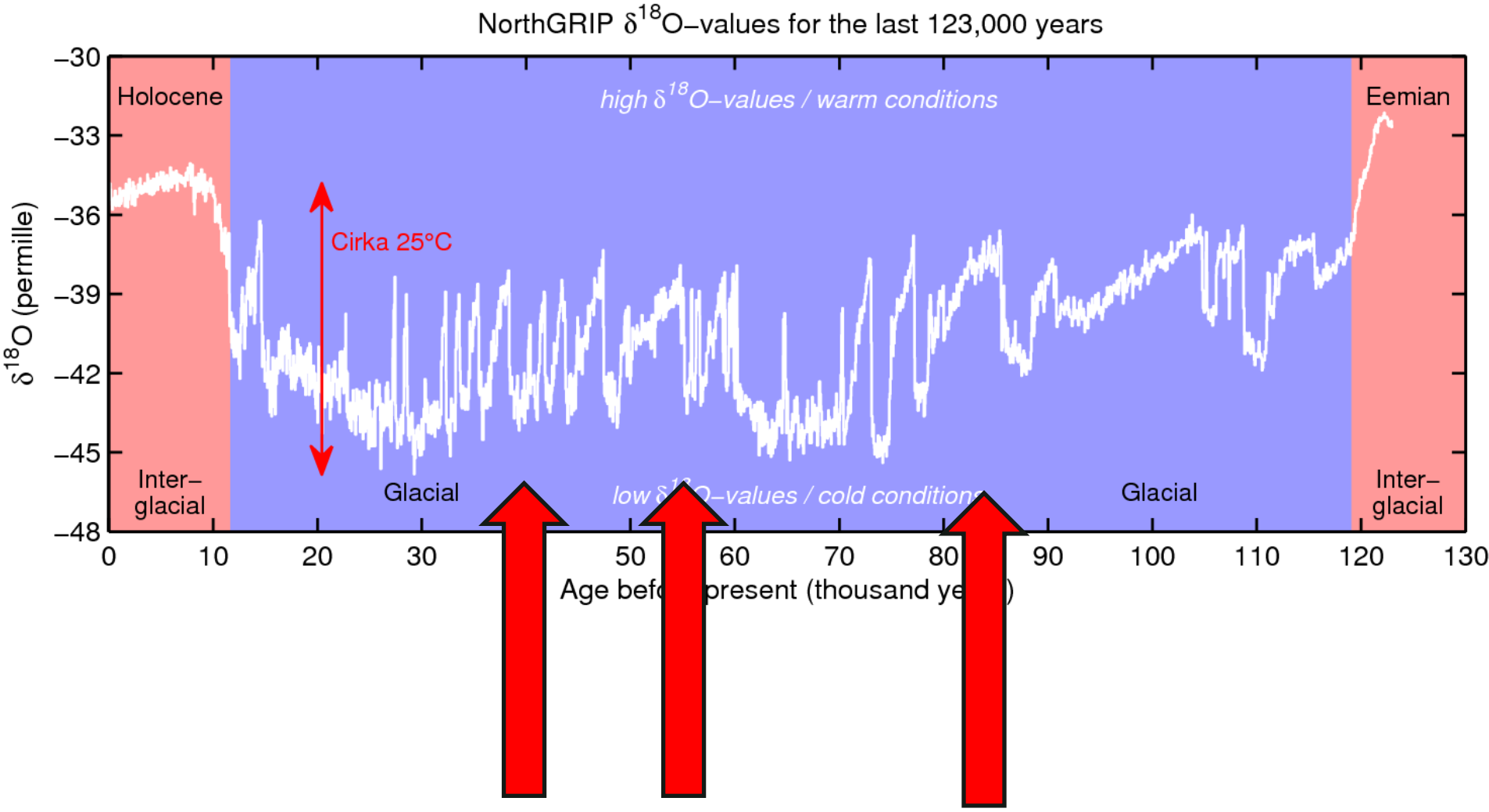


Ice-albedo feedback:

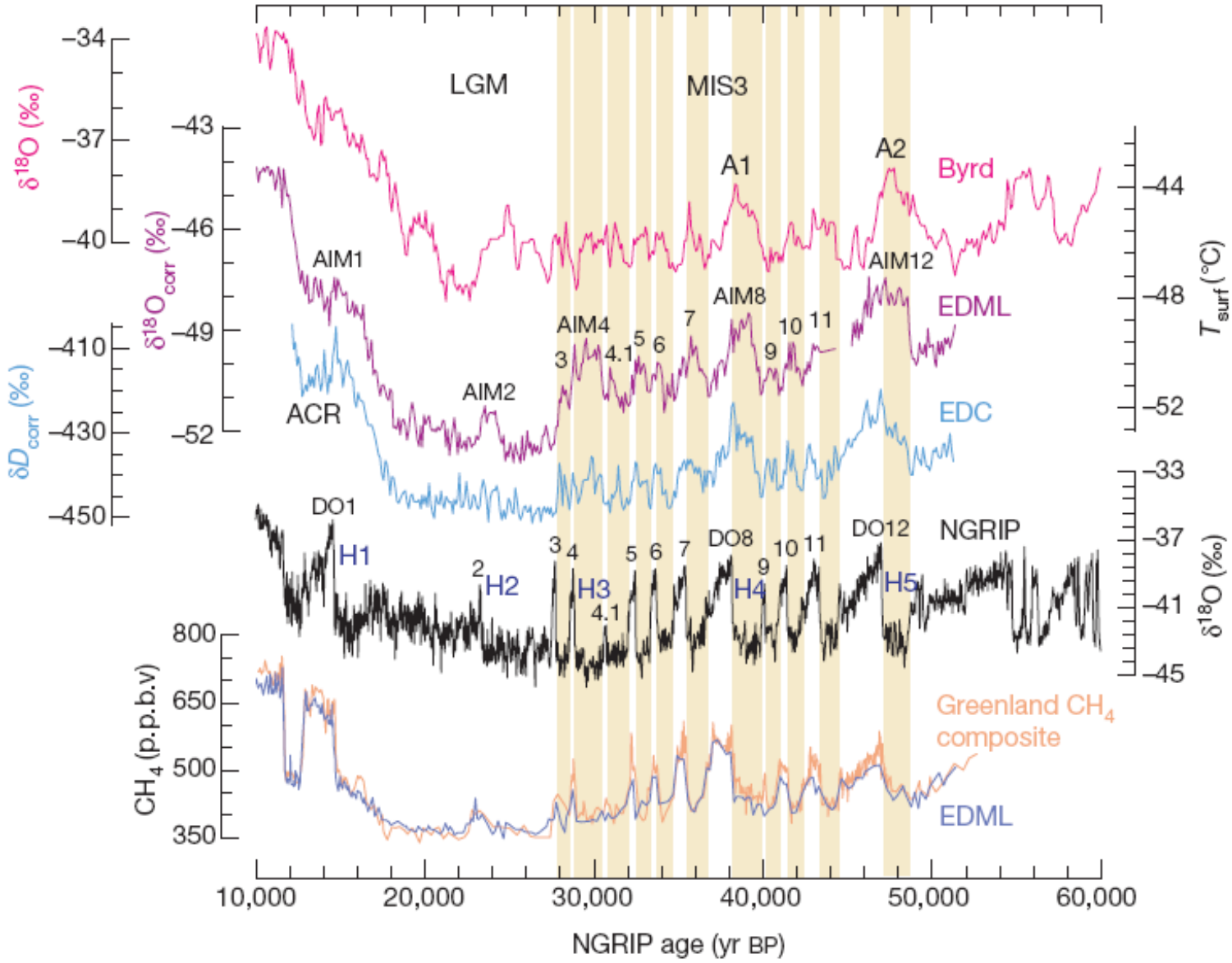


The dynamical glacial climate - tipping points *in action*

NorthGRIP stable isotope ratios: Dansgaard Oeschger events



The bipolar seesaw



Dansgaard-Oeschger events and the thermohaline circulation

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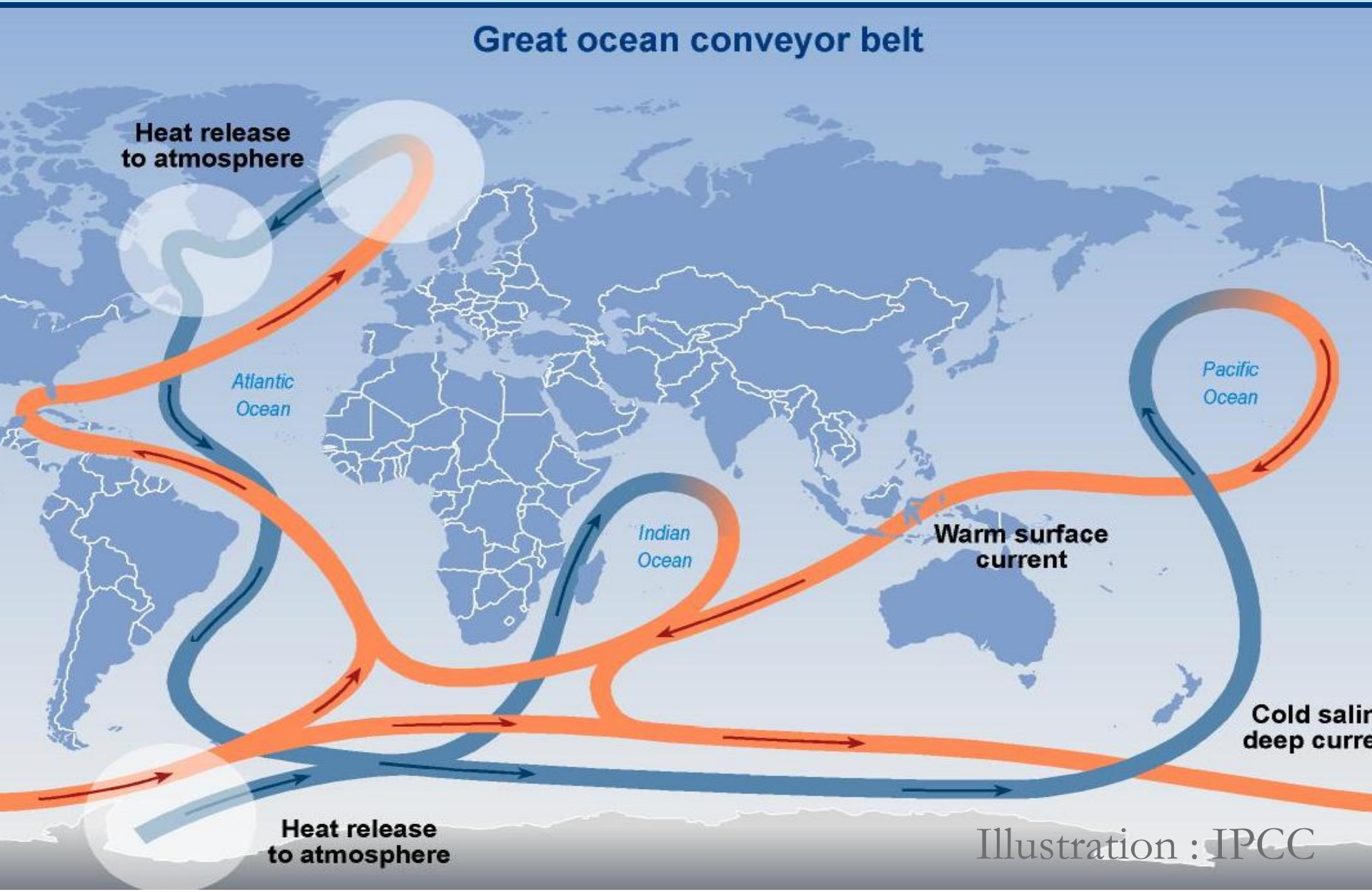
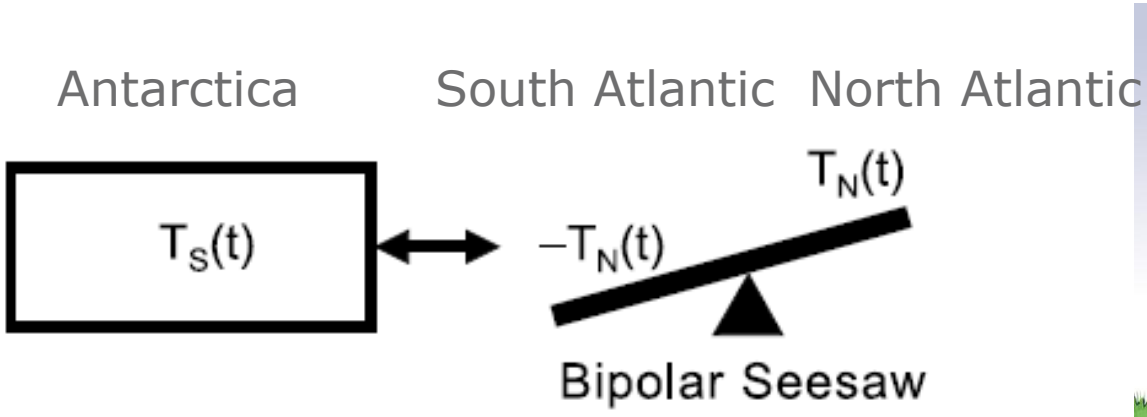
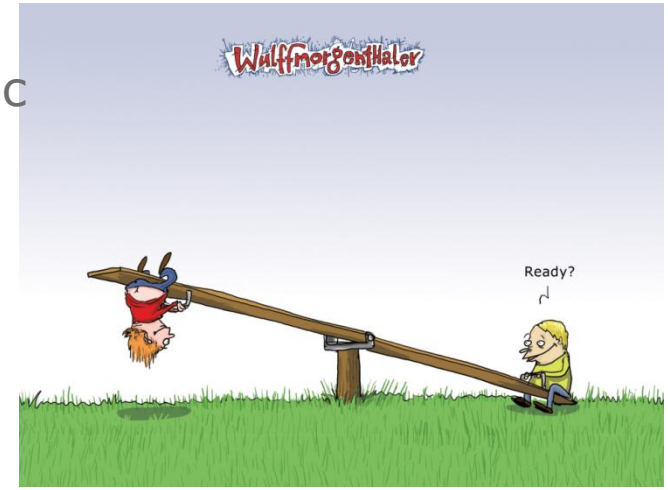
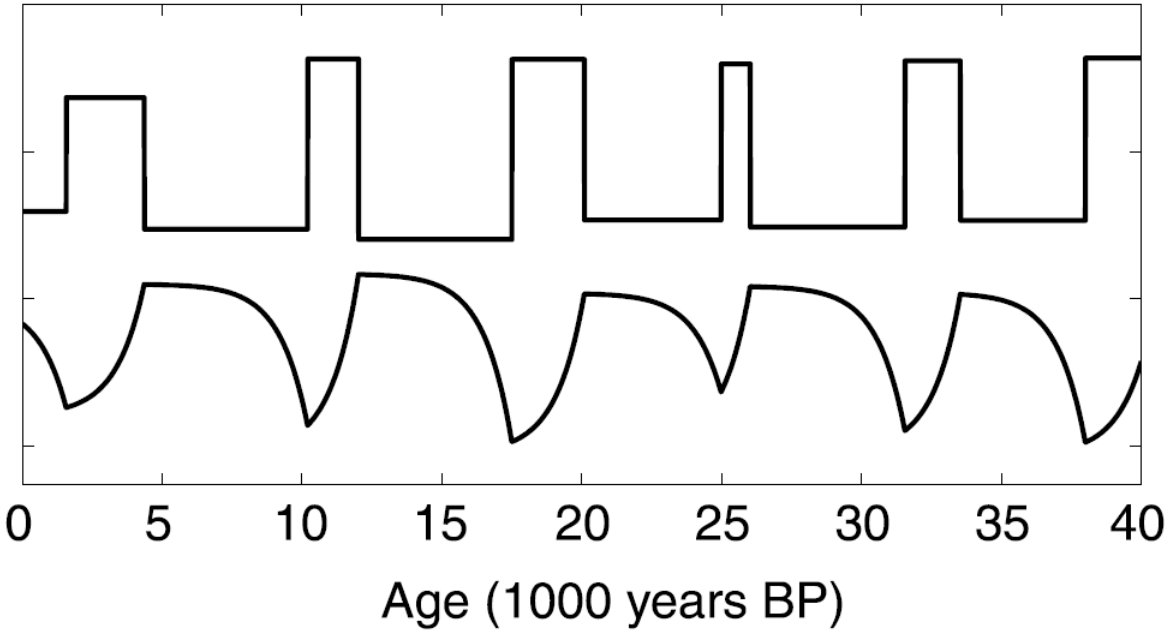


Illustration : IPCC

The bipolar seesaw







When Greenland is **warm**, …

… Antarctica **cools**

and vice vera

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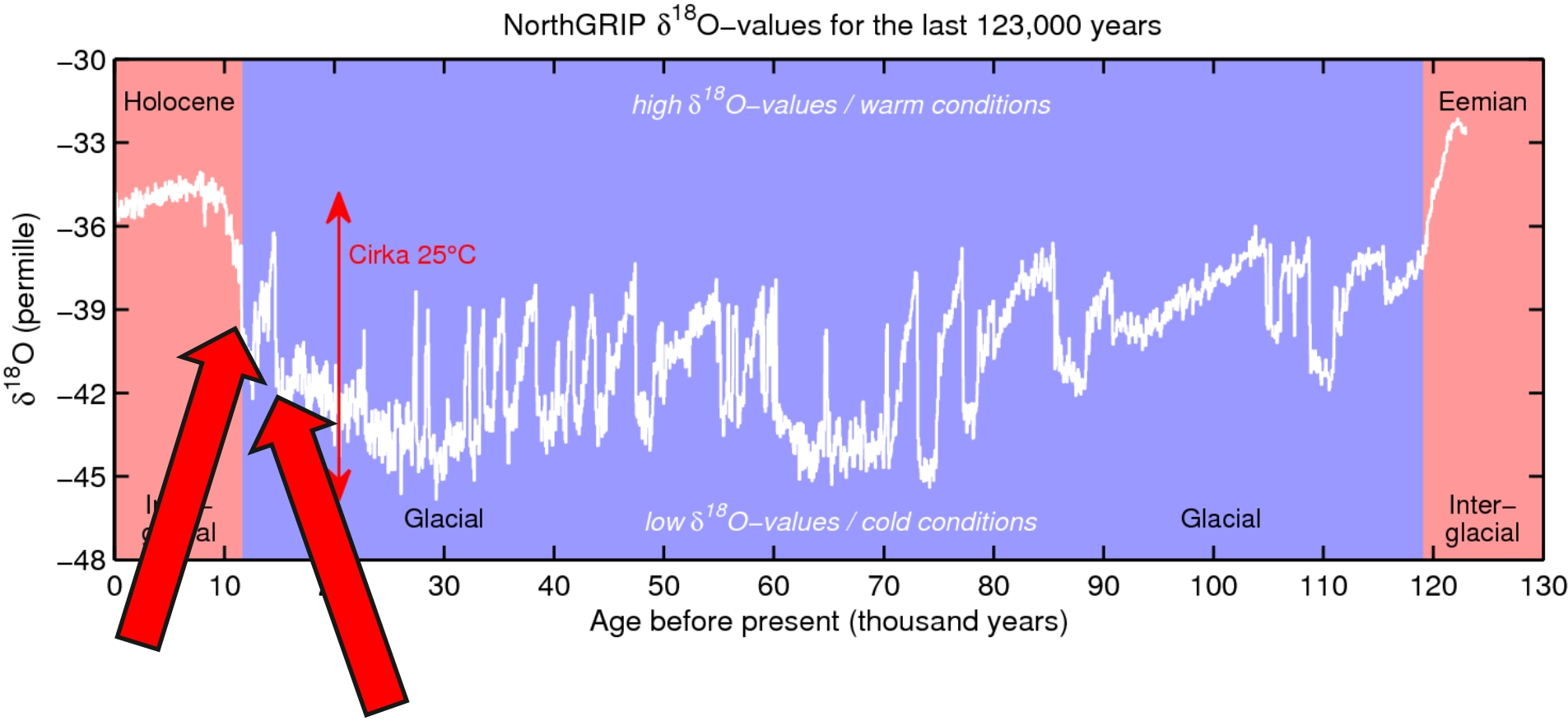
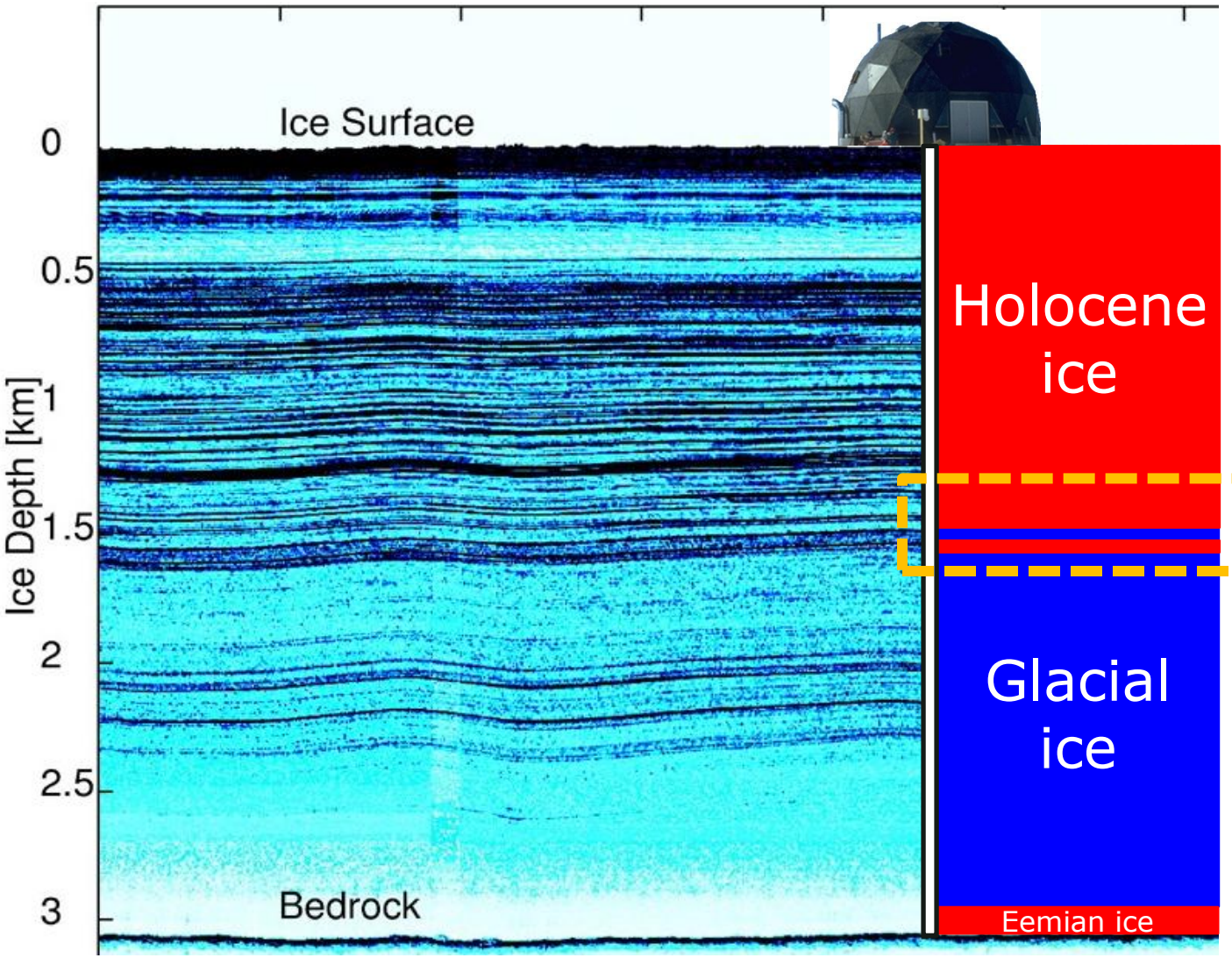
The termination of the glacial in Greenland:

Year-by-year investigations of the climate

NorthGRIP stable isotope ratios: Dansgaard Oeschger events



Radar profile from the area around NorthGRIP



Annual layer thickness

Today: 19 cm

Mid-Holocene: 12 cm

Preboreal: 6 cm

Young. Dryas: 3 cm

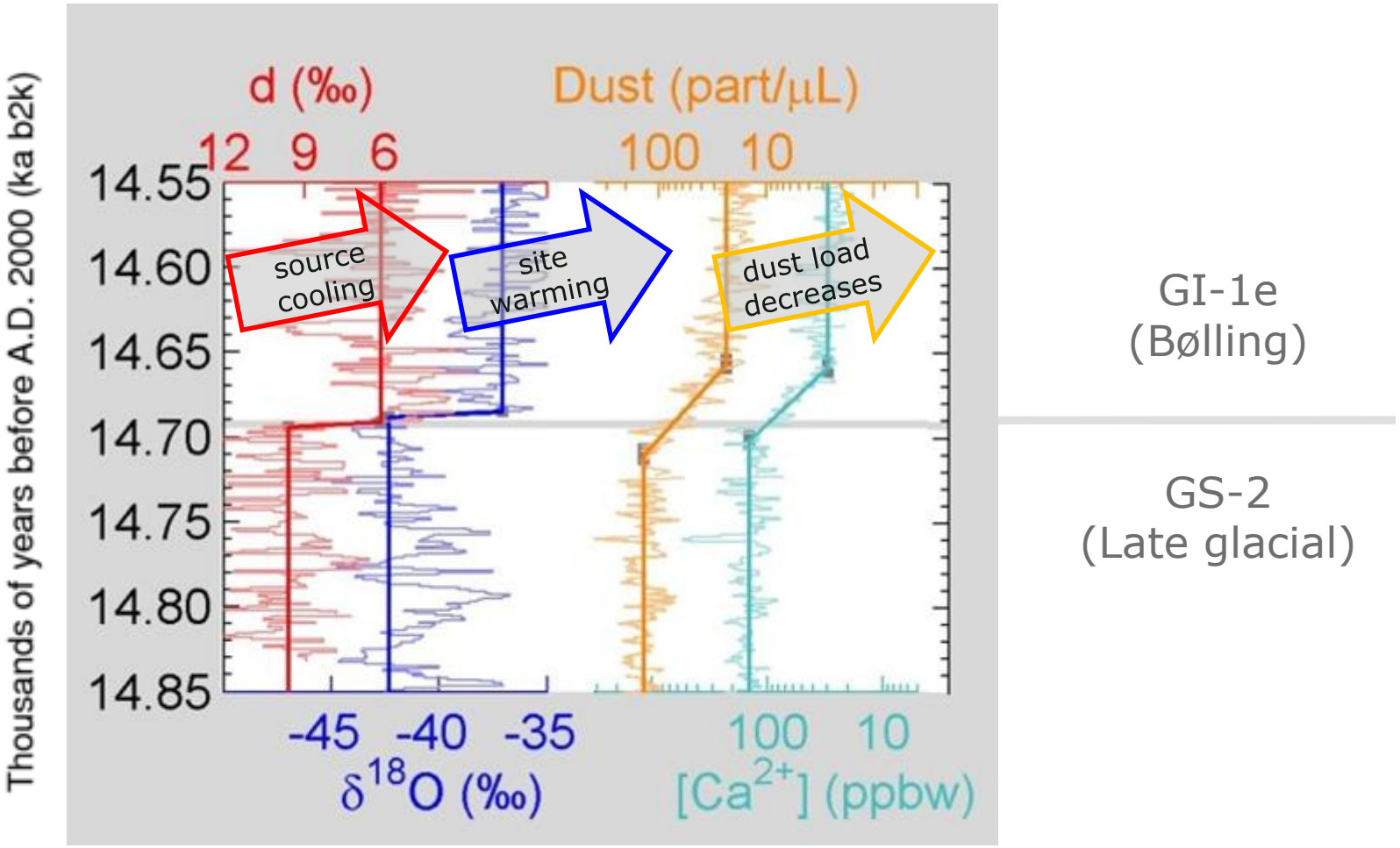
Bølling: 4-5 cm

Late glacial:1-2 cm

Early glacial:<1 cm

Eemian: ~1 cm

Abrupt warming from GS-2 to GI-1 (onset of Bølling)



The results are backed up by similar data in other Greenland ice cores where data are available.

Read the full story in **Steffensen et al.**, Science, vol. 321, p. 680, 2008

Sequence of events during abrupt warmings

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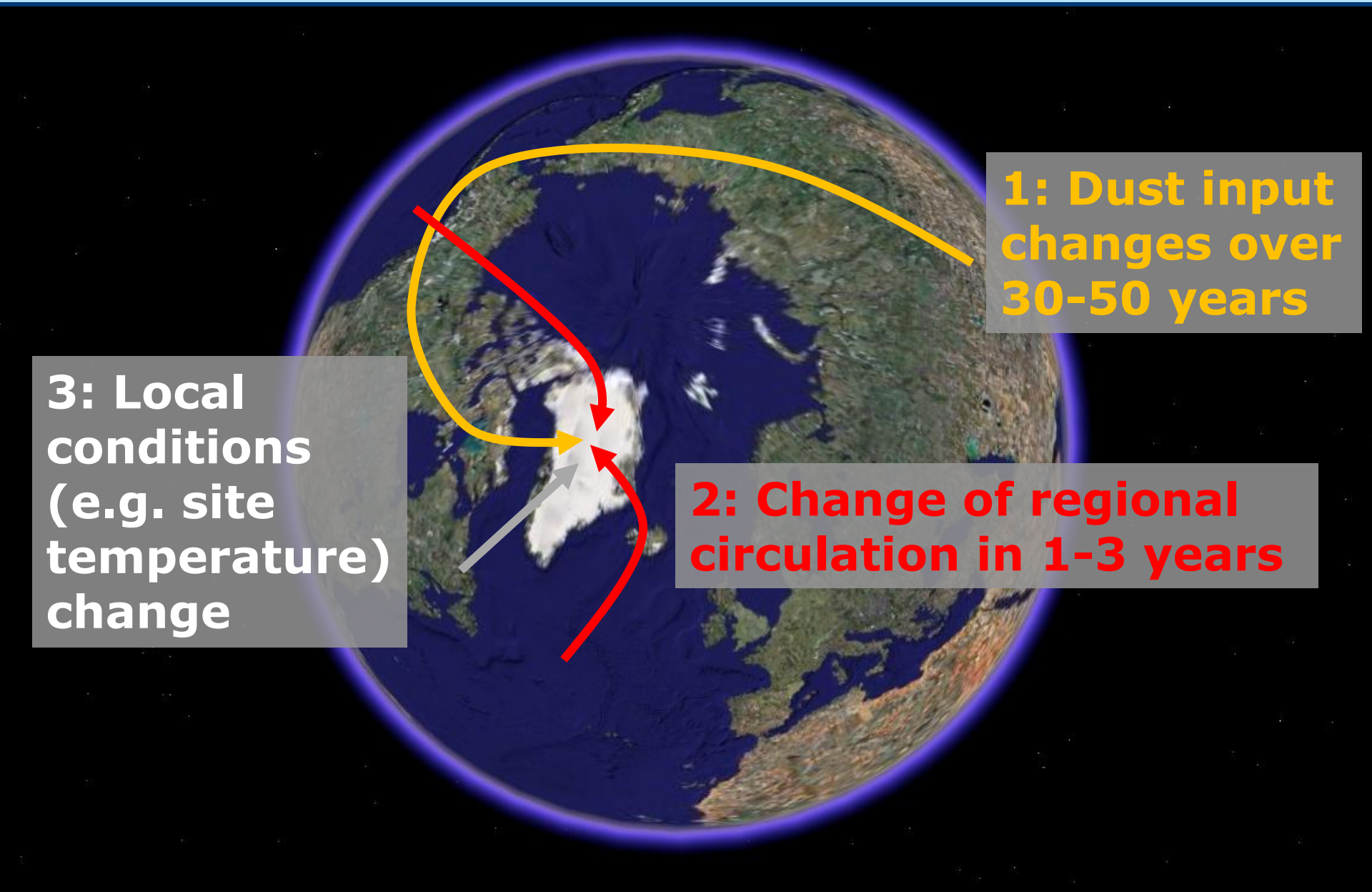

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The best analogies to future climate

Temperatures and greenhouse gas concentrations from Antarctic ice cores

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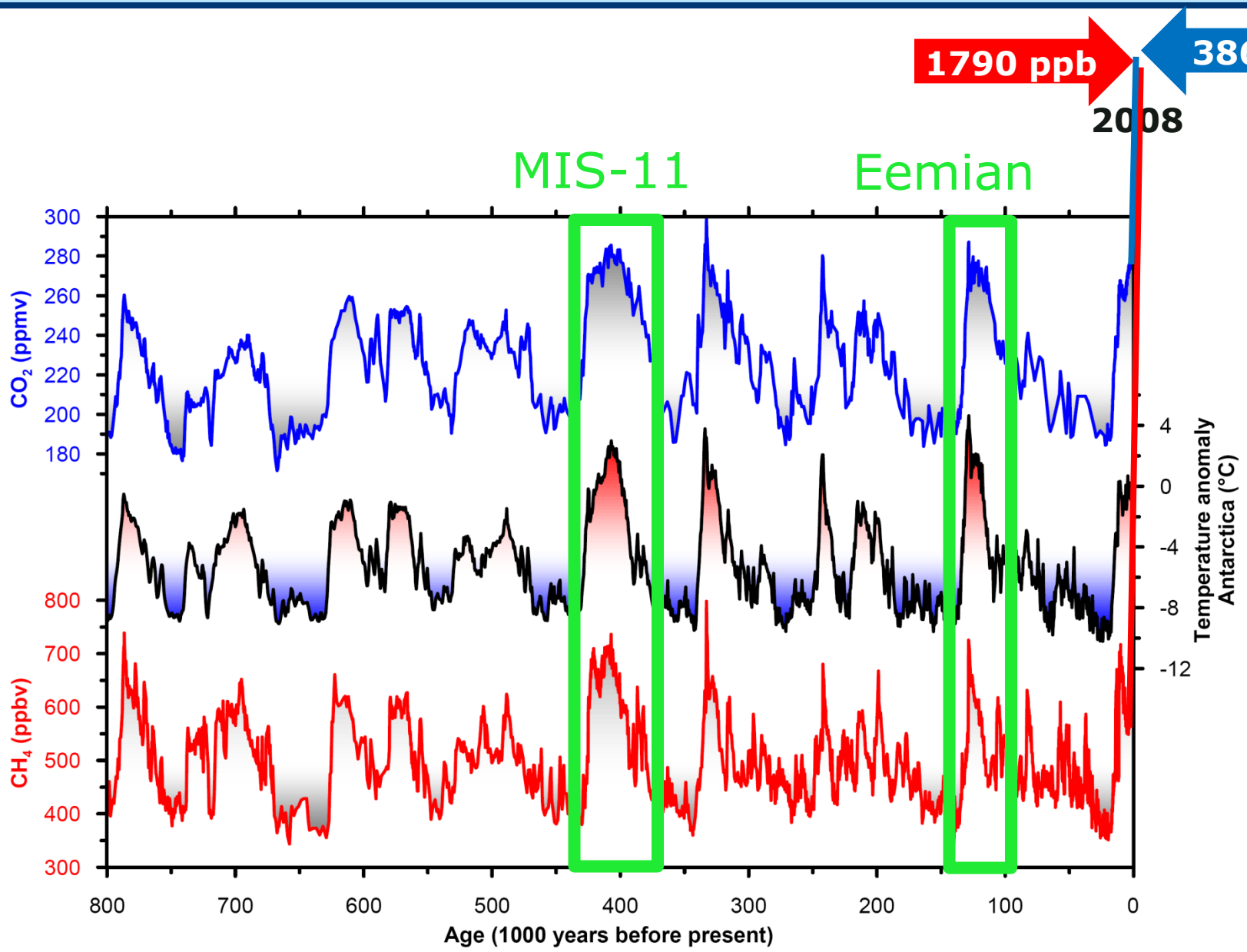
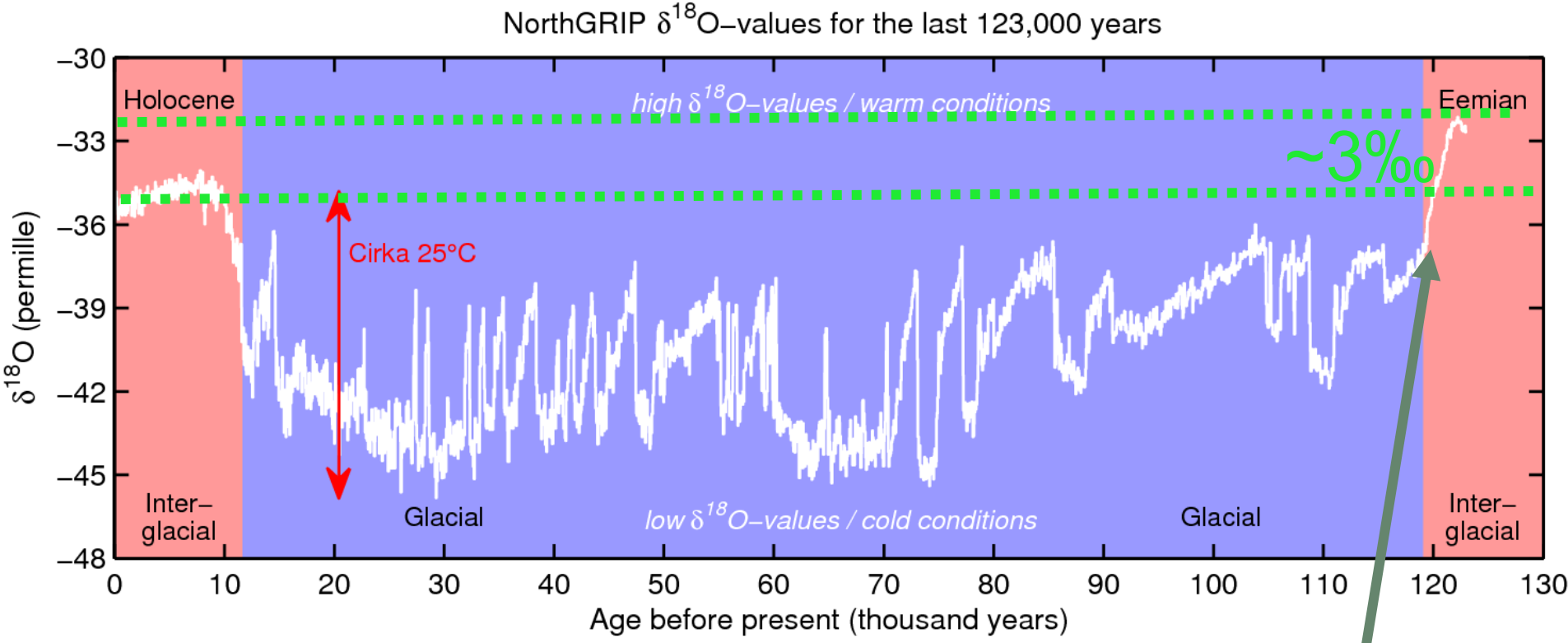


NorthGRIP Eemian record



- Temperature during the late Eemian:
  3‰ difference in $\delta^{18}O$: ~ 5°C warmer than today
- Termination of the Eemian: slow cooling, then a small jump
- But what about the early Eemian and the gradual warming?

That's why we start again

A full annually resolved record from the Eemian interglacial

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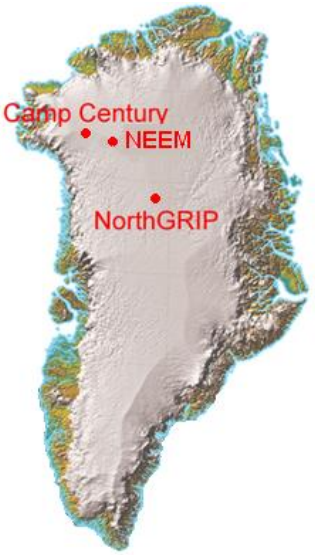
The North Greenland Eemian Ice Drilling (NEEM) project

- 100+ scientists from 14 nations
- 18 months of field work and more than 10,000 (wo)man-days on the ice cap
- 2500 meter of ice core
- 135,000 years of climate record (projected)



Science goals

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Build gas extraction/analysis facilities. Obtain the first Greenland CO_2 record

Improve dating and enable high-resolution study of interglacial climate by improving impurity measurement techniques

CENTRE FOR ICE AND CLIMATE

Integrate ice core results and (inverse) flow modelling efforts

Integrate ice core proxy studies with GCM/ESM modelling efforts

Based mainly on NGRIP and NEEM data


Read more at
www.isogklima.dk / www.iceandclimate.dk
and
www.neem.ku.dk