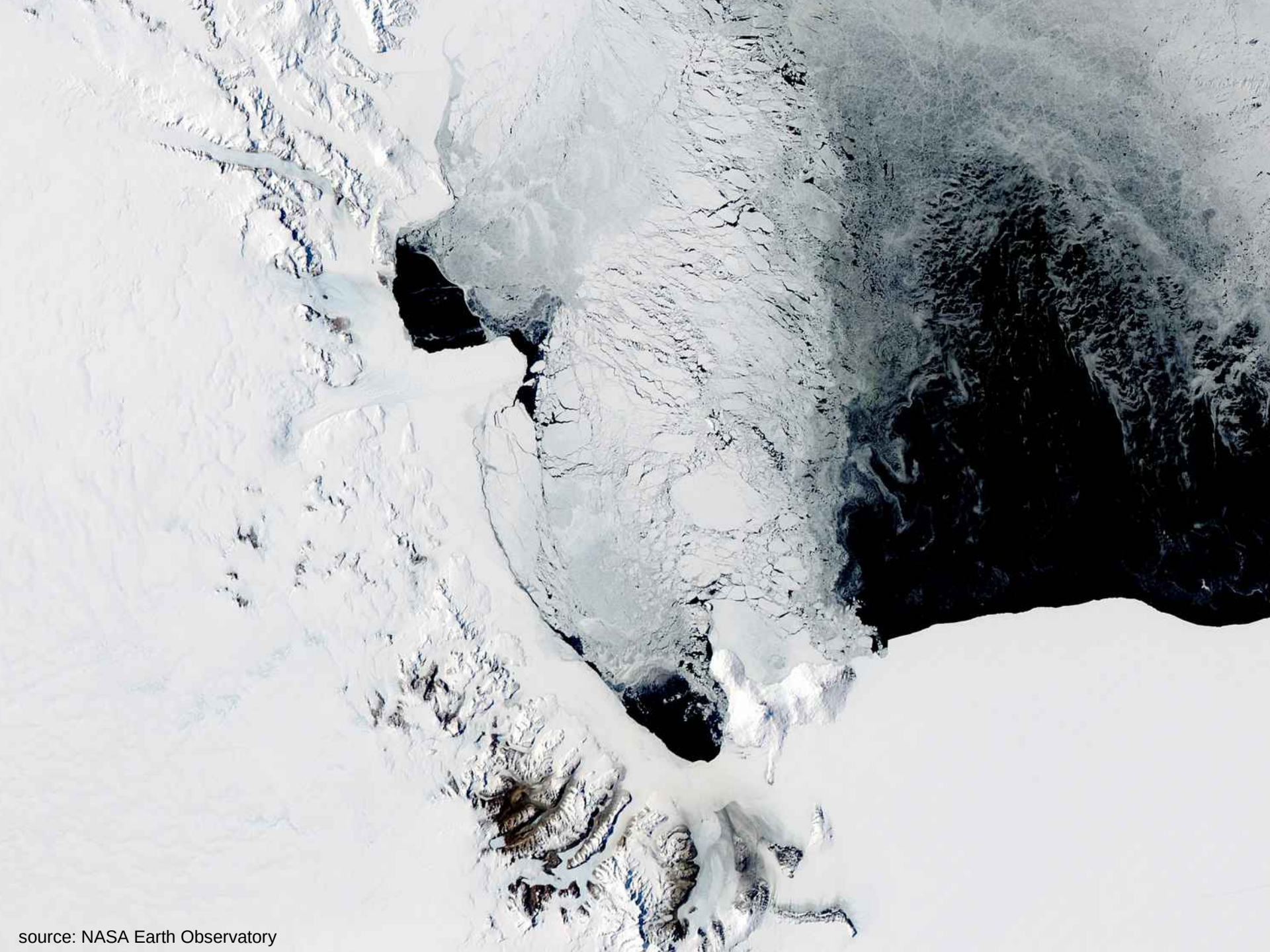
Paleoclimate

source: NASA

Link to Slides

Yesterday's Summary

- Pleistocene Climate
- Glacial-Interglacial Cycles
- Glacial Ice Sheets
- The oceans in the climate system
  - ocean surface
  - deep ocean
  - ocean biochemistry
- Orbital Forcing
- The Mid-Pleistocene Transition



source: NASA Earth Observatory

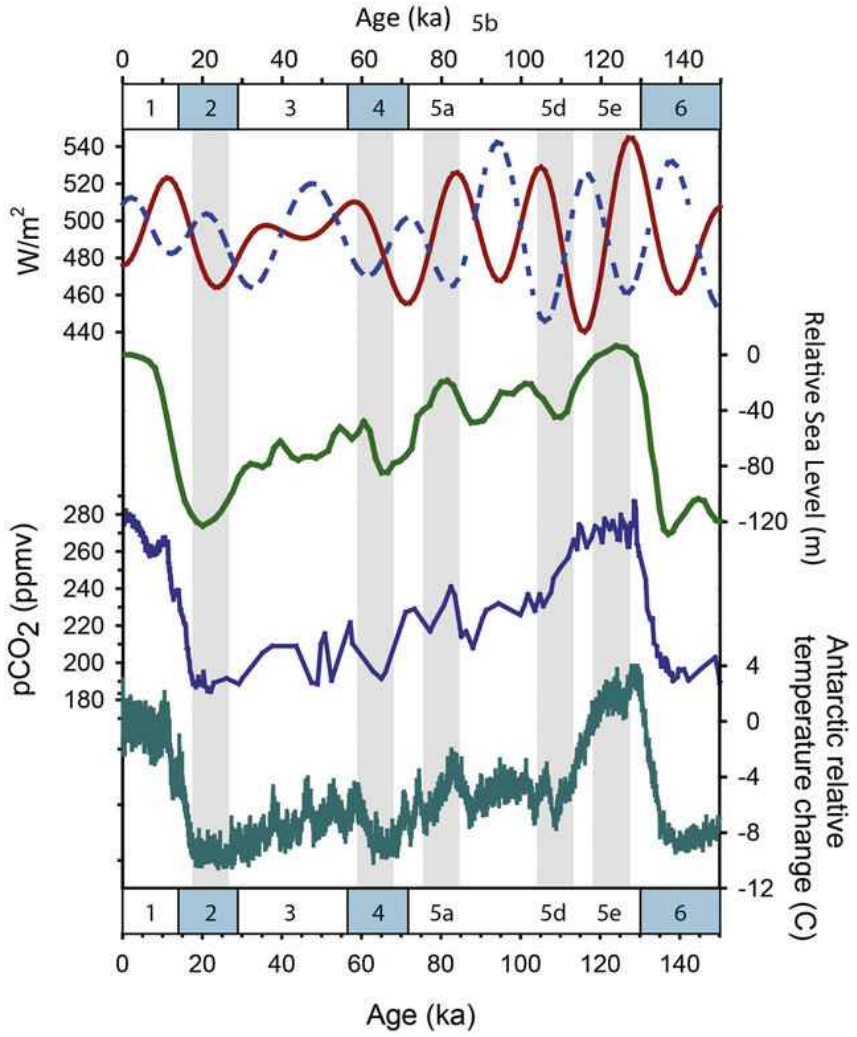
Lecture Progress

Monday	Introduction	Earth History
Tuesday	Proxies I	Cenozoic Hot & Warm House
Wednesday	Specific Climate System components	Pleistocene G-IG climate
Thursday	Proxies II & Climate System Interactions	Abrupt Climate Change
Friday	Current Climate Change	Future & Synthesis

Today's Overview

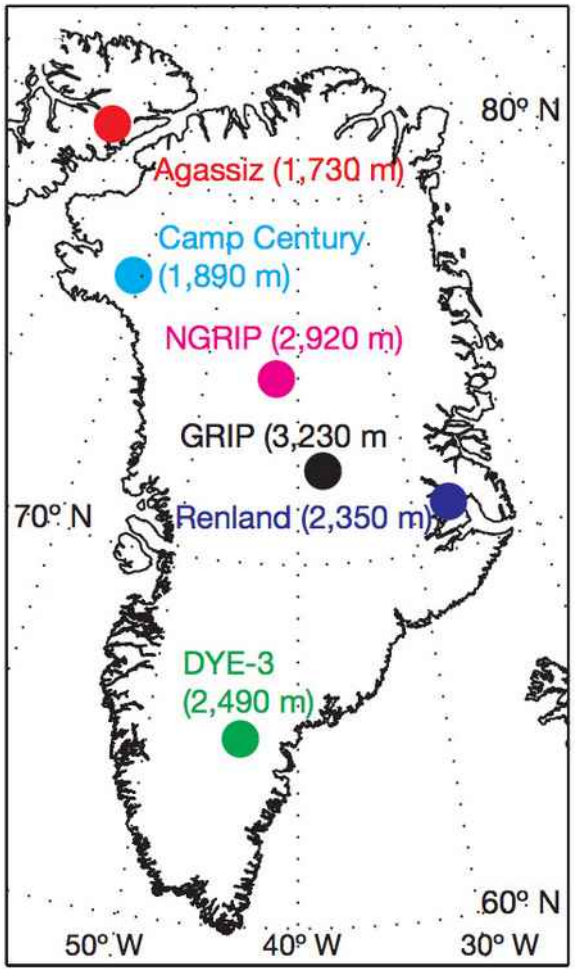
- Ice cores for climate science
- The time machine
  - decay series dating
  - cosmogenic nuclide dating
  - application examples
  - surface exposure dating
- Abrupt climate change during the last glacial cycle
  - Dansgaard-Oeschger Events
  - Bipolar seesaw
  - Heinrich Events
  - Pa/Th proxy for ocean circulation rate

Last Glacial Cycle

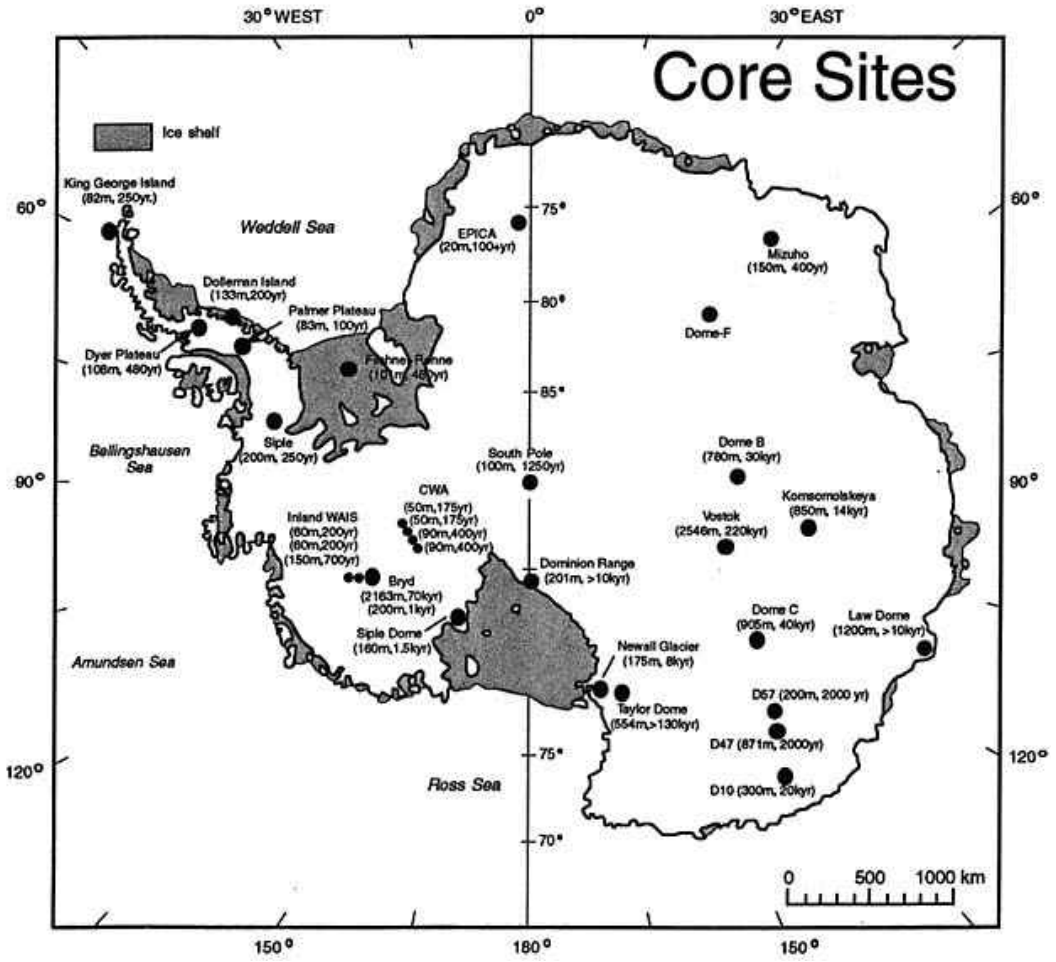


Kohfeld & Chase (2017)
Earth and Planetary Science Letters

Polar Ice Cores



desmog.com



antarcticglaciers.org

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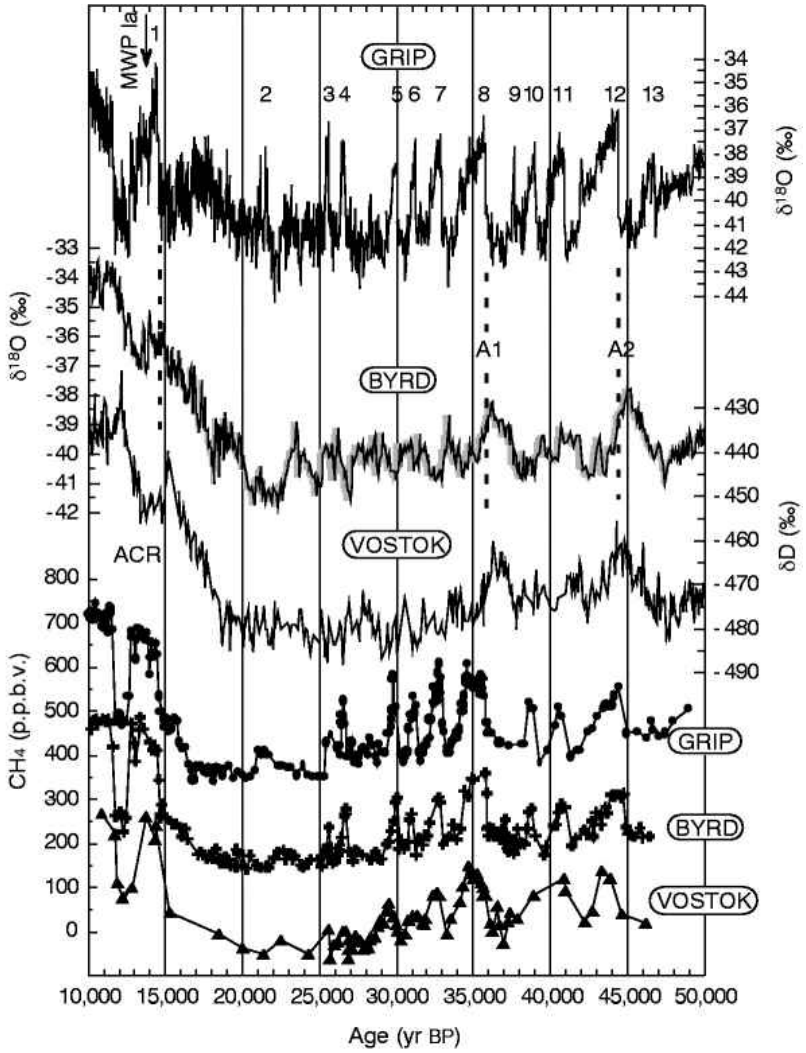
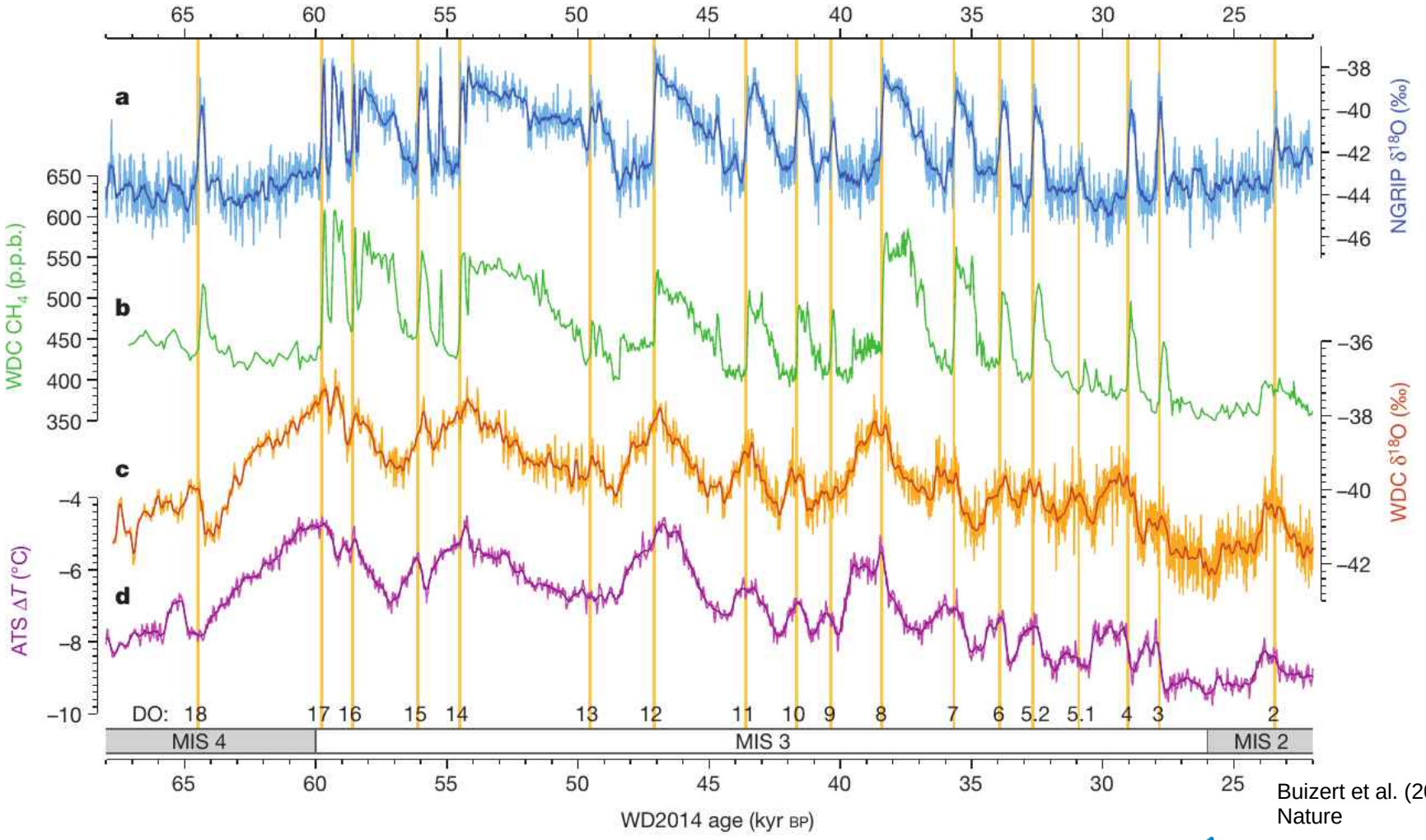
Polar Ice Cores



Blunier et al. (1998), Nature

Polar Ice Cores



Buizert et al. (2015), Nature

Polar Ice Cores

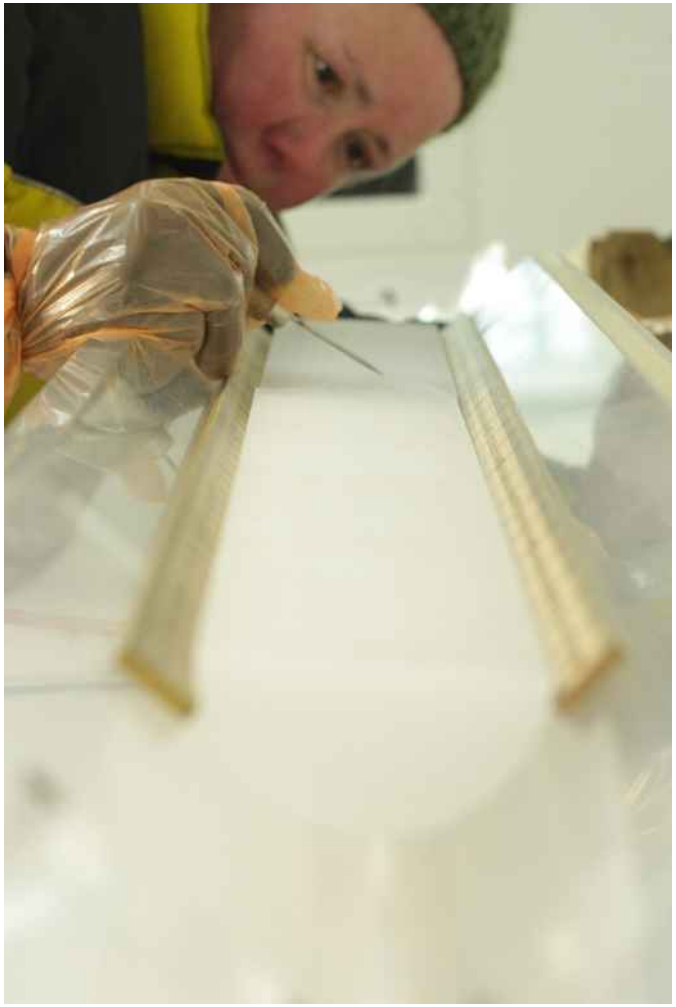
How old is the ice?

learning4kids.net

Polar Ice Cores

learning4kids.net

Polar Ice Cores



Australian Antarctic Program
Photo: David Reilly

Polar Ice Cores

How to determine ages of other archives?

learning4kids.net

The time machine

dating time!

The time machine

A proper method for dating samples is essential

if only the archives had a clock built in...

The time machine

A proper method for dating samples is essential

if only the archives had a clock built in...
well, they have!

The isotopic clock of radioactive decay!

The time machine

A proper method for dating samples is essential

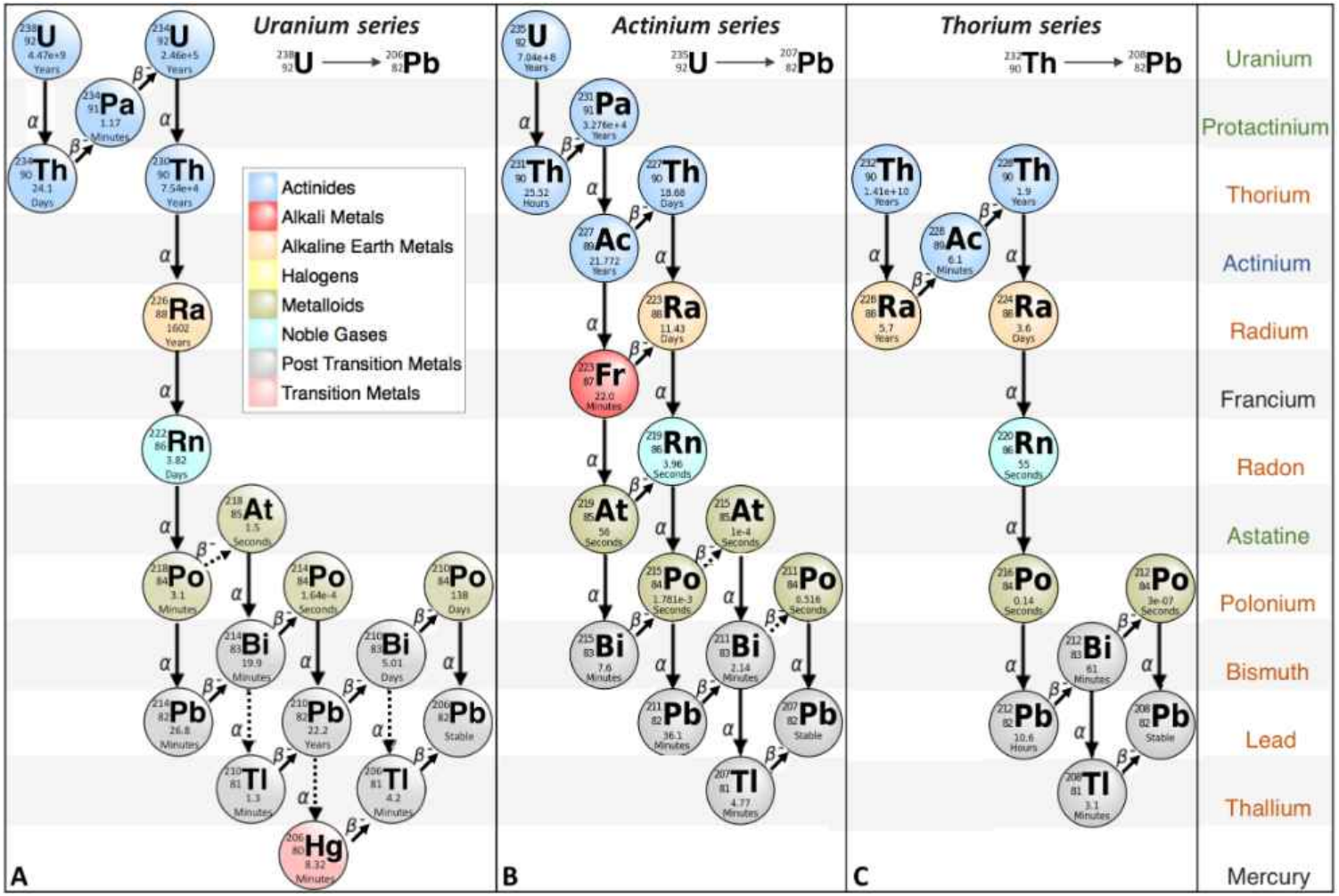
if only the archives had a clock built in...
well, they have!

The isotopic clocks of radioactive decay!

We only need to make sure that

- we know what the starting point is
- there is no exchange of material (“closed system”)

The time machine



Tan (2016), Answers in Genesis

The time machine

U-Pb dating

great for old material with lots of U and little Pb

- e.g. zircon crystals in rocks
- both ^{238}U-^{206}Pb and ^{235}U-^{207}Pb can be used
- system often not closed, and zircons hard to dissolve
- usually concordia dating with LA-ICP-MS
- $T_{1/2}$ = 4.47 Ga and 704 Ma
- precision usually few %

The time machine

Sm-Nd dating (and similar Rb-Sr and Lu-Hf dating)

great for old rocks and meteorites

- can trace age of rock formation from mantle
- Sm and Nd are similar rare earth elements, but fractionate during rock formation
- efficient, but often isochron dating necessary
- $T_{1/2}$ = 106 Ga
- precision < 1 ‰ achievable

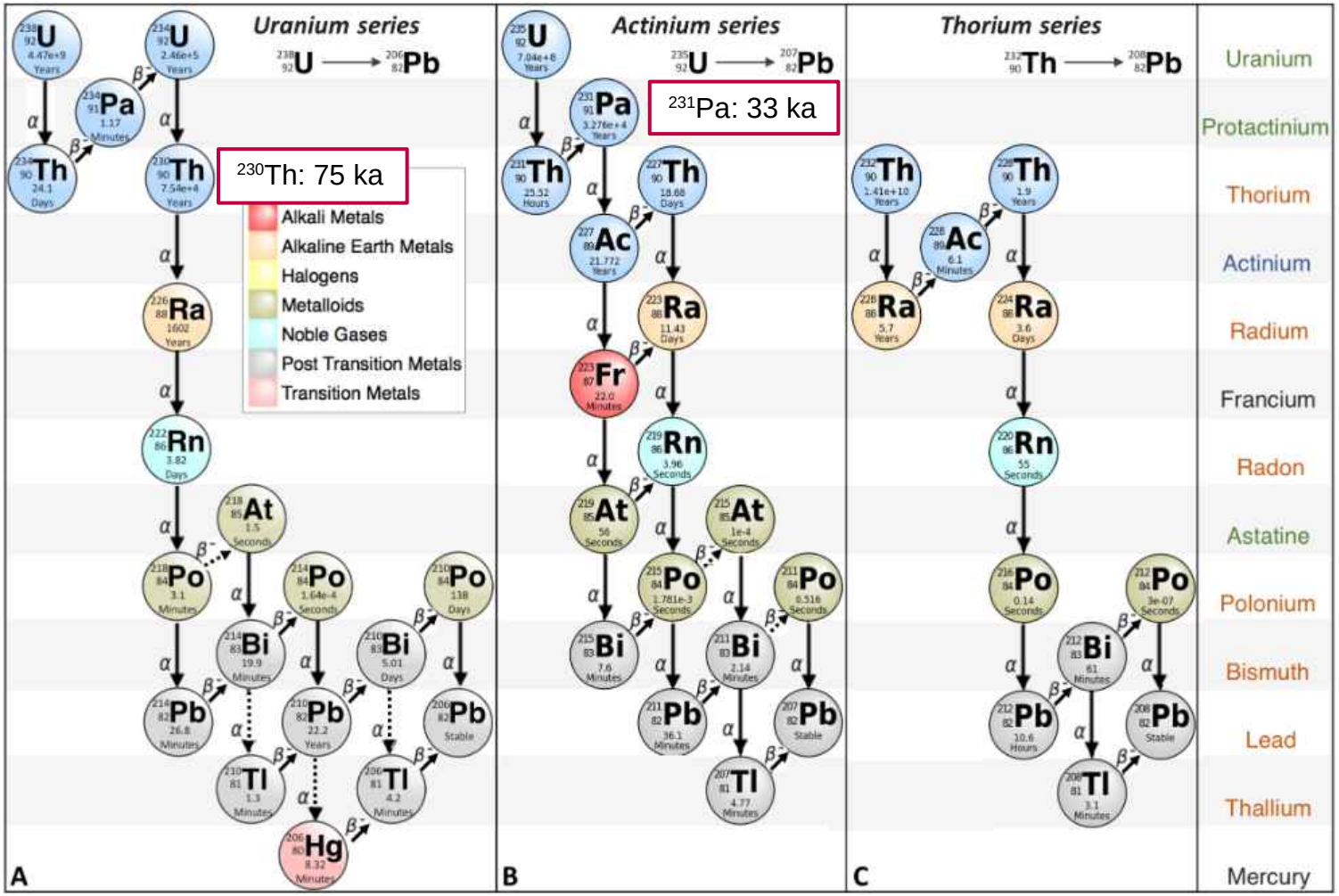
The time machine

K-Ar dating

great for old rocks

- can trace age of rock formation from mantle
- Ar escapes from melts, but is captured in solids
- Ar must not have escaped
- ideal for volcanic material
- $T_{1/2}$ = 1.2 Ga
- precision ~ 1 % achievable

The time machine



Tan (2016), Answers in Genesis

The time machine

U-Th dating

great for material with lots of U and little Th

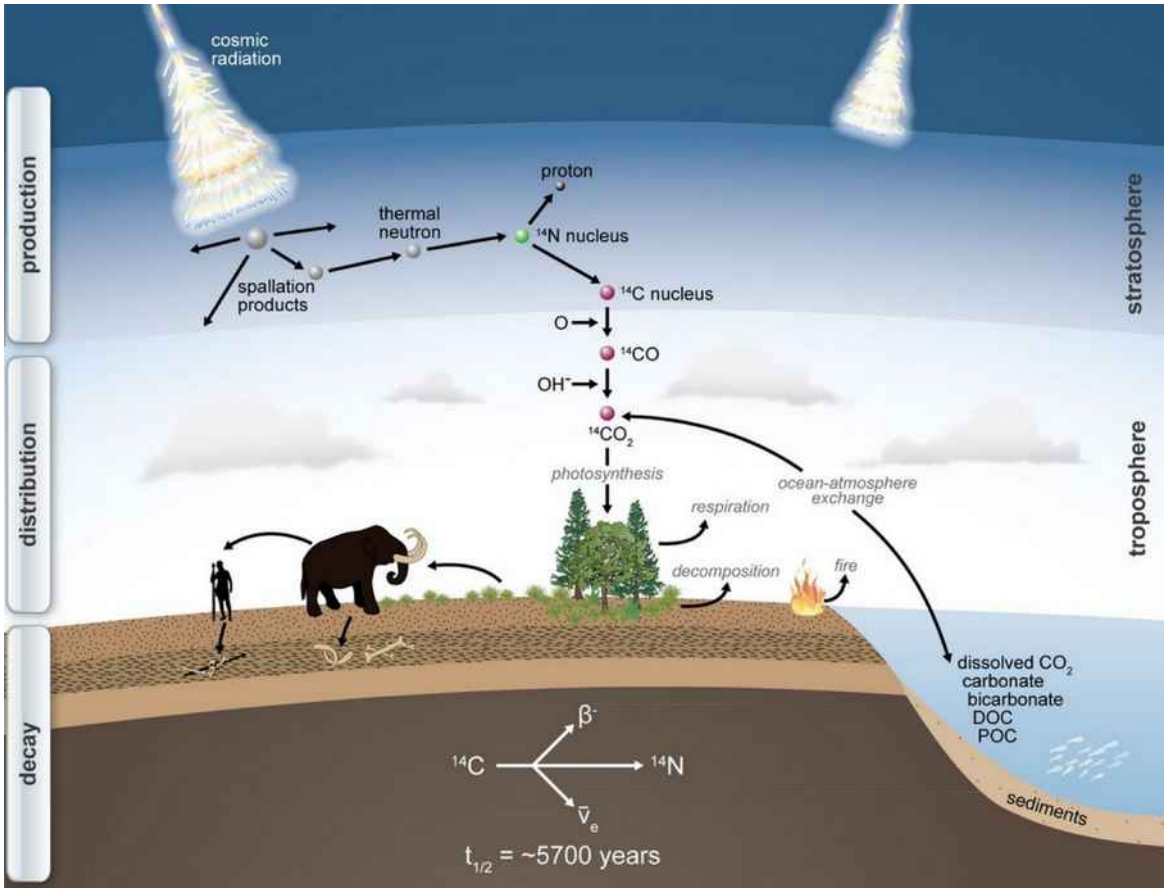
- e.g. carbonates (speleothems, corals)
- daughter ^{230}Th is radioactive
- measure $^{238}U/^{234}U$ & $^{234}U/^{230}Th$ and evaluate how similar activities are
- measurements can be very precise
- very efficient with wet chemistry ICP-MS
- dating range ~ 1 – 350 ka
- precision < 1 ‰ achievable

The time machine

radiocarbon dating (^{14}C)

The time machine

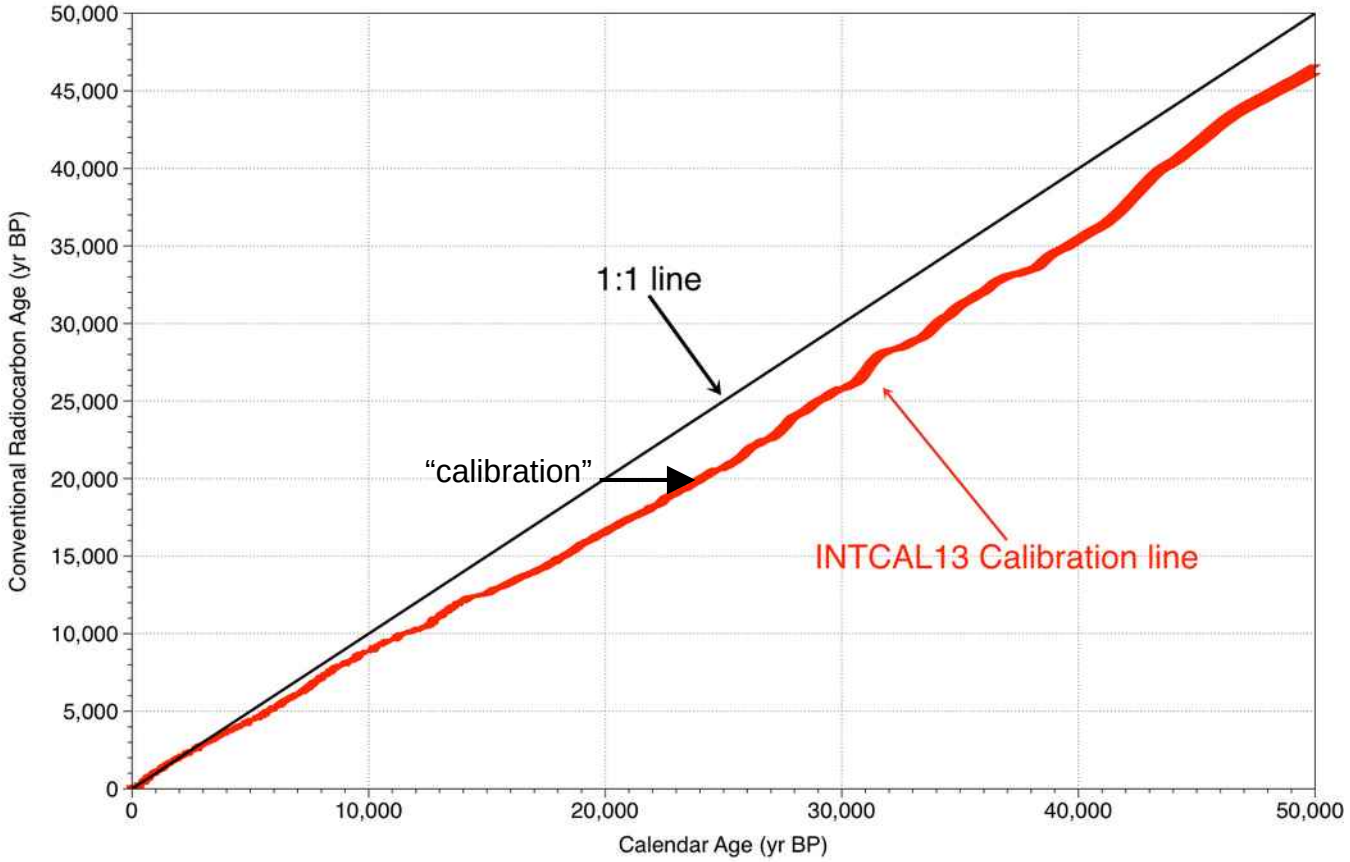
radiocarbon dating



Soil Carbon Information Hub
international-soil-radiocarbon-database.github.io

The time machine

radiocarbon calibration



ANU Radiocarbon Laboratory

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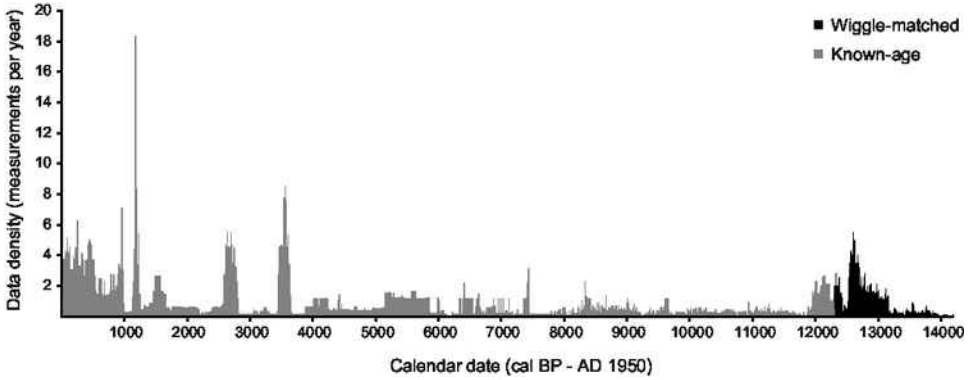
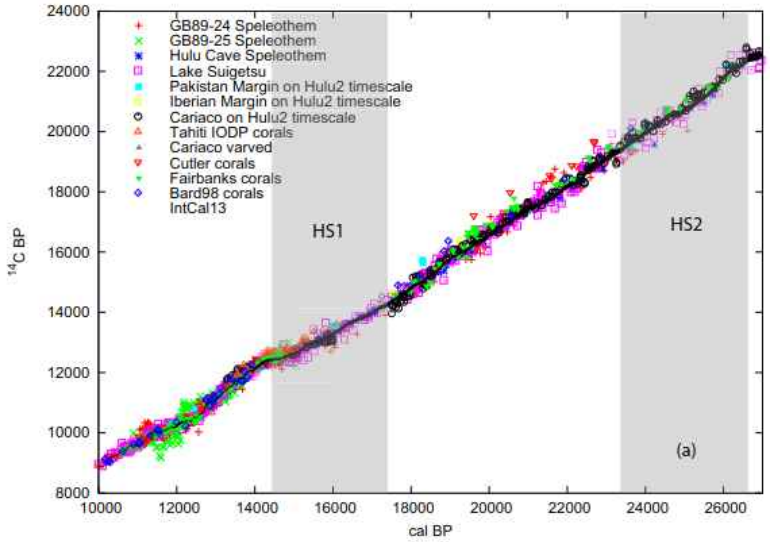
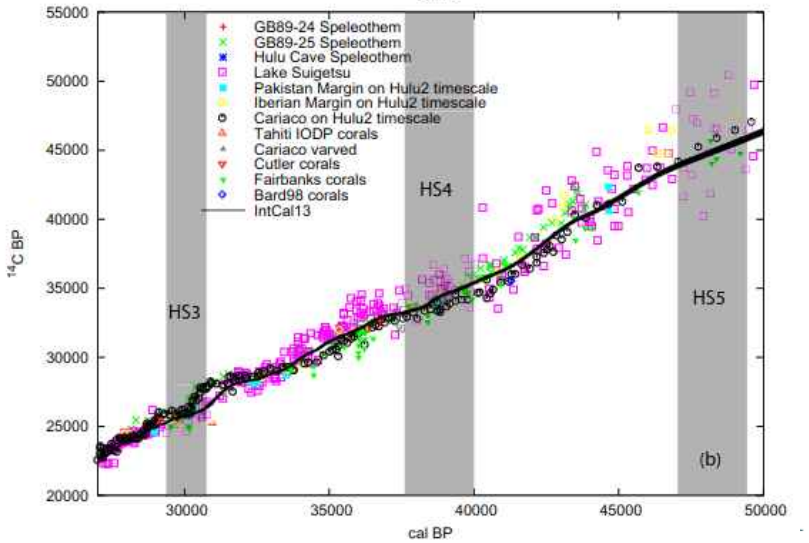
The time machine

radiocarbon calibration



Bayliss et al. (2020), Radiocarbon

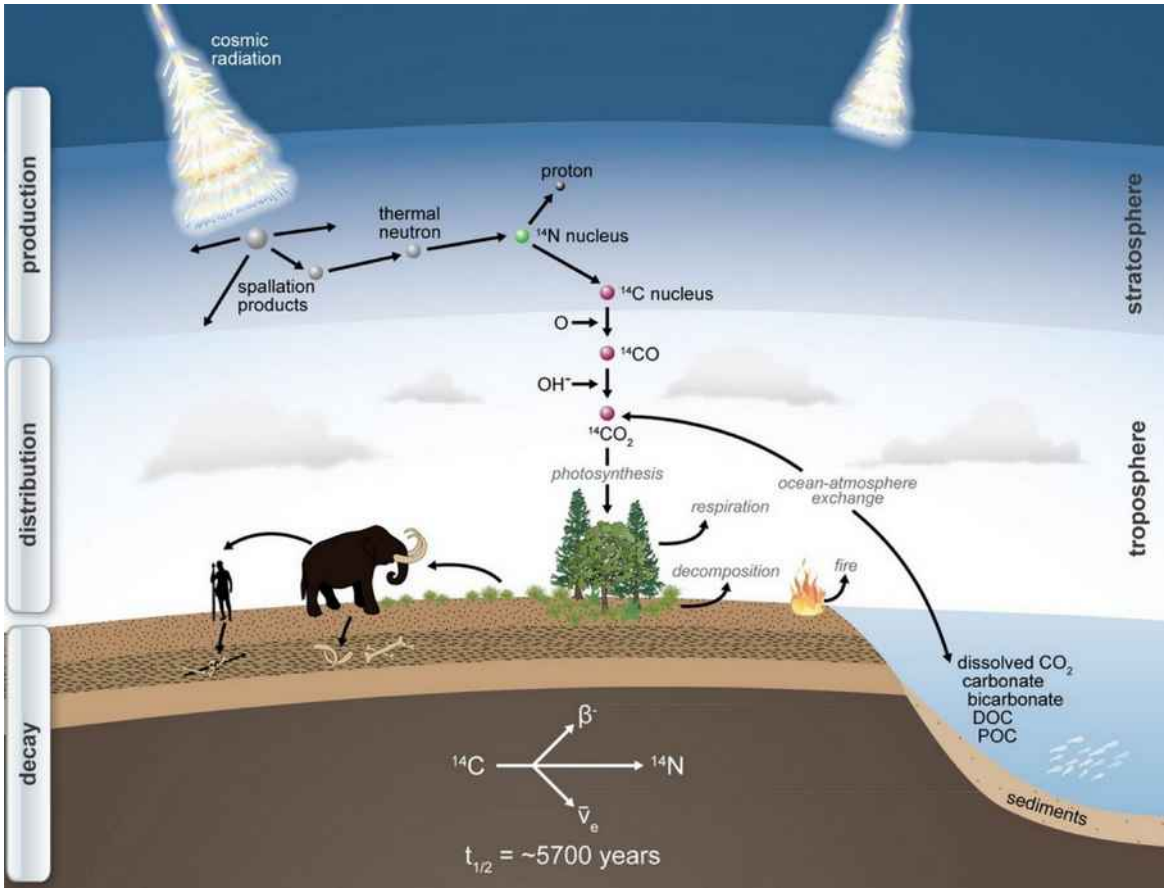




Reimer et al. (2013), Radiocarbon

The time machine

radiocarbon dating in the oceans

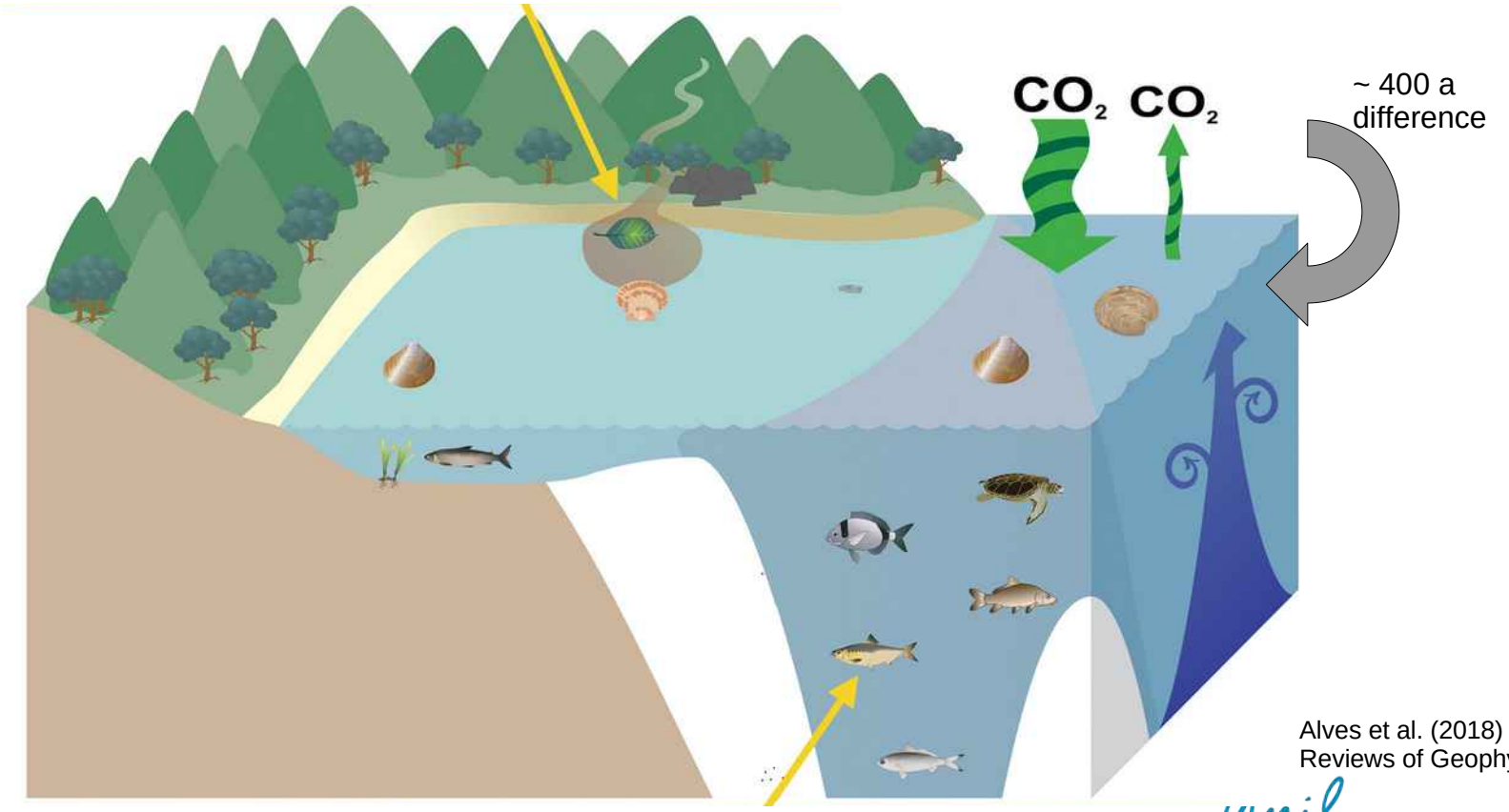


Soil Carbon Information Hub
international-soil-radiocarbon-database.github.io

The time machine

radiocarbon dating in the oceans

the marine reservoir effect

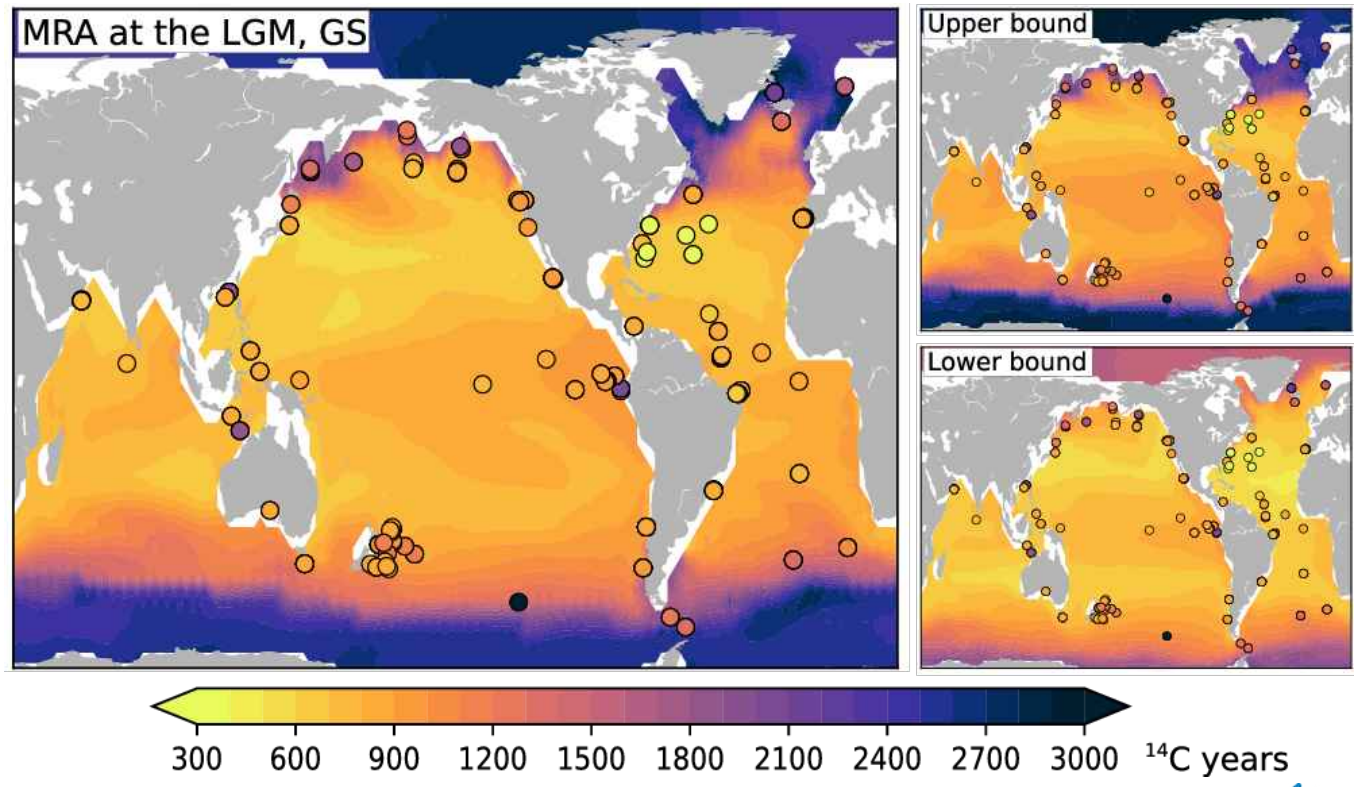


Alves et al. (2018)
Reviews of Geophysics

The time machine

radiocarbon dating in the oceans

the marine reservoir effect



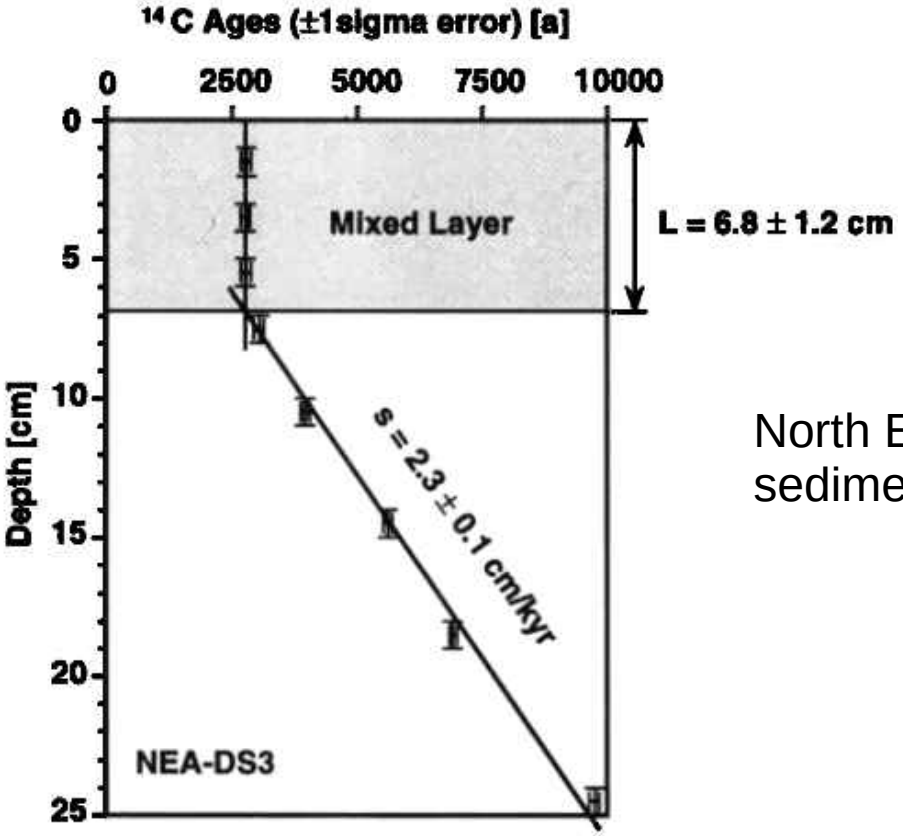
uncertainty at least centuries

Butzin et al. (2020) Radiocarbon

The time machine

radiocarbon dating in the oceans

sediment bioturbation



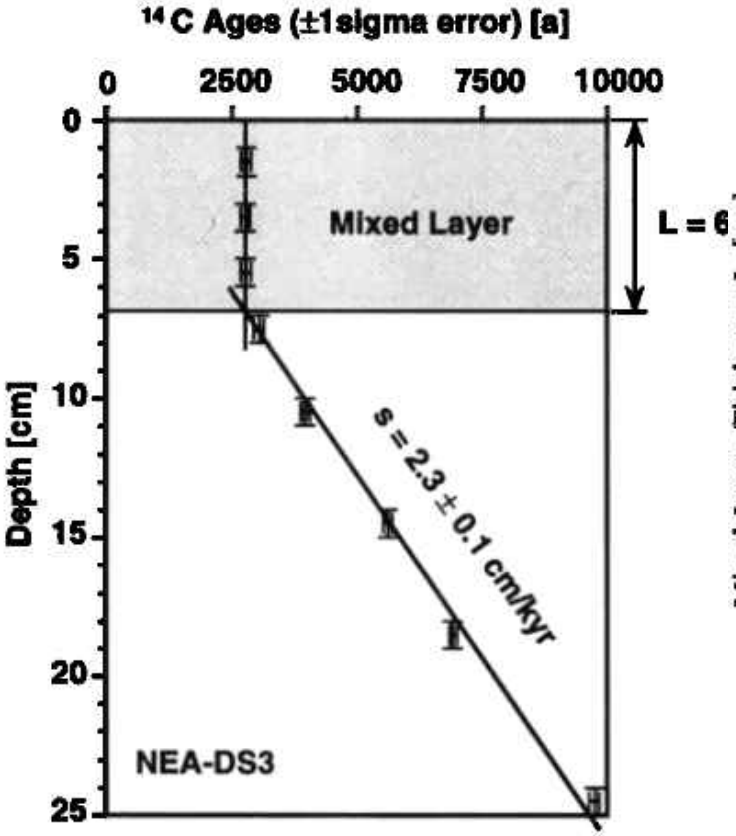
North East Atlantic sediment core

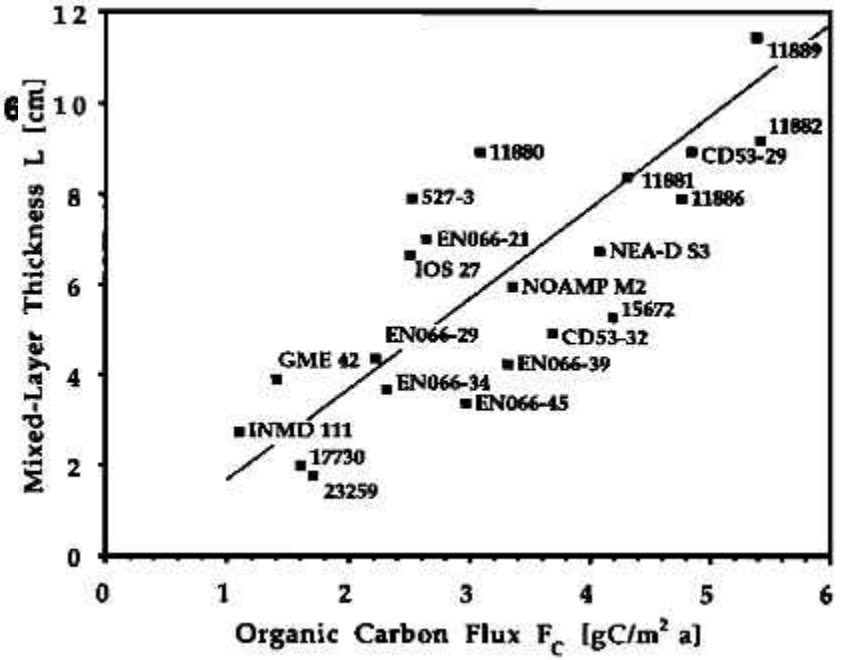
Trauth et al. (1997), Paleoceanography

The time machine

radiocarbon dating in the oceans

sediment bioturbation

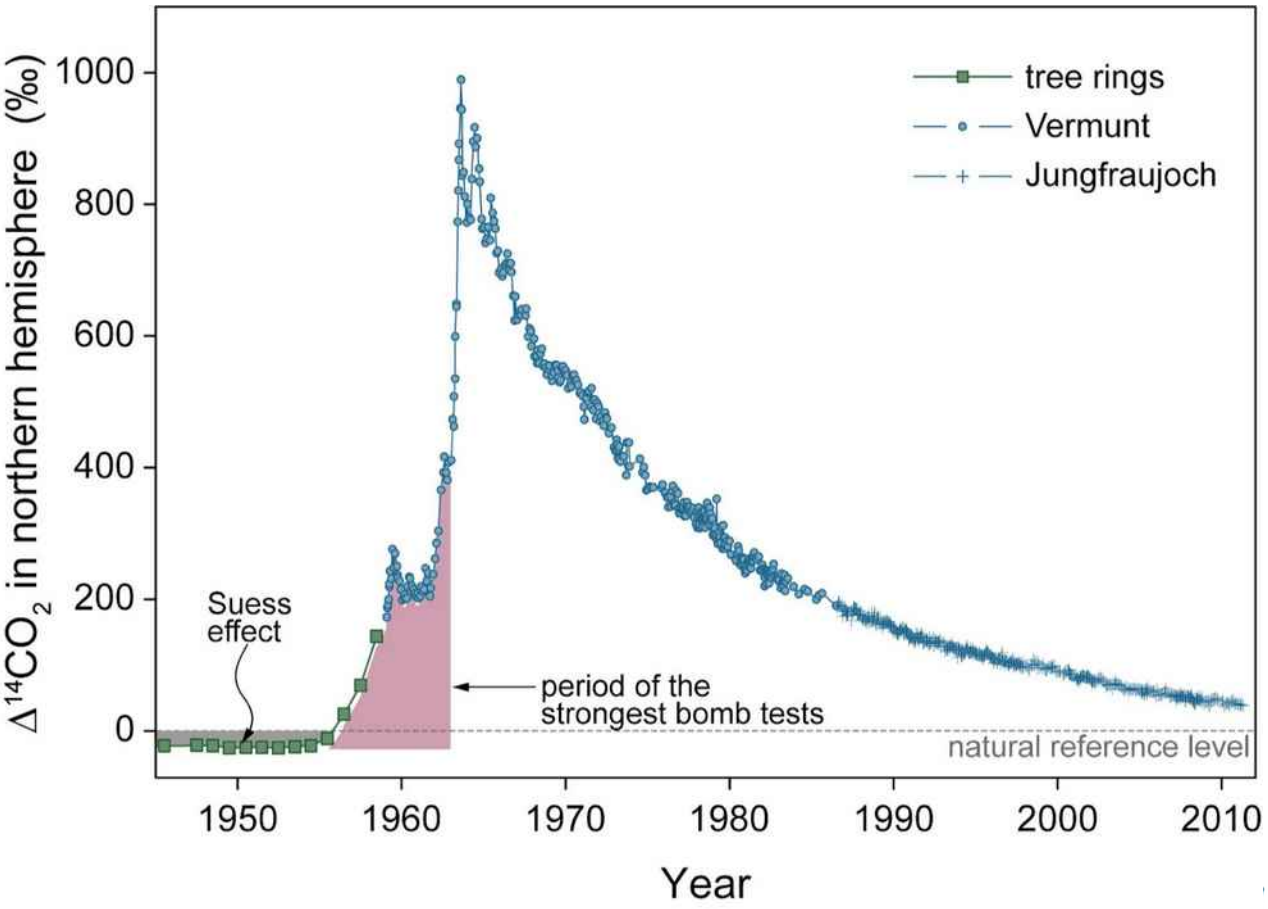




Trauth et al. (1997), Paleoceanography

The time machine

radiocarbon dating – young samples



The time machine

radiocarbon dating – U/Th dated carbonates

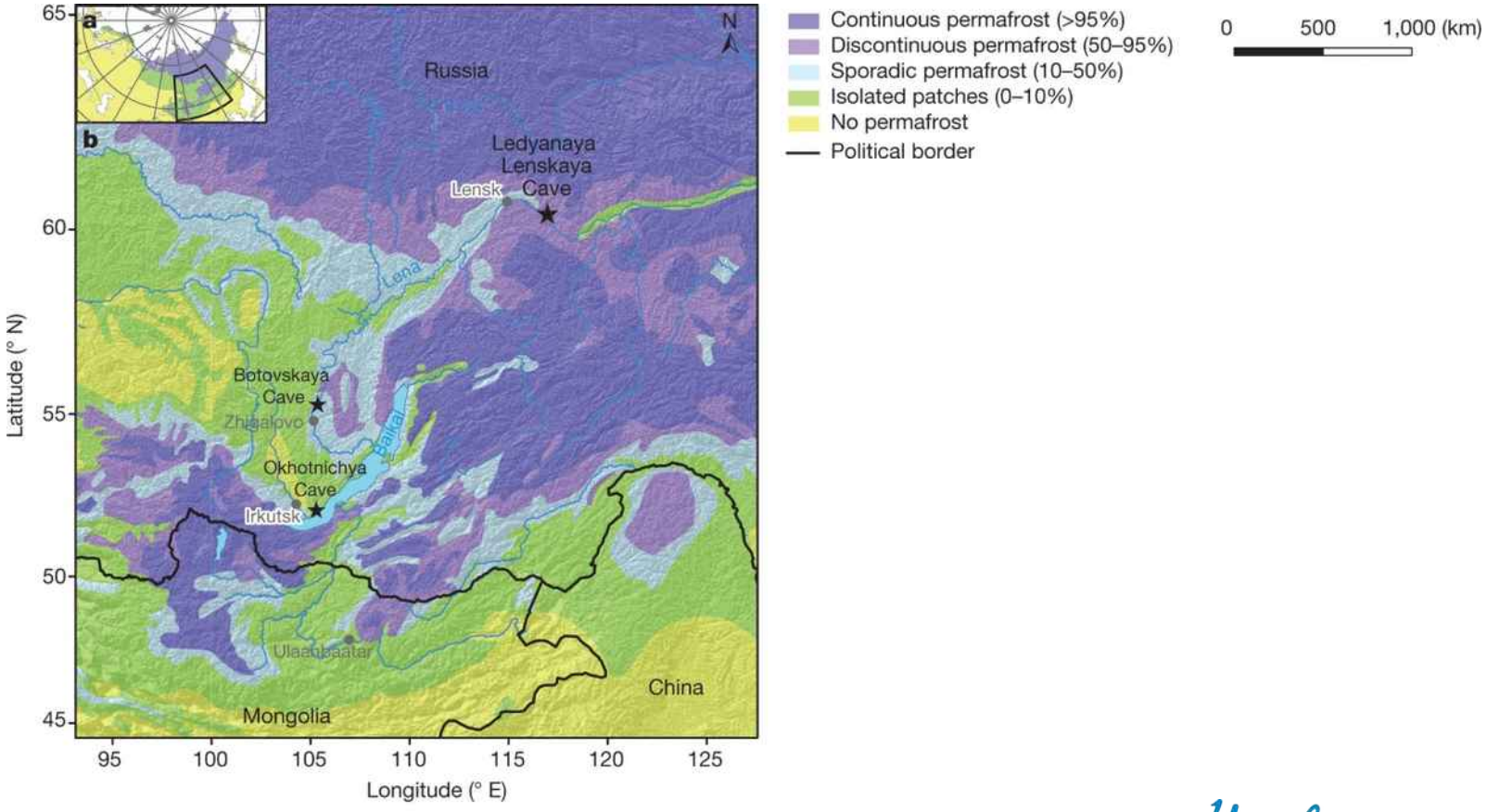
recall deep water “ages”
dated with radiocarbon from water

we can use (deep water) corals and

- date them reliably with U/Th
- infer past radiocarbon “ages” with ^{14}C

The time machine

the power of dating – example: Arctic permafrost



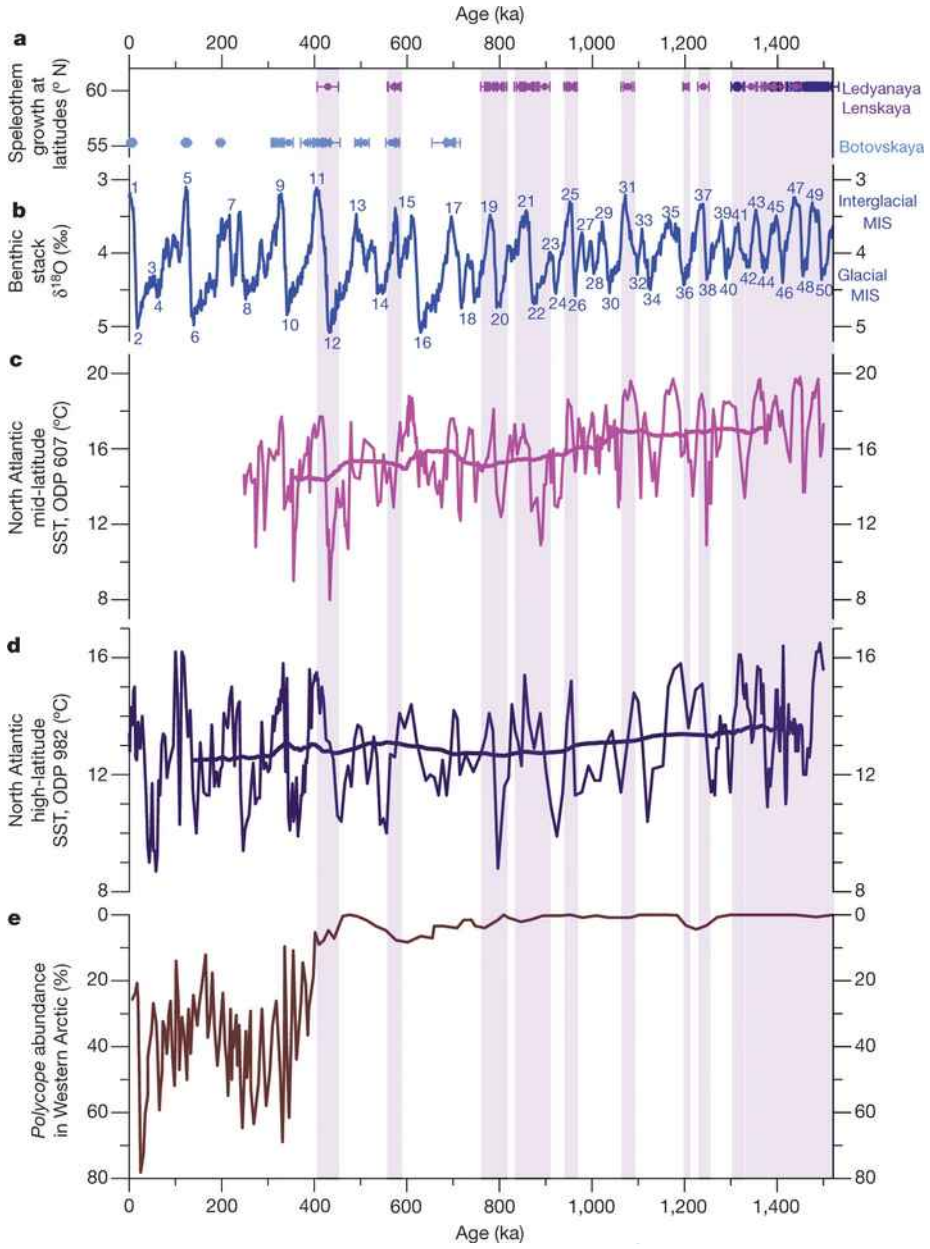
Vaks et al. (2020)
Nature

The time machine

the power of dating

example:

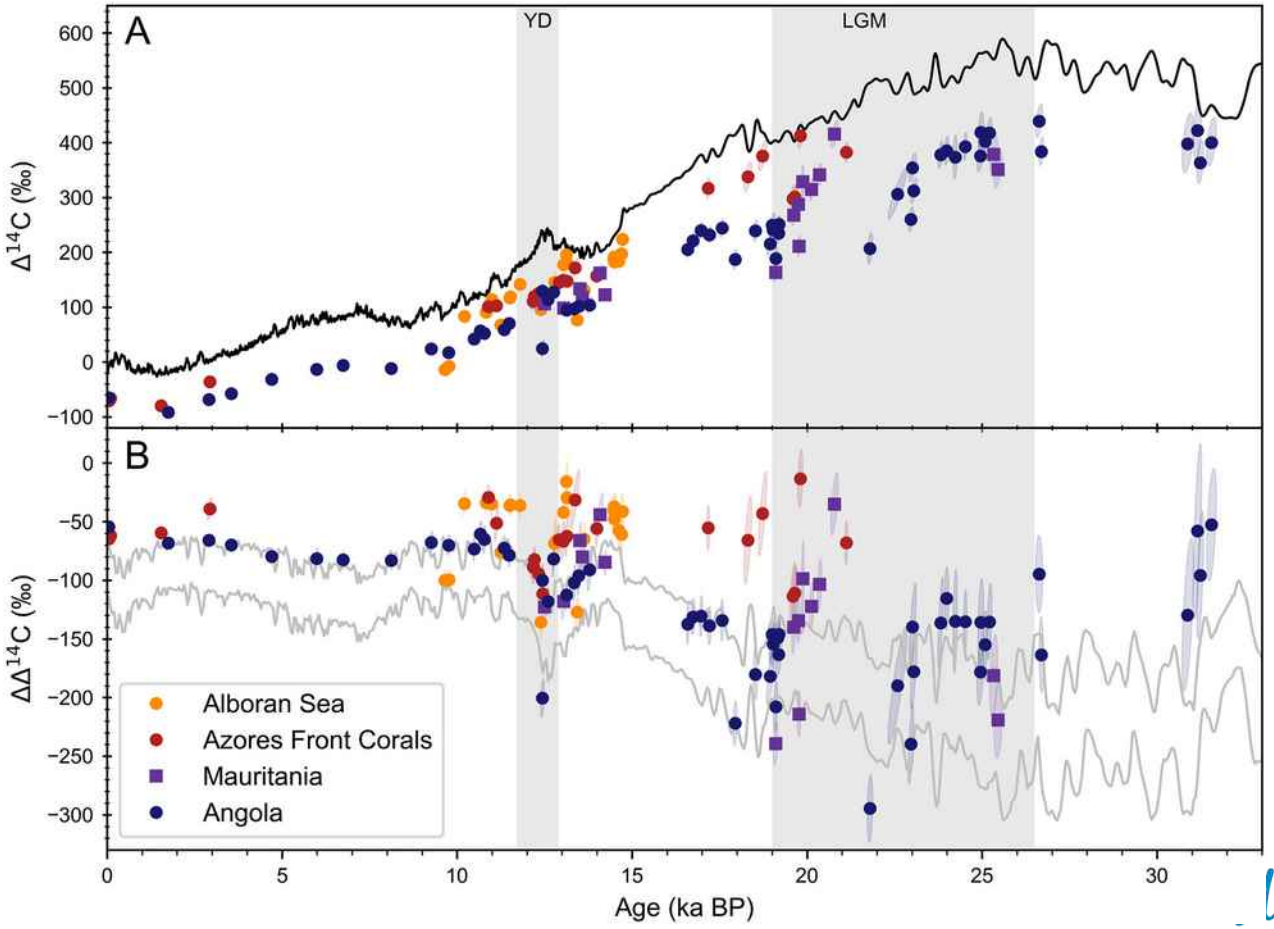
Arctic permafrost



Vaks et al. (2020)
Nature

The time machine

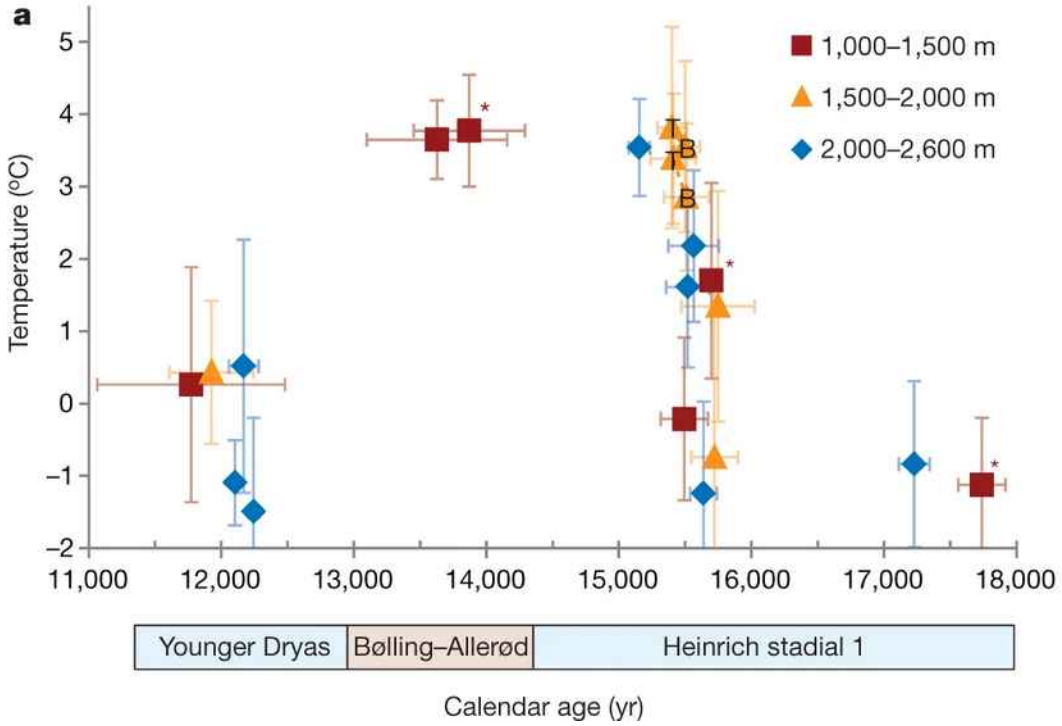
the power of dating – example: ^{14}C + U/Th in corals

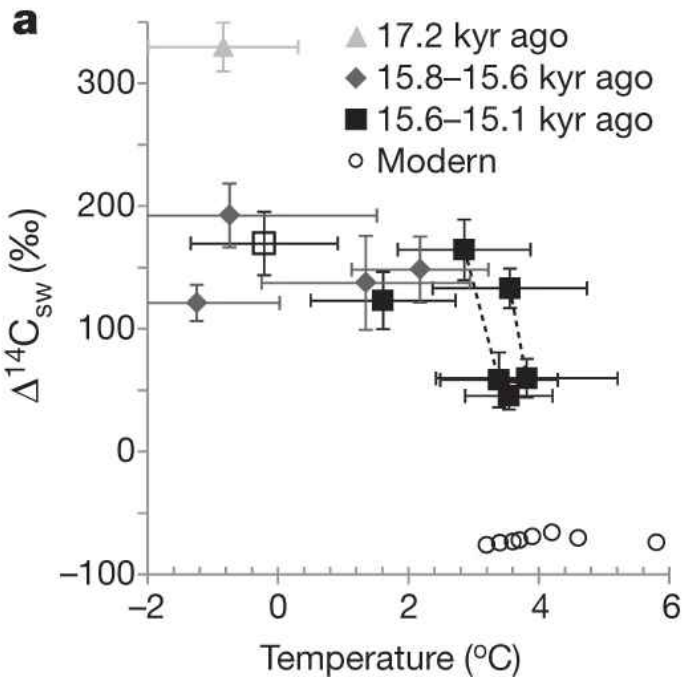


Beisel et al. (2023),
Paleoceanography and Paleoclimatology

The time machine

the power of dating: ^{14}C + U/Th + $\Delta 47$ in corals





Thiagarajan et al. (2014), Nature

The time machine

other types of dating: e.g. exposure dates

The time machine

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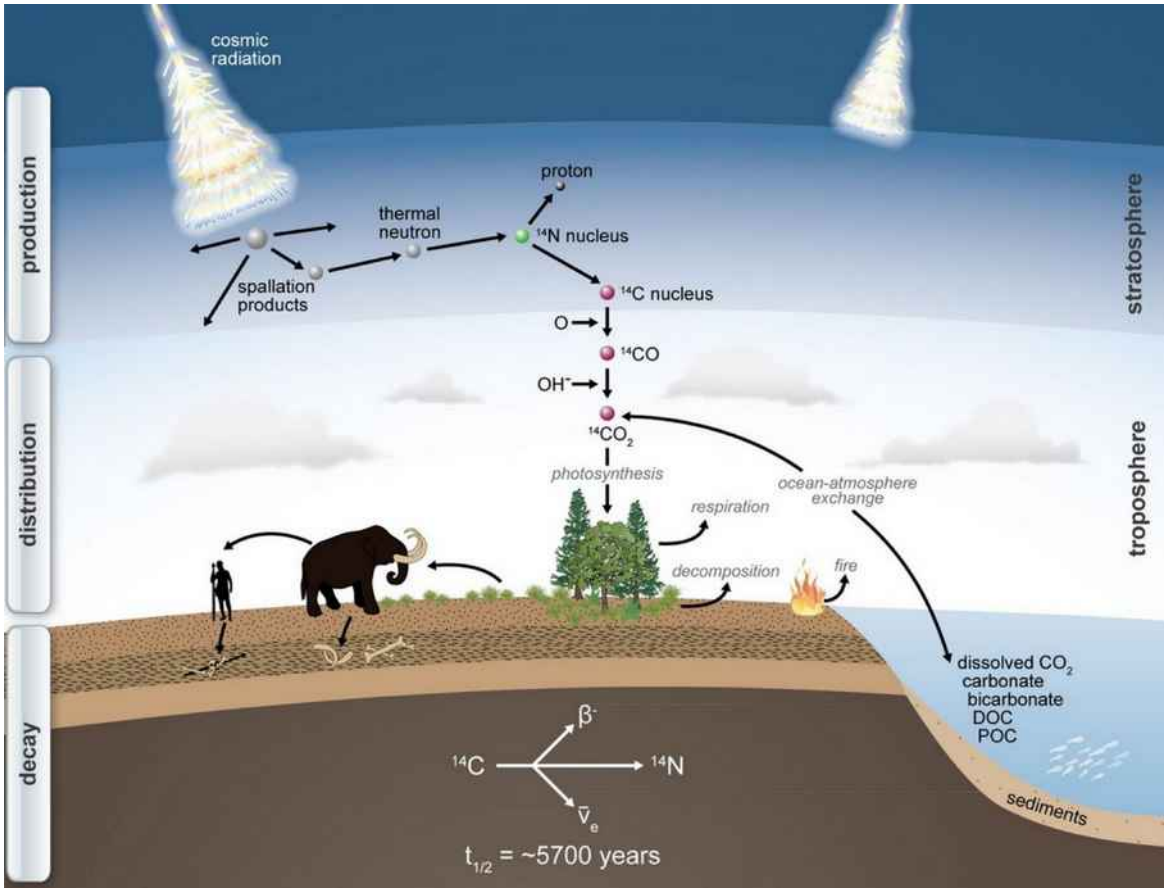
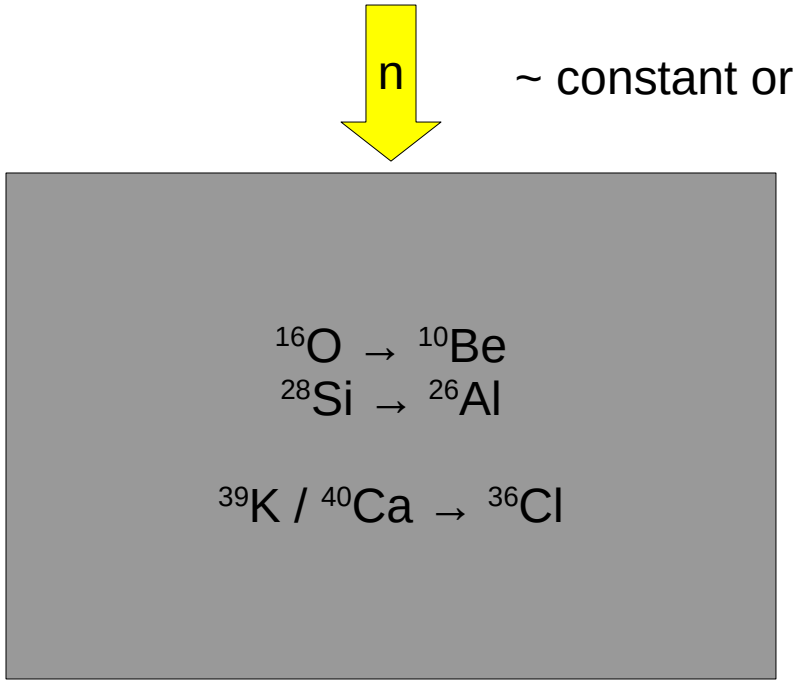


Soil Carbon Information Hub
international-soil-radiocarbon-database.github.io

The time machine

other types of dating: e.g. surface exposure dates

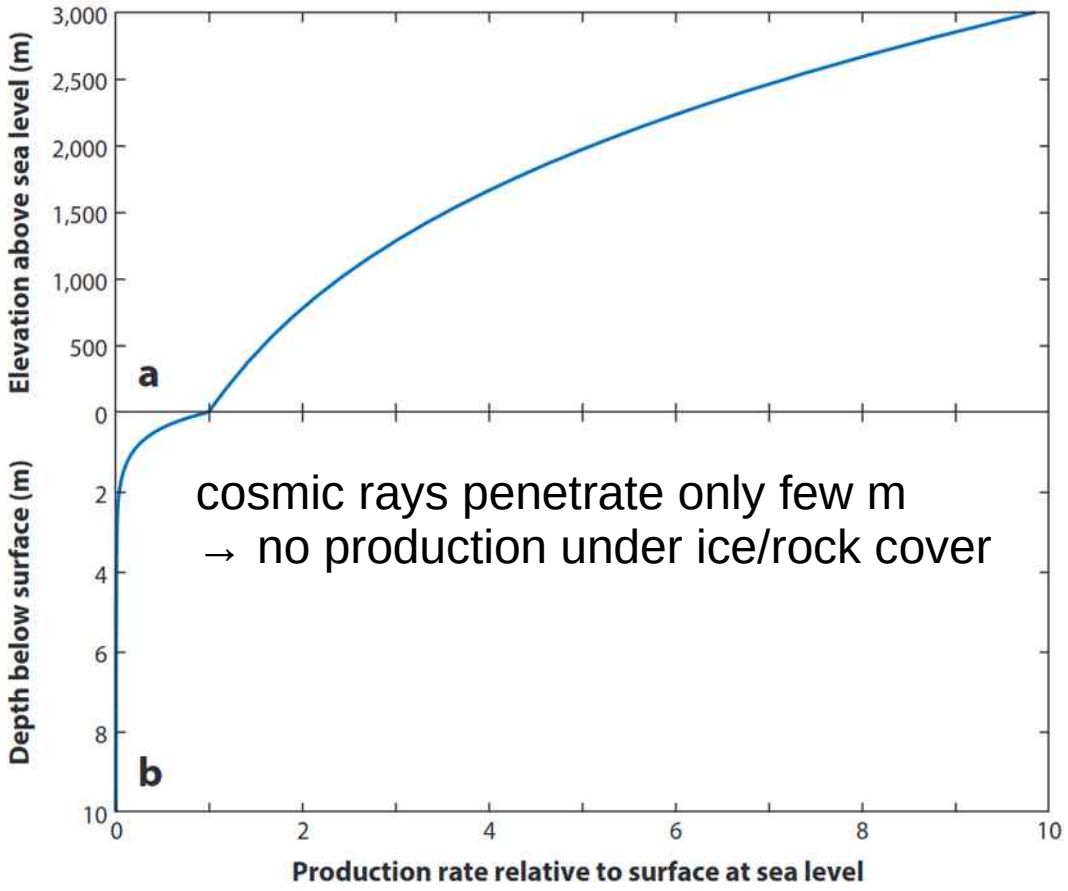


slow accumulation of
rare cosmogenic nuclides

1SD precisions ~ >= 6 %

The time machine

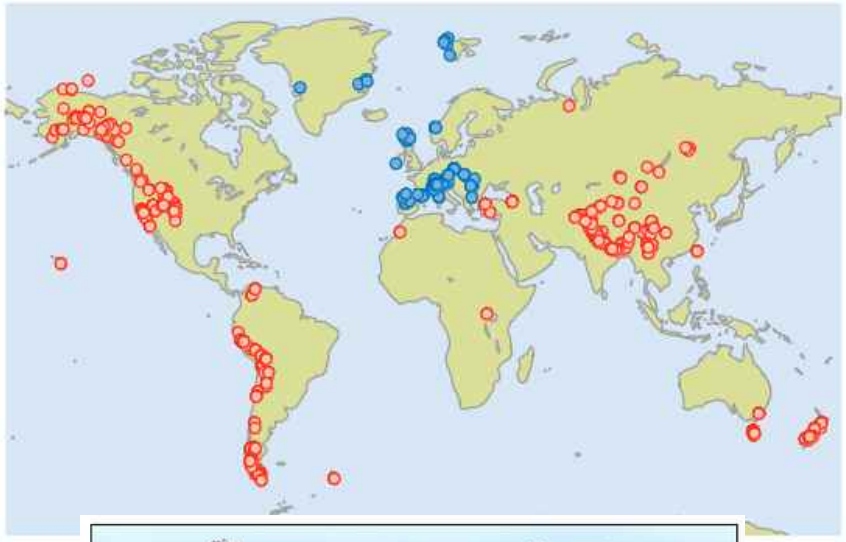
other types of dating: e.g. surface exposure dates

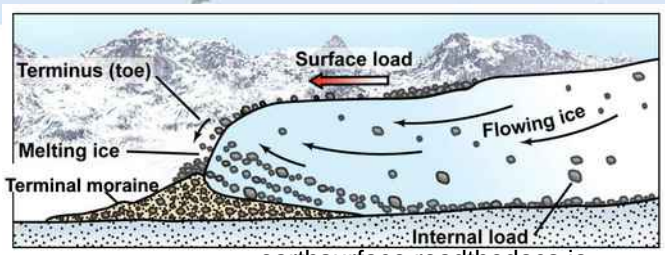


Balco (2020),
Annual Review of Earth and Planetary Sciences

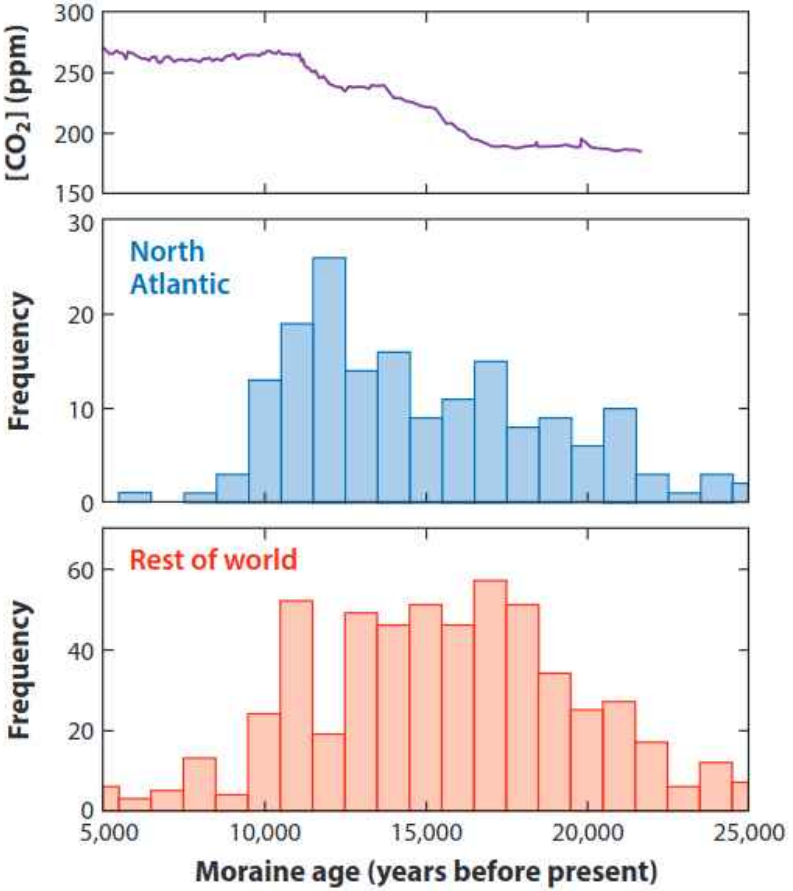
The time machine

other types of dating: e.g. surface exposure dates





earthsurface.readthedocs.io

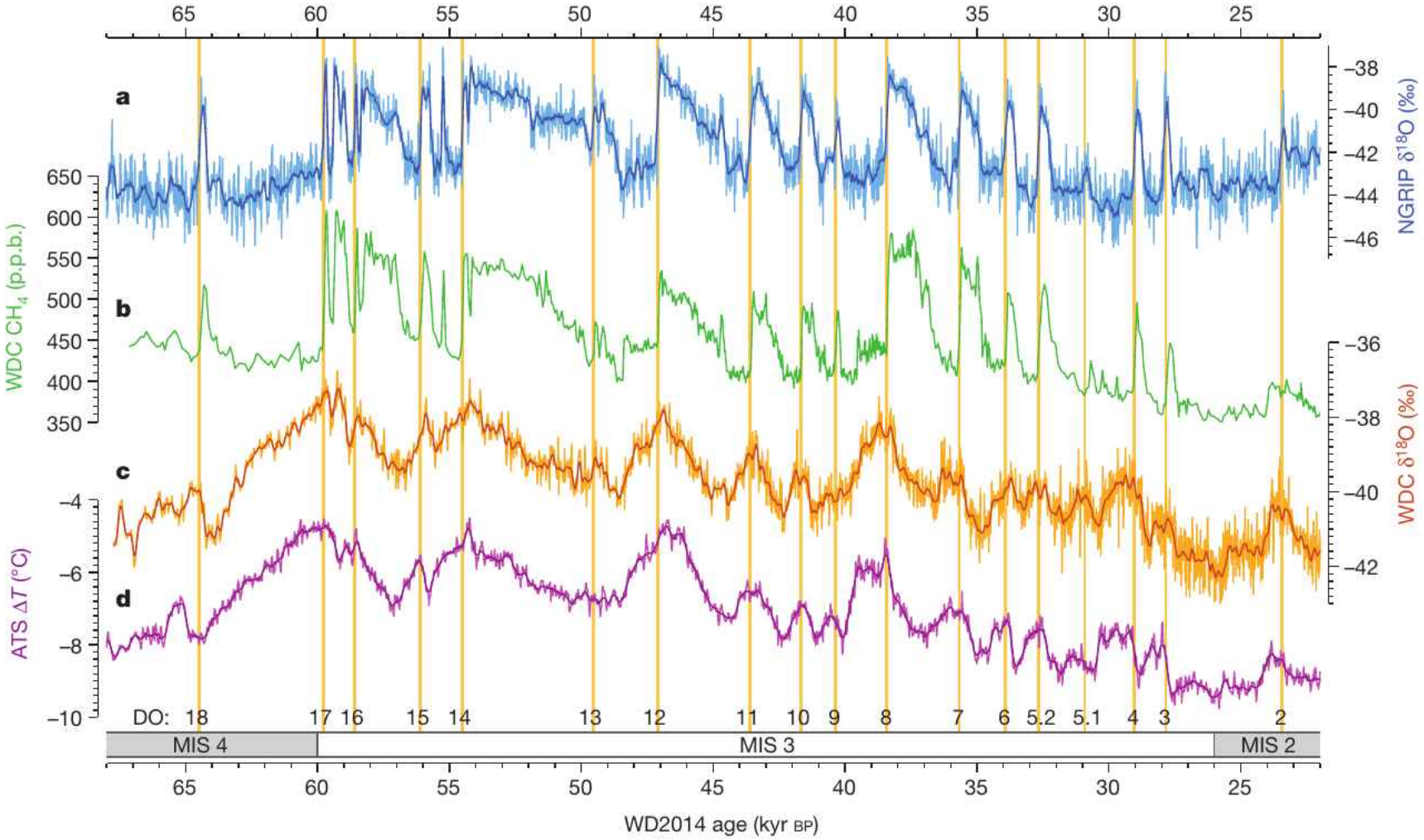


Balco (2020),
Annual Review of Earth and Planetary Sciences

Abrupt Climate Change

Abrupt Climate Change

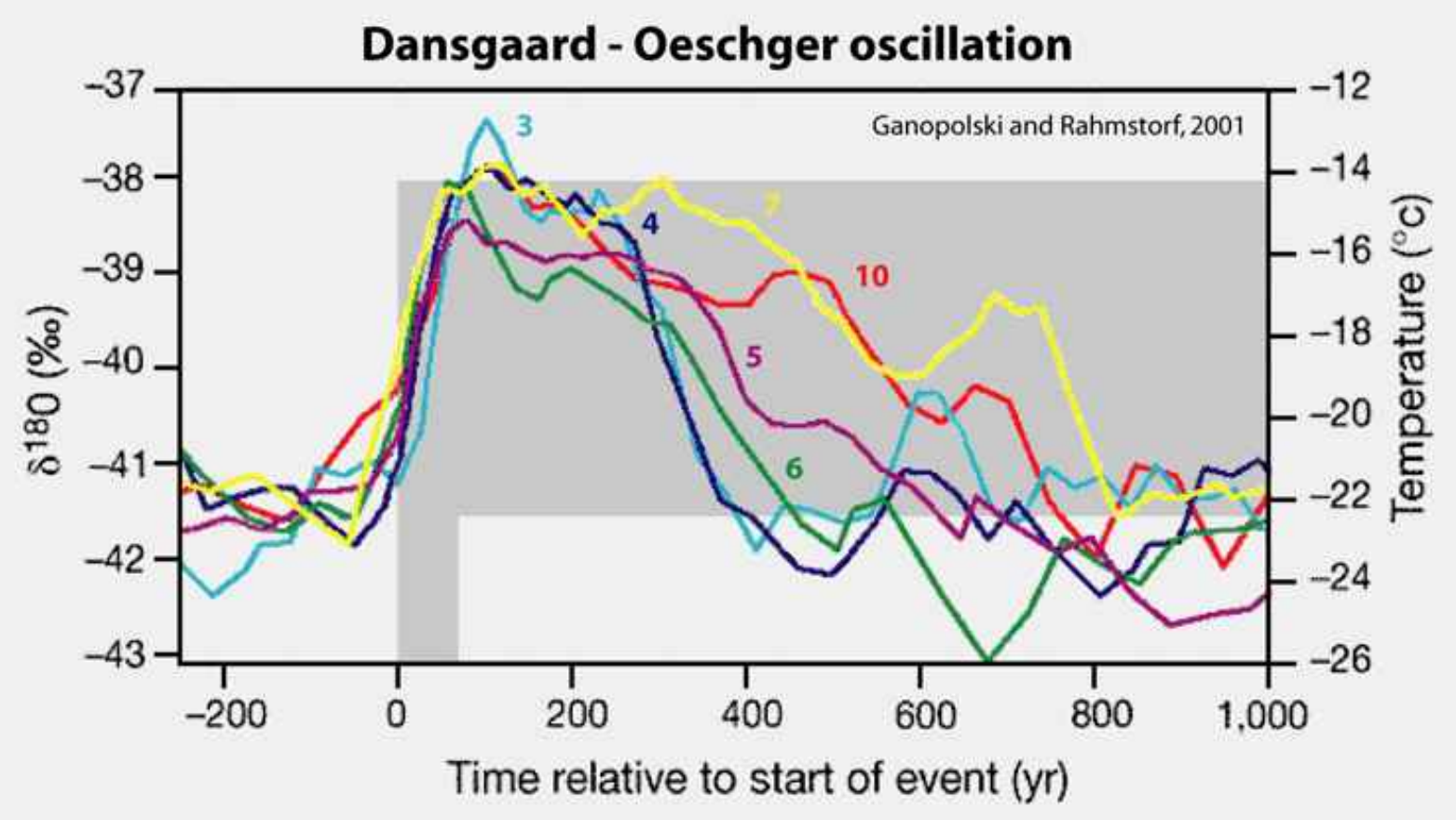
Dansgaar – Oeschger Events



Buizert et al. (2015), Nature

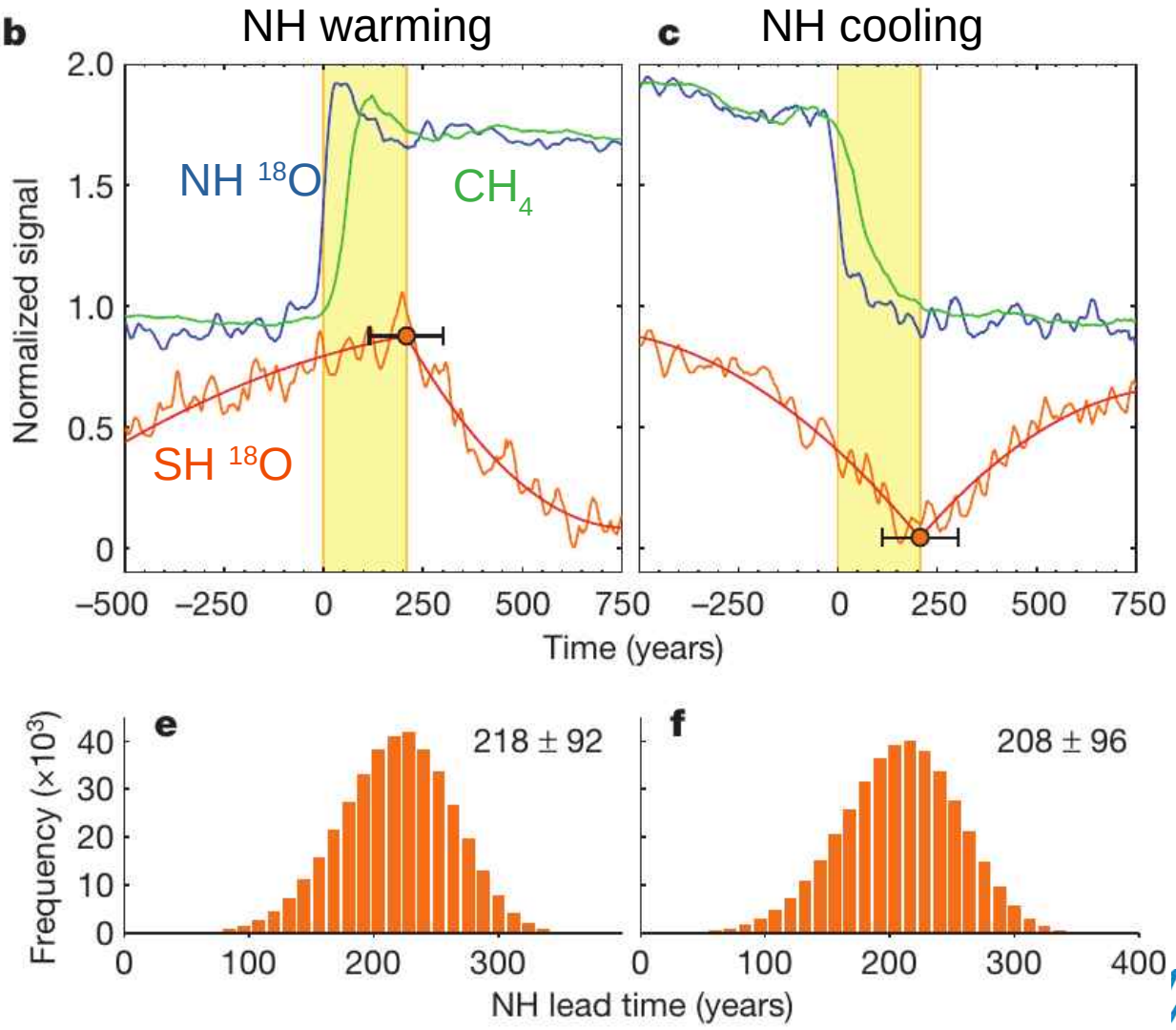
Abrupt Climate Change

Dansgaar – Oeschger Events



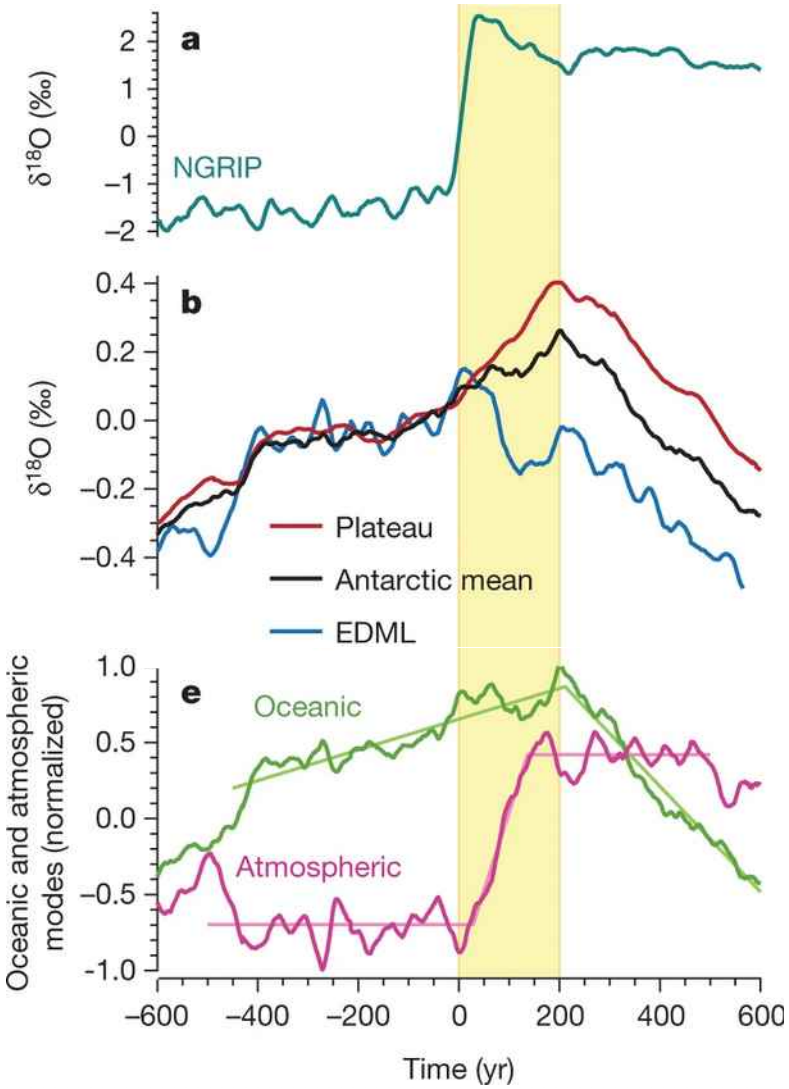
Climate Etc. Blog
judithcurry.com

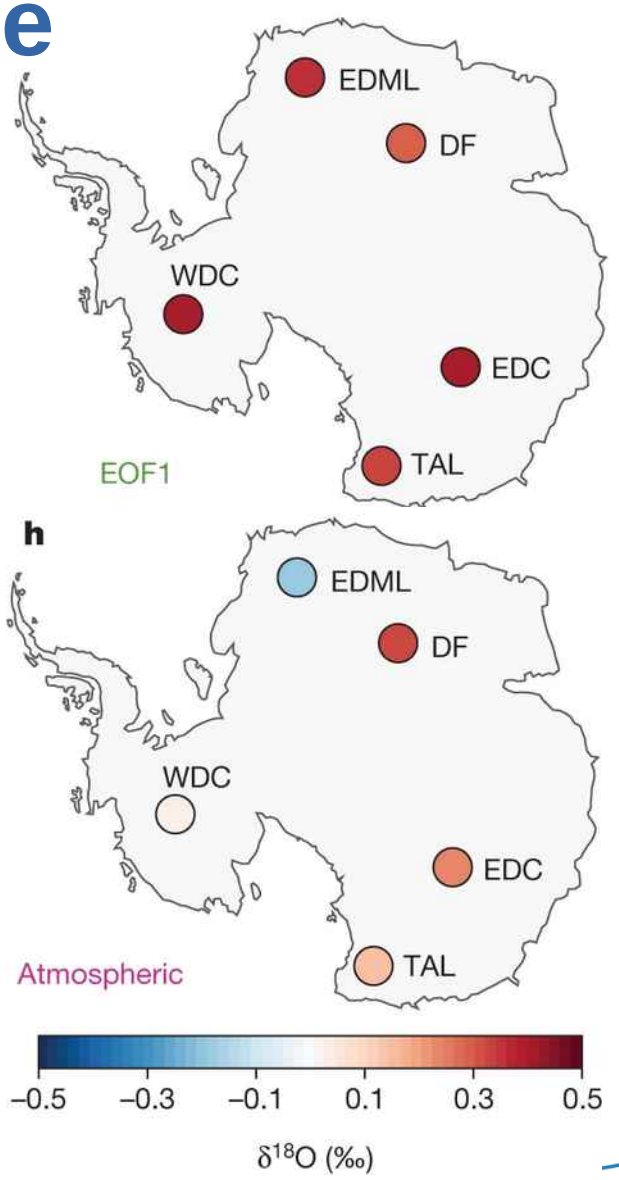
Abrupt Climate Change



Buizert et al. (2015), Nature

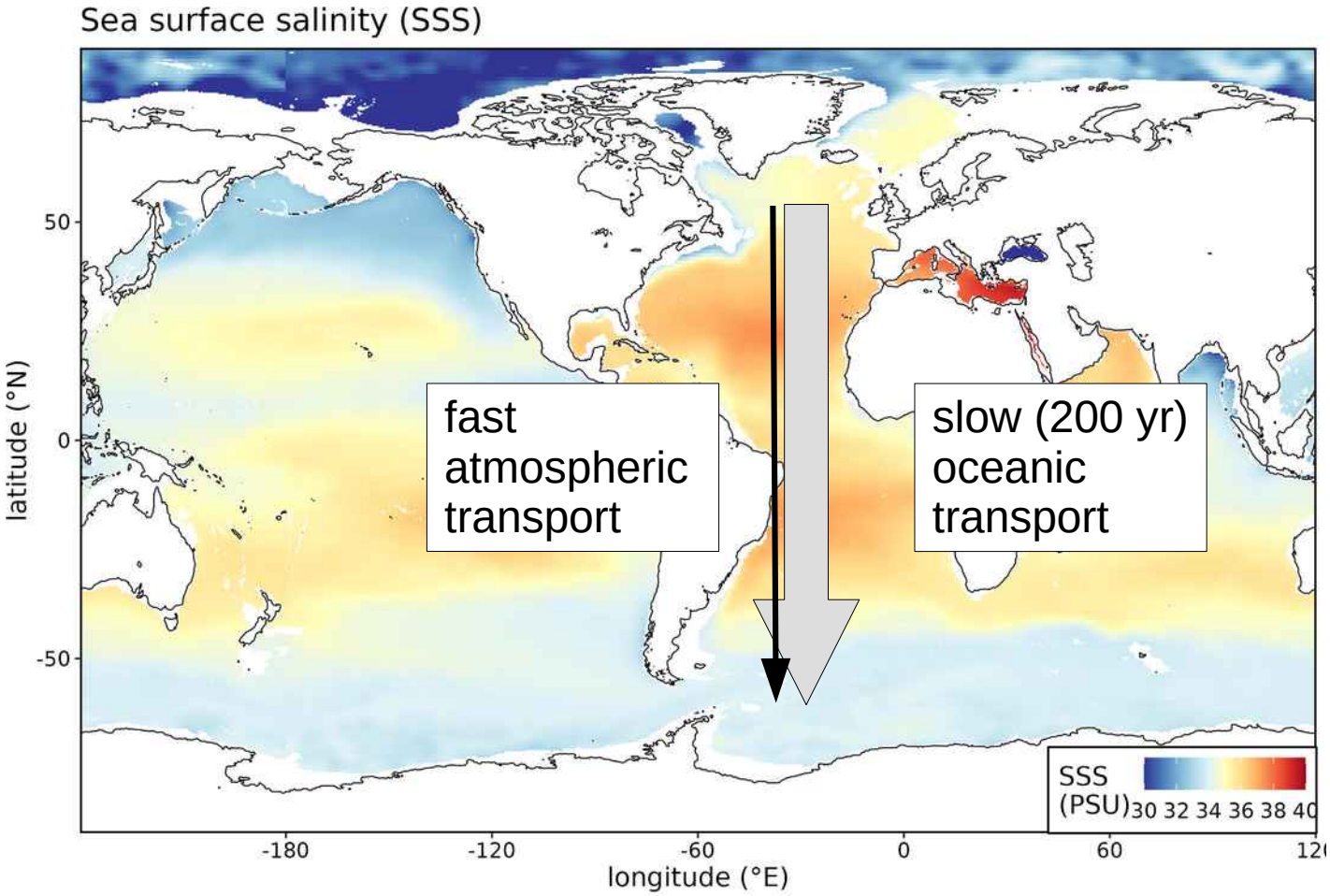
Abrupt Climate Change





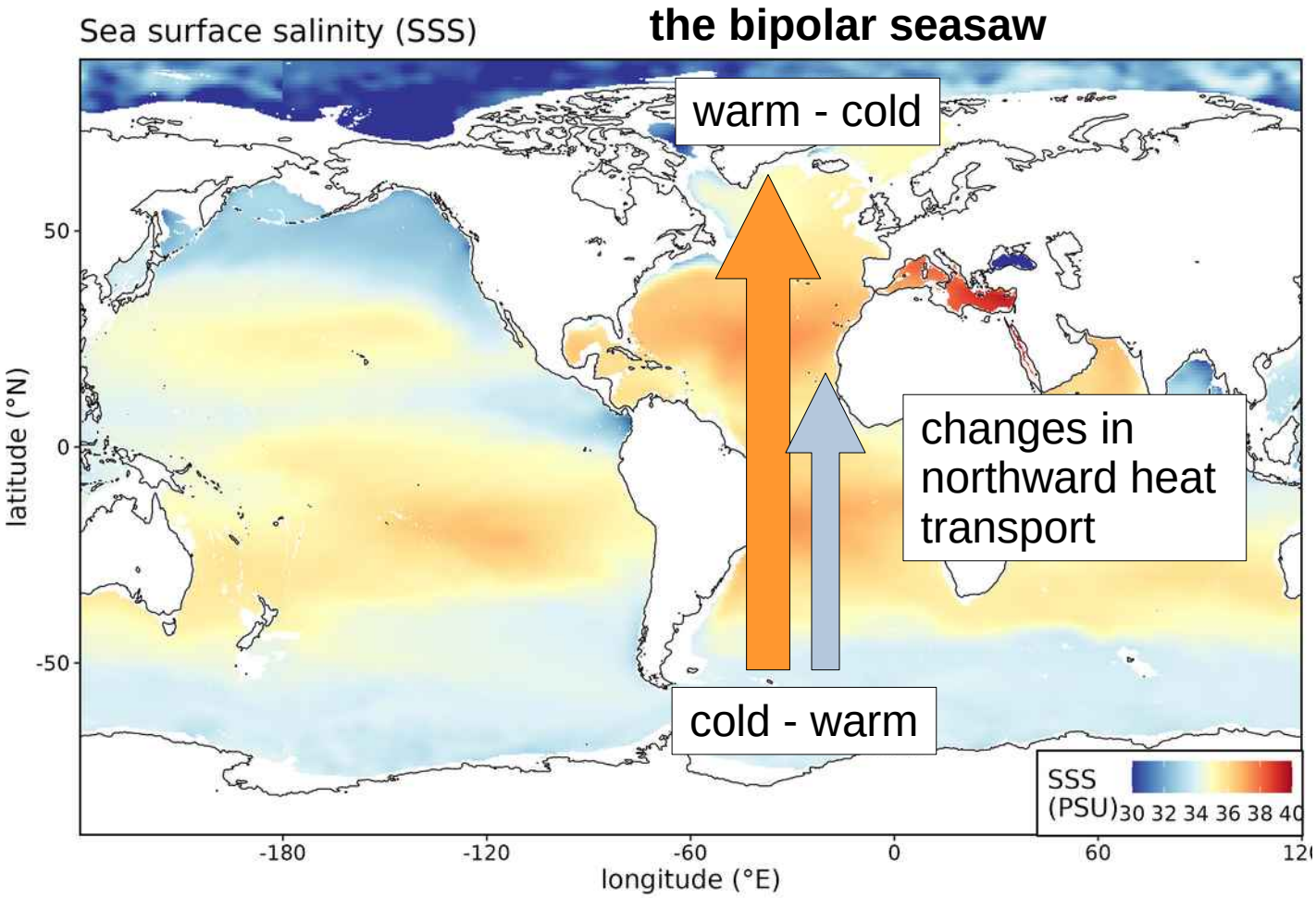
Buizert et al. (2018), Nature

Abrupt Climate Change



Buizert et al. (2018), Nature

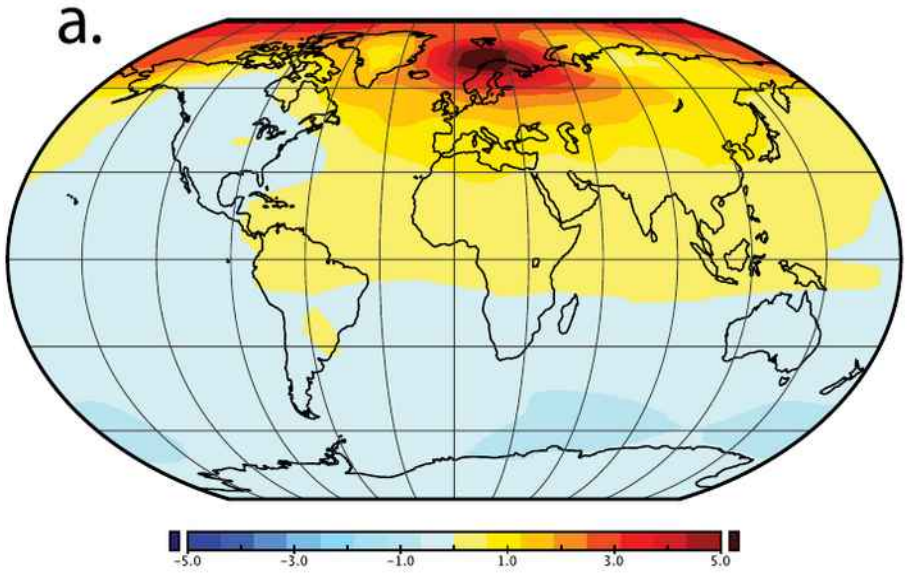
Abrupt Climate Change



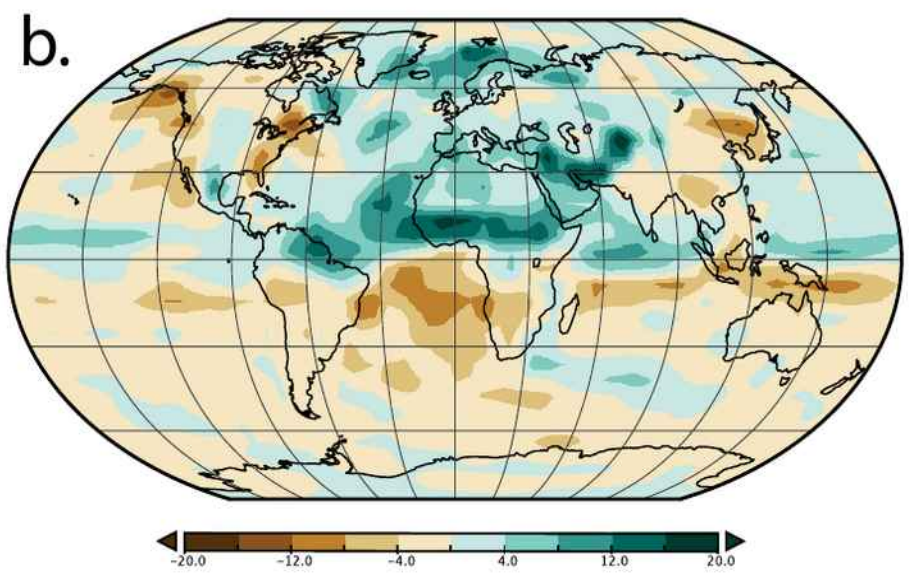
Abrupt Climate Change

modelled climate effects from DO Events

temperature

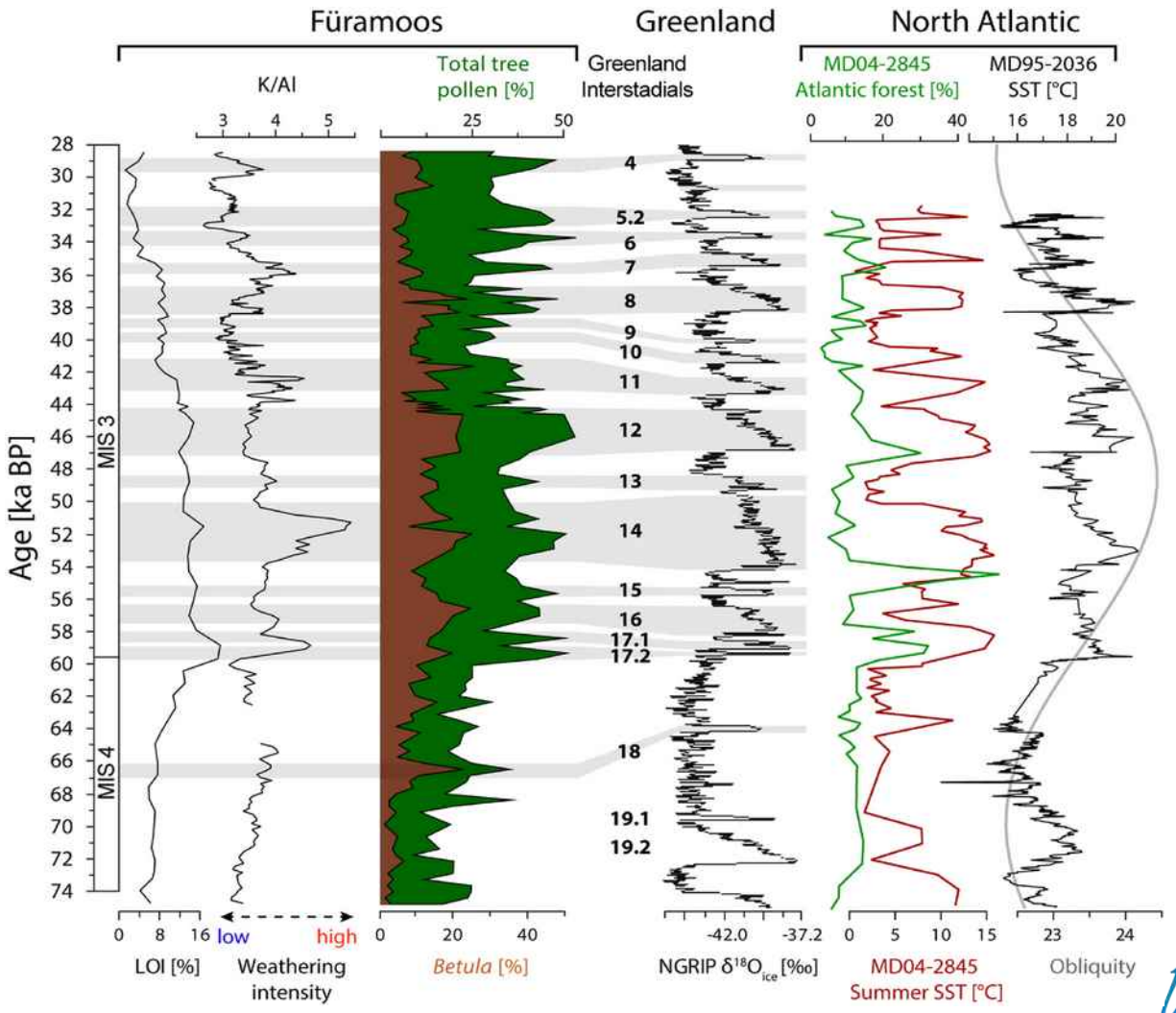


precipitation



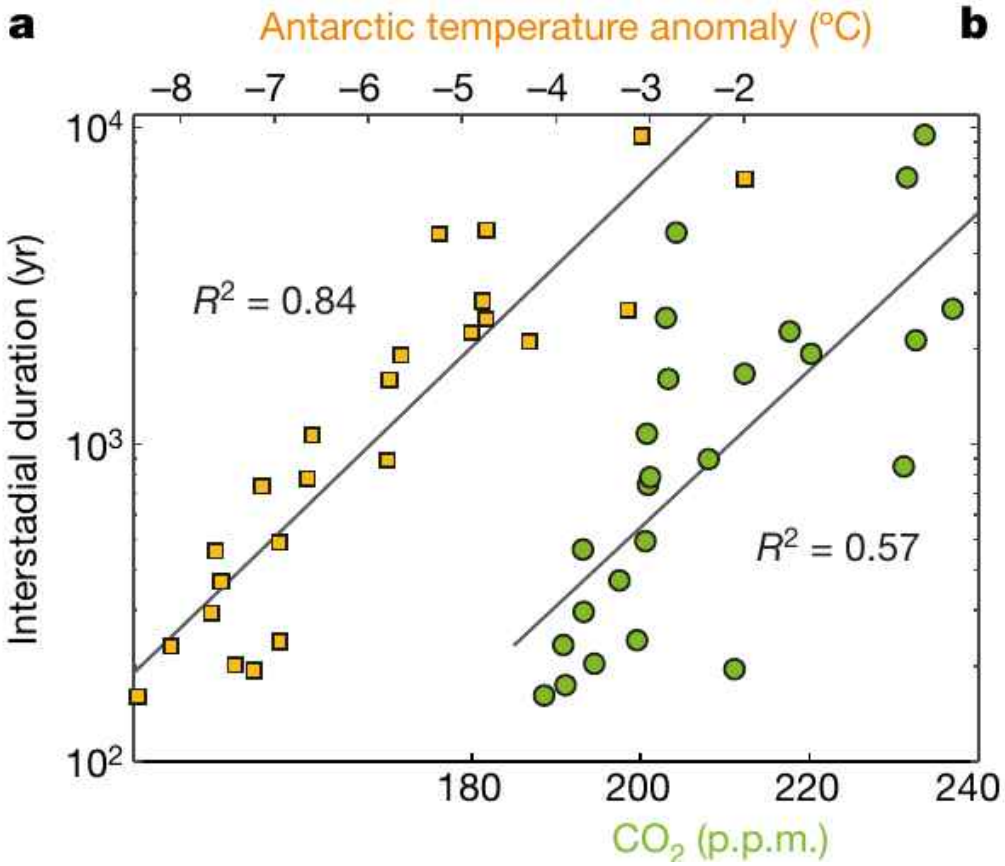
Menviel et al. (2014), Climate of the Past

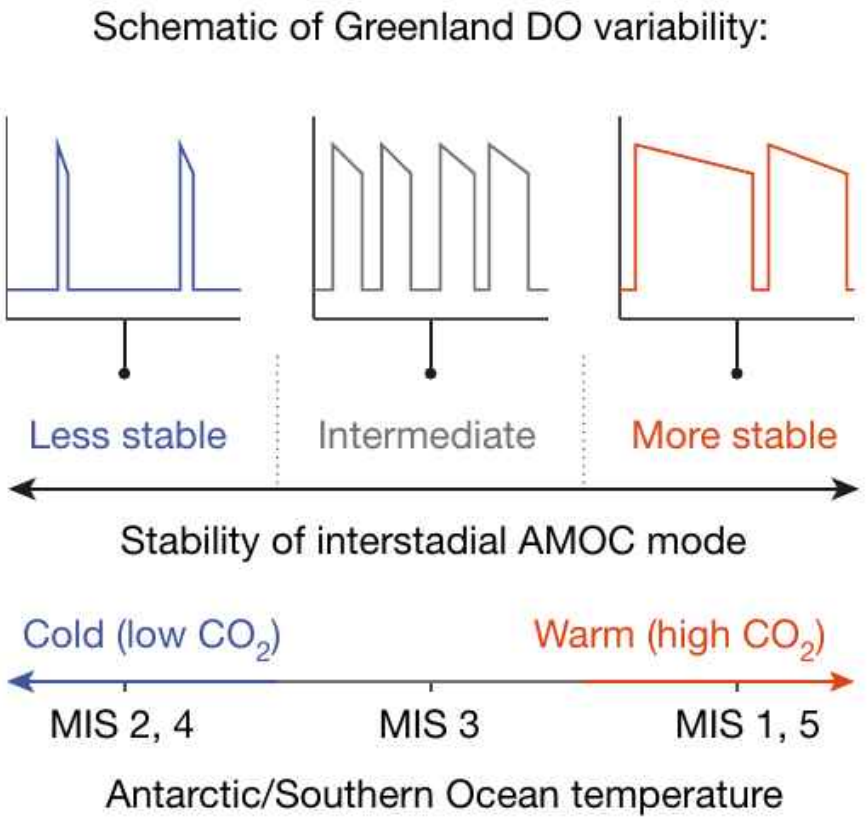
Abrupt Climate Change



Kern et al. (2022), Quaternary Science Reviews

Abrupt Climate Change





Brook & Buizert (2018), Nature

Abrupt Climate Change

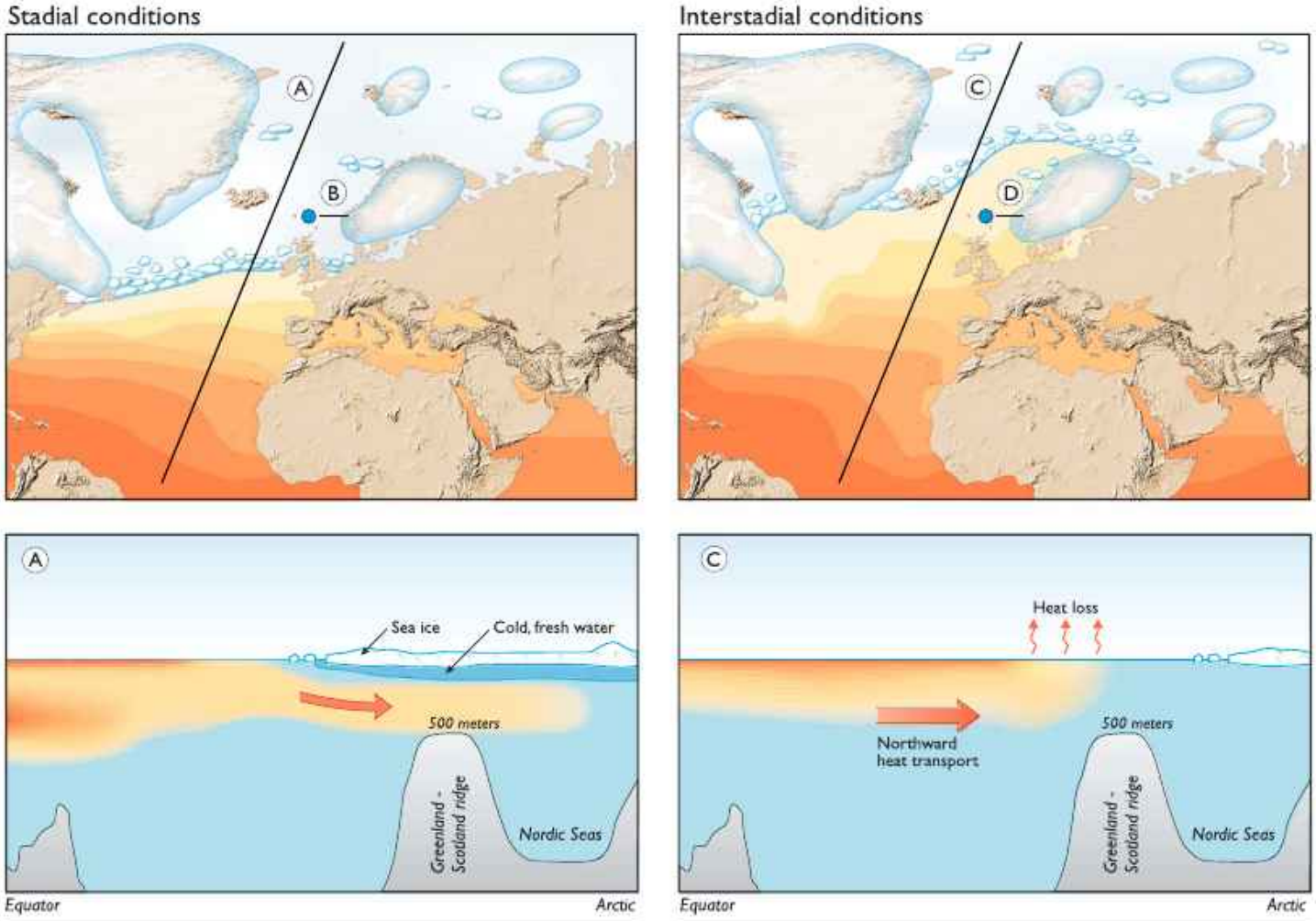
Dansgaar – Oeschger Events

- (forcing) periodicity ~ 1500 years
- no regular orbital forcing at these frequencies

  → internal system variations

- but how do they occur?

Abrupt Climate Change

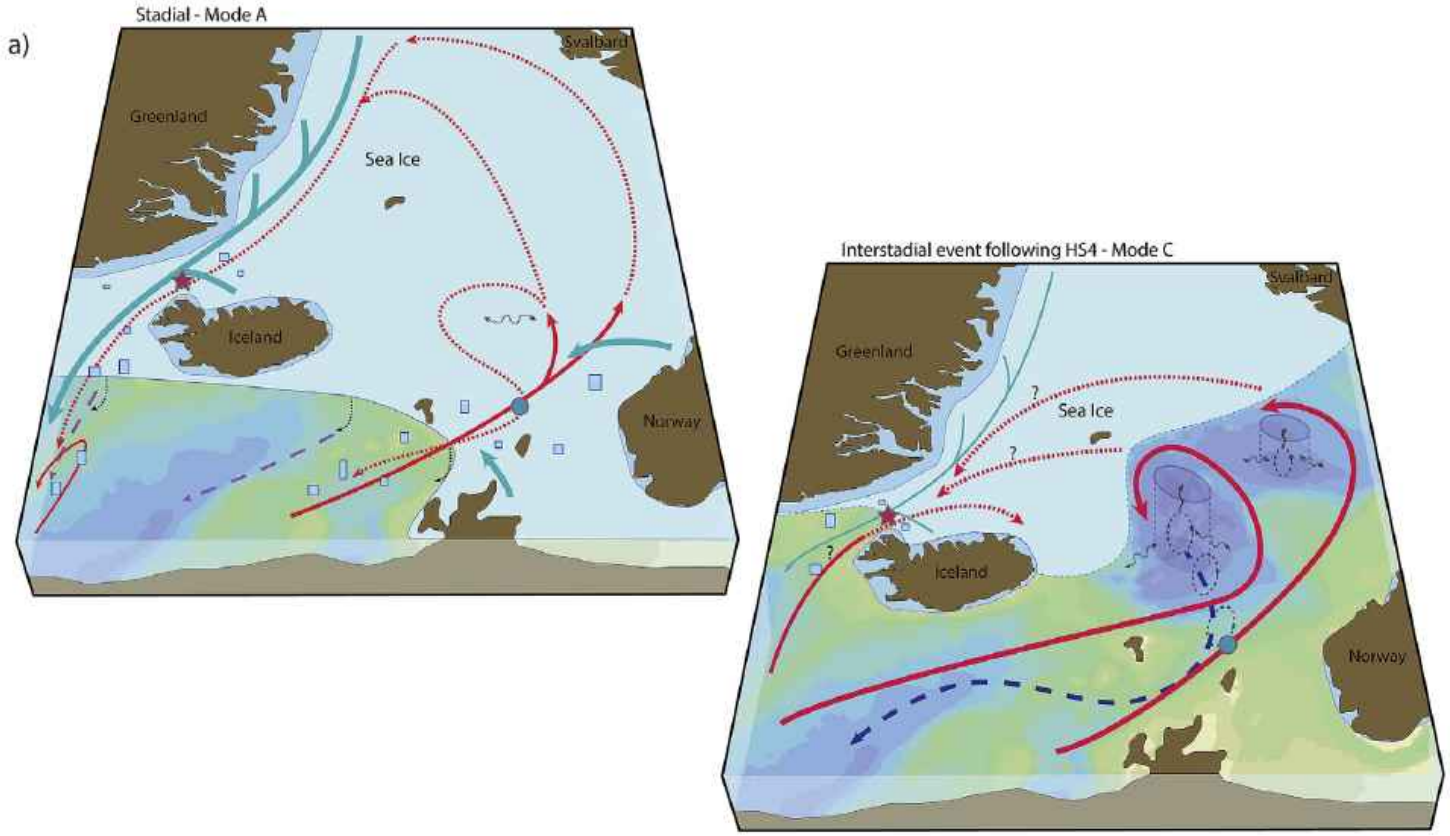


NH winters

Dokken et al. (2013), Paleoceanography

Abrupt Climate Change

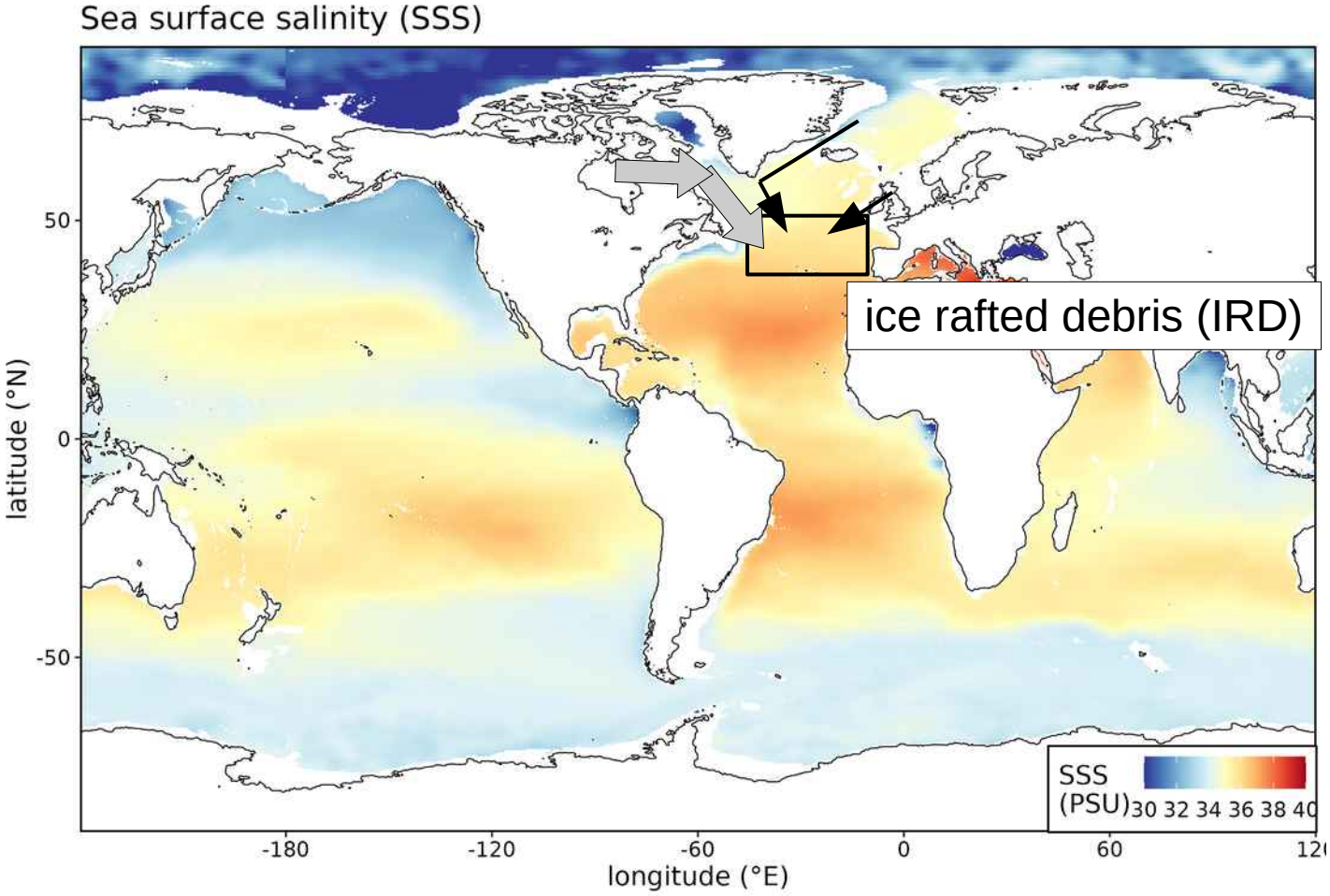
Nordic Seas stadial – interstadial changes



Sessford et al. (2019), Quaternary Science Reviews

Abrupt Climate Change

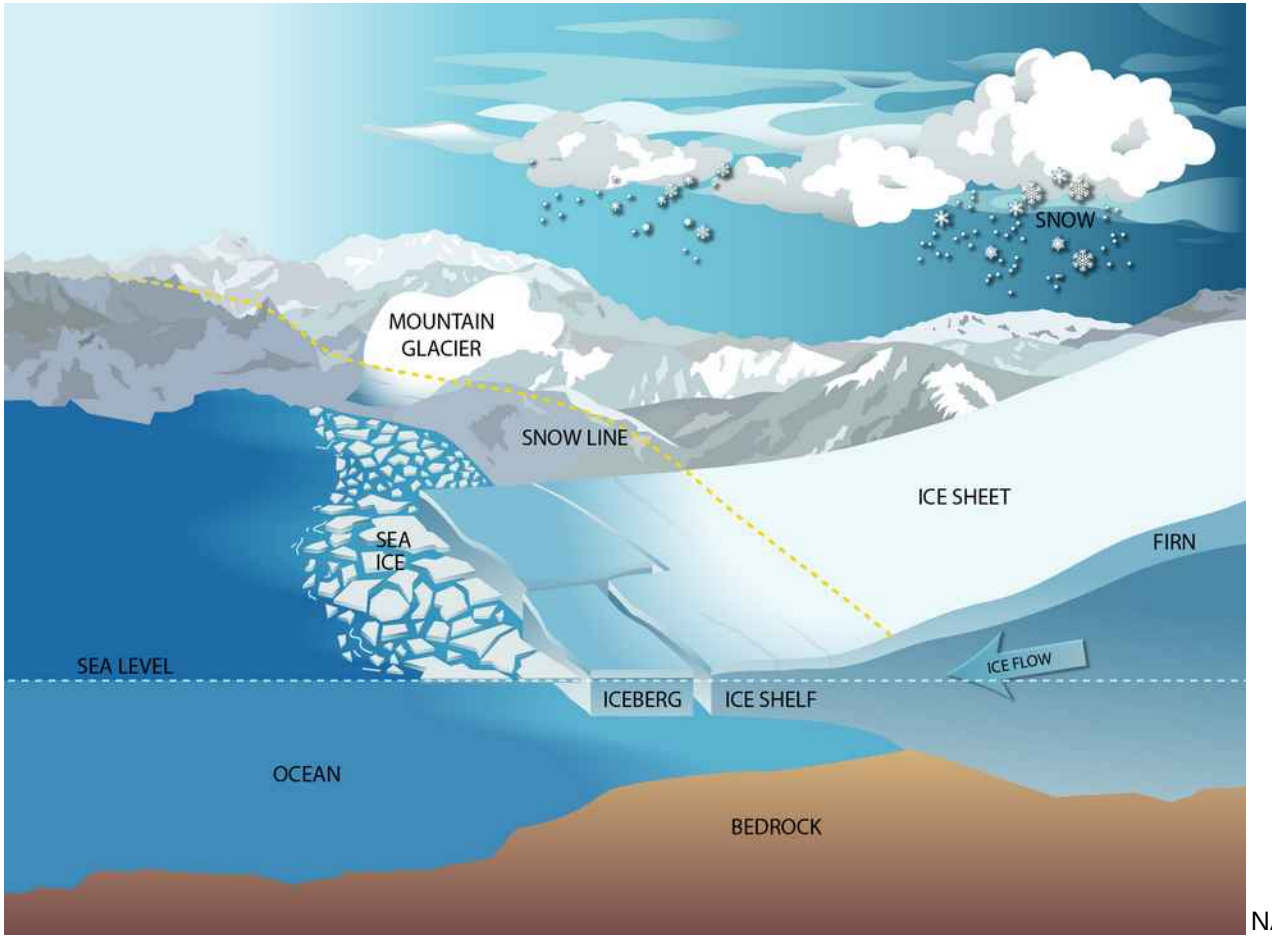
Heinrich Events



Max et al. (2022), Nature Communications

Abrupt Climate Change

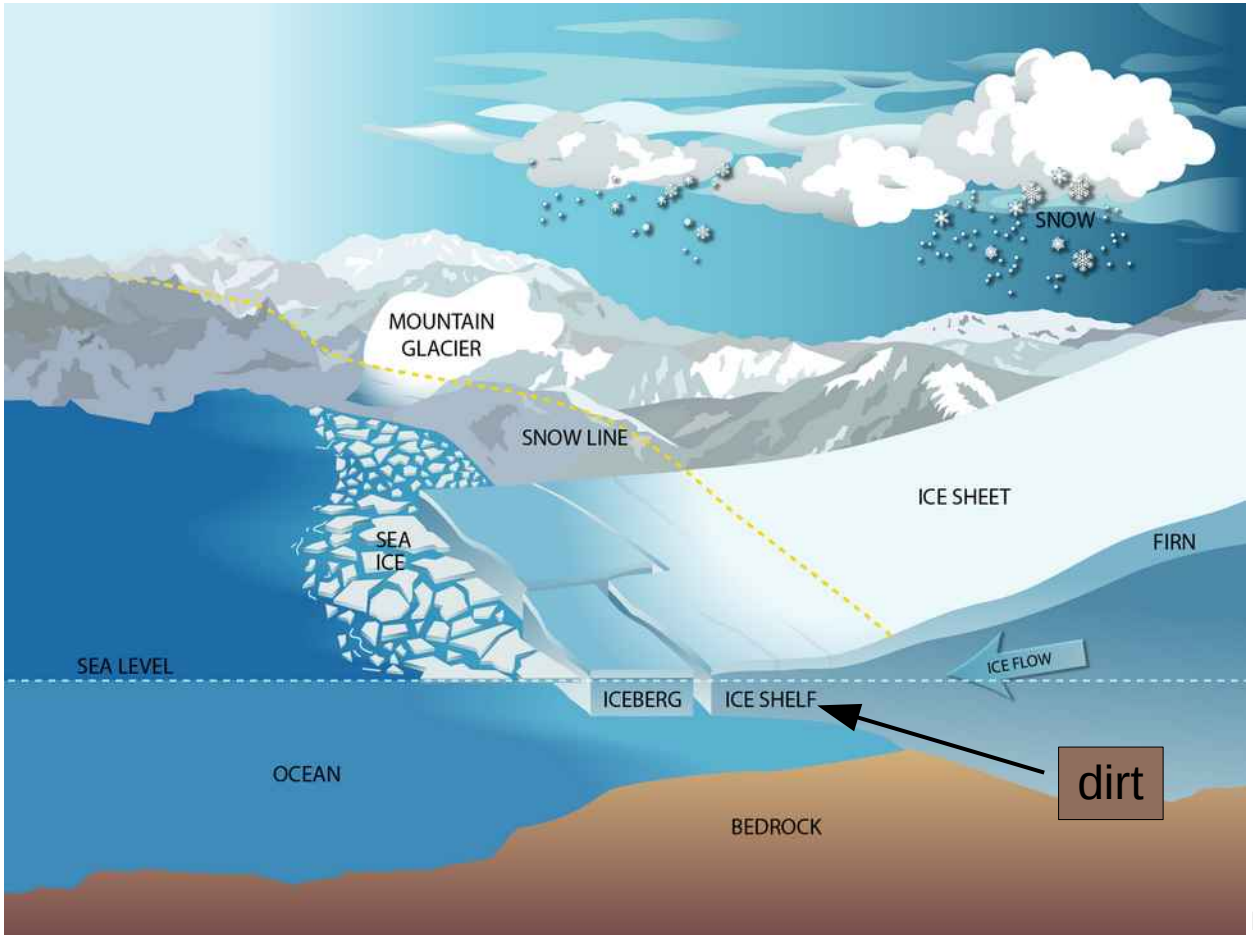
Heinrich Events



NASA

Abrupt Climate Change

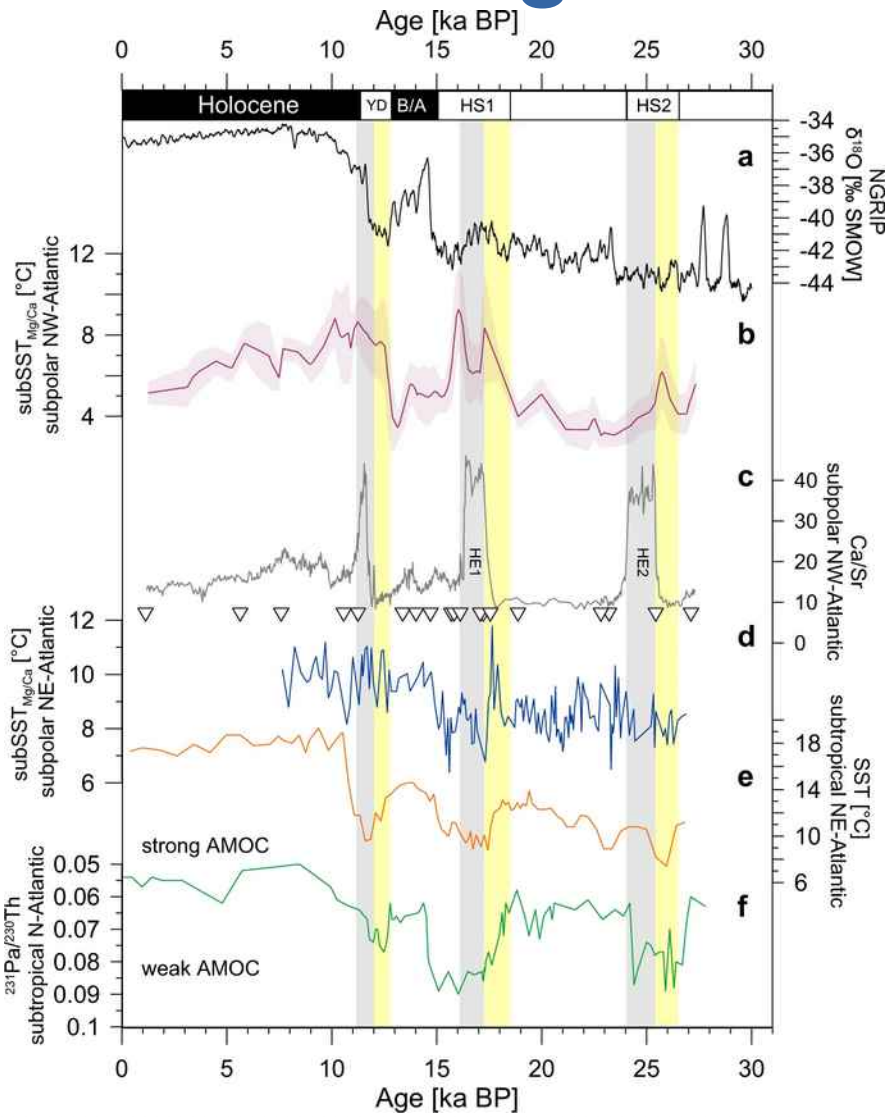
Heinrich Events



NASA

Abrupt Climate Change

Heinrich Events



Max et al. (2022), Nature Communications

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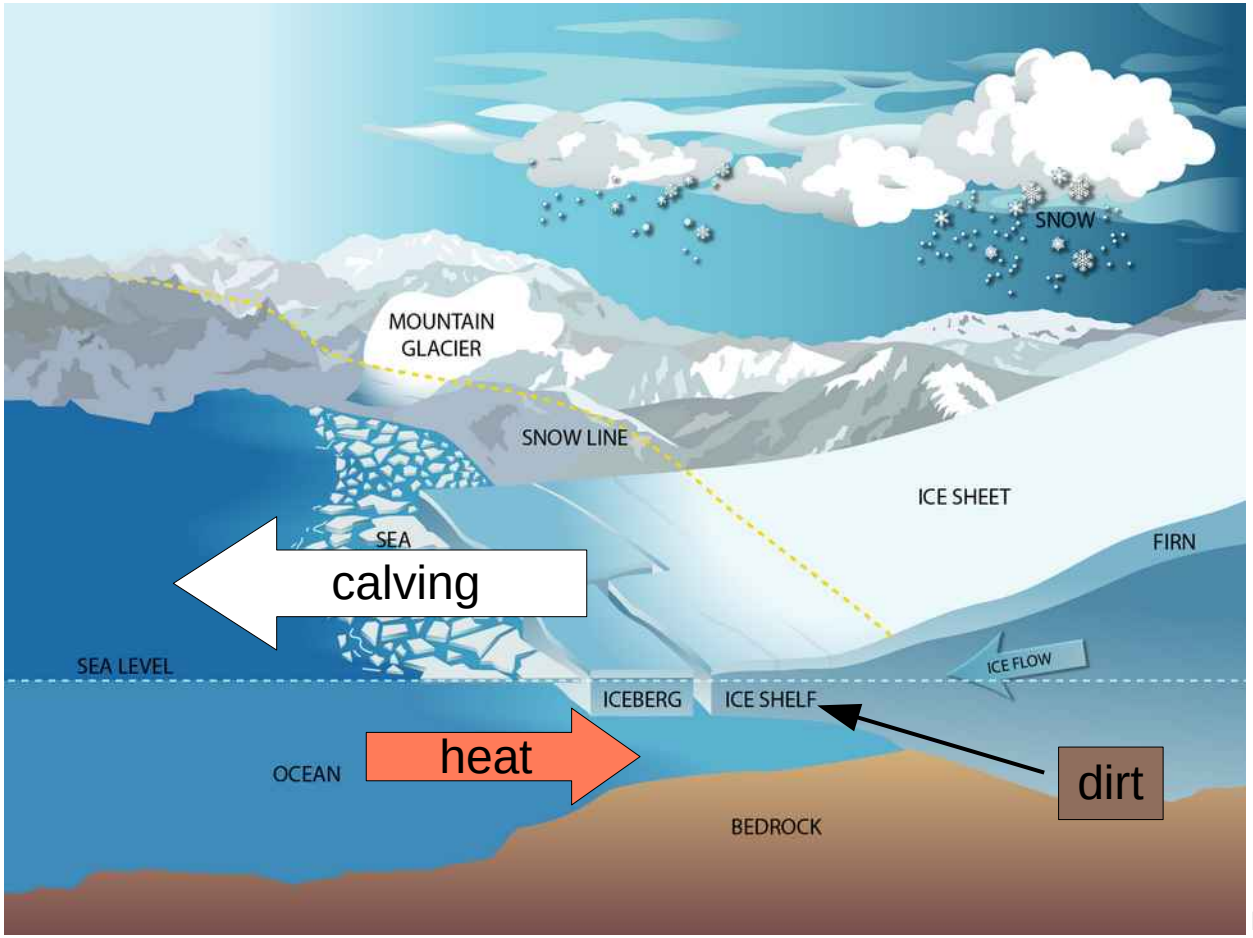
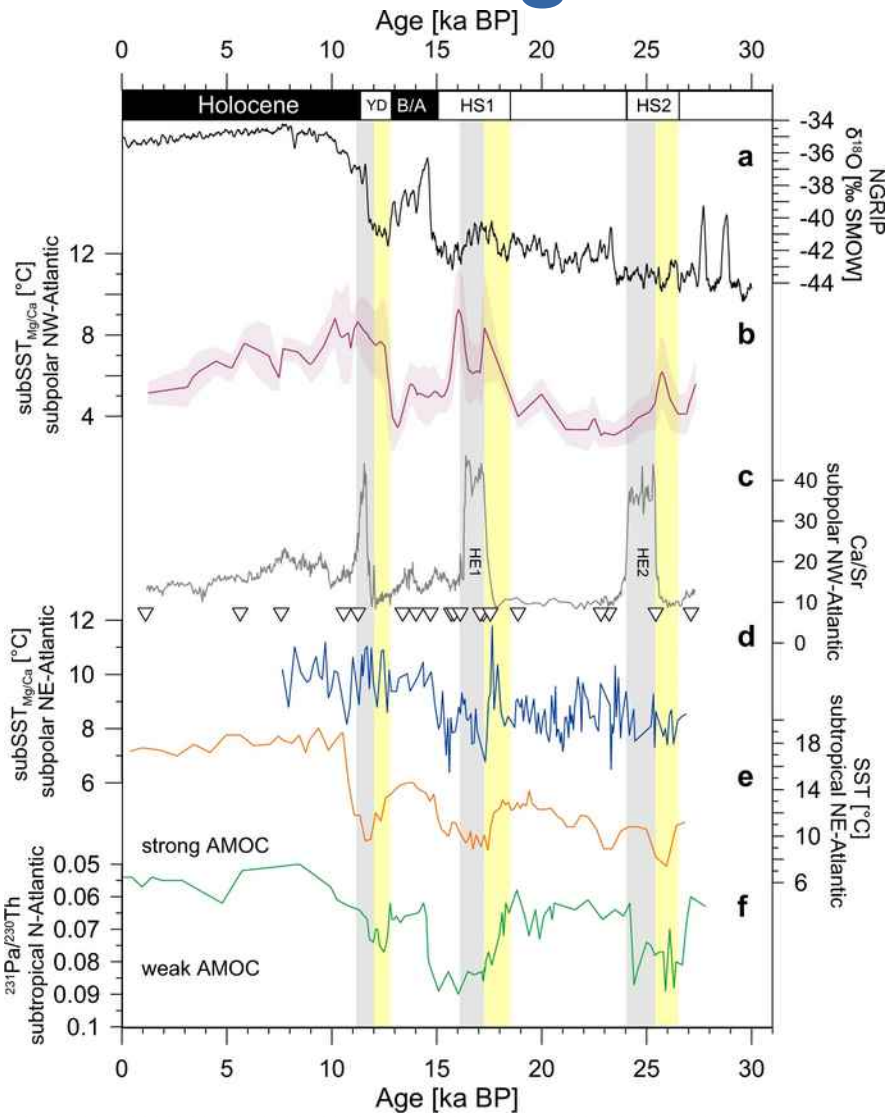
Heinrich Events



NASA

Abrupt Climate Change

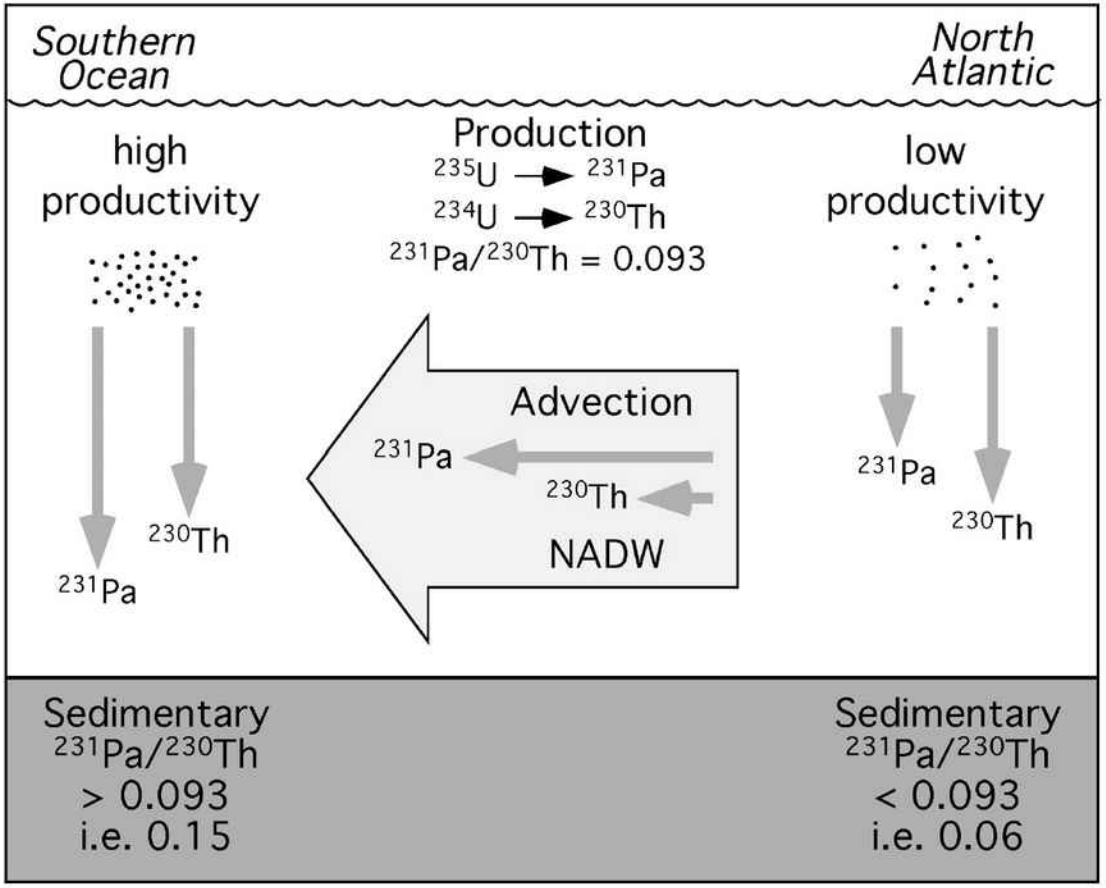
Heinrich Events



Max et al. (2022), Nature Communications

Abrupt Climate Change

The Pa-Th proxy



Henderson & Anderson (2003)
Reviews in Mineralogy and Geochemistry

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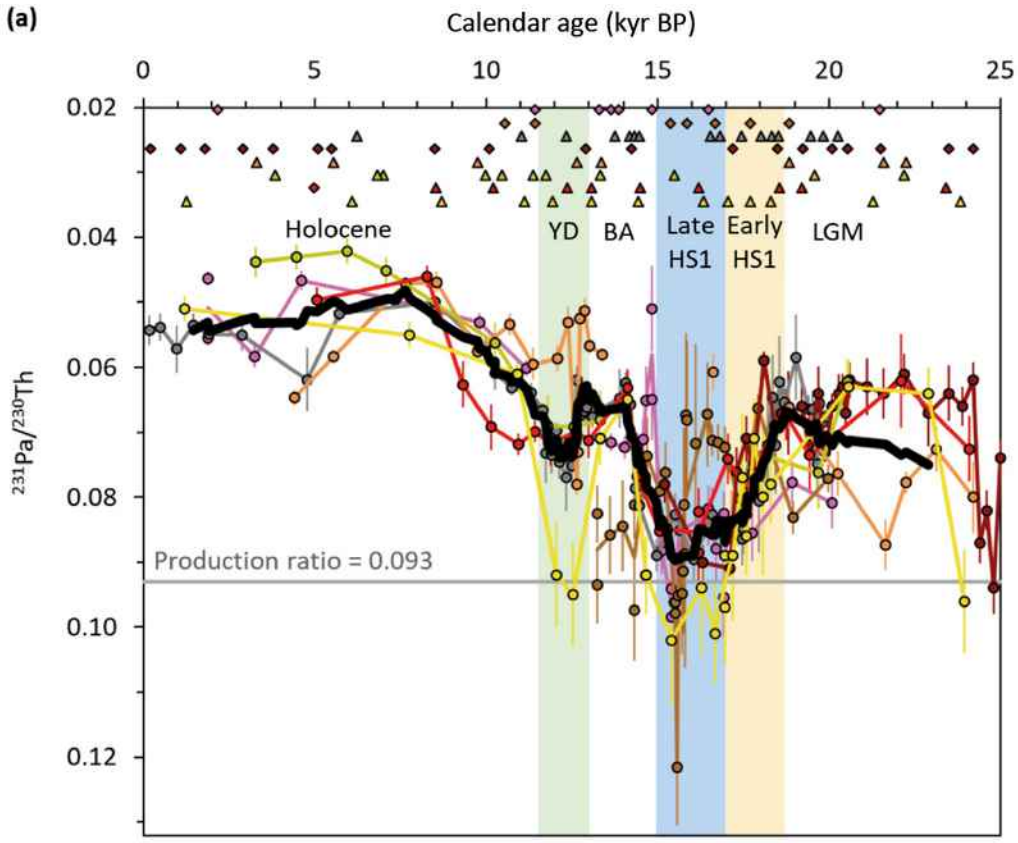
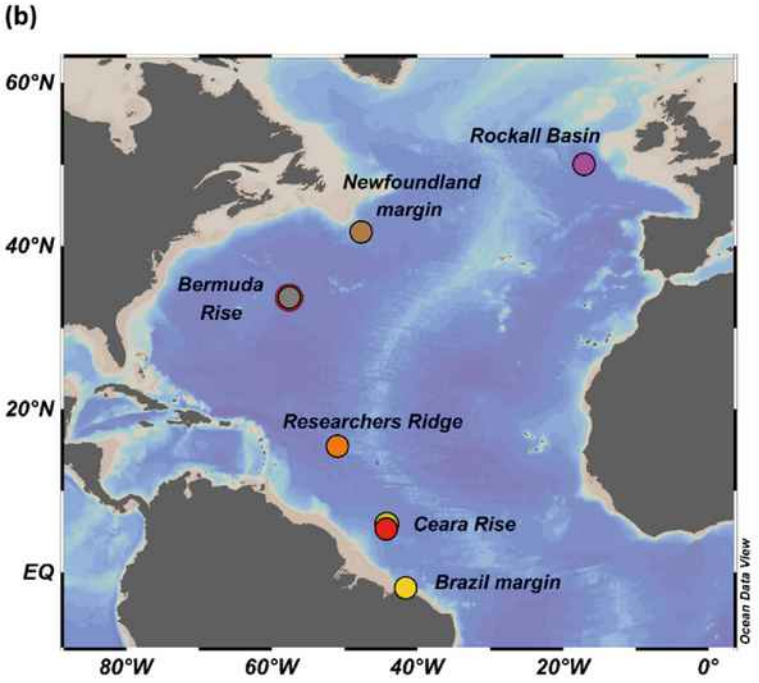
The Pa-Th proxy

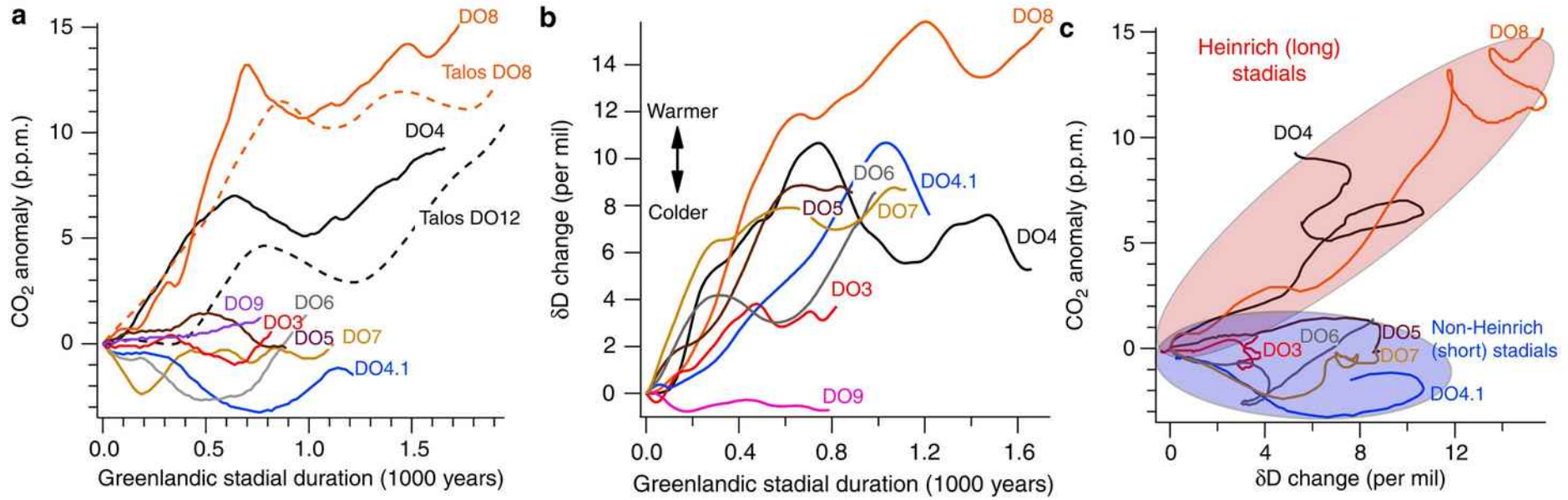




Robinson et al. (2019)
PAGES Magazine

Abrupt Climate Change

DO and Heinrich Events



Ahn & Brook (2014)
Nature Communications

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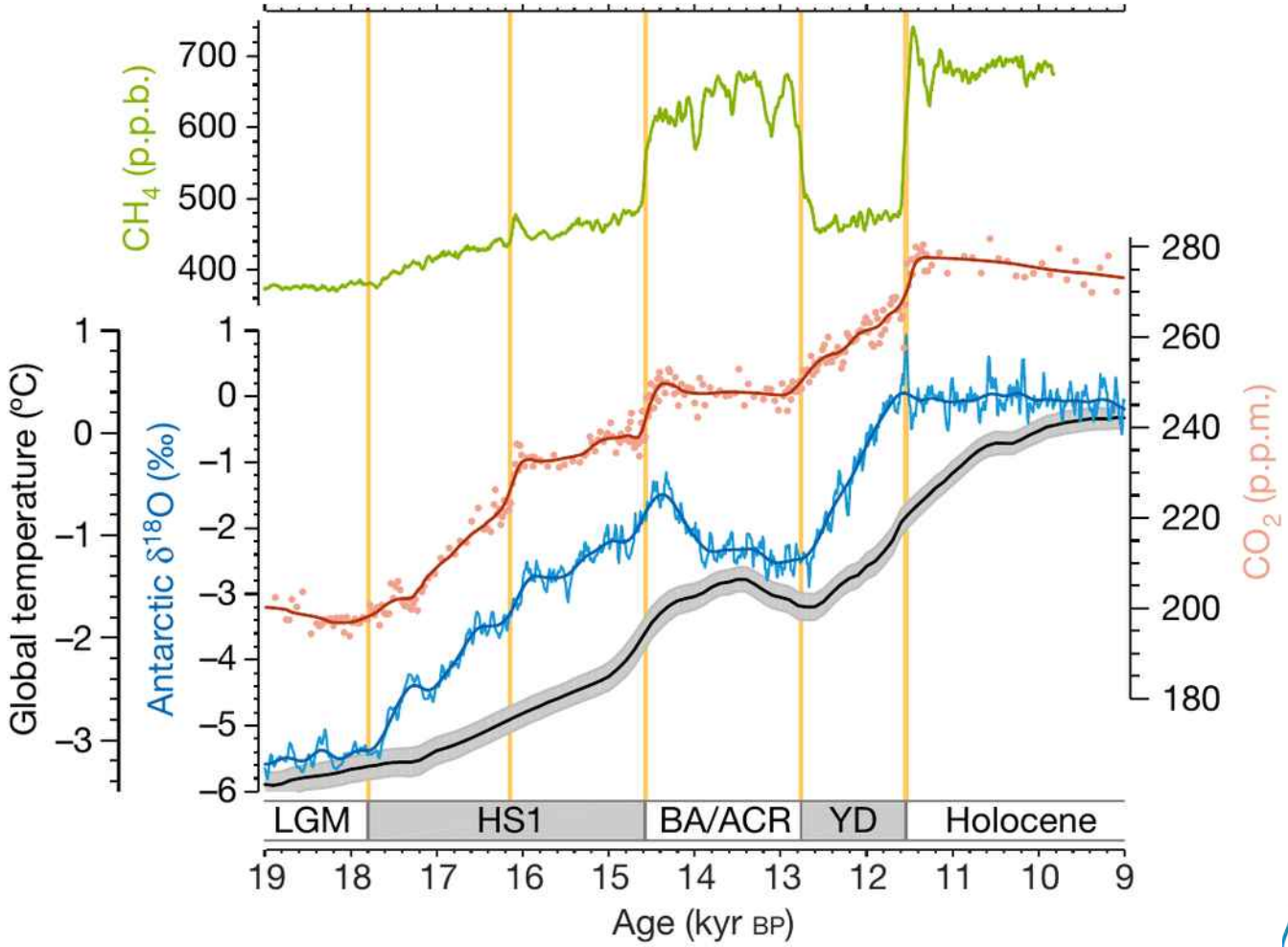
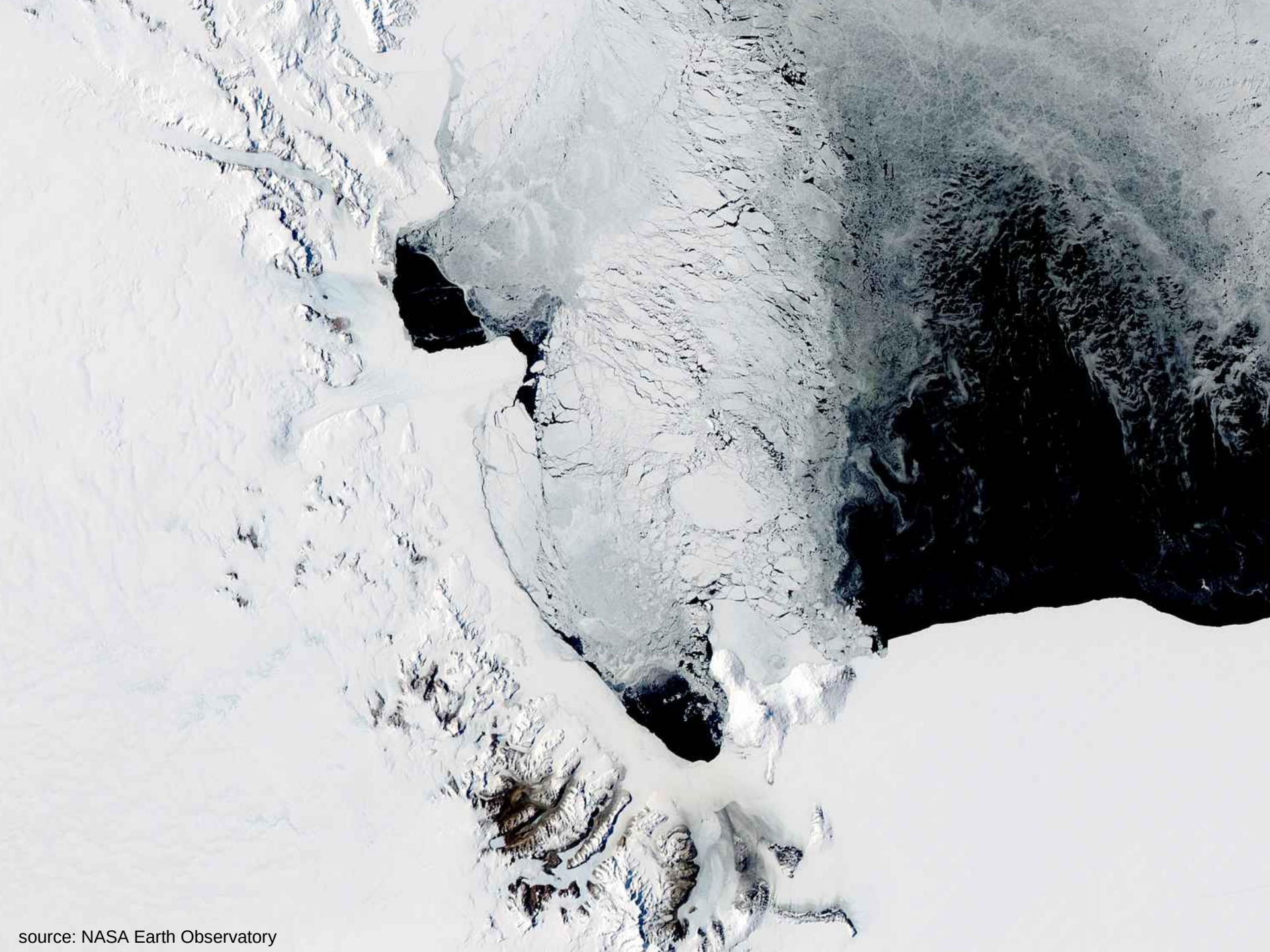
The deglaciation



Brook & Buizert (2018), Nature



source: NASA Earth Observatory

Today's Overview

- Ice cores for climate science
- The time machine
  - decay series dating
  - cosmogenic nuclide dating
  - application examples
  - surface exposure dating
- Abrupt climate change during the last glacial cycle
  - Dansgaard-Oeschger Events
  - Bipolar seesaw
  - Heinrich Events
  - Pa/Th proxy for ocean circulation rate

Outlook

Monday	Introduction	Earth History
Tuesday	Proxies I	Cenozoic Hot & Warm House
Wednesday	Specific Climate System components	Pleistocene G-IG climate
Thursday	Proxies II & Climate System Interactions	Abrupt Climate Change
Friday	Current Climate Change	Future & Synthesis