SPSAS Climate Change

São Paulo School of Advanced Science on Climate Change: Scientific basis, adaptation, vulnerability and mitigation

3-15 July 2017

Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, São Paulo, Brazil

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SPSAS Climate Change

Information from paleoclimate archives

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Outline

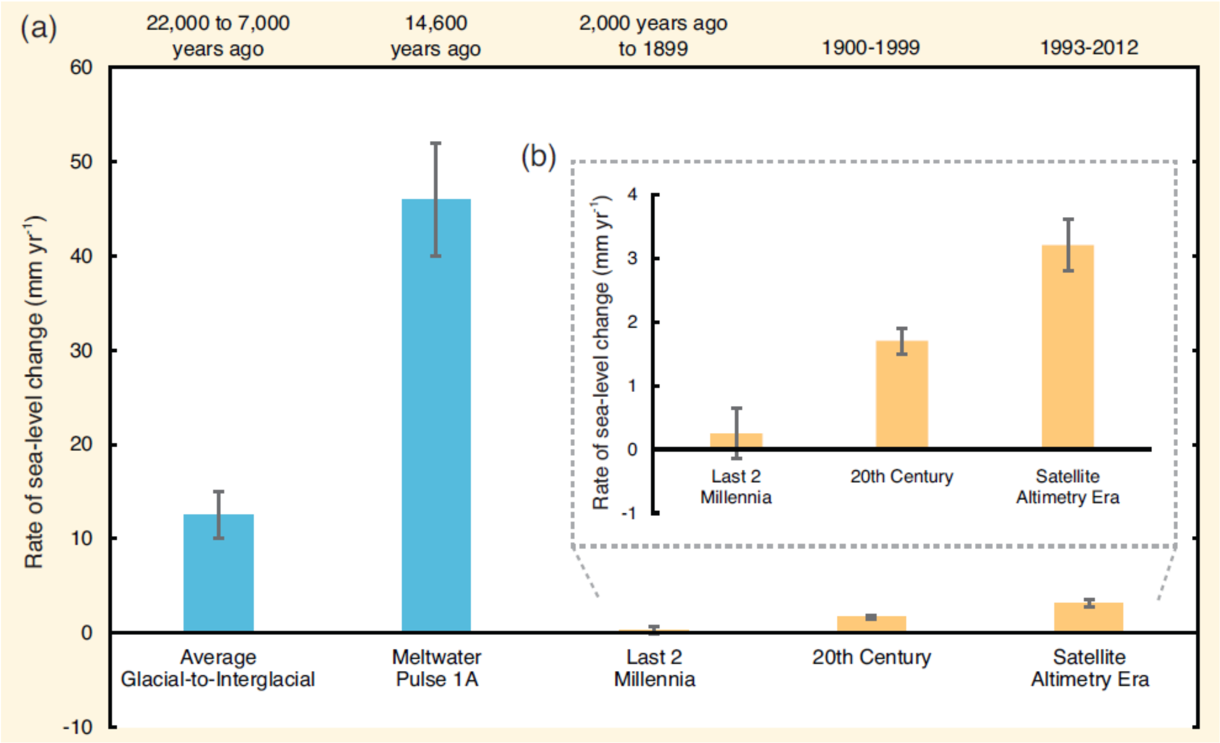
- Why study past climates?
- Main paleoclimate archives
- A selection of paleoclimate proxies
- Paleoclimate records: *the editor's cut*

Outline

- **Why study past climates?**
- **Main paleoclimate archives**
- **A selection of paleoclimate proxies**
- **Paleoclimate records: *the editor's cut***

Why study past climates?

1. **Past climates provide a longer-term perspective than the instrumental record on understanding the controls, magnitudes, and spatial/temporal aspects of climate change**

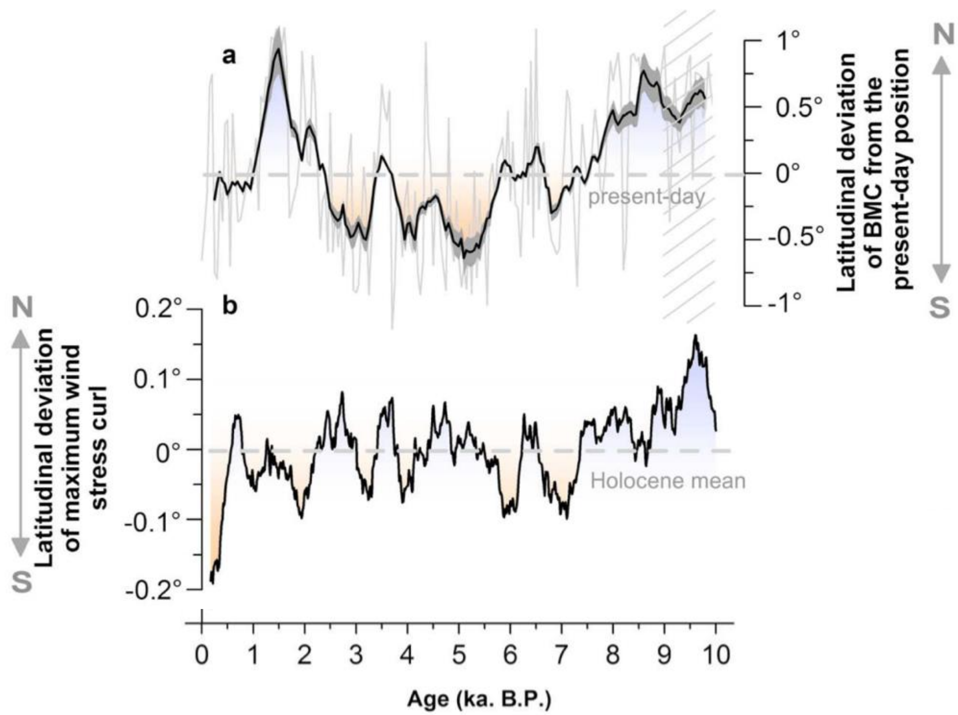


Mock (2007); Masson-Delmotte et al. (2013)

Current rate of mean global sea level change is unusual relative to the last 2 kyr
Higher rates occurred, but especially during glacial-interglacial transitions

Why study past climates?

2. **Testing the accuracy (validating) of general circulation models by comparing hindcasts to paleoclimate archives**



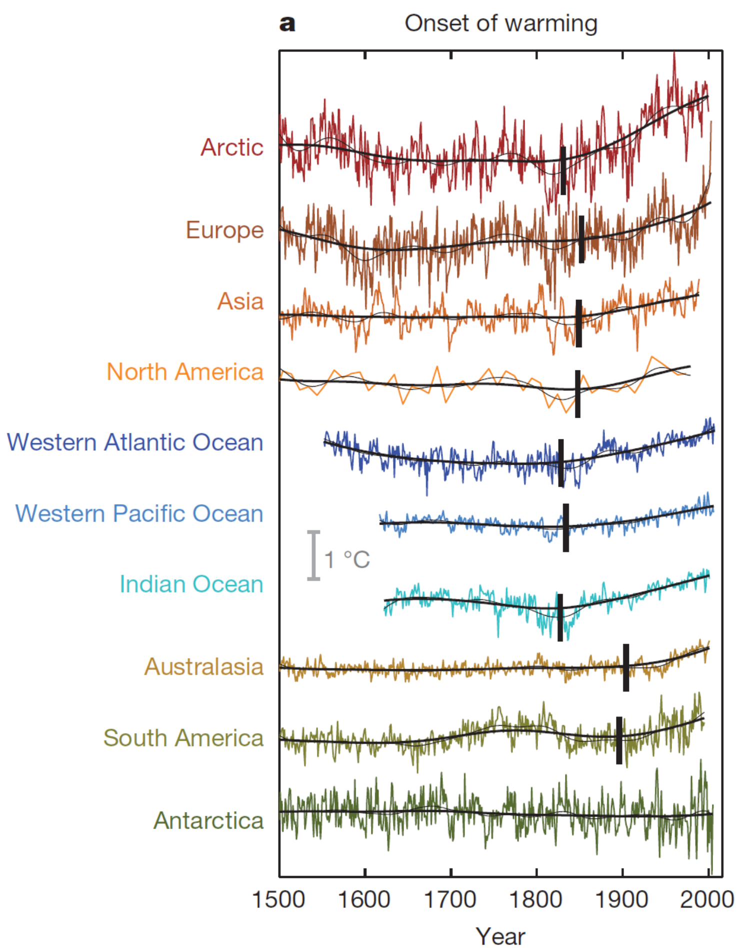
Mock (2007); Voigt et al. (2015)

Proxy-inferred and modeled SWW shifts compare qualitatively, but the model underestimates SWW variability by an order of magnitude

The underestimated natural variability implies a substantial uncertainty in mode projections of future SWW shifts

Why study past climates?

3. **Past climates provide long records of natural climate variability that allow a clear understanding of natural climatic variability, and decoupling natural from anthropogenic variability**



Mock (2007); Abram et al. (2016)

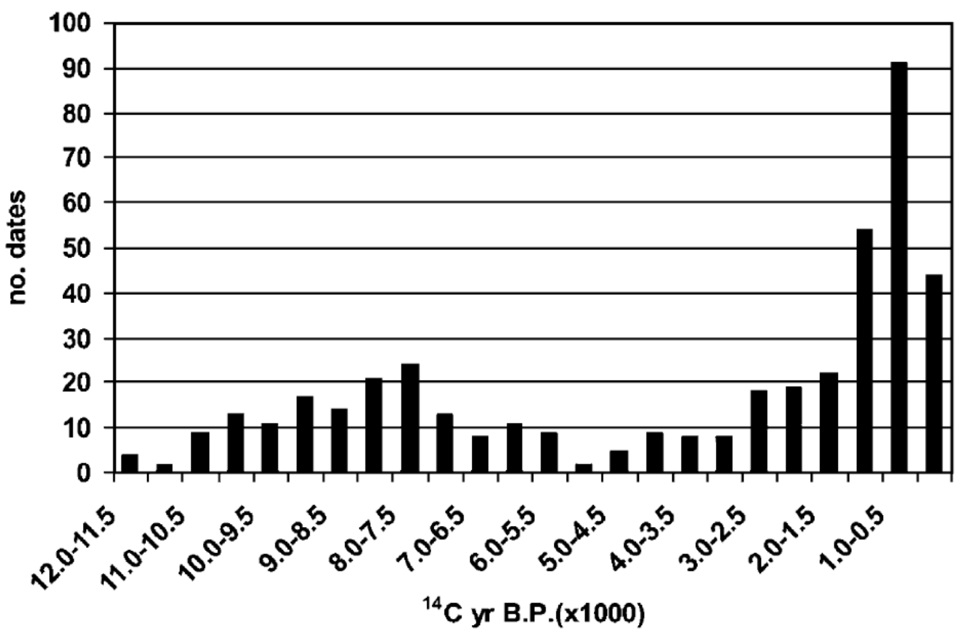
Instrumental records are too short to comprehensively assess anthropogenic climate change

In some regions, about 180 years of industrial-era warming has already caused surface temperatures to emerge above pre-industrial values

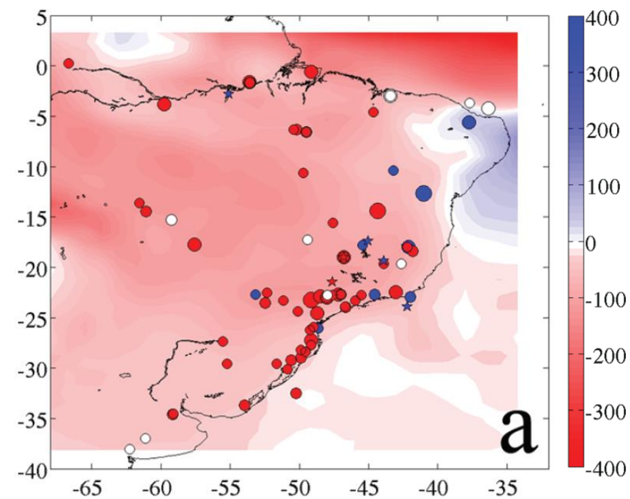
Why study past climates?

4. Past climates provide detailed records to understand the role of climate change on ecosystems and society

Archaeological ages for central Brazil



MH-PI precipitation anomalies from PMIP3/CMIP5 and paleoclimate archives



Mock (2007); Araujo et al. (2005); Prado et al. (2013)

Mid Holocene depopulation in central Brazil is most likely related to a negative precipitation anomaly

Why study past climates?


nature geoscience

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NATURE GEOSCIENCE | COMMENTARY

Climate change narratives

Richard D. Pancost

Nature Geoscience **10**, 466–468 (2017) | doi:10.1038/ngeo2981

Published online 26 June 2017

Reconstructions of Earth's past are much more than benchmarks for climate models

They also help us comprehend risk by providing concrete narratives for diverse climates

Pancost (2017)

Why study past climates?

Paleoclimatology and paleoceanography are interdisciplinary fields of research that involve a multiscale (spatial and temporal) approach

Archaeology
Climatology
Ecology
Environmental chemistry
Geomorphology
Glaciology
Limnology
Paleontology
Palynology
Oceanography
Pedology
Sedimentology
Vulcanology

Outline

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- **Main paleoclimate archives**
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Main paleoclimate archives

Sediment cores

Ice cores

Tree rings

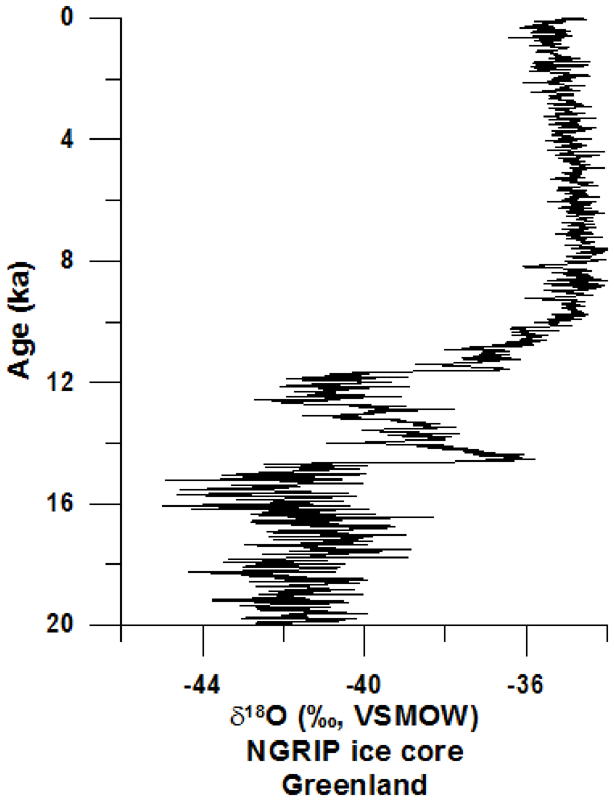
Corals

Speleothems

Main paleoclimate archives

A good paleoclimate archive should meet certain criteria

1. Its physical, chemical or biological properties must represent environmental conditions



NGRIP Members (2004)

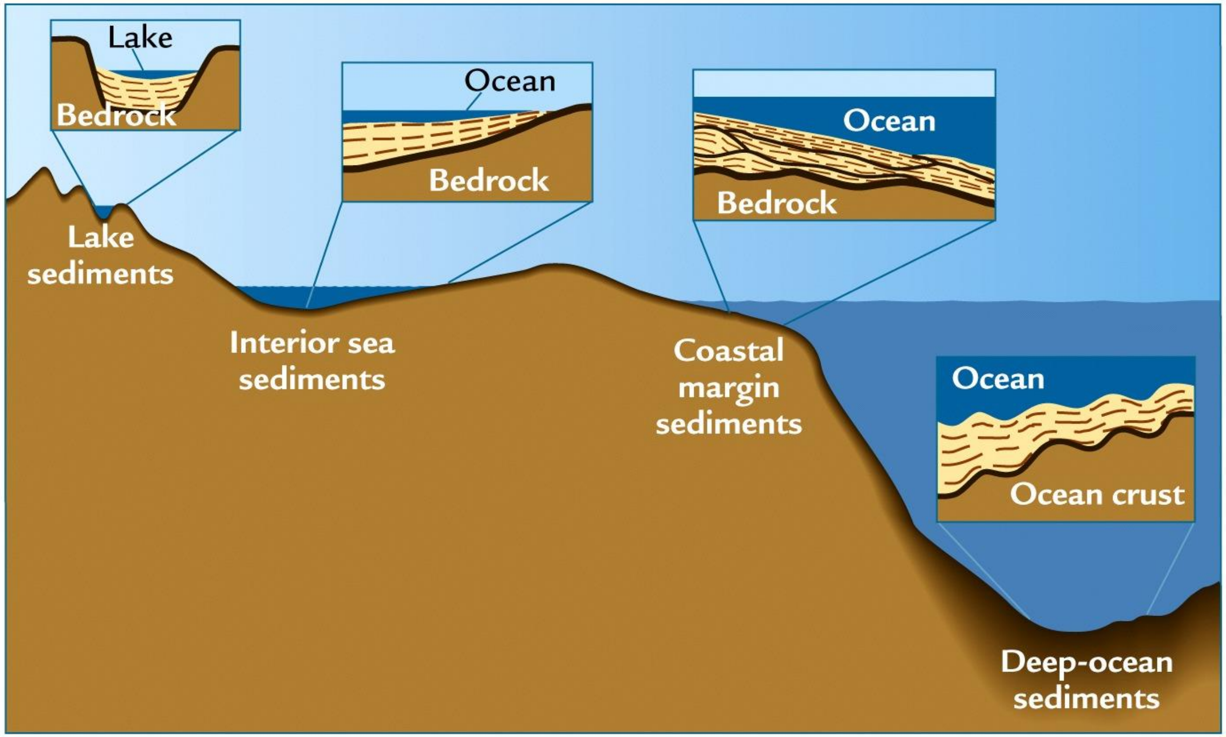
Main paleoclimate archives

A good paleoclimate archive should meet certain criteria

2. **It must be possible to determine the age of deposition/formation of the paleoclimate archive**

Main paleoclimate archives

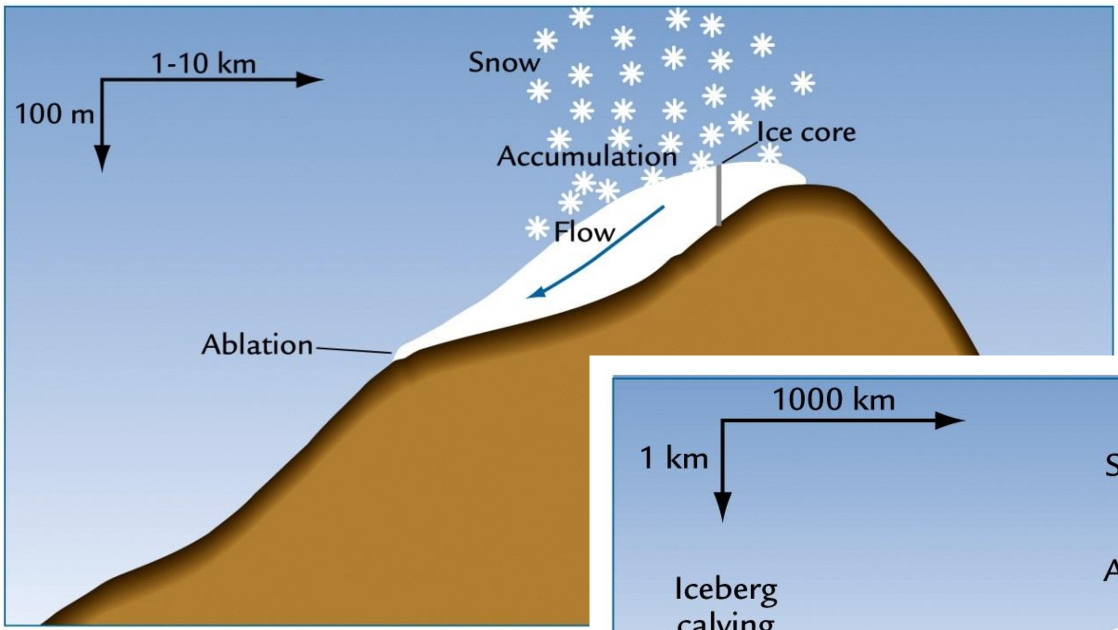
Sediments are transported as particulate or dissolved matter and deposited in sedimentary basins (continental or marine) forming potential paleoclimate archives



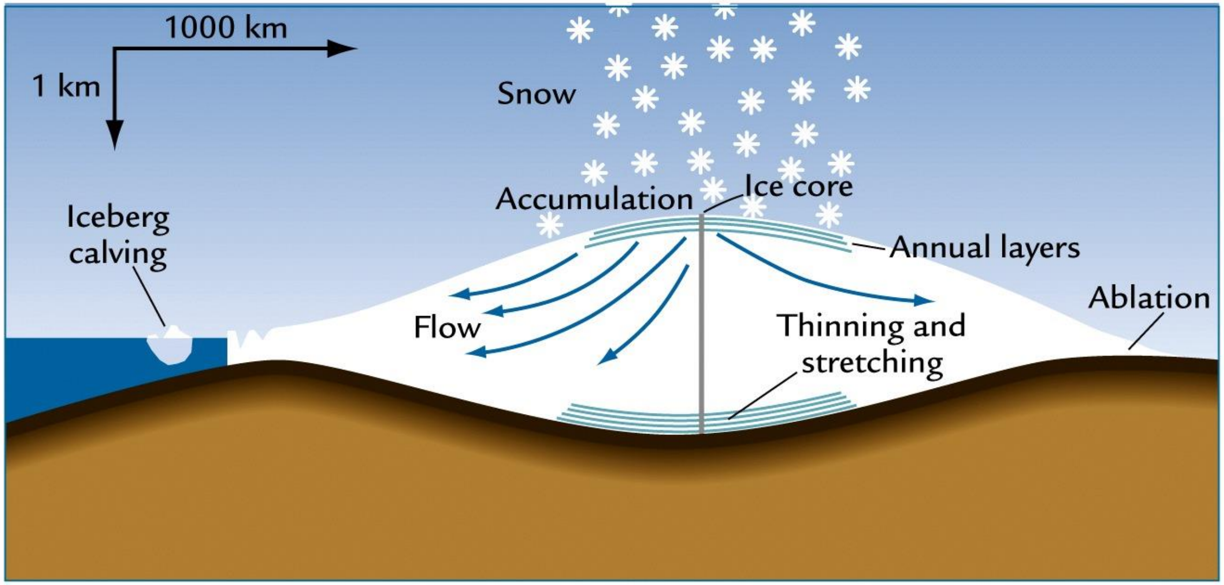
Ruddiman (2014)

Main paleoclimate archives

Snow accumulates in cold regions to form ice and accumulation mainly occurs in high latitudes or altitudes potentially giving rise of paleoclimate archives



Mountain glaciers



Continental glaciers

Ruddiman (2014)

Main paleoclimate archives

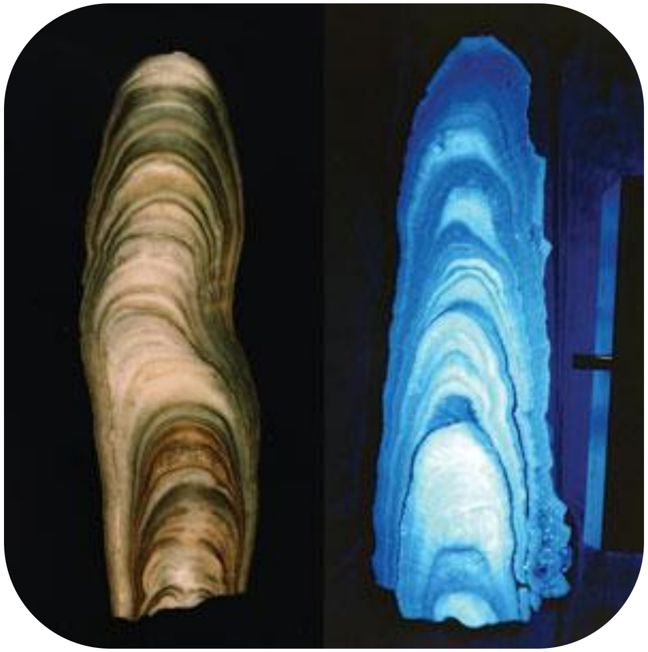
Tropical and subtropical clear waters may be suitable for the growth of corals and some build layered skeletons suitable as paleoclimate archives

Main paleoclimate archives

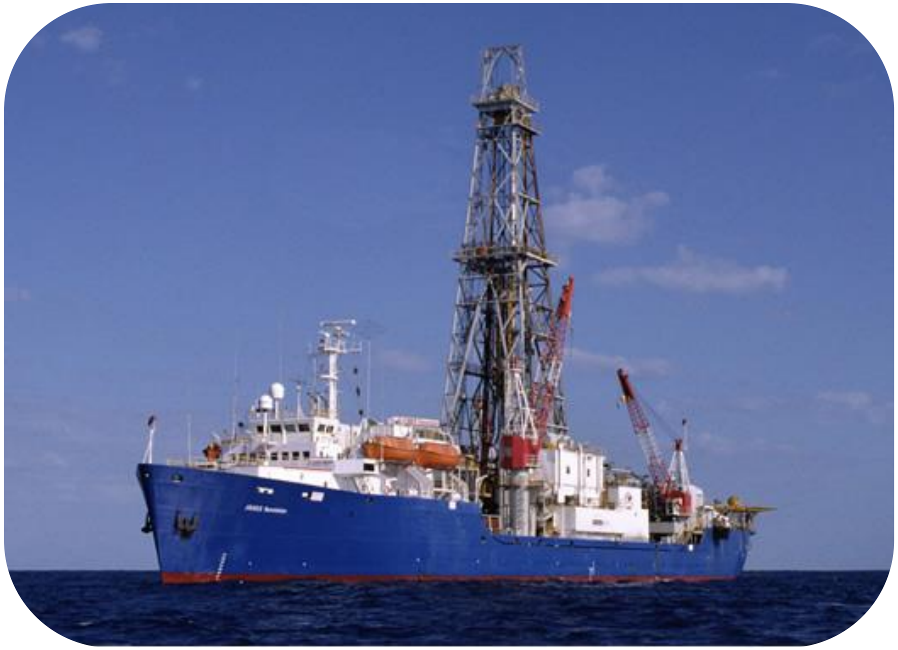
Trees growth by adding rings to the trunk, and mid-latitude trees under strong seasonality show great potential as paleoclimate archives

Main paleoclimate archives

Stalagmites growth by the deposition of layers; in caves with stable environmental conditions, the chemical composition of these layers may record regional climate parameters constituting good paleoclimate archives



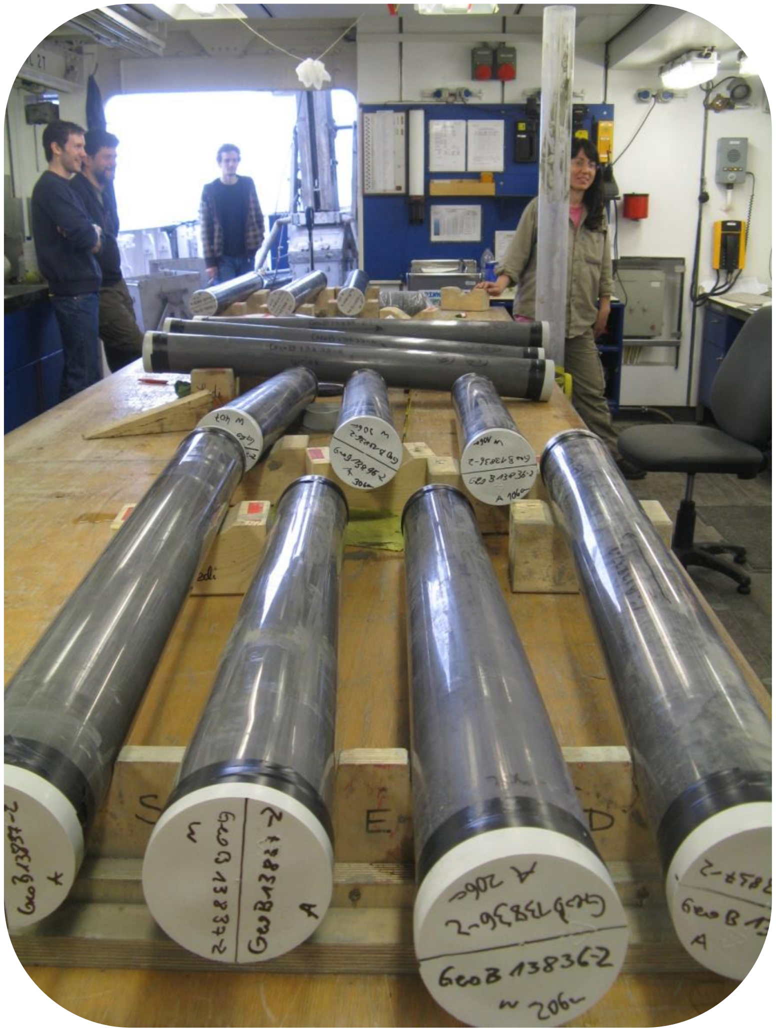
Main paleoclimate archives – *an insight into marine cores*



Gravity corer

- **Up to ~12m**
- **No water depth limitation**
- **"Easy" operation**
- **High efficiency**
- **Large diameter (~12cm)**
- **Short ship time**

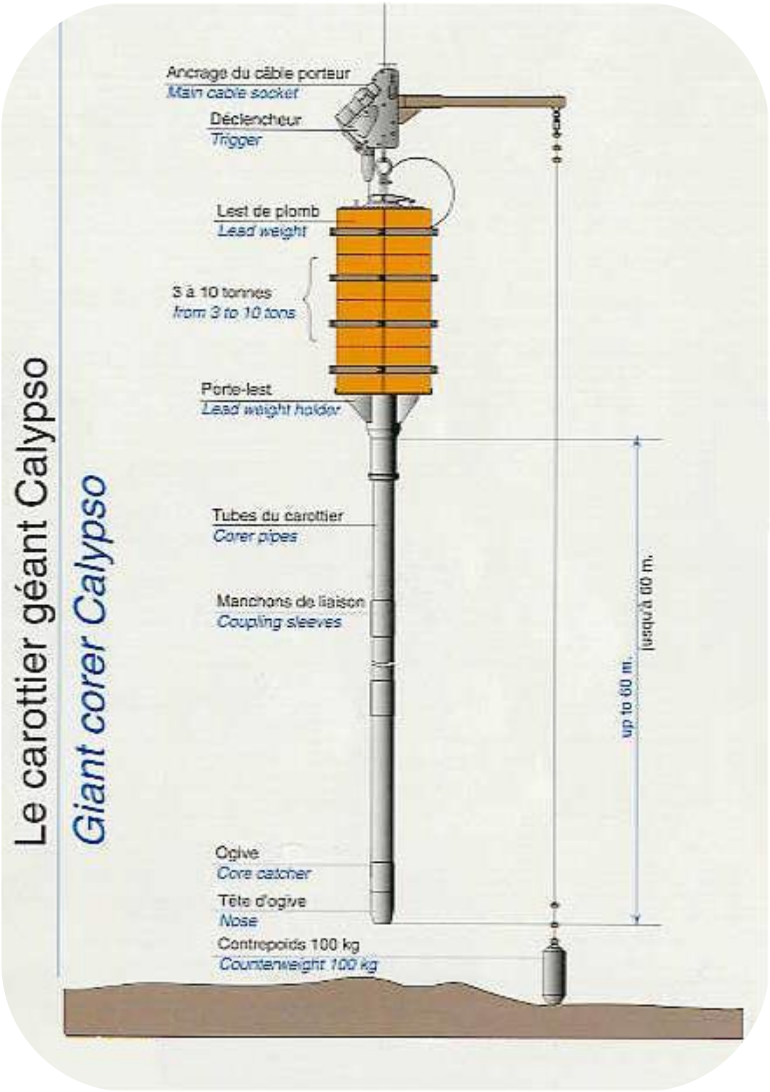
Main paleoclimate archives – *an insight into marine cores*



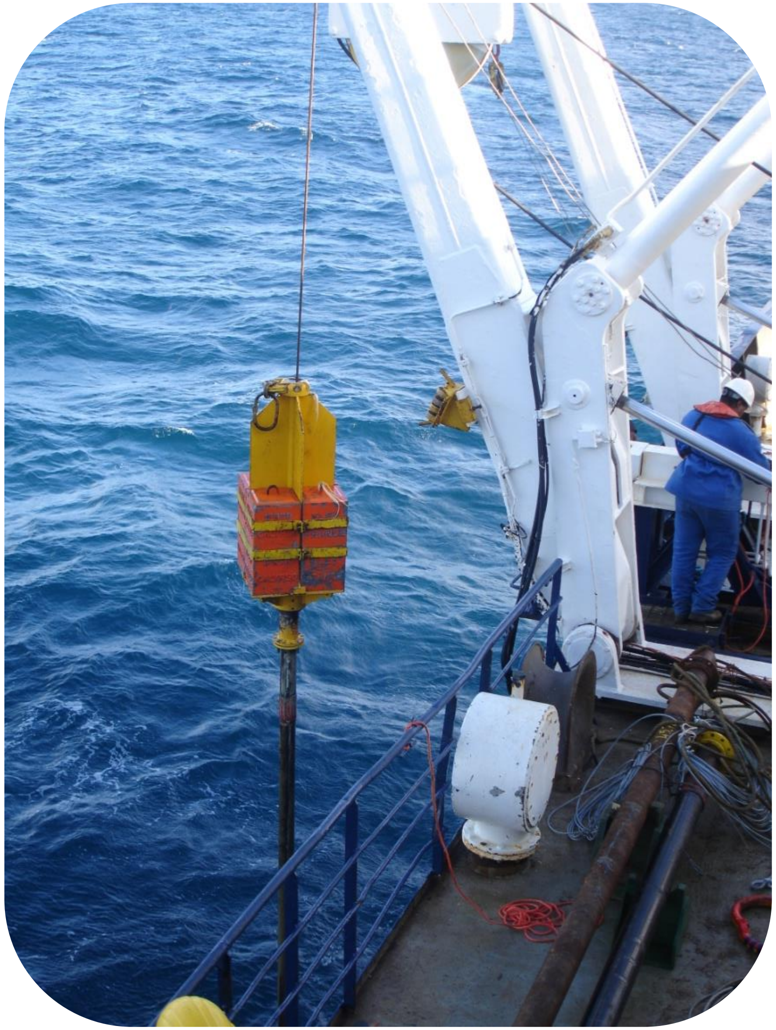
Main paleoclimate archives – *an insight into marine cores*

Giant piston corer (Calypso)

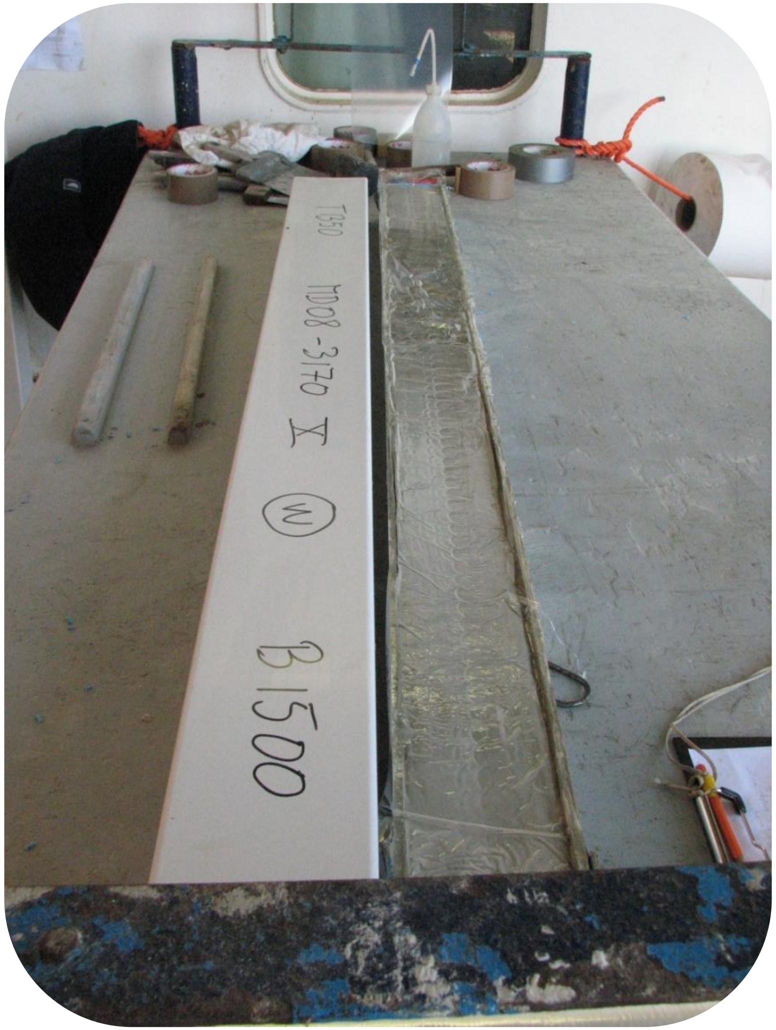
•Up to ~65m
•No water depth limitation
•Relatively complex operation
•Medium to high efficiency (*gaps*)
•Large diameter (~12cm)
•Short ship time



Main paleoclimate archives – *an insight into marine cores*



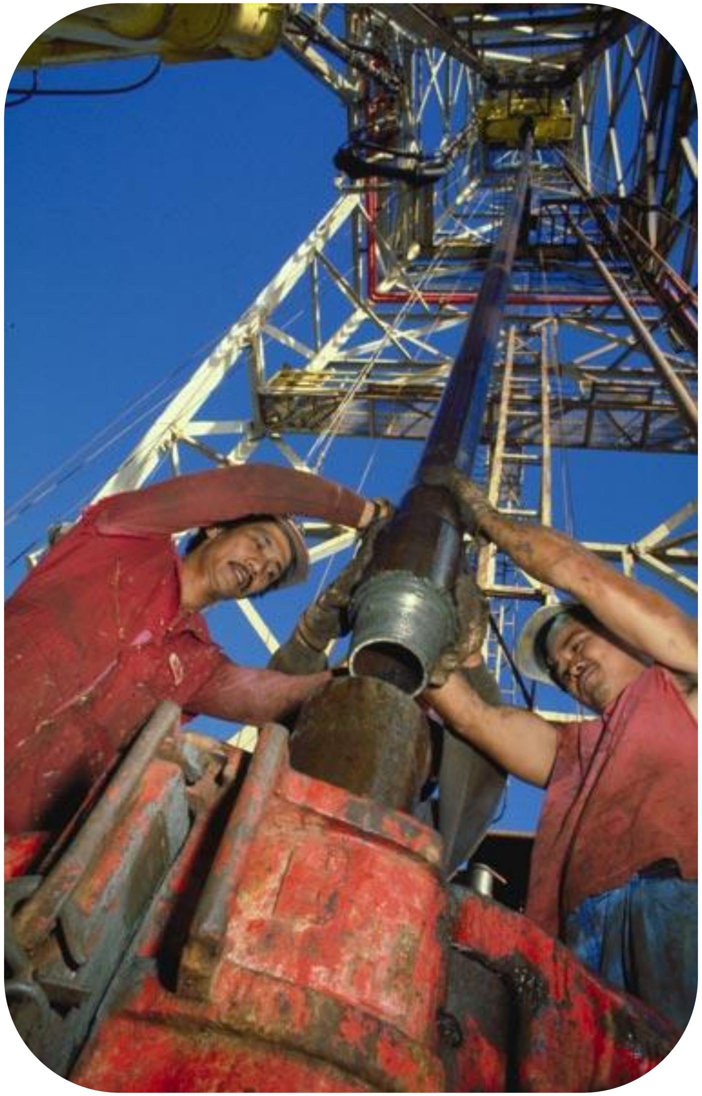
Main paleoclimate archives – *an insight into marine cores*



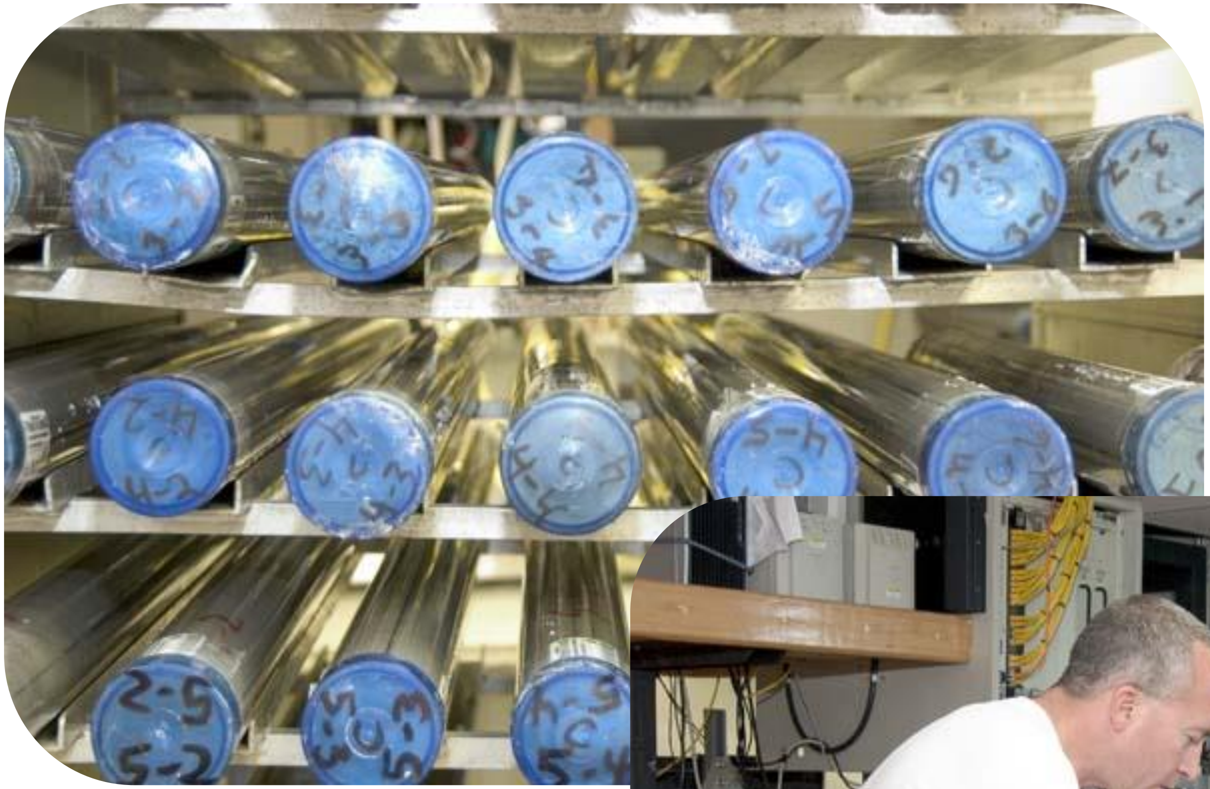
Main paleoclimate archives – *an insight into marine cores*

Drilling device (ship based)

- Hundreds of m
- No water depth limitation
- Highly complex operation
- Medium to high efficiency
- Small diameter (~6cm)
- Long ship time



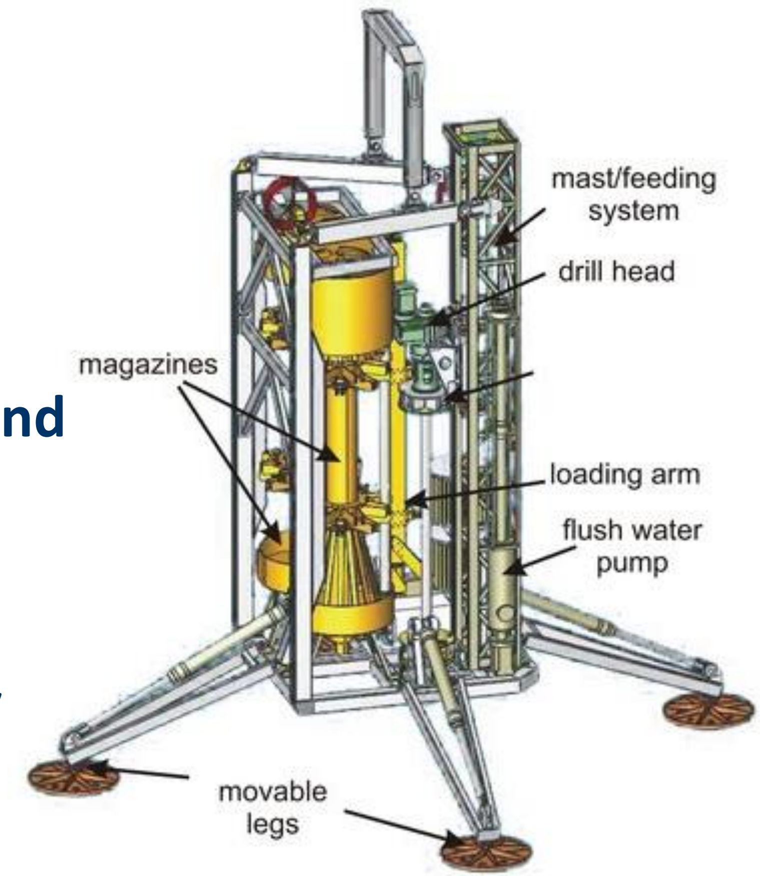
Main paleoclimate archives – *an insight into marine cores*

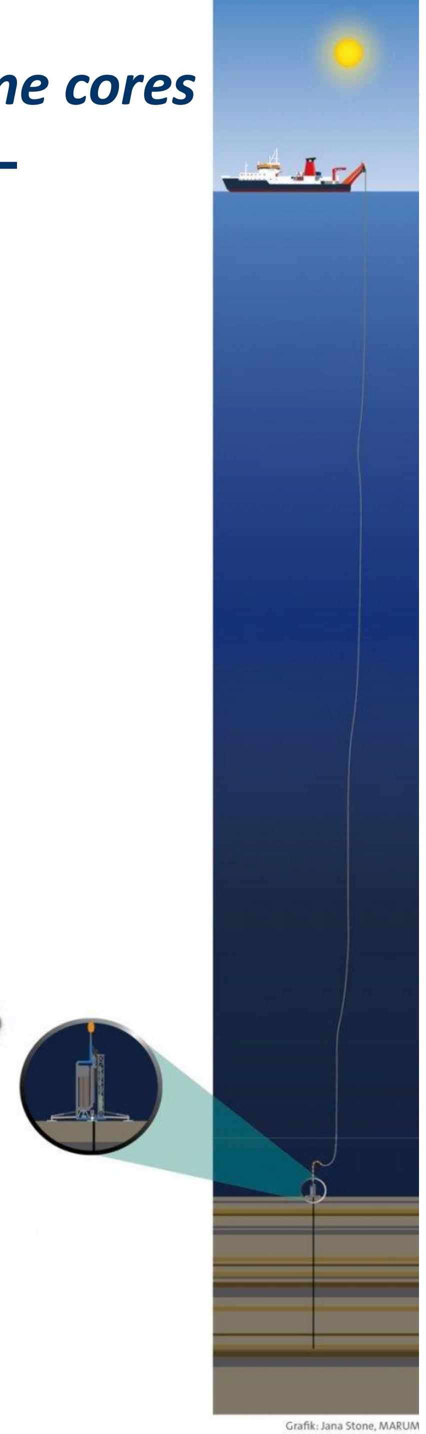


Main paleoclimate archives – *an insight into marine cores*

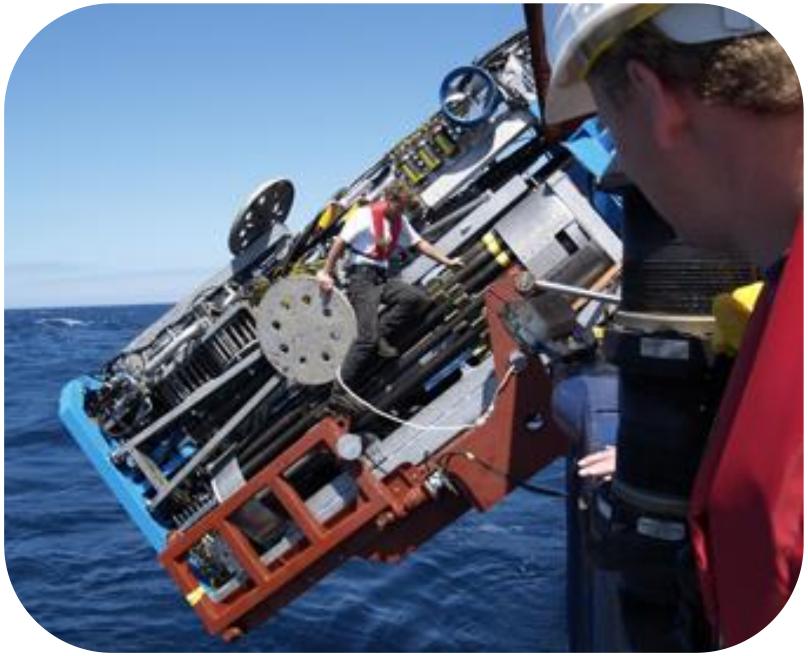
Drilling device (in situ)

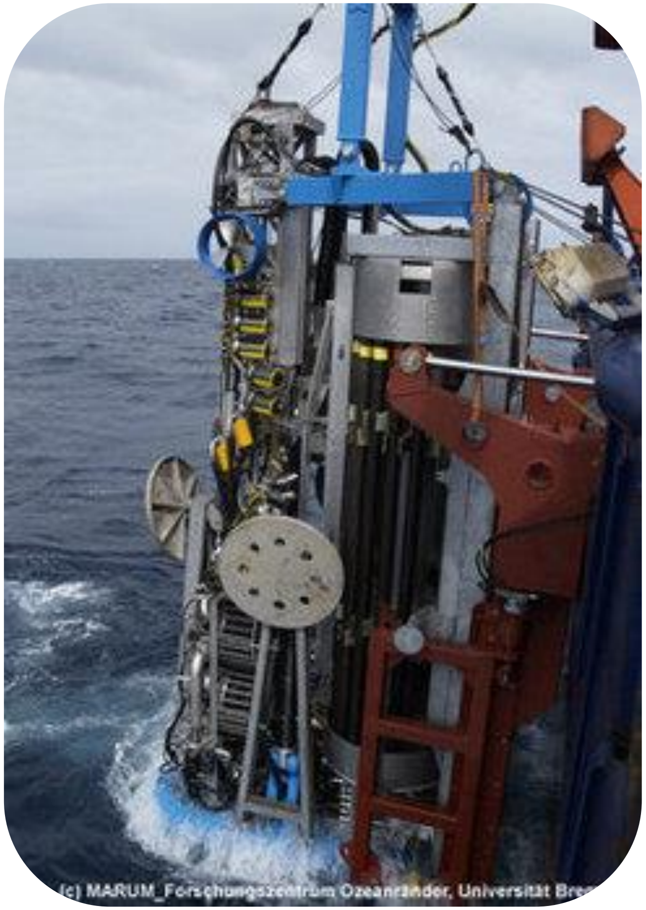
- **Up to 70 m**
- **Operation between 200 and 2000m**
- **Medium to high complex operation**
- **Medium to high efficiency**
- **Small diameter**
- **Long ship time**





Main paleoclimate archives – *an insight into marine cores*





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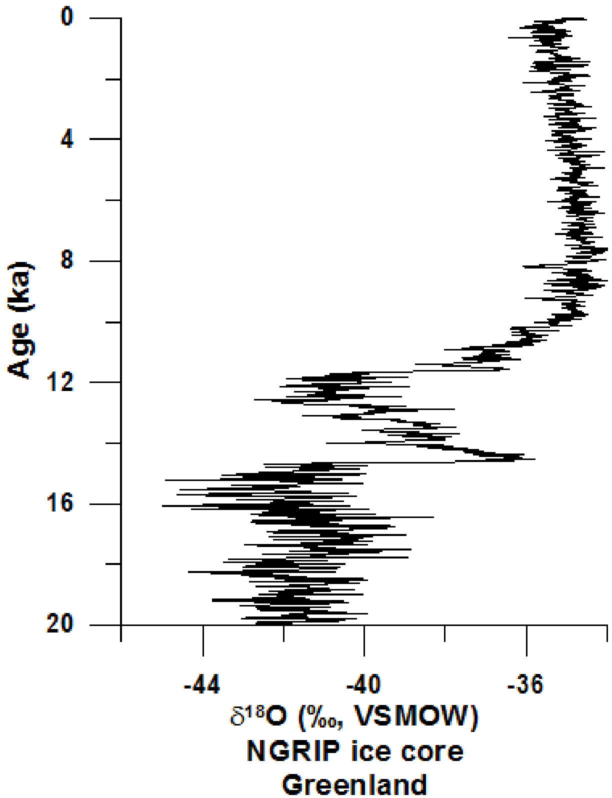
A selection of paleoclimate proxies

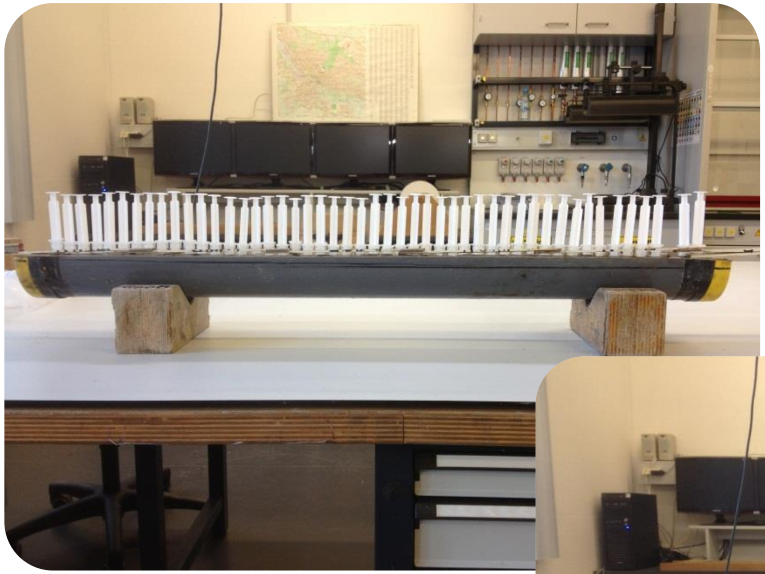
A good paleoclimate archive should meet certain criteria

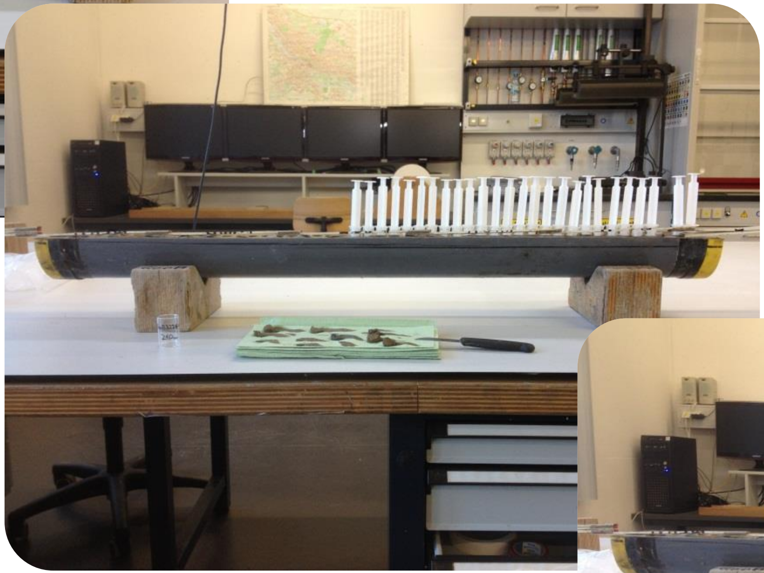
1. Its physical, chemical or biological properties must represent environmental conditions

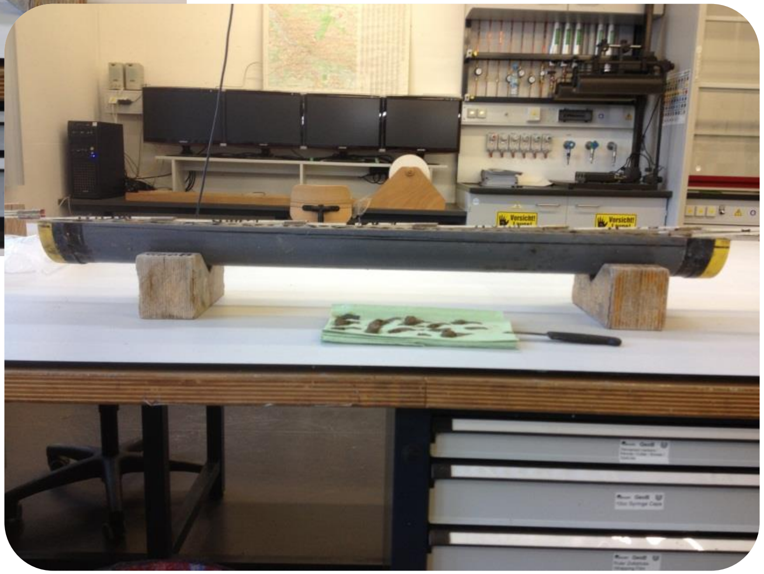


NGRIP Members (2004)

A selection of paleoclimate proxies

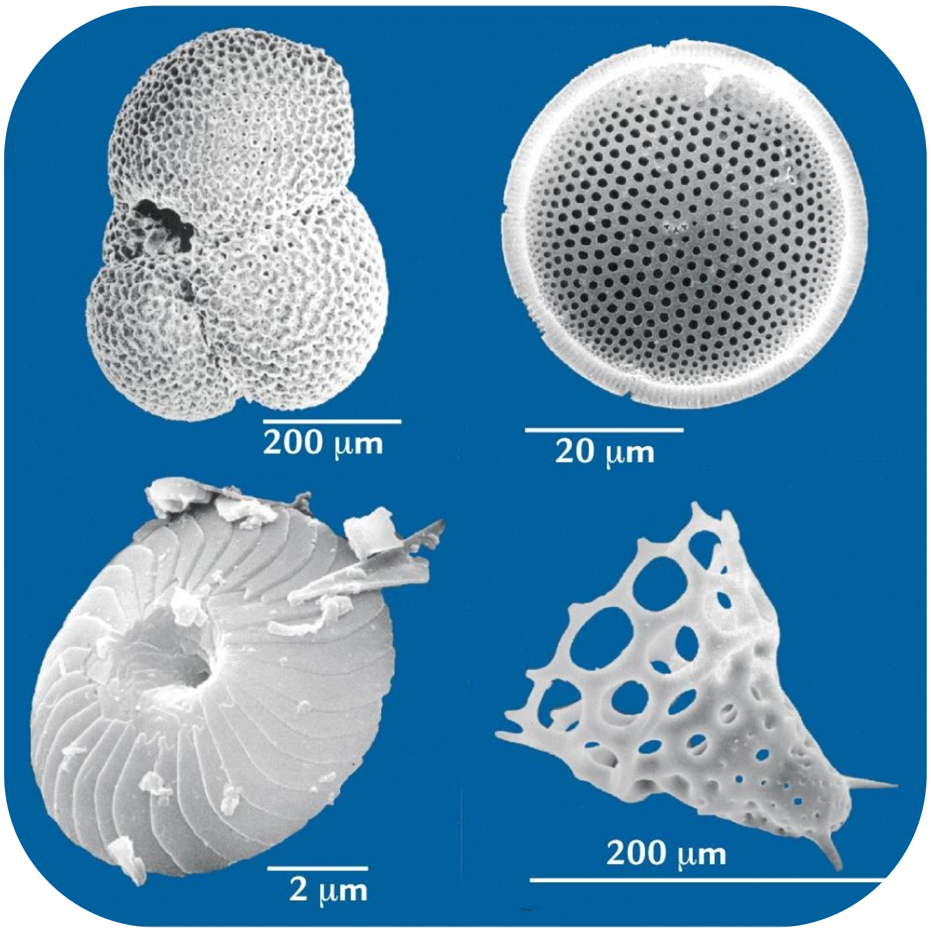






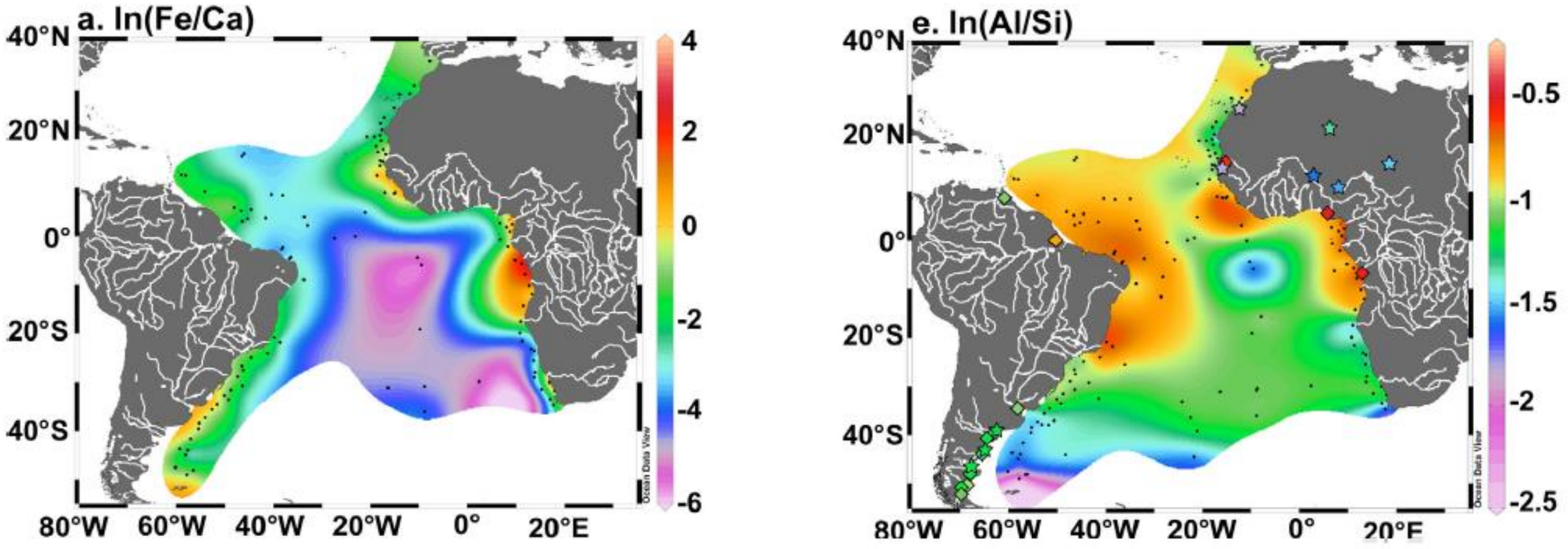
A selection of paleoclimate proxies

Autochtonous vs. alloctonous sediments



Ruddiman (2014)

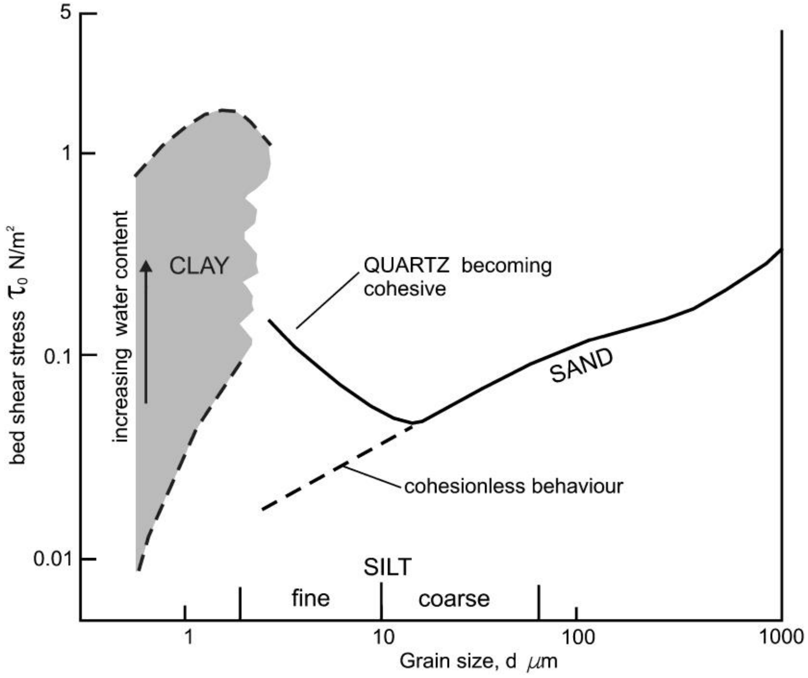
• Major elements in bulk sediment

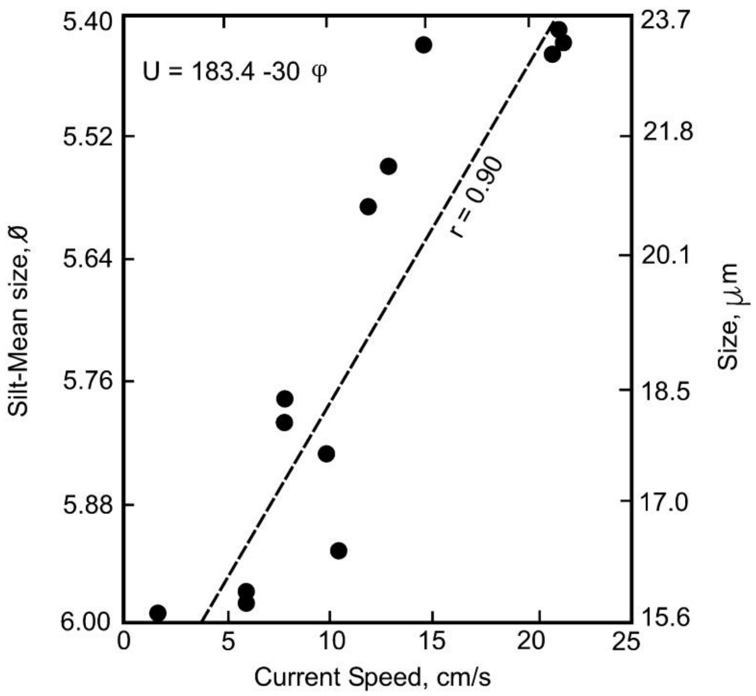


Govin et al. (2012)

A selection of paleoclimate proxies

• **Grain size distribution of the terrigenous fraction**

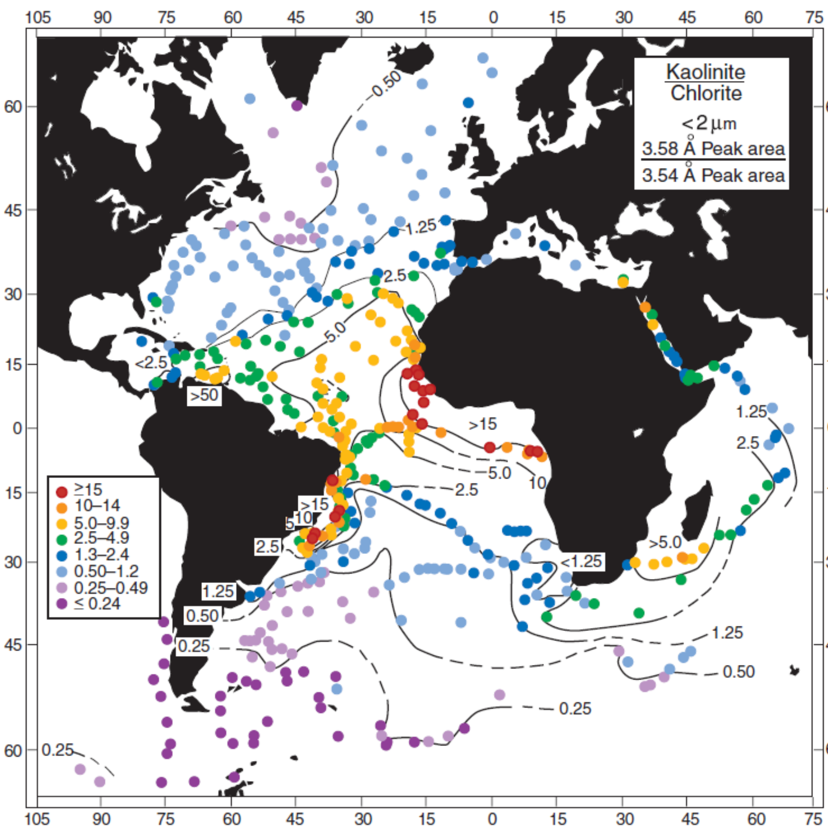


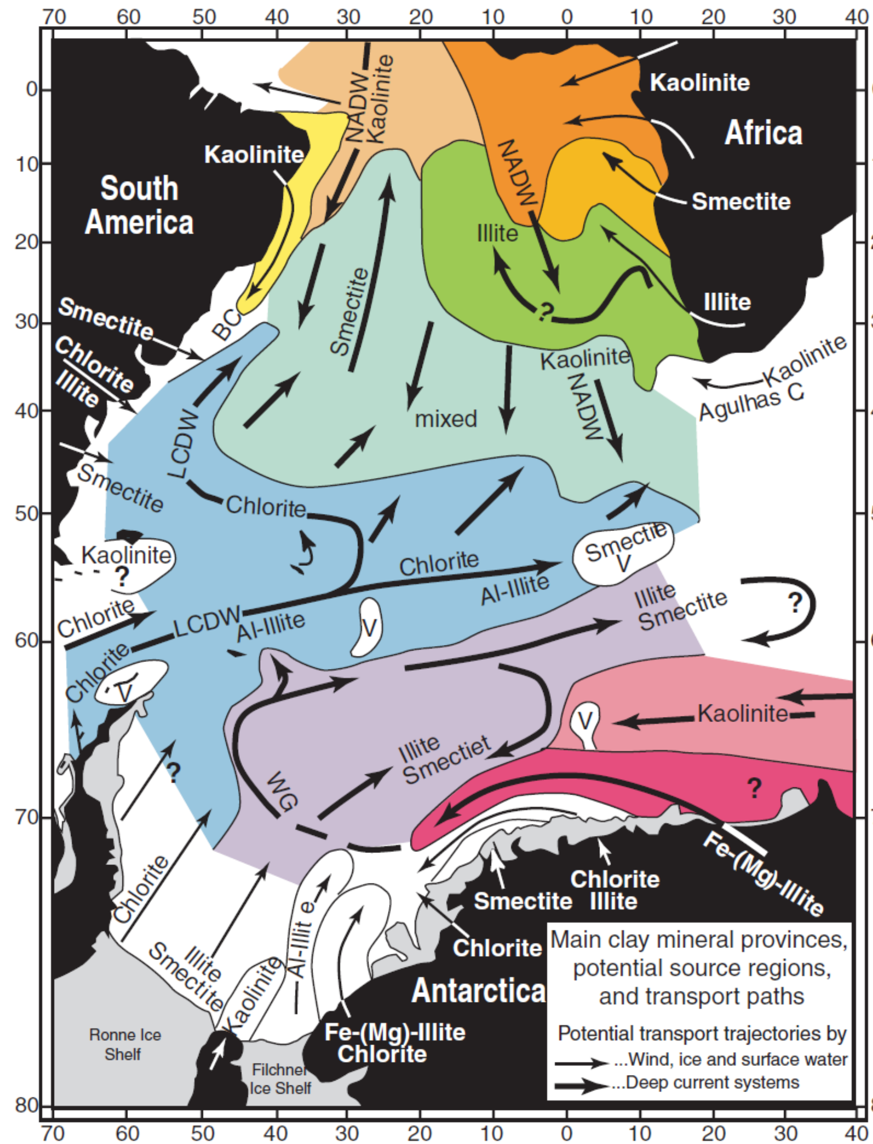


McCave (2007)

A selection of paleoclimate proxies

- Clay minerals assemblage

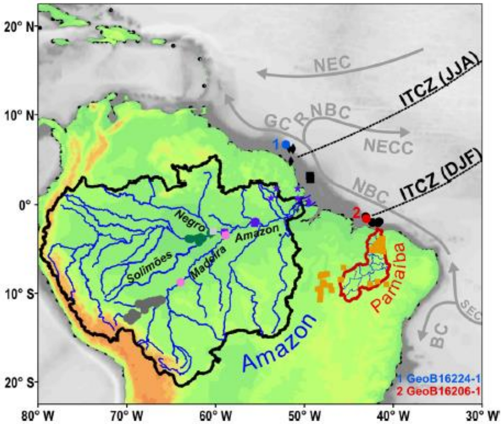


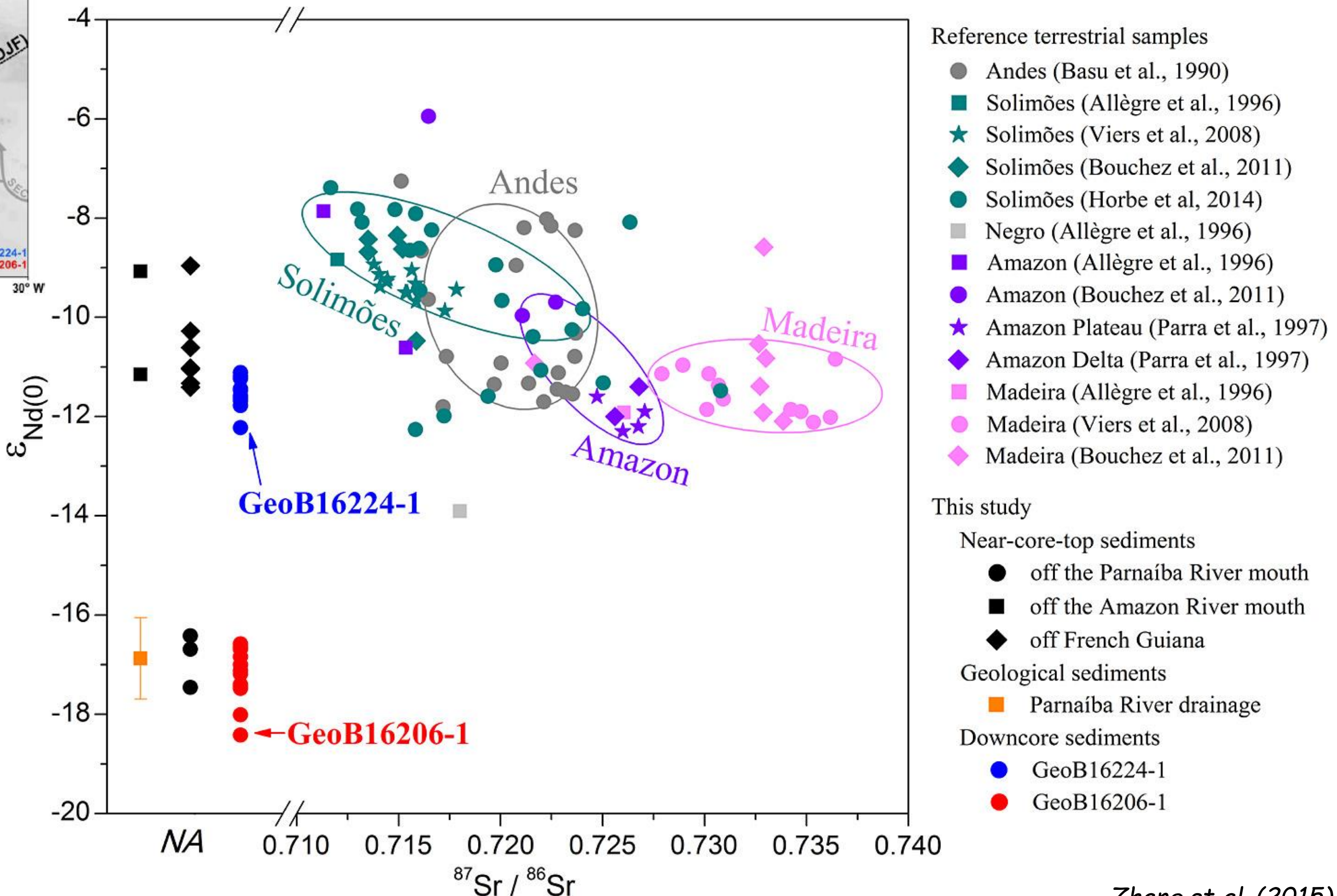


Biscaye (1965), Petschick et al. (1996)

A selection of paleoclimate proxies

- **Nd isotopes in the terrigenous fraction**

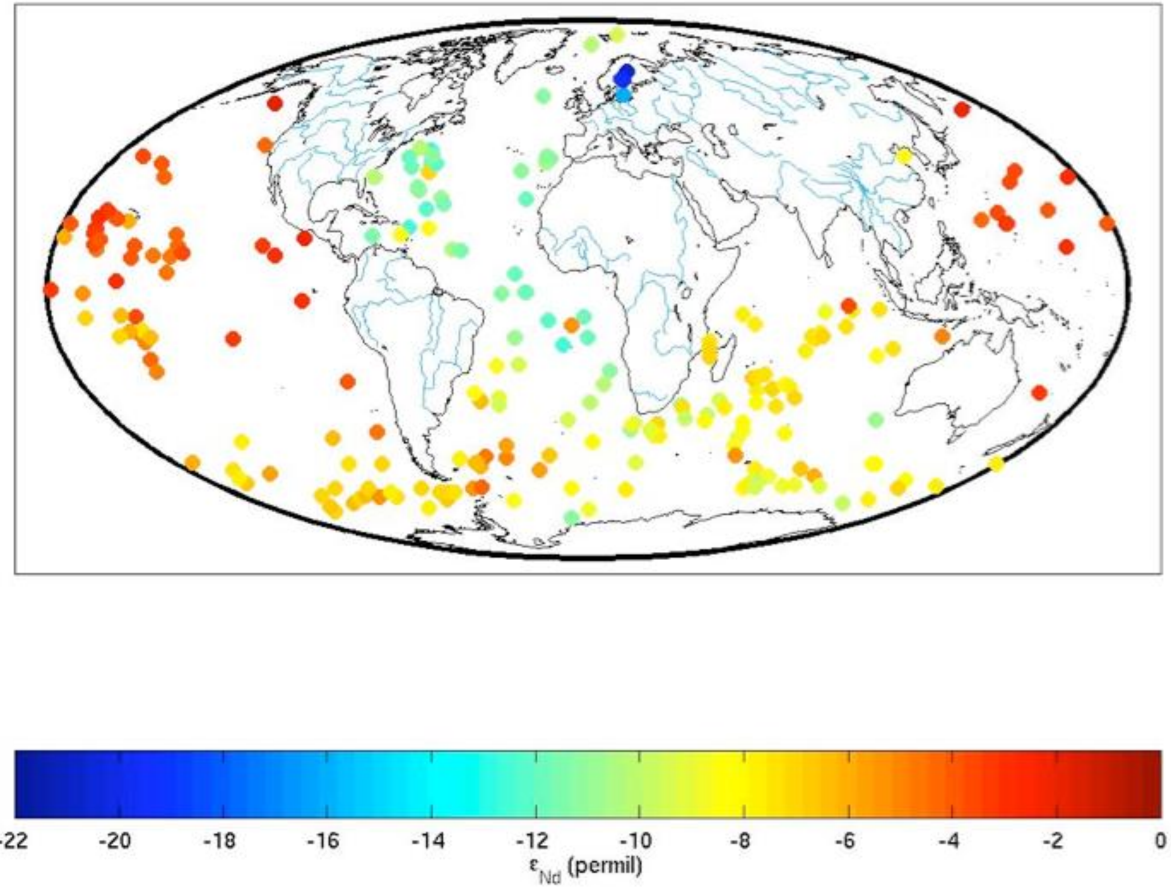




Zhang et al. (2015)

A selection of paleoclimate proxies

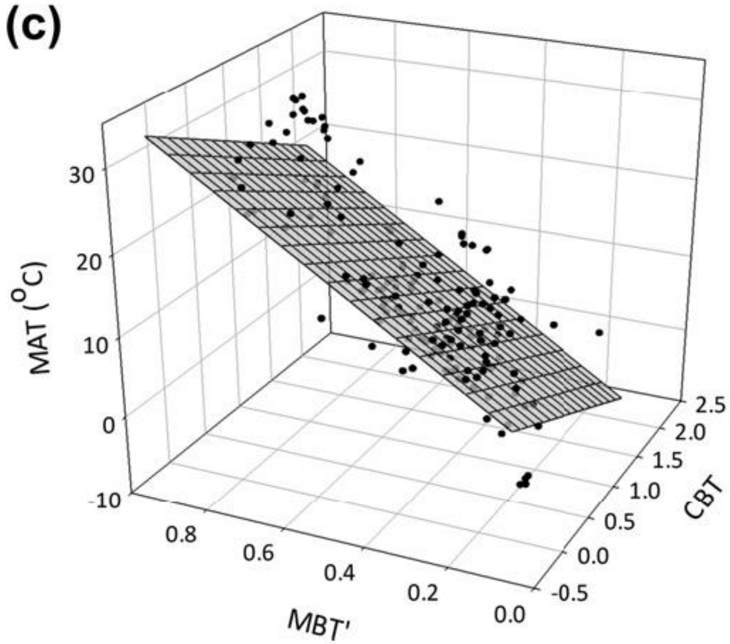
- **Nd isotopes in autochtonous fractions**



Frank (2002)

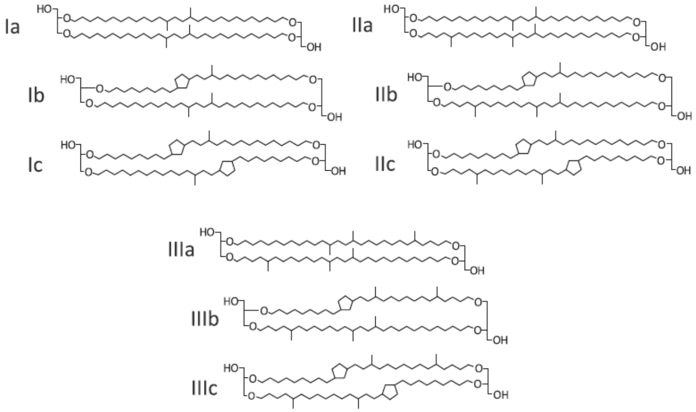
A selection of paleoclimate proxies

•**Biomarkers**



MATs reconstructed via branched glycerol dialkyl glycerol tetraethers (GDGTs) analyses

Global soil calibration

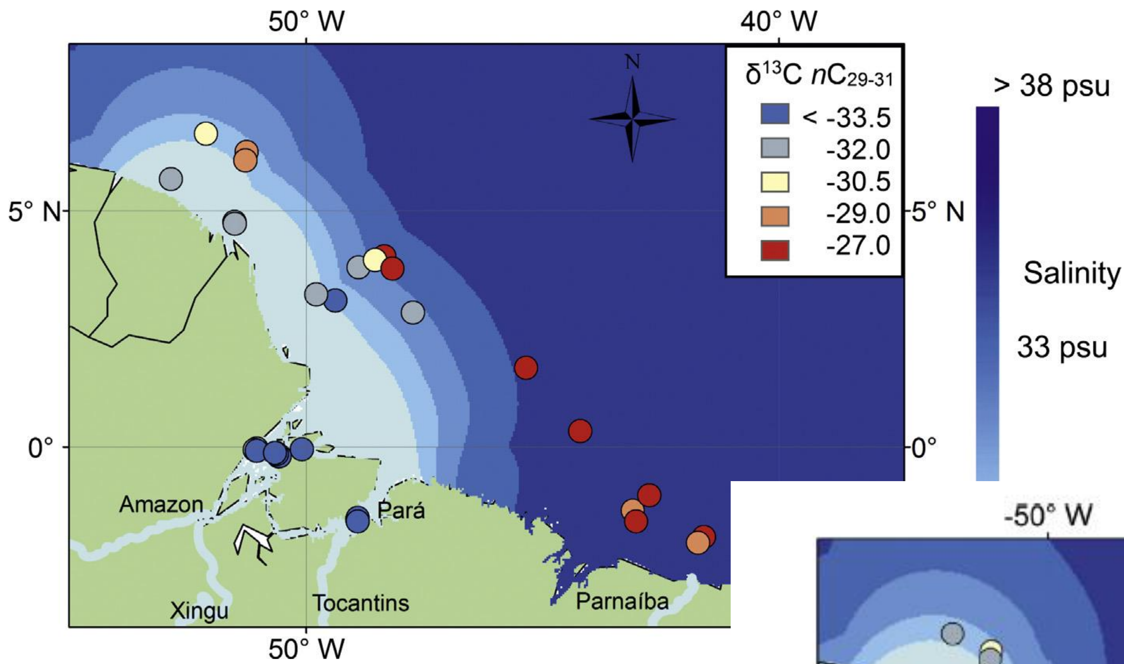


Branched GDGTs

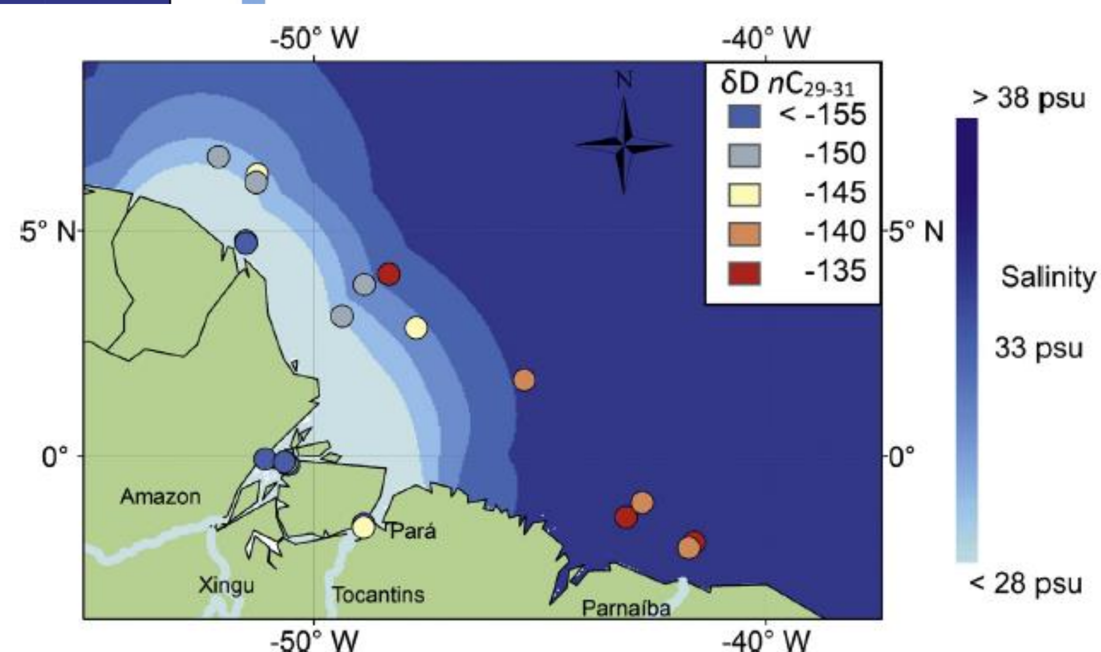
Peterse et al. (2012)

A selection of paleoclimate proxies

- **Biomarkers**



Long-chain n-alkane (plant wax) $\delta^{13}C$ and δD

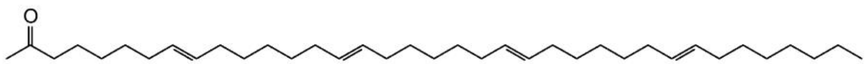


Häggi et al. (2016)

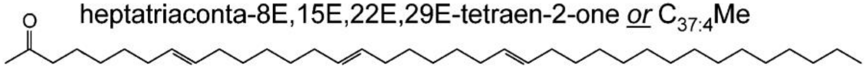
A selection of paleoclimate proxies

•Biomarkers

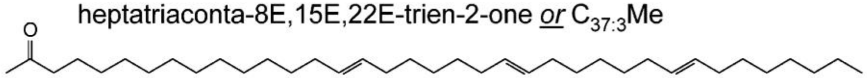
A) Alkenones:



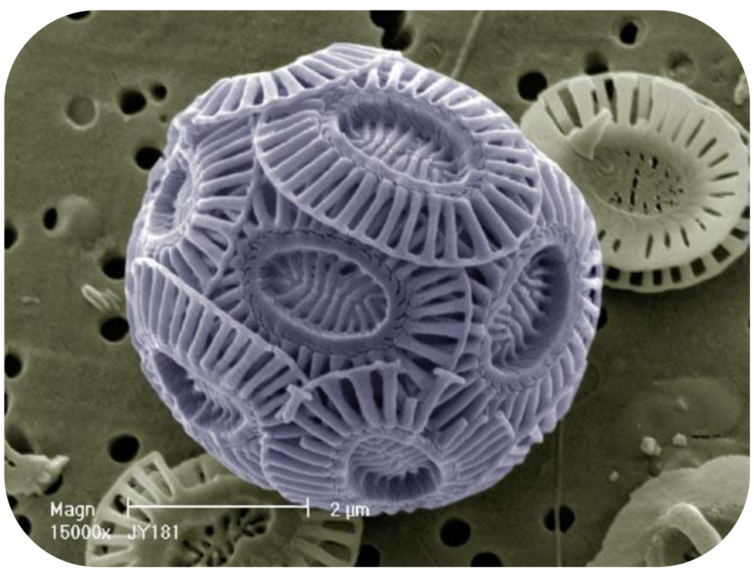
heptatriaconta-8E,15E,22E,29E-tetraen-2-one *or* $C_{37:4}Me$

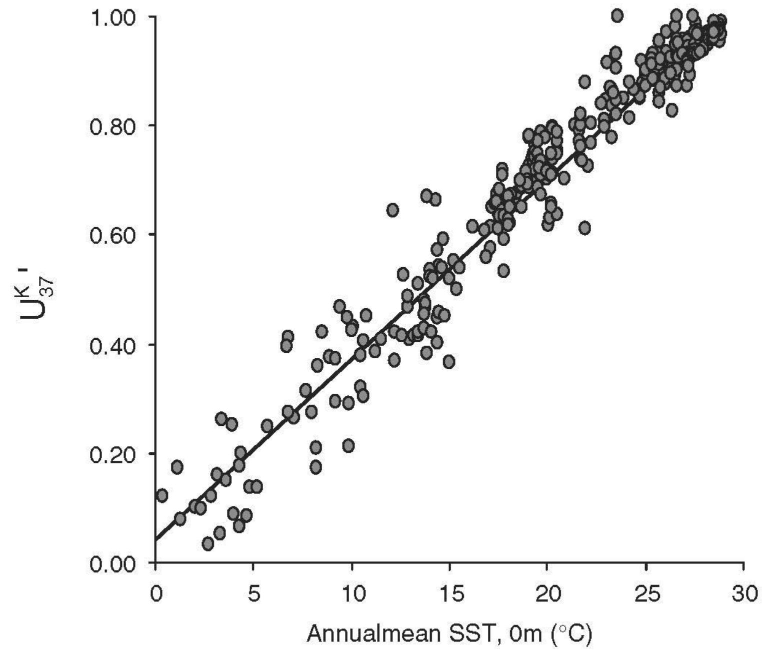


heptatriaconta-8E,15E,22E-trien-2-one *or* $C_{37:3}Me$



heptatriaconta-15E,22E-dien-2-one *or* $C_{37:2}Me$

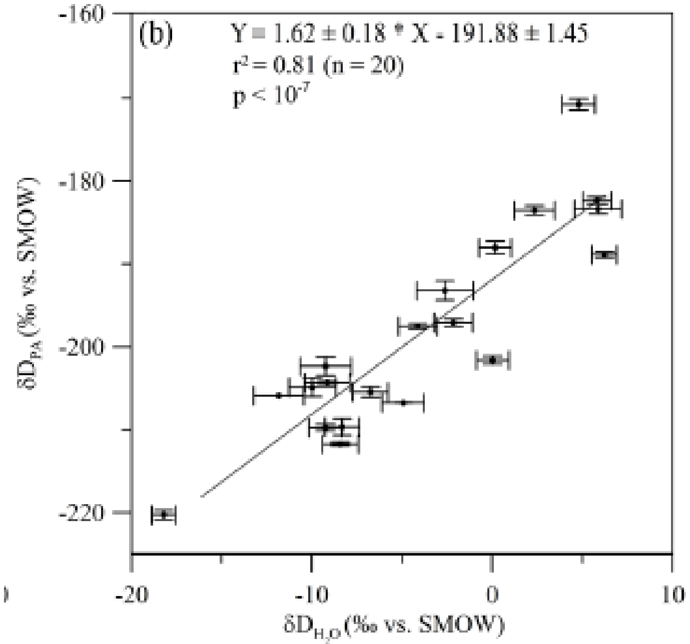




Rosell-Melé and McClymont (2007)

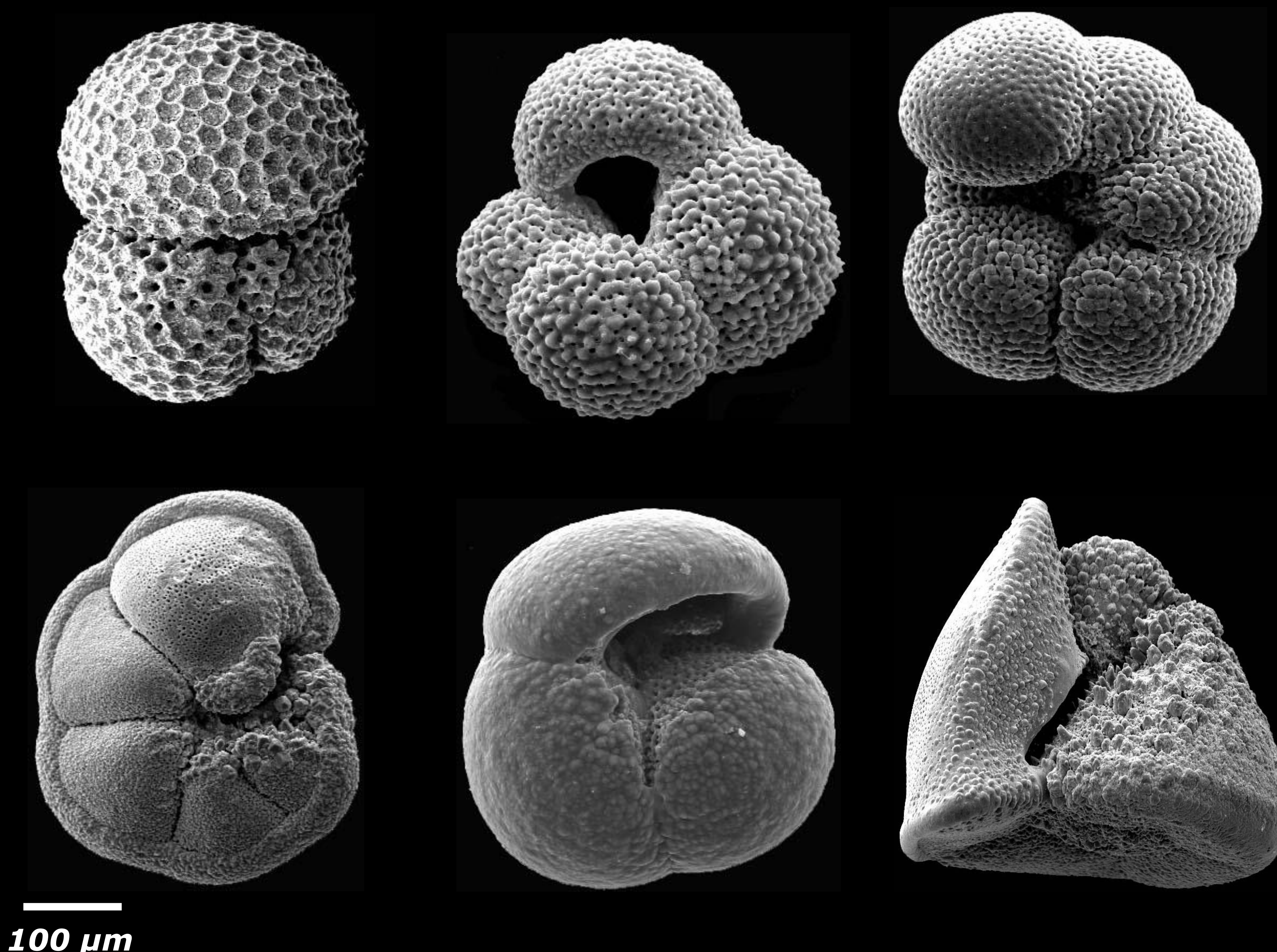
A selection of paleoclimate proxies

- **Biomarkers**

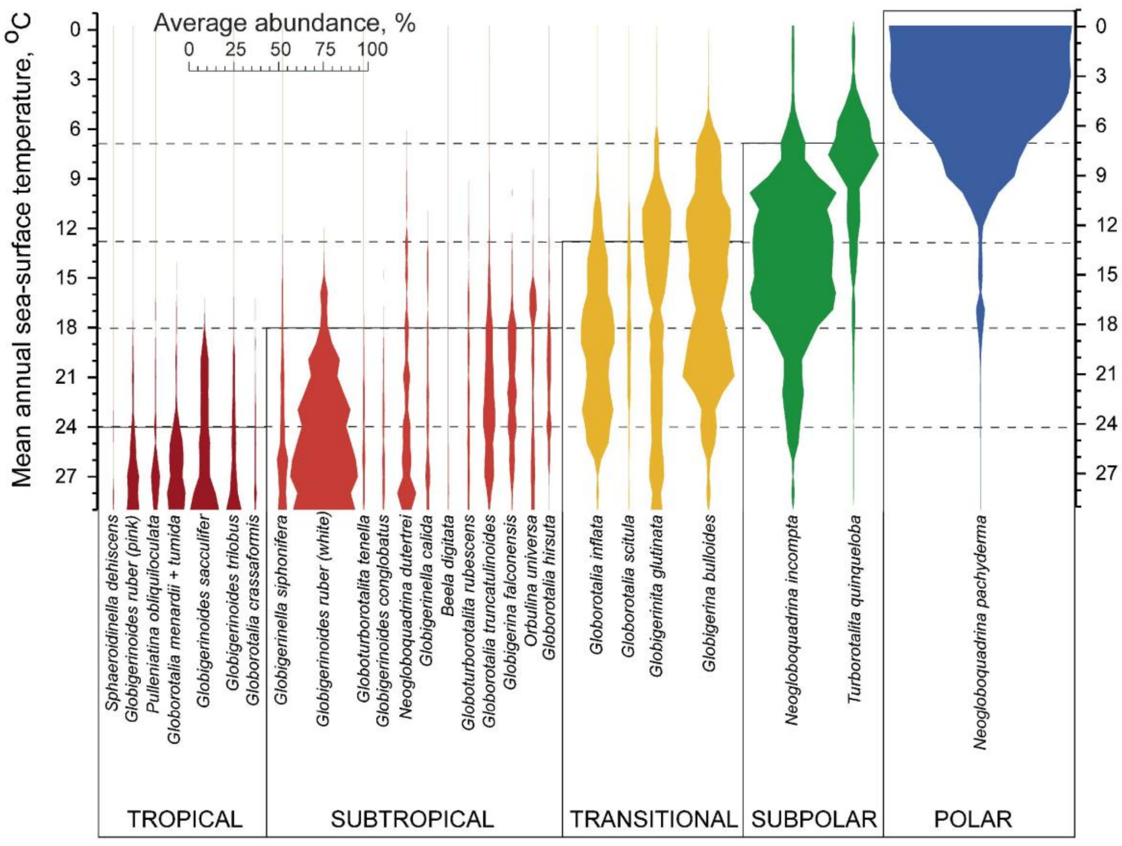


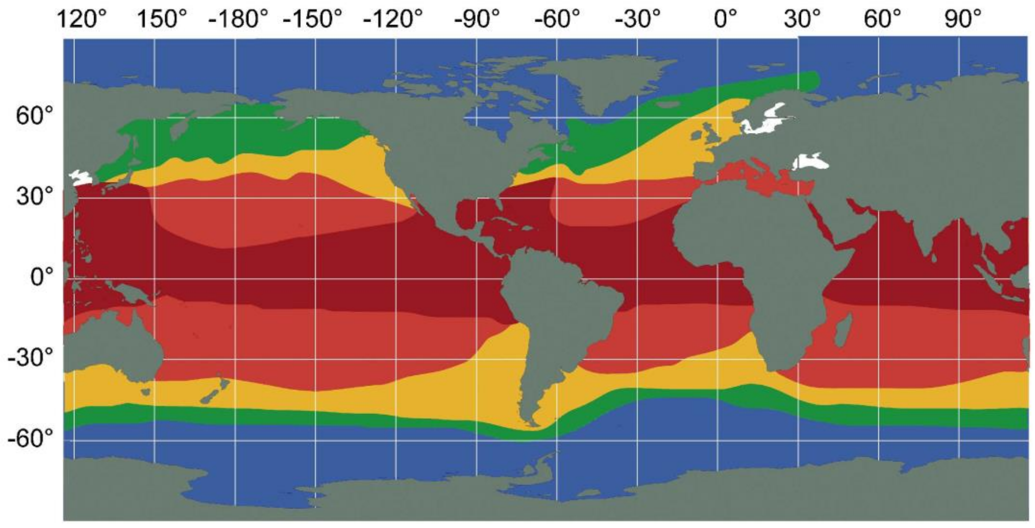
Palmitic acid (an unsaturated fatty acid highly abundant in most aquatic environments) δD

Häggi et al. (2015)


100 µm

•Planktonic foraminifera

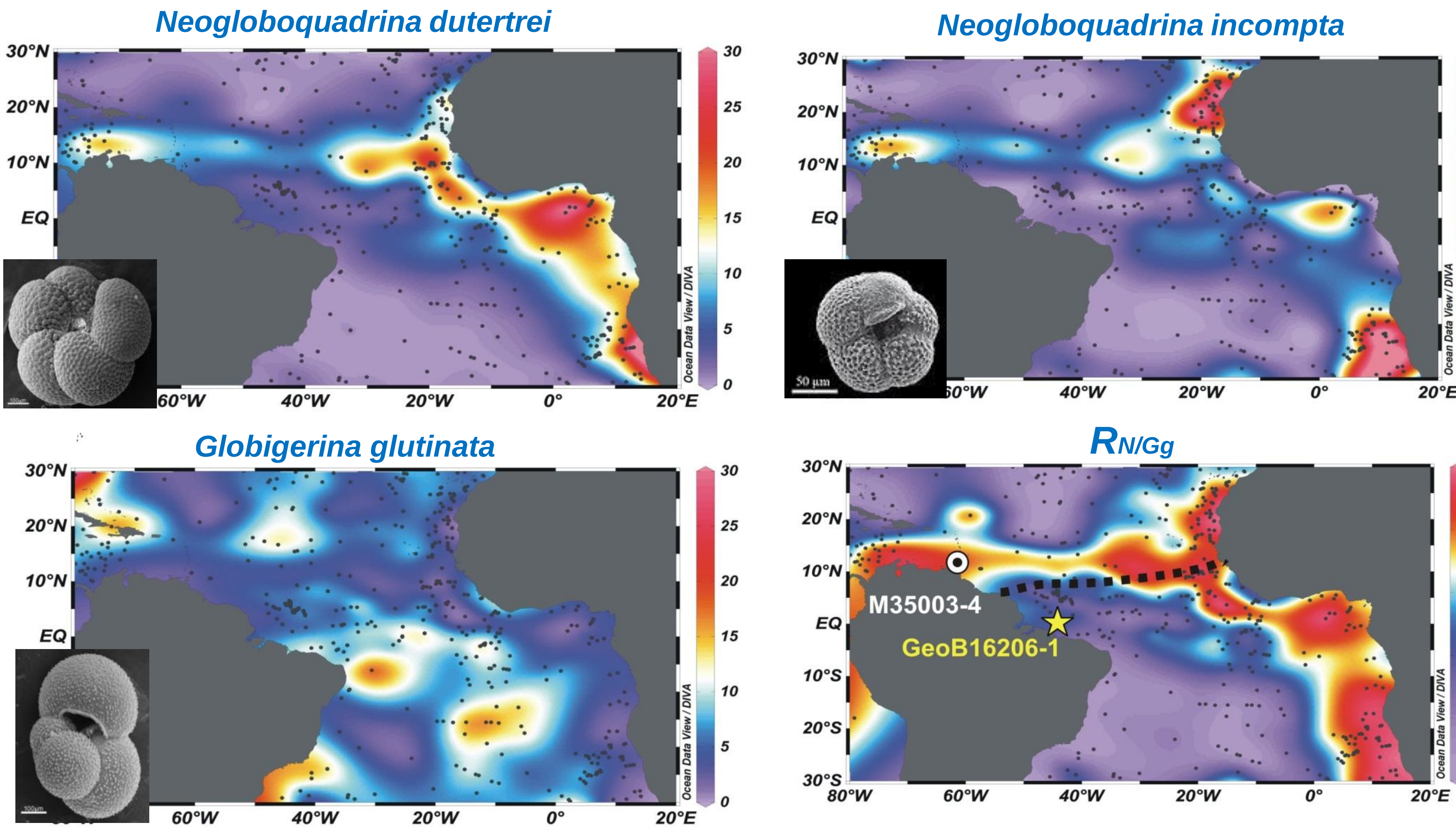




Kucera (2007)

A selection of paleoclimate proxies

• **Planktonic foraminifera**

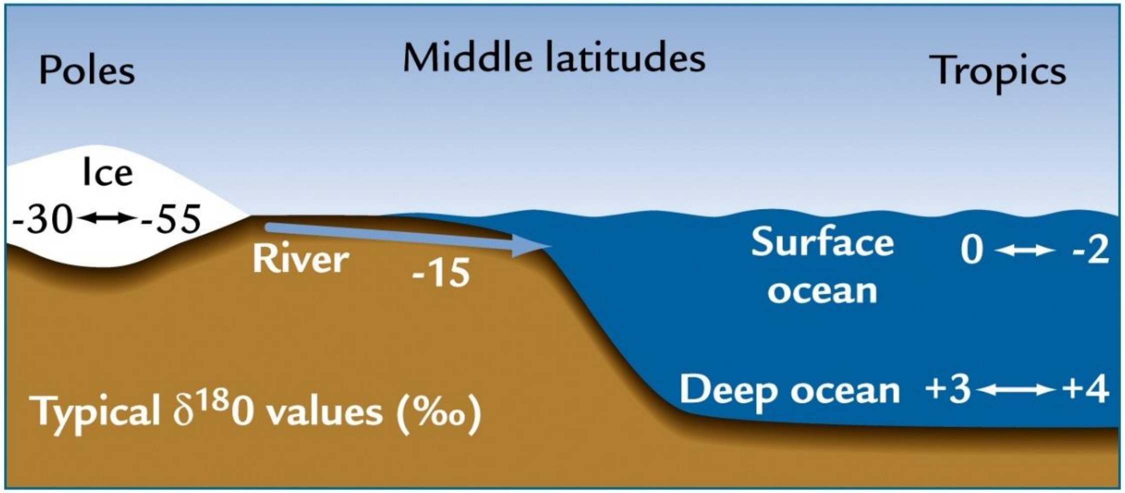


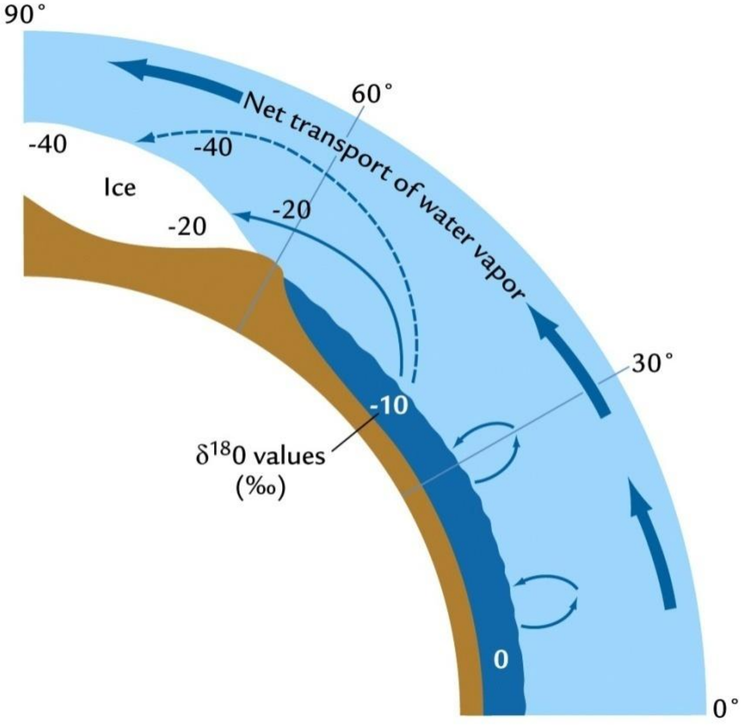
$R_{N/Gg}$ = *%Neogloboquadrina / (%Neogloboquadrina + %G. glutinata)*

Portilho-Ramos et al. (2017)

A selection of paleoclimate proxies

•Oxygen stable isotopes in marine carbonates (e.g., foraminifera) but also ice cores and continental carbonates (e.g., stalagmites)

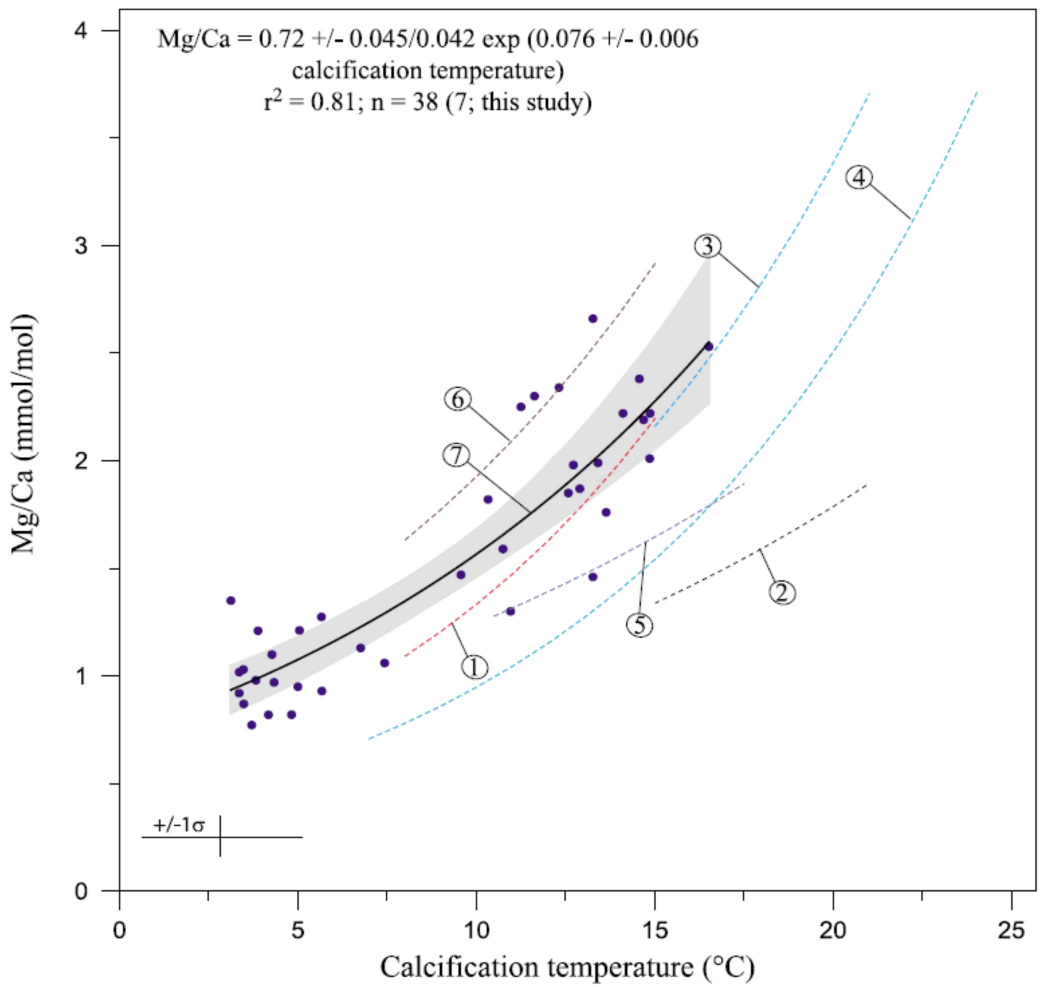




Ruddiman (2014)

A selection of paleoclimate proxies

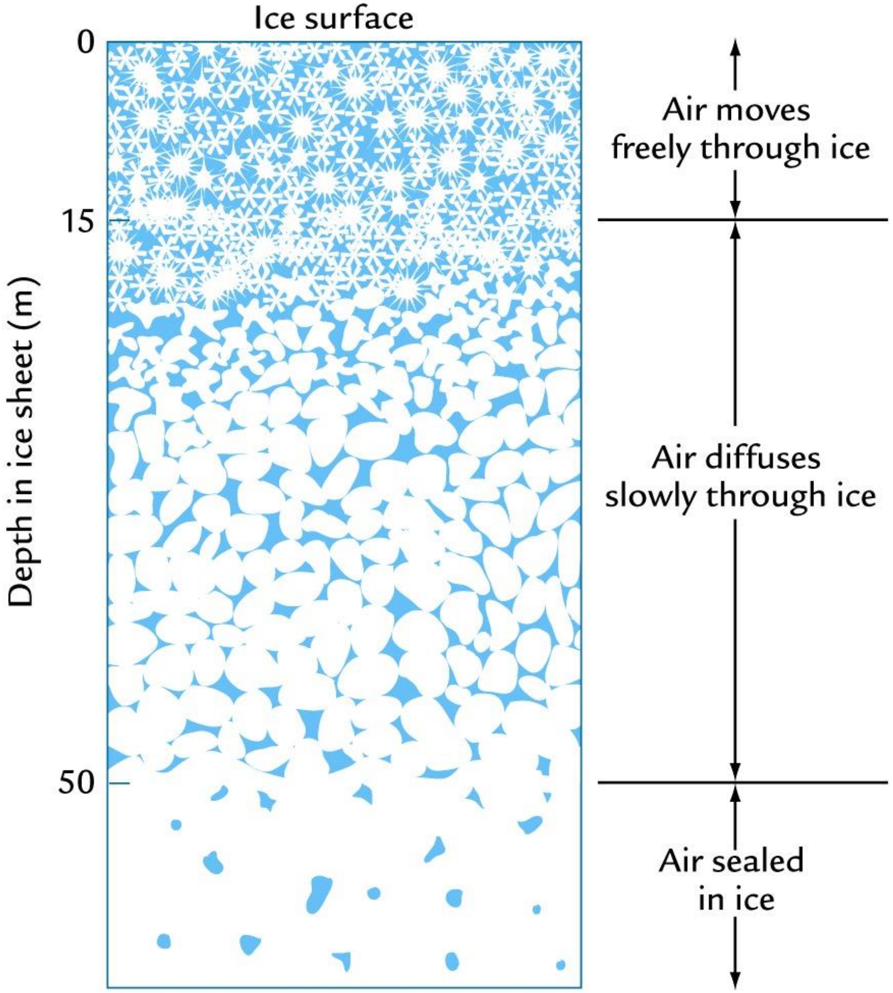
•Mg/Ca in planktonic foraminifera



Groeneveld and Chiessi (2011)

A selection of paleoclimate proxies

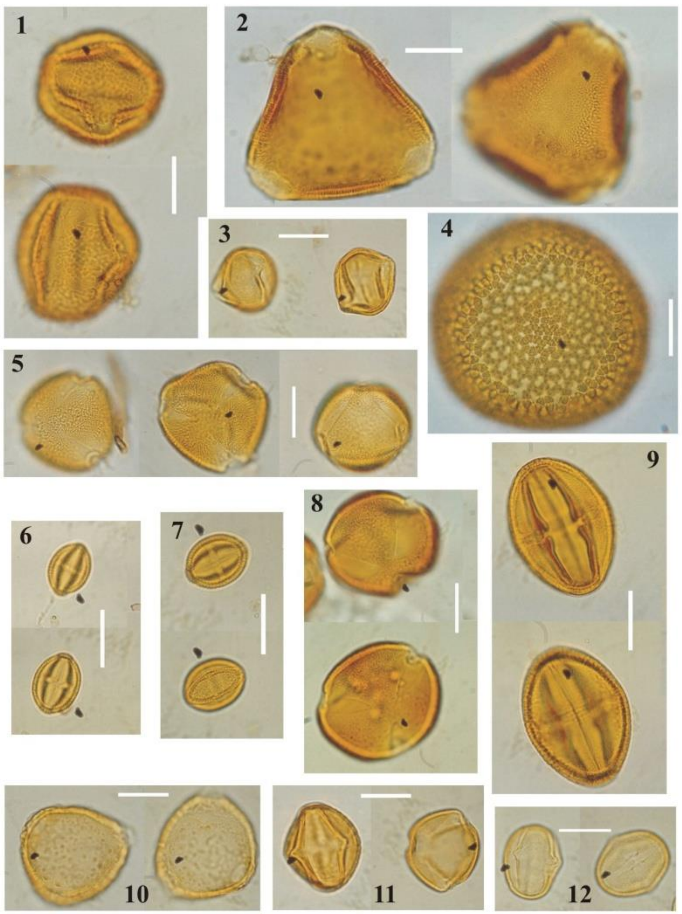
- **Air trapped in ice**



Ruddiman (2014)

A selection of paleoclimate proxies

- Pollen in continental and marine sediments



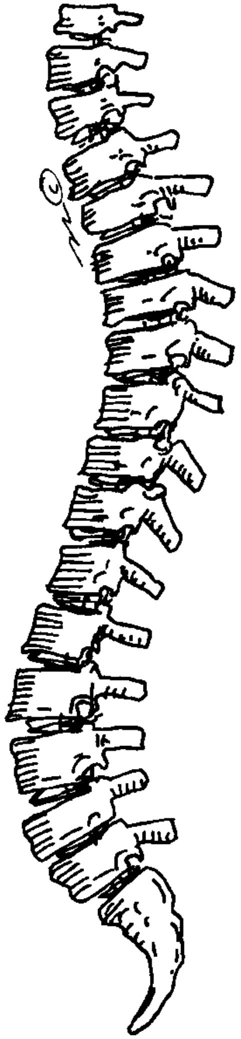
A selection of paleoclimate proxies

A good paleoclimate archive should meet certain criteria

2. It must be possible to determine the age of deposition/formation of the paleoclimate archive

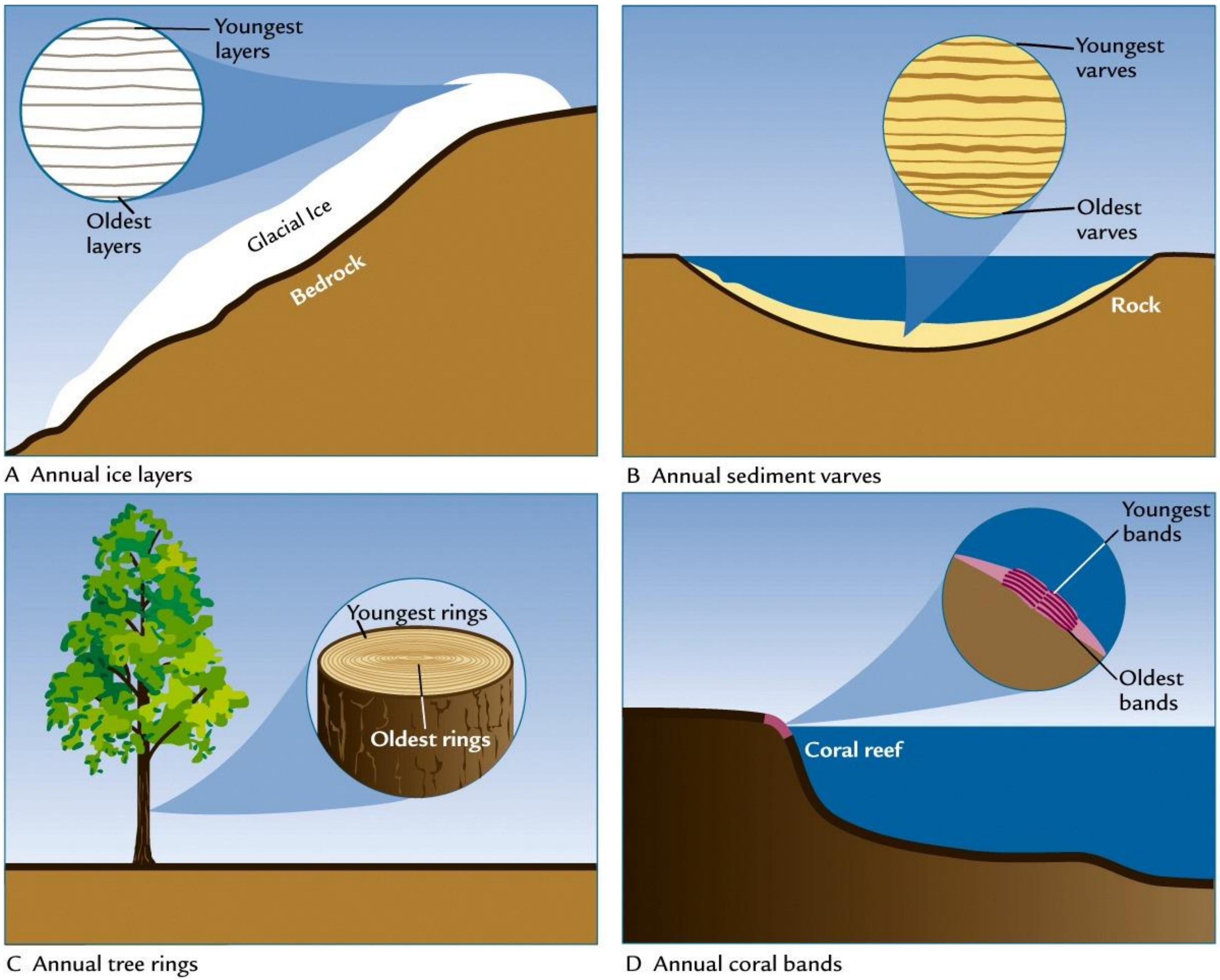
A selection of paleoclimate proxies

Dating is the backbone of paleoclimatology and paleoceanography



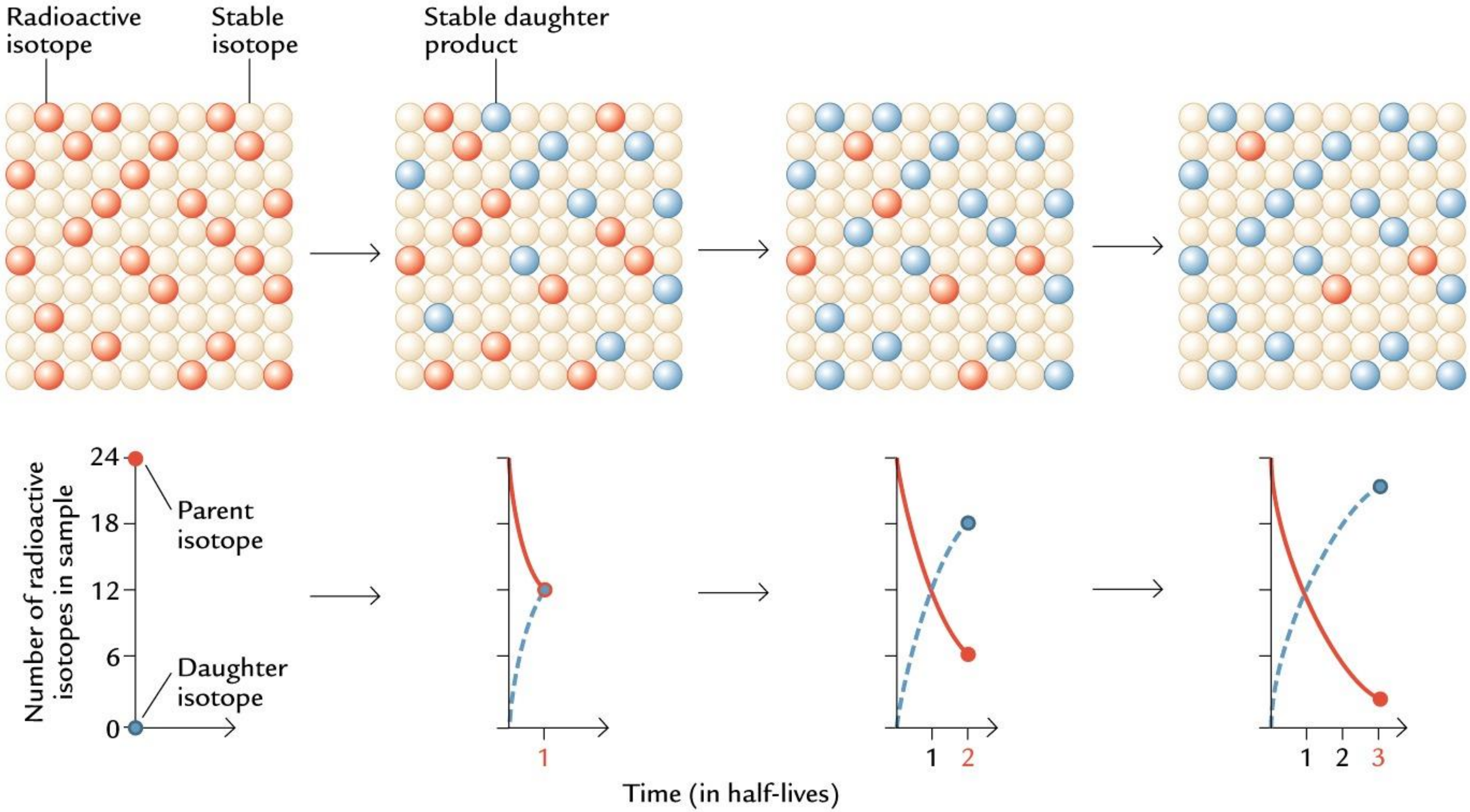
A selection of paleoclimate proxies

1. Layer counting



Ruddiman (2014)

2. Radiometric dating



Ruddiman (2014)

A selection of paleoclimate proxies

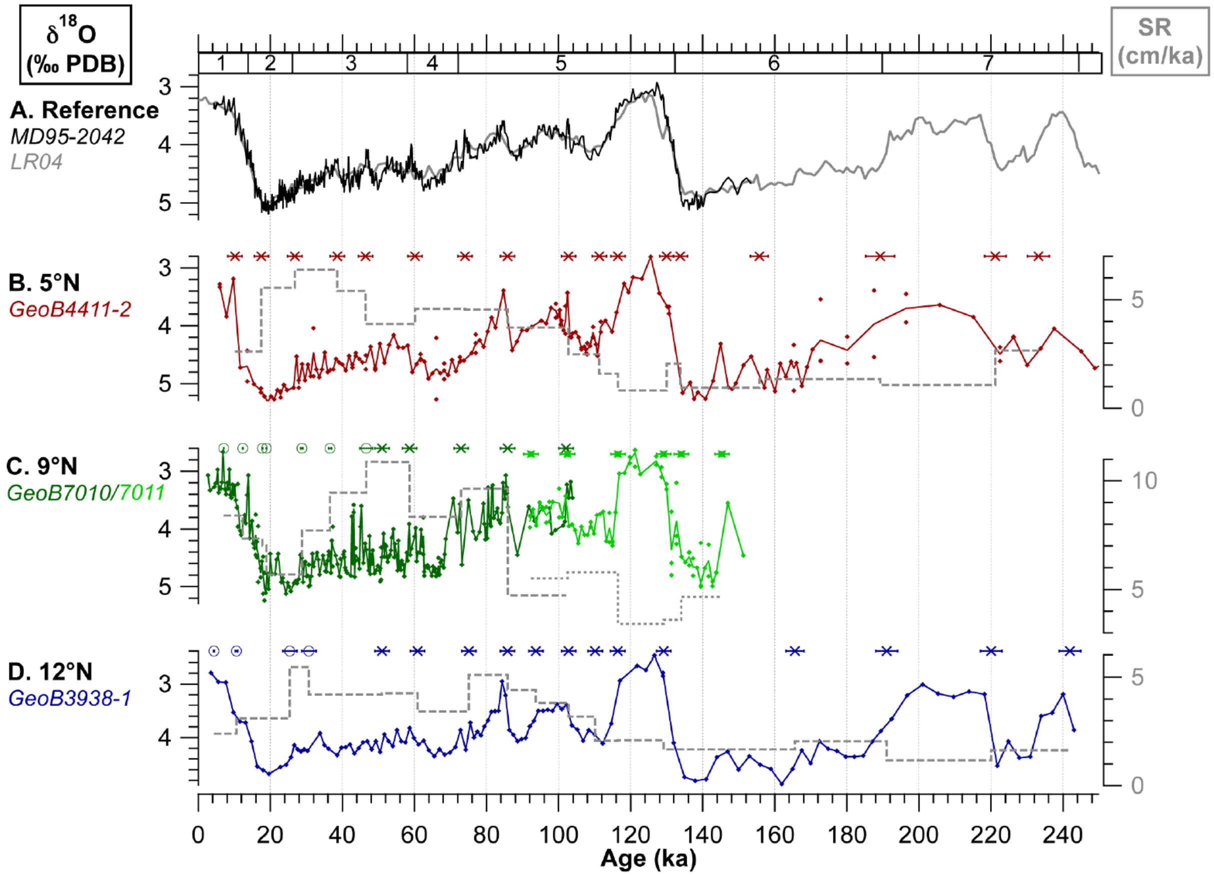
2. Radiometric dating

Given the concentration of the daughter and parent isotope as well as the half-live it is possible to calculate the age

Parent isotope	Daughter isotope	Half-life	Useful for ages
^{230}Th	^{226}Ra	75 kyr	< 600 kyr
^{14}C	^{14}N	5.8 kyr	< 50 kyr

A selection of paleoclimate proxies

3. Stratigraphic tuning



The age model from a different core is imported to the core without an age model by correlating a specific record of both cores that are mechanistically related

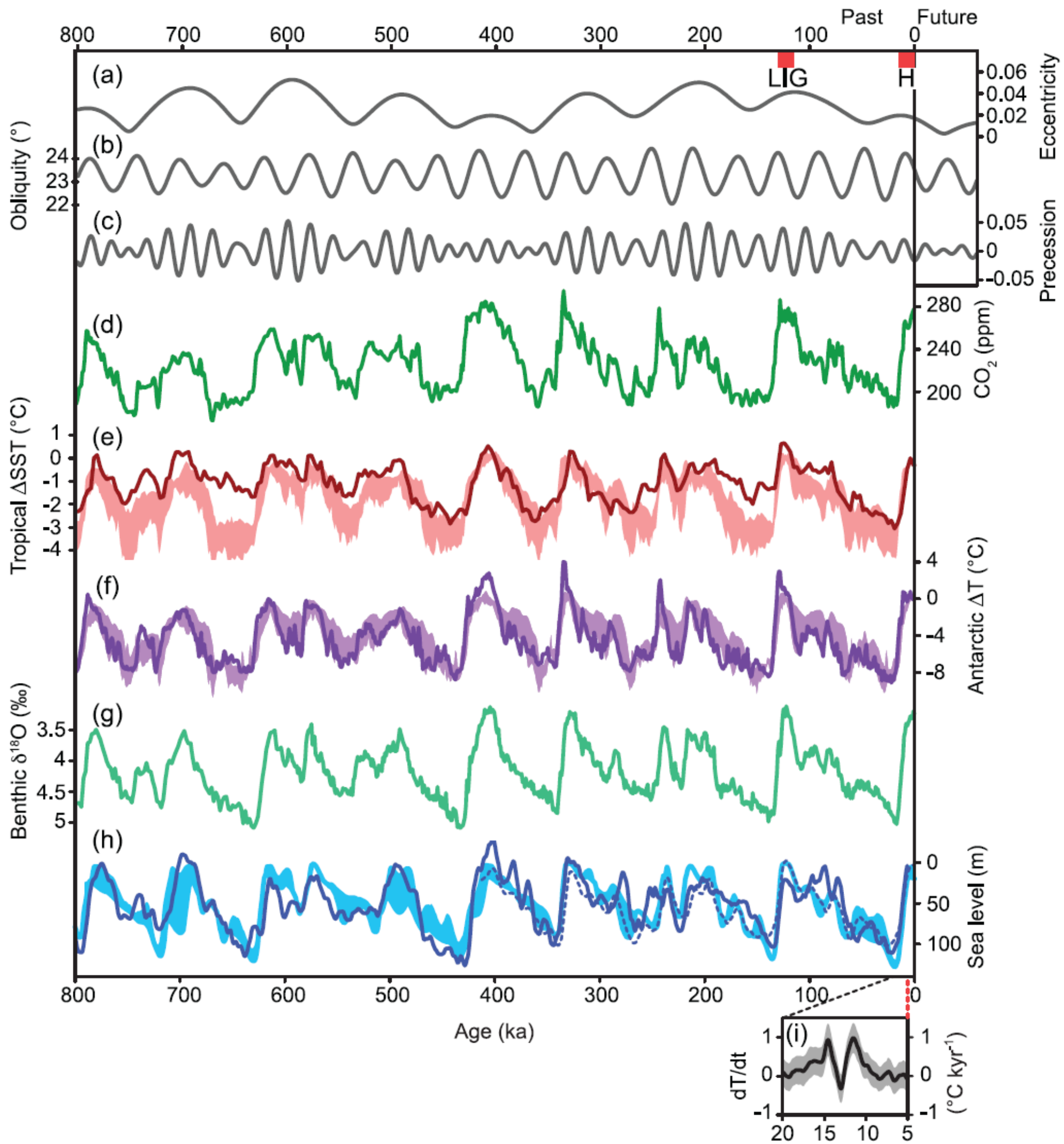
Govin et al. (2014)

Outline

- Why study past climates?
- Main paleoclimate archives
- A selection of paleoclimate proxies
- **Paleoclimate records: *the editor's cut***

Paleoclimate records: *the editor's cut*

Greenhouse-gas variations and past climate responses

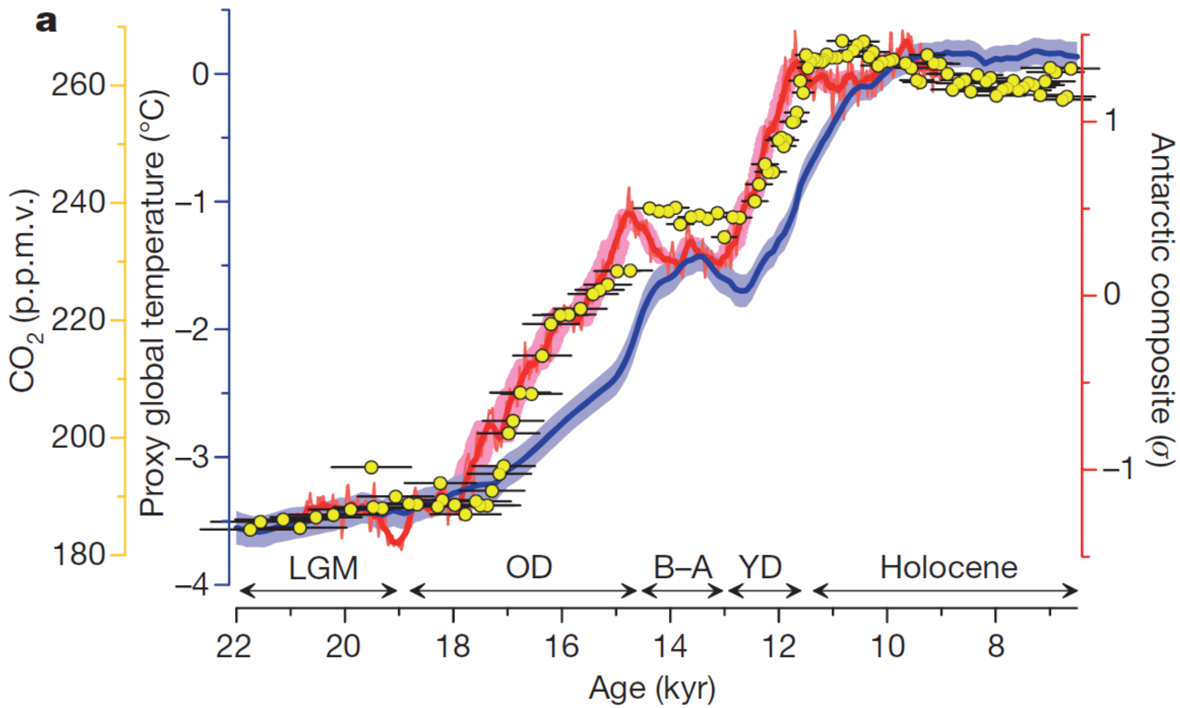


It is a fact that present-day (2011) concentrations of the atmospheric greenhouse gases CO_2, CH_4 and N_2O exceed the range of concentrations recorded in ice cores during the past 800,000 years

Masson-Delmotte et al. (2013)

Paleoclimate records: *the editor's cut*

Greenhouse-gas variations and past climate responses

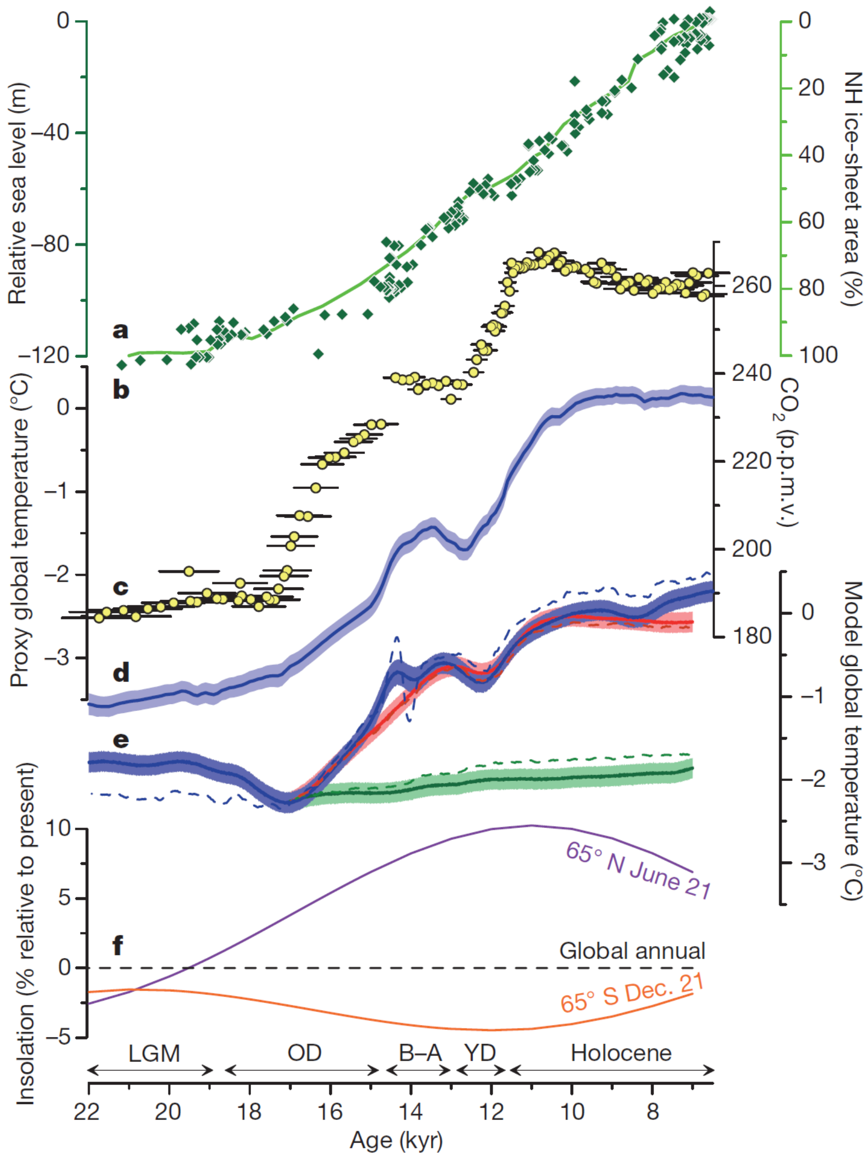


There is high confidence that changes in atmospheric CO_2 concentration play an important role in glacial–interglacial cycles

Shakun et al. (2012), Masson-Delmotte et al. (2013)

Paleoclimate records: *the editor's cut*

Greenhouse-gas variations and past climate responses



During the last deglaciation, it is very likely that global mean temperature increased by 3 to 8°C; while the mean rate of global warming was very likely 0.3 to 0.8°C per thousand years, two periods were marked by faster warming rates (likely 1-1.5°C per thousand years), although regionally and on shorter time scales higher rates may have occurred

Shakun et al. (2012), Masson-Delmotte et al. (2013)

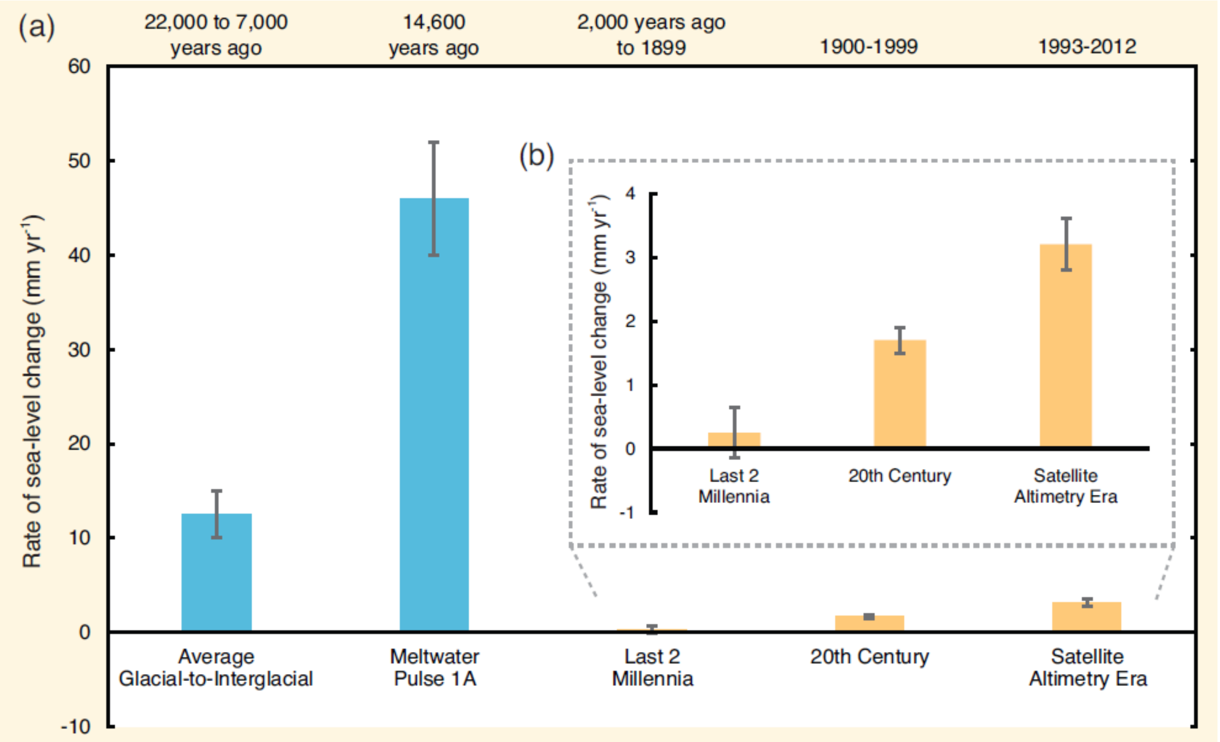
Greenhouse-gas variations and past climate responses

With medium confidence, global mean surface temperature was significantly above pre-industrial levels during several past periods characterized by high atmospheric CO_2 concentrations

Masson-Delmotte et al. (2013)

Paleoclimate records: *the editor's cut*

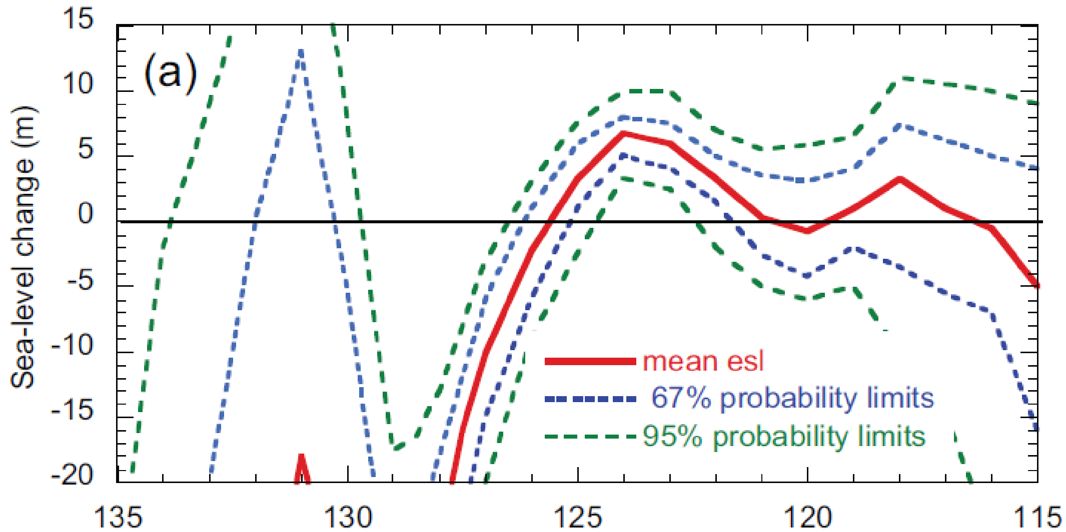
Global sea level changes during past warm periods



The current rate of global mean sea level change, starting in the late 19th-early 20th century, is, with medium confidence, unusually high in the context of centennial-scale variations of the last two millennia

Masson-Delmotte et al. (2013)

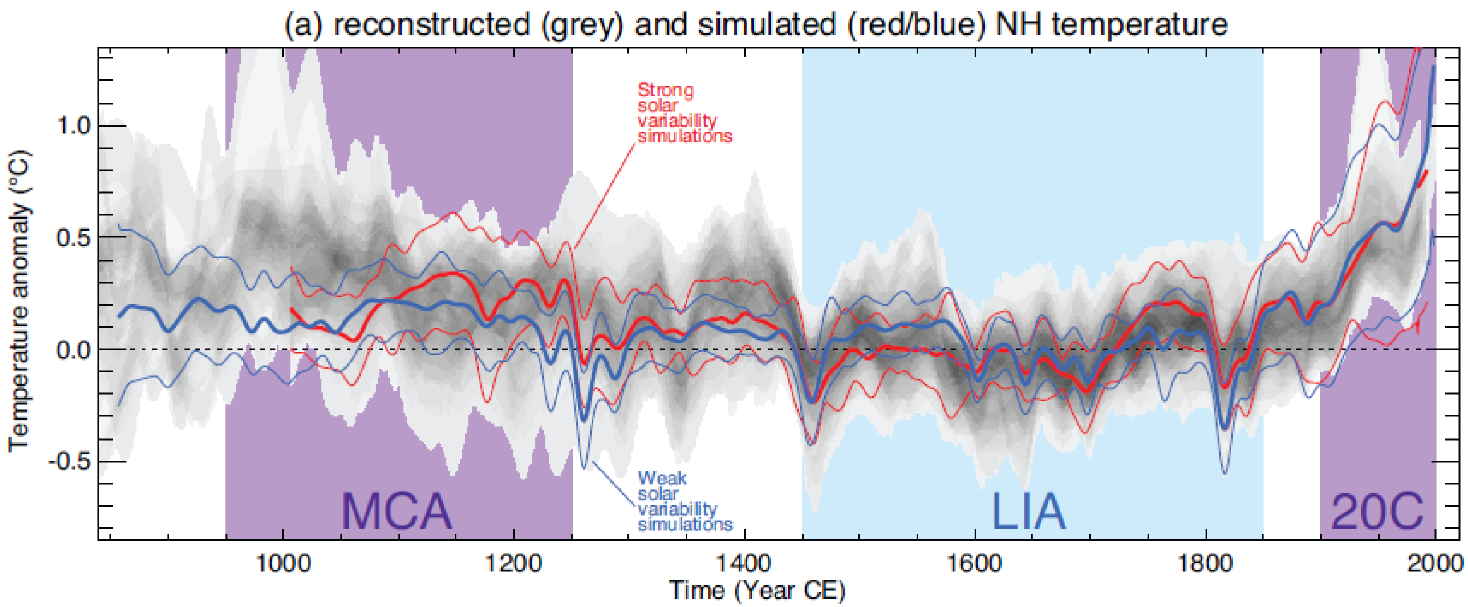
Global sea level changes during past warm periods



There is very high confidence that the maximum global mean sea level during the last interglacial period (129,000 to 116,000 years ago) was, for several thousand years, at least 5 m higher than present and high confidence that it did not exceed 10 m above present (contribution from Greenland 1.4-4.3 m and Antarctica)

Masson-Delmotte et al. (2013)

Observed recent climate change in the context of interglacial climate variability



There is high confidence that annual mean surface warming since the 20th century has reversed long-term cooling trends of the past 5000 years in mid-to-high latitudes of the Northern Hemisphere

Masson-Delmotte et al. (2013)

Paleoclimate records: *the editor's cut*

Observed recent climate change in the context of interglacial climate variability

There is high confidence for droughts during the last millennium of greater magnitude and longer duration than those observed since the beginning of the 20th century in many regions

With high confidence, floods larger than those recorded since 1900 occurred during the past five centuries in northern and central Europe, western Mediterranean region and eastern Asia

Masson-Delmotte et al. (2013)

Paleoclimate records: *the editor's cut*

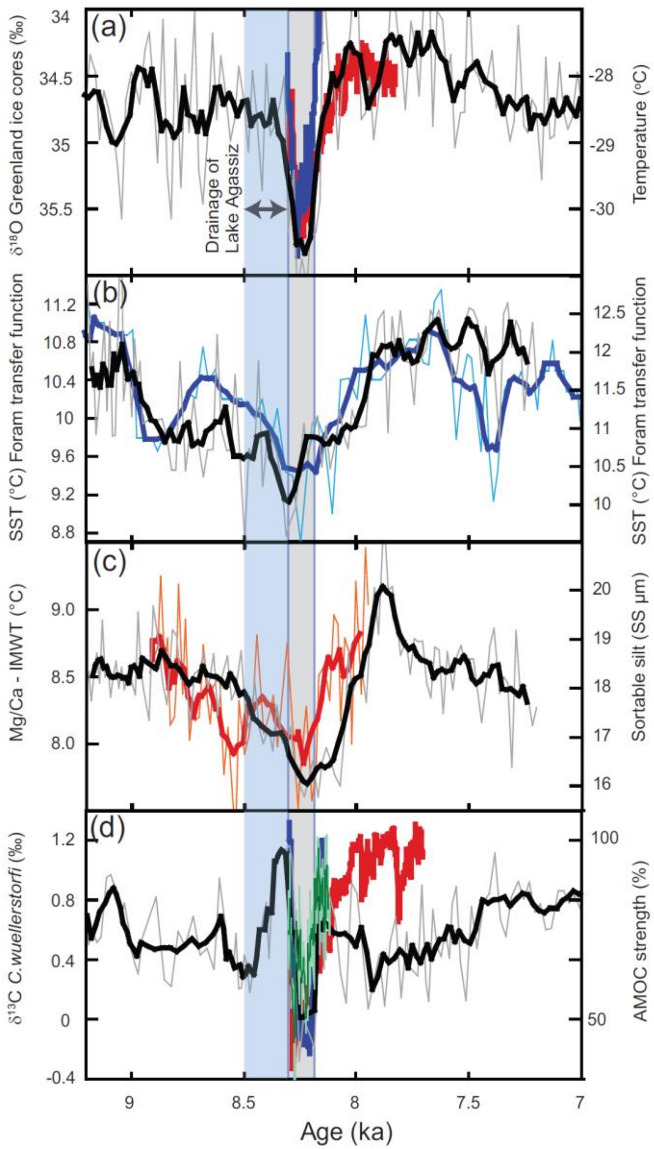
Abrupt climate change and irreversibility

Black: Greenland $\delta^{18}O$

Nordic Seas

Red: Atlantic interm. water T

Black: 3.4 km depth, S Greenland



Red/blue: simulated T

North Atlantic

Black: sortable silt Gardar drift

Red/blue/ green: simulated AMOC strength

With high confidence, the interglacial mode of the Atlantic meridional overturning circulation can recover from a short-term freshwater input into the subpolar North Atlantic

Masson-Delmotte et al. (2013)

Paleoclimate records: *the editor's cut*

Observed recent climate change in the context of interglacial climate variability

It is virtually certain that orbital forcing will be unable to trigger widespread glaciation during the next 1000 years

Paleoclimate records indicate that, for orbital configurations close to the present one, glacial inceptions only occurred for atmospheric CO_2 concentrations significantly lower than pre-industrial levels

Climate models simulate no glacial inception during the next 50,000 years if CO_2 concentrations remain above 300 ppm.

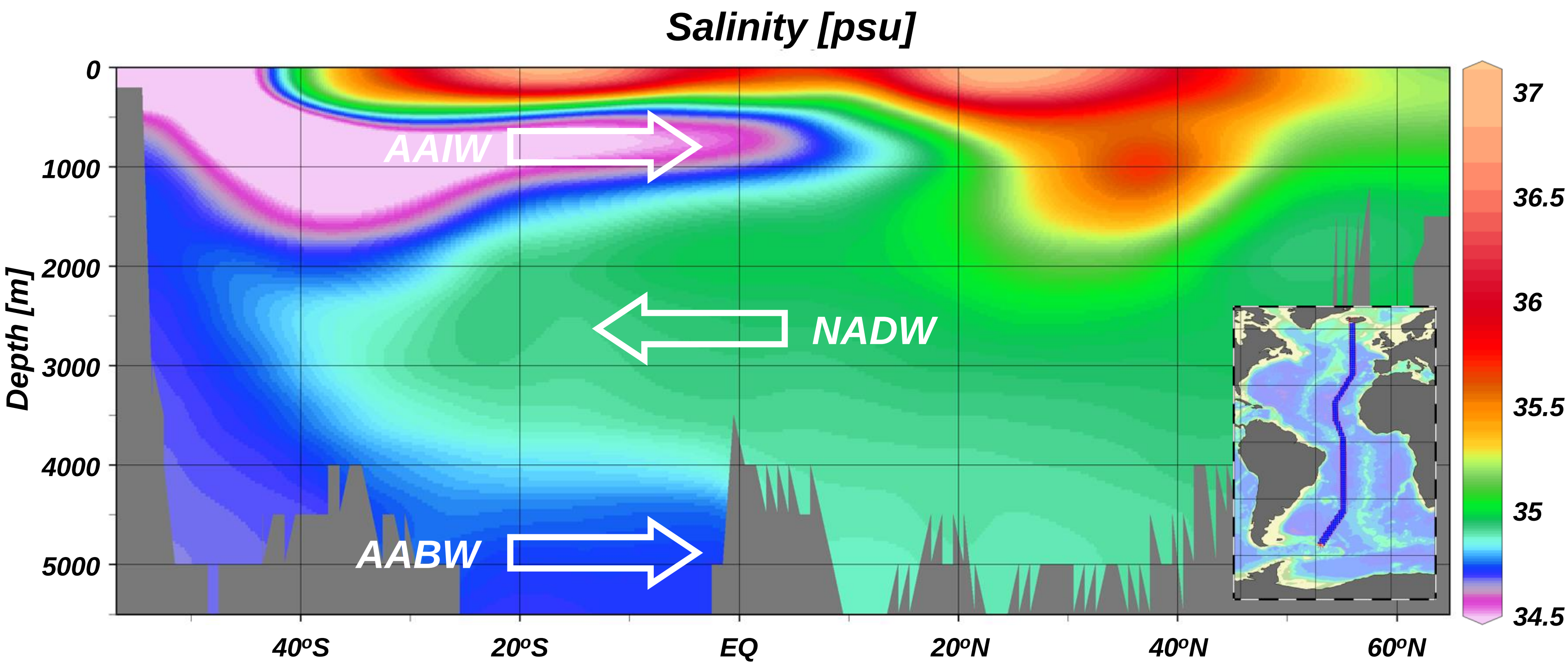
Masson-Delmotte et al. (2013)

Abrupt climate change and irreversibility

Confidence in the link between changes in North Atlantic climate and low-latitude precipitation patterns has increased since AR4

Masson-Delmotte et al. (2013)

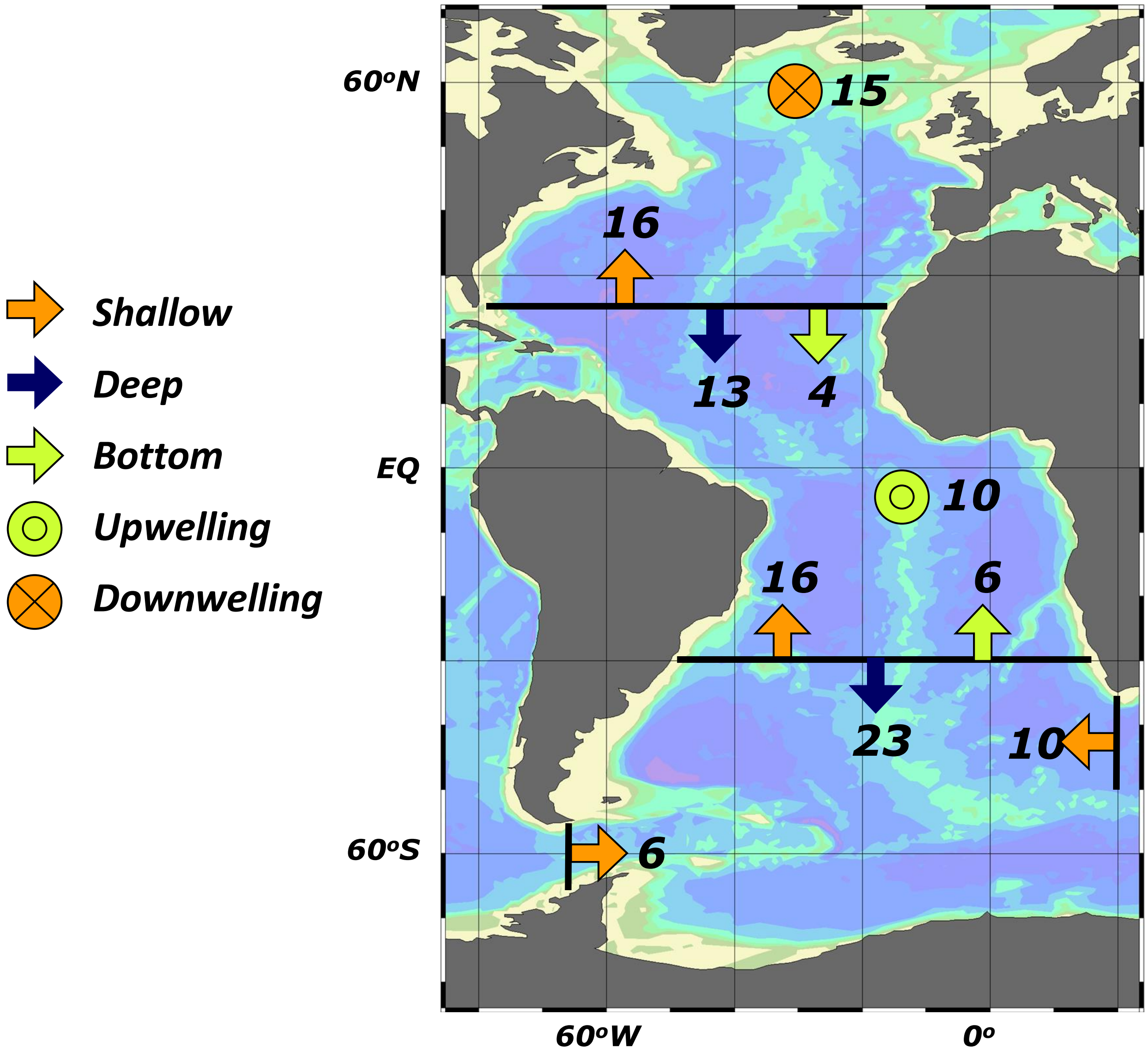
Paleoclimate records: *the editor's cut*



Atlantic meridional overturning circulation (AMOC)

Antonov et al. (2010)

Paleoclimate records: *the editor's cut*

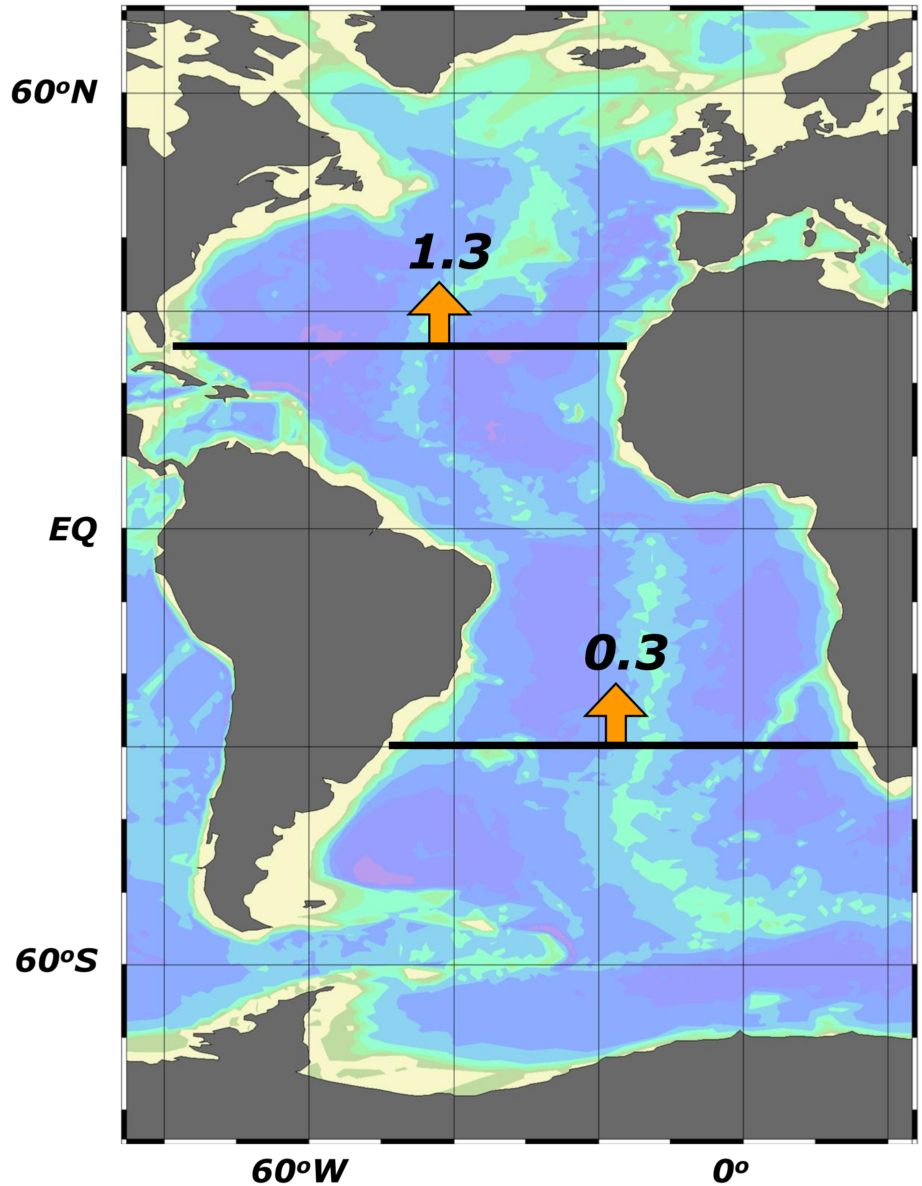


$1Sv = 10^6\ m^3\ s^{-1}$

The inflow of Indian Ocean high salinity waters preconditions the Atlantic for NADW formation

Ganachaud and Wunsch (2000), Schmid et al. (2000), Lutjeharms (2006)

Paleoclimate records: *the editor's cut*



1PW = 10^{15} W

Itaipu generates 0,000014 PW (14 GW)

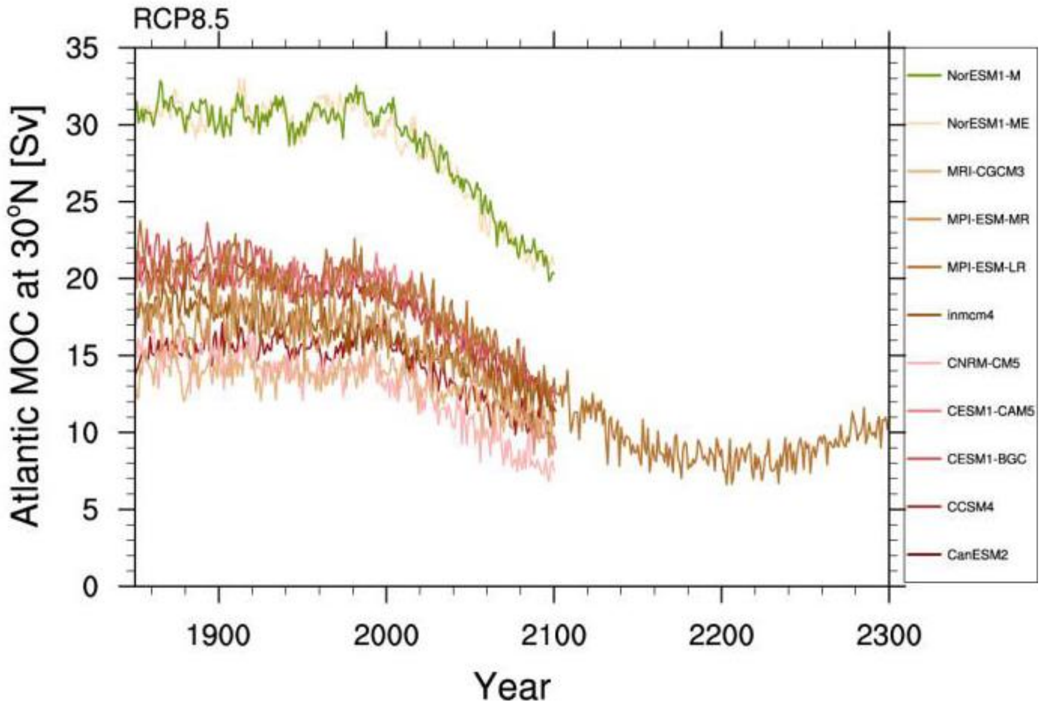
Large influence over global climate

Ganachaud and Wunsch (2000)

Paleoclimate records: *the editor's cut*

IPCC AR5 numerical models suggest a decrease in strength of the AMOC

Between 20–30% (RCP4.5) e 36–44% (RCP8.5) in 2100



Changes in AMOC may impact global climate

Weaver et al. (2012), Collins et al. (2013)

Paleoclimate records: *the editor's cut*

nature climate change
LETTERS
PUBLISHED ONLINE: 29 JANUARY 2012 | DOI: 10.1038/NCLIMATE1353

Enhanced warming over the global subtropical western boundary currents

Lixin Wu[1]*, Wenju Cai[2], Liping Zhang[1], Hisashi Nakamura[3], Axel Timmermann[4], Terry Joyce[5], Michael J. McPhaden[6], Michael Alexander[7], Bo Qiu[4], Martin Visbeck[8], Ping Chang[9] and Benjamin Giese[9]

SCIENCE 19 JUNE 2015

Observing the Atlantic Meridional Overturning Circulation yields a decade of inevitable surprises

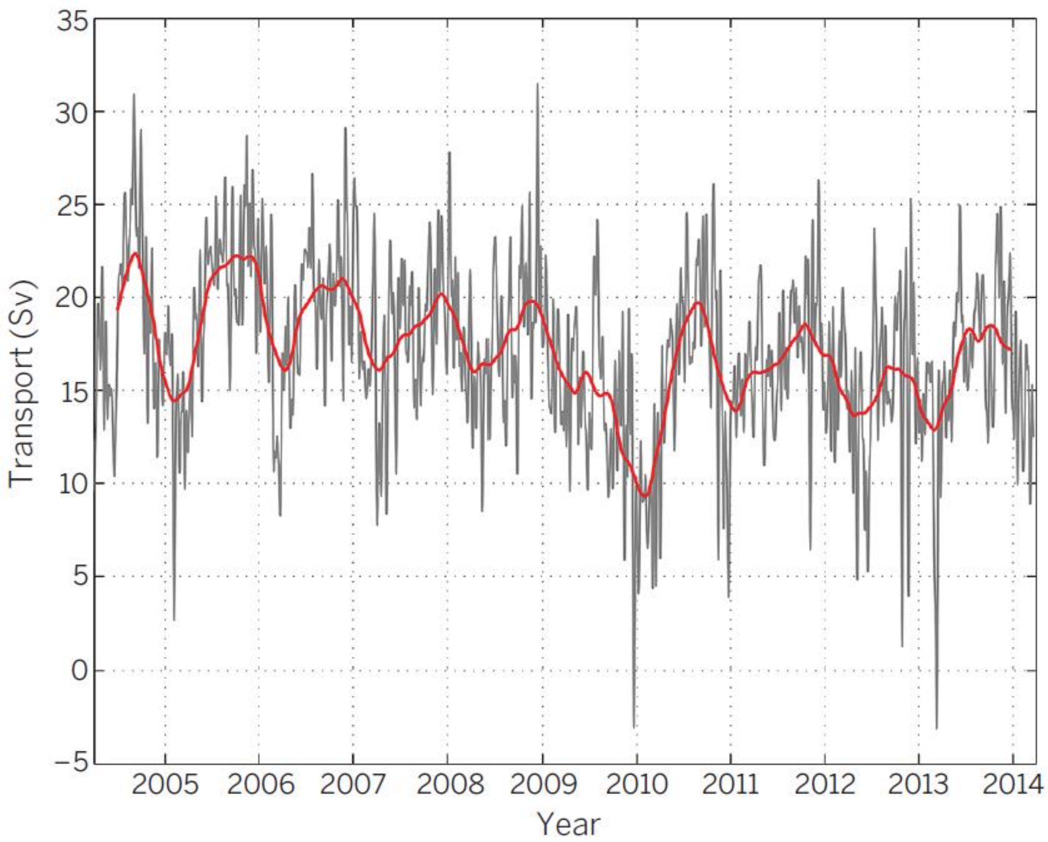
M. A. Srokosz[1]* and H. L. Bryden[2]

nature climate change
ARTICLES
PUBLISHED ONLINE: 23 MARCH 2015 | DOI: 10.1038/NCLIMATE2554

Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation

Stefan Rahmstorf[1]*, Jason E. Box[2], Georg Feulner[1], Michael E. Mann[3,4], Alexander Robinson[1,5,6], Scott Rutherford[7] and Erik J. Schaffernicht[1]

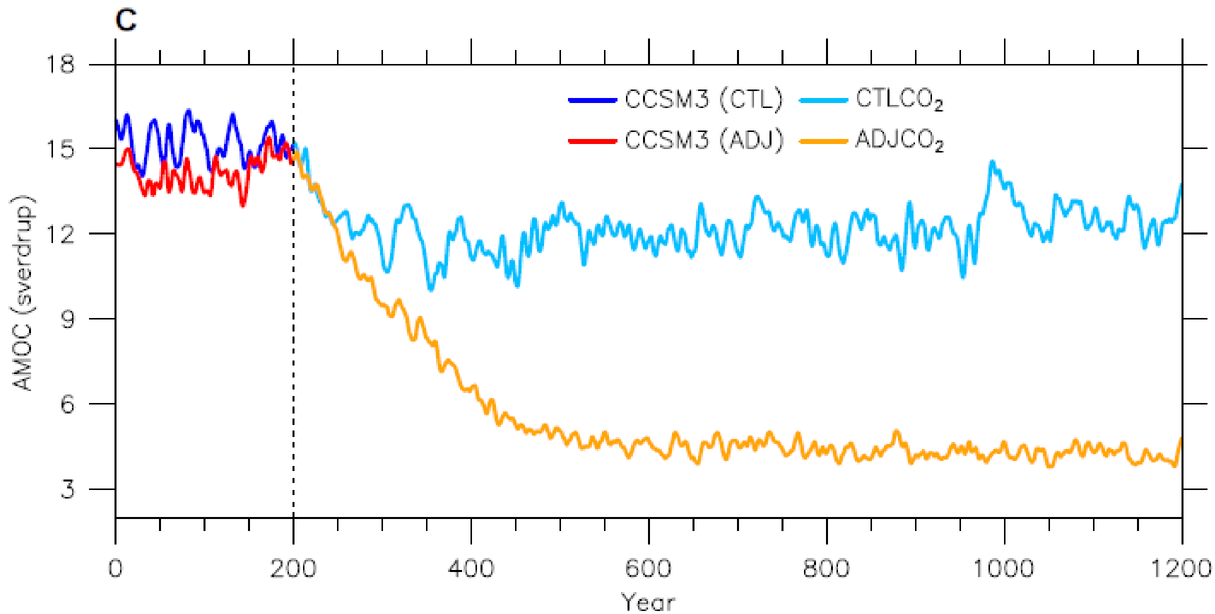
Paleoclimate records: *the editor's cut*



Instrumental records are too short to appropriately investigate changes in AMOC

Srokosz and Bryden (2015)

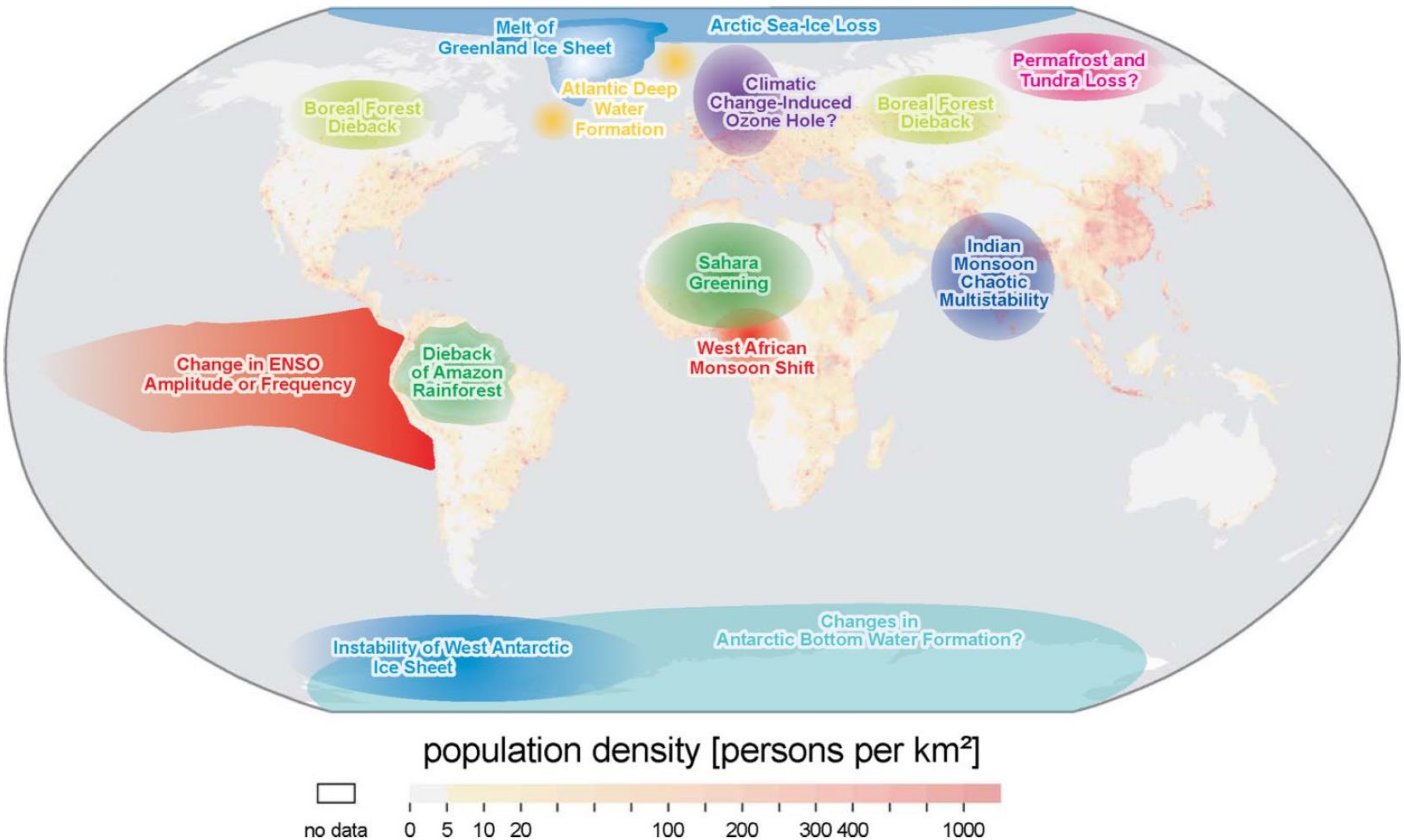
Paleoclimate records: *the editor's cut*



Overlooked possibility of a collapsed Atlantic meridional overturning circulation in warming climate

Liu et al. (2017)

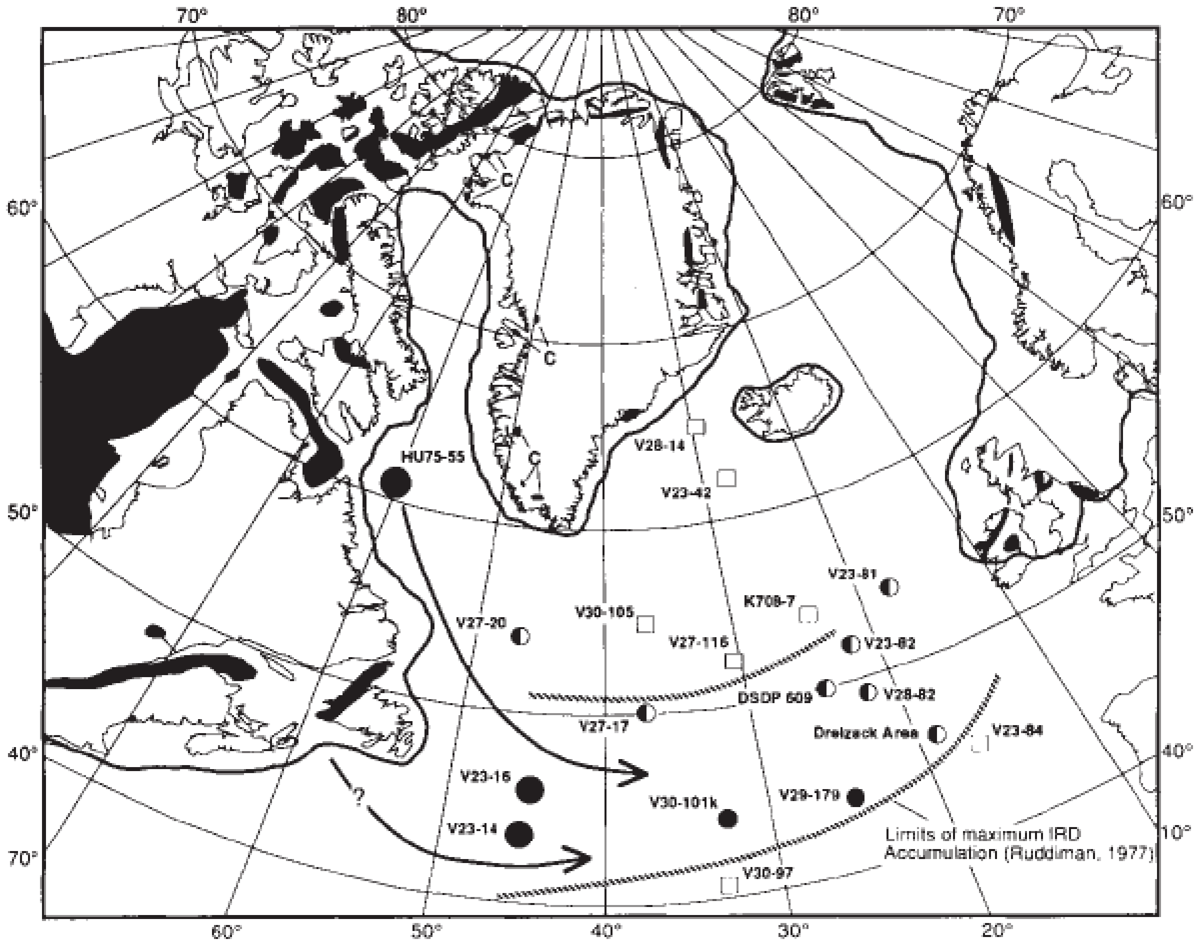
Paleoclimate records: *the editor's cut*



Formation of NADW: a tipping element in the climate system whose threshold could be reached this century

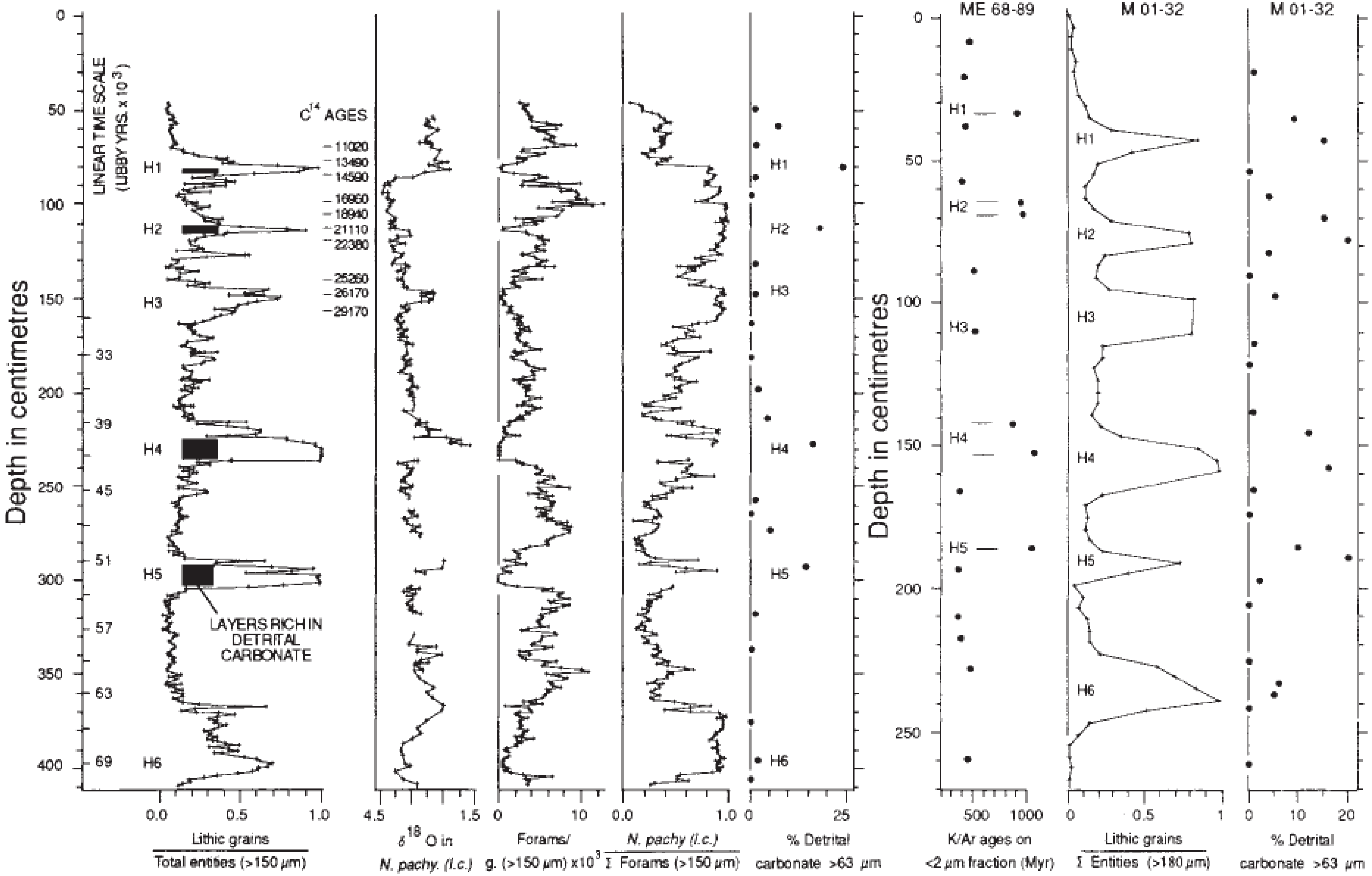
Lenton et al. (2008)

Paleoclimate records: *the editor's cut*



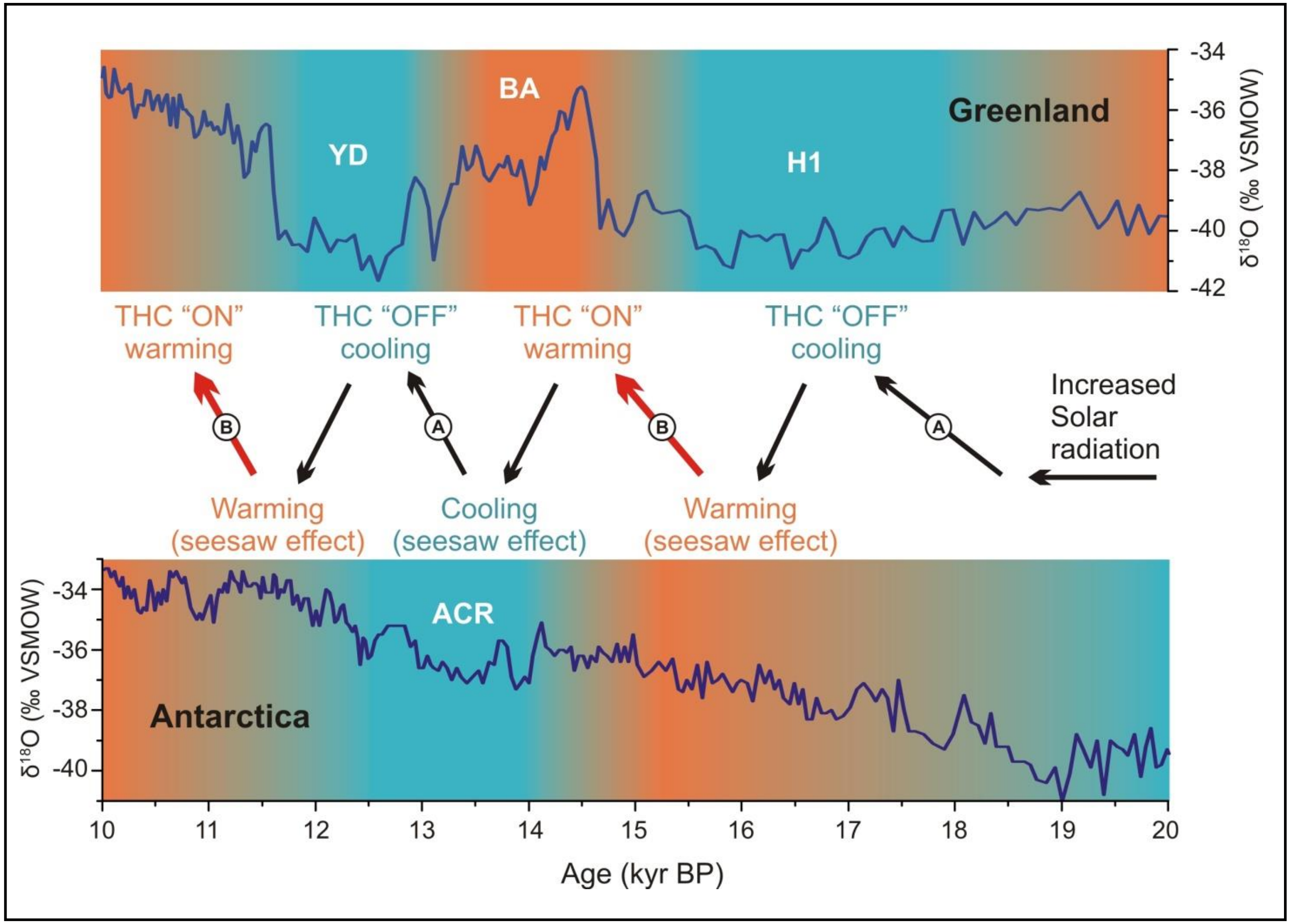
Bond et al. (1992)

Paleoclimate records: *the editor's cut*



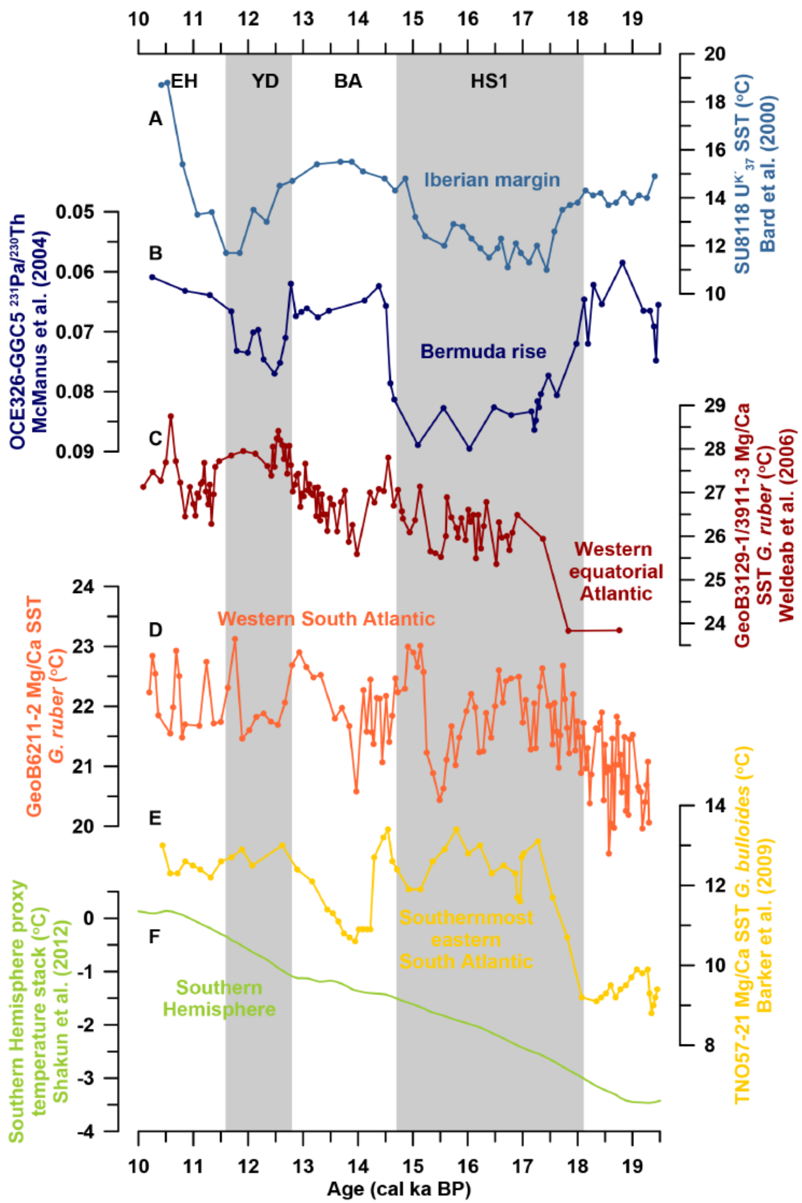
Bond et al. (1992)

Paleoclimate records: *the editor's cut*



Stocker (2003)

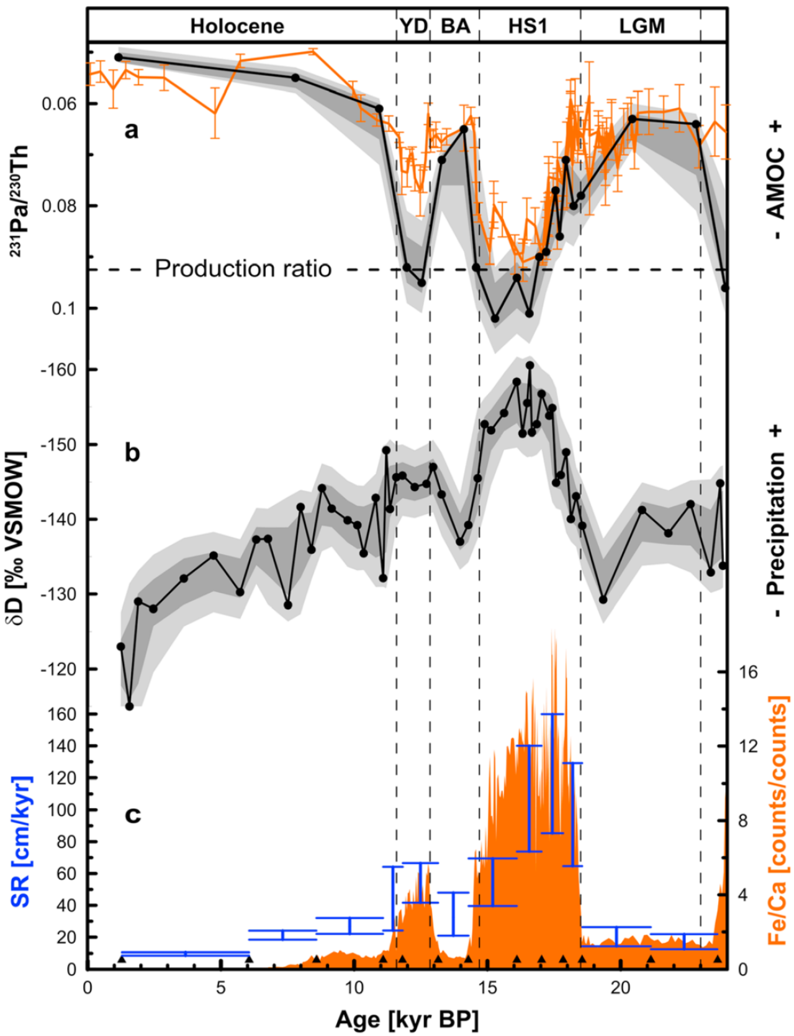
Paleoclimate records: *the editor's cut*

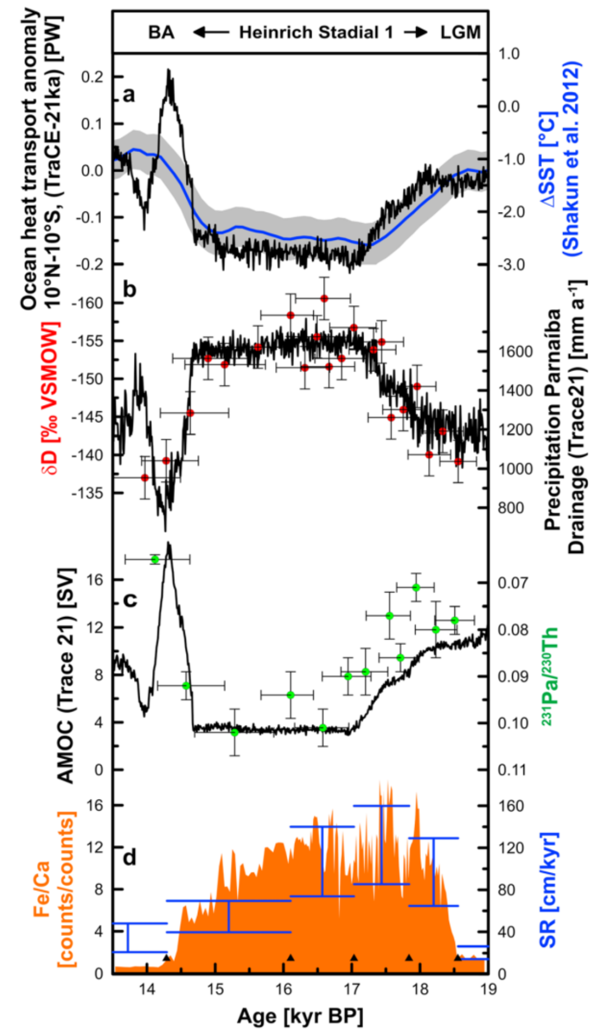


Opposite changes in sea surface temperatures between the North and South Atlantic during AMOC slowdown events

Chiessi et al. (2015)

Paleoclimate records: *the editor's cut*

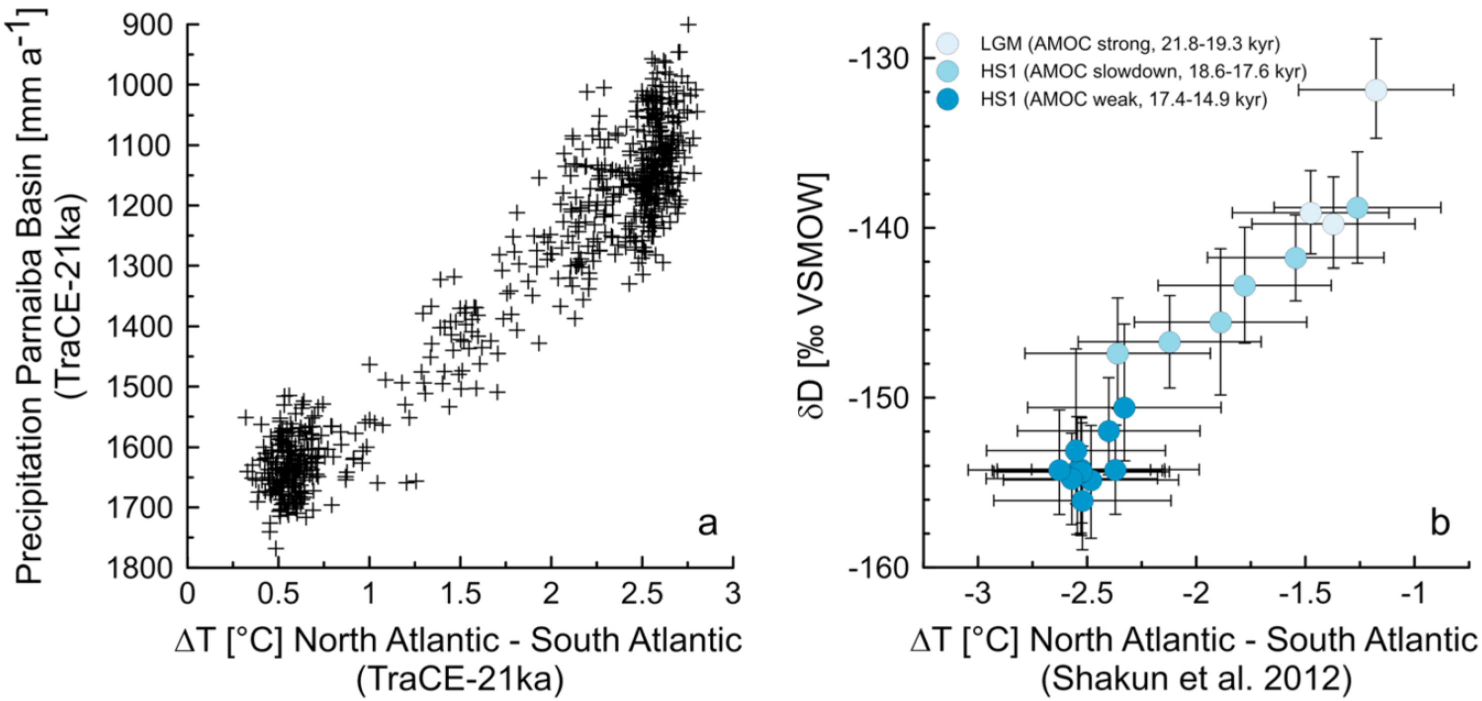




Precipitation over NE Brazil varied linearly and synchronously with AMOC strength

Mulitza et al. (2017)

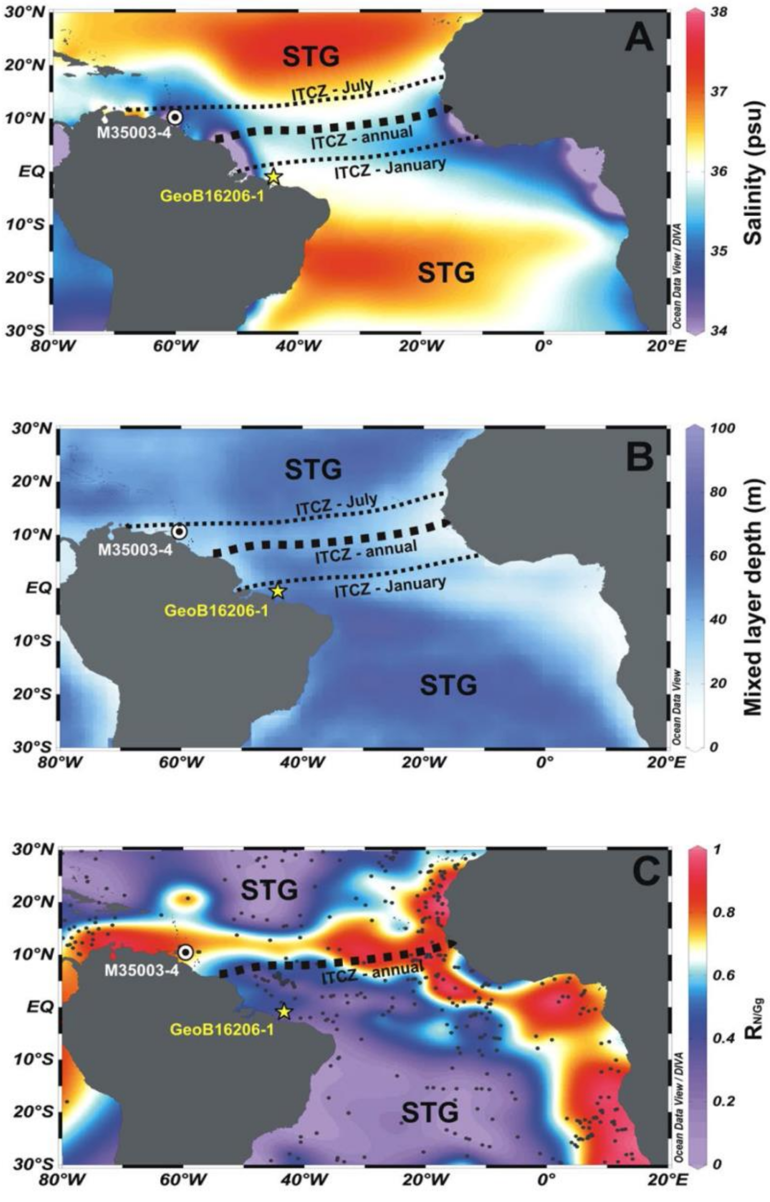
Paleoclimate records: *the editor's cut*



Intertropical Convergence Zone over the western Atlantic closely followed the change in the meridional sea surface temperature gradient

Mulitza et al. (2017)

Paleoclimate records: *the editor's cut*

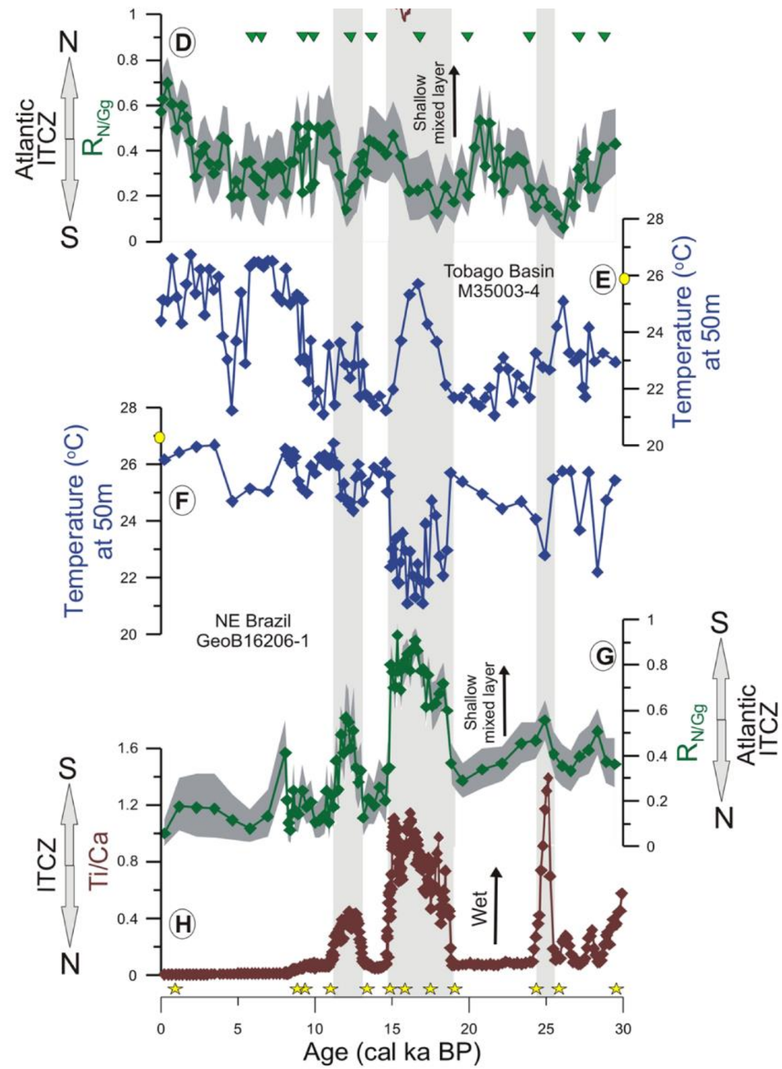


But, what happened with the shallowest mixed layer linked to the Intertropical Convergence Zone?

Portilho-Ramos et al. (2017)

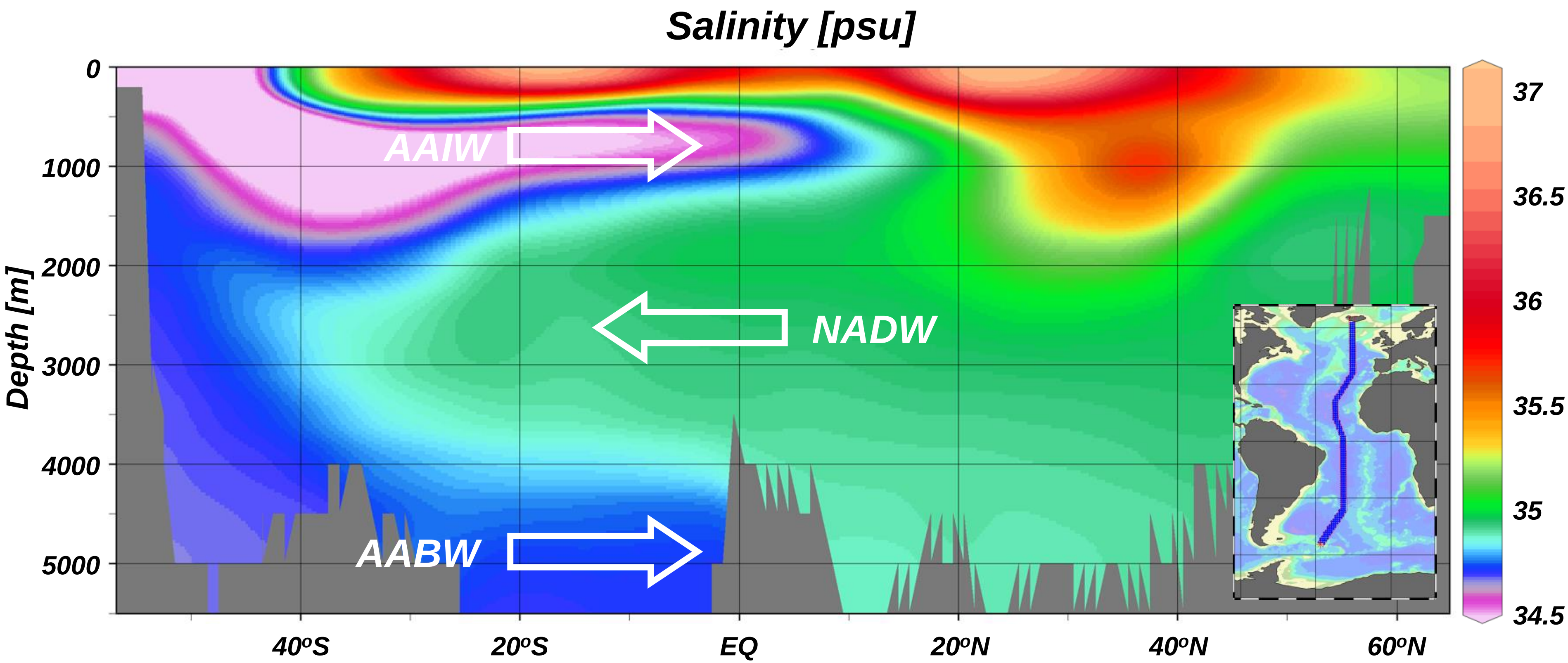
Paleoclimate records: *the editor's cut*

The shallowest mixed layer associated with the Intertropical Convergence Zone unambiguously shifted southwards during periods of a weakened AMOC



Portilho-Ramos et al. (2017)

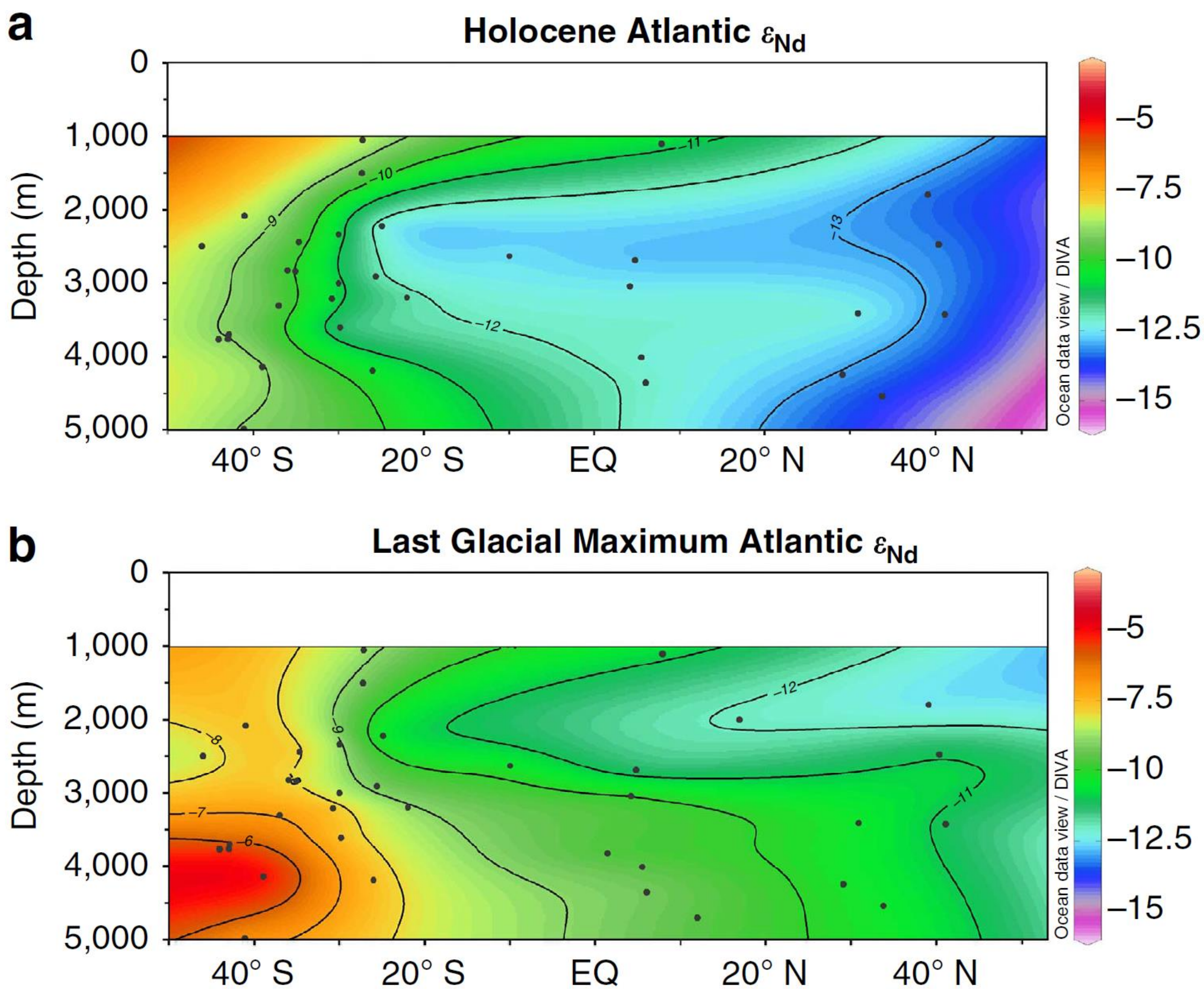
Paleoclimate records: *the editor's cut*



And, what about deep water geometry in the Atlantic during the Last Glacial Maximum?

Howe et al. (2016)

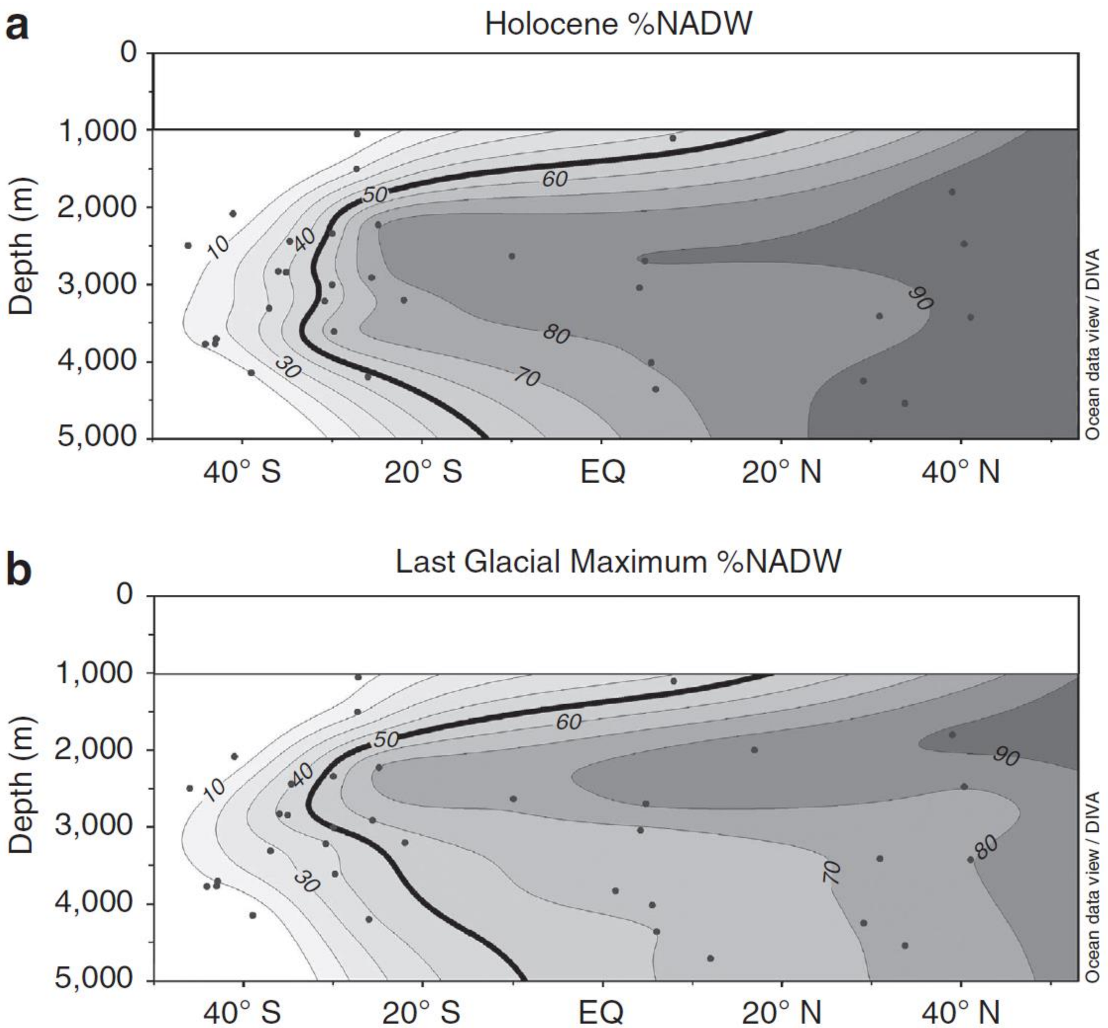
Paleoclimate records: *the editor's cut*



Marked N-S gradient at deep waters suggest the sustained production of NADW and another northern-sourced water mass at intermediate water depth

Howe et al. (2016)

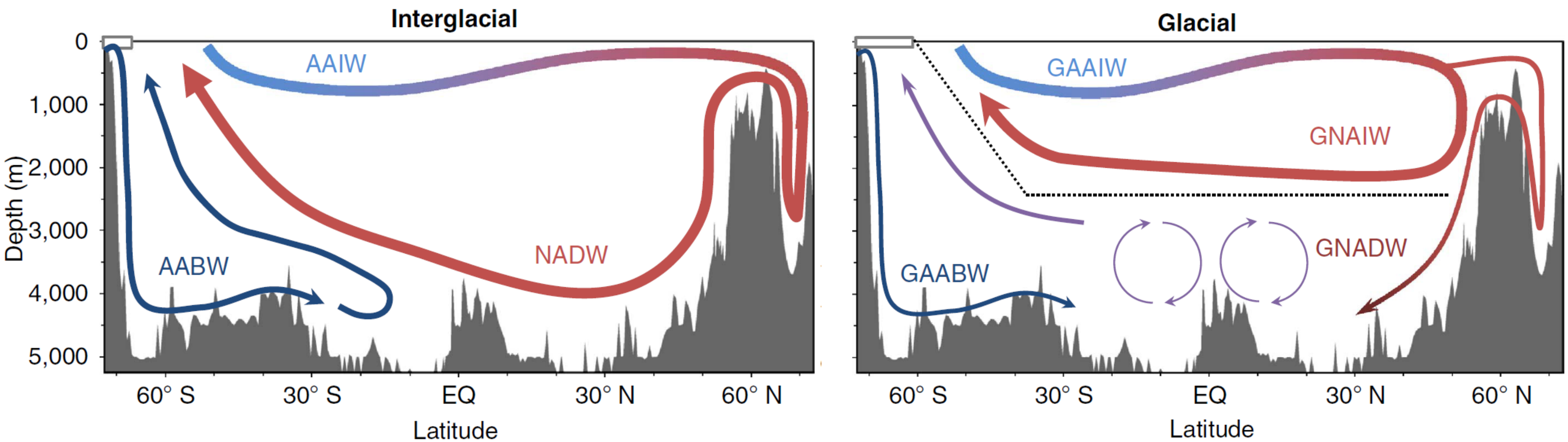
Paleoclimate records: *the editor's cut*



Marked N-S gradient at deep waters suggest the sustained production of NADW and another northern-sourced water mass at intermediate water depth

Howe et al. (2016)

Paleoclimate records: *the editor's cut*



A greater amount of respired carbon must have been stored in the abyssal Atlantic during the Last Glacial Maximum by a sluggish deep overturning cell, comprised of well-mixed northern- and southern-sourced waters

Howe et al. (2016)

Suggested reading

Lowe et al., 2007. Understanding Quaternary Climate Change. In: Elias (ed.), Encyclopedia of Quaternary Science, Elsevier, 28-39

Masson-Delmotte, et al. 2013. Information from Paleoclimate Archives. In: Stocker et al. (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 383-464

Ruddiman W.F. 2014. Earth's Climate: Past and Future. W.H. Freeman and Company, 445 p

SPSAS Climate Change

Many thanks for your attention!

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chiessi@usp.br