Cancellation of the precessional cycle in δ18O records during the Early Pleistocene

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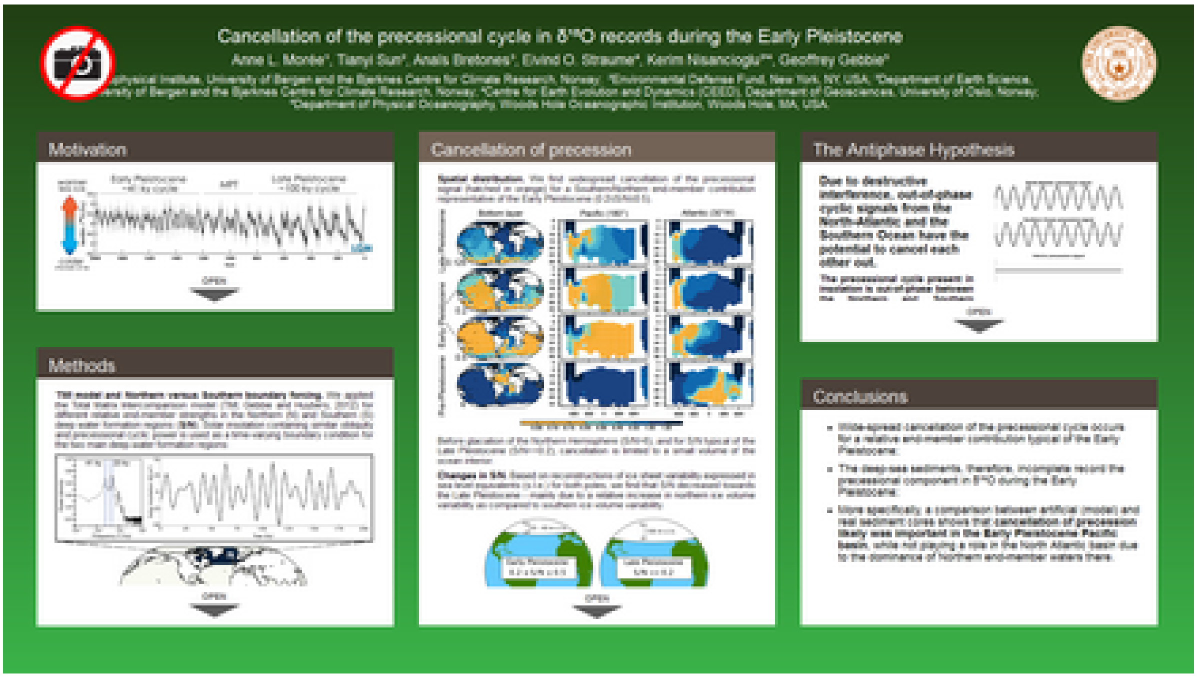
Abstract

Deep-sea δ18O records show a pronounced difference in Milankovitch periodicity between the Early and Late Pleistocene. δ18O is interpreted as a proxy for ice sheet volume and temperature, which led to the conclusion that glacial-interglacial cycles considerably changed their rhythm during the mid-Pleistocene. This transition is referred to as the mid-Pleistocene Transition (MPT). Specifically, the precessional component of the Milankovitch cycles is absent in Early Pleistocene δ18O records, despite its continuous presence in solar insolation forcing to the ice sheets. Climate feedbacks involving (sea) ice, geological processes and carbon and nutrient cycling have been proposed as causes of this marked change. We however show that the absence of an Early Pleistocene precession signal in deep-sea δ18O records could be the result of destructive interference of the precessional cycle in the interior ocean. Such cancellation is caused by the anti-phasing of the precessional cycle between the North Atlantic and Southern Ocean deep-water sources (see Figure). We explore the potential for cancellation in the transient setup of the Total Matrix Intercomparison model for a wide range of source signal strengths. Our results show that cancellation can cause the absence of the precessional signal due to cancellation in the interior South-Atlantic, Indian and Pacific basins. Cancellation is especially widespread for a relative end-member contribution typical for the Early Pleistocene. We therefore conclude that the precessional component is likely incompletely archived in Early Pleistocene δ18O records, and appears as an actual change in Milankovitch periodicity across the MPT. Proxies not susceptible to cancellation of precession (such as those currently retrieved across the MPT from Antarctica) would be able to verify to what extent deep-sea δ18O correctly represents Pleistocene climate.

Cancellation of the precessional cycle in $\delta^{18}O$ records during the Early Pleistocene



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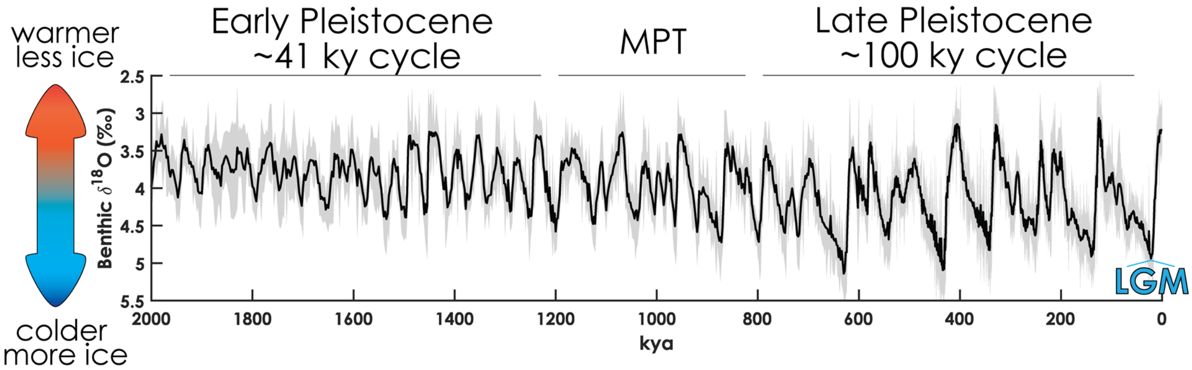
UiO University of Oslo

Woods Hole Oceanographic Institution

BJERKNES CENTRE for Climate Research

PRESENTED AT:

MOTIVATION

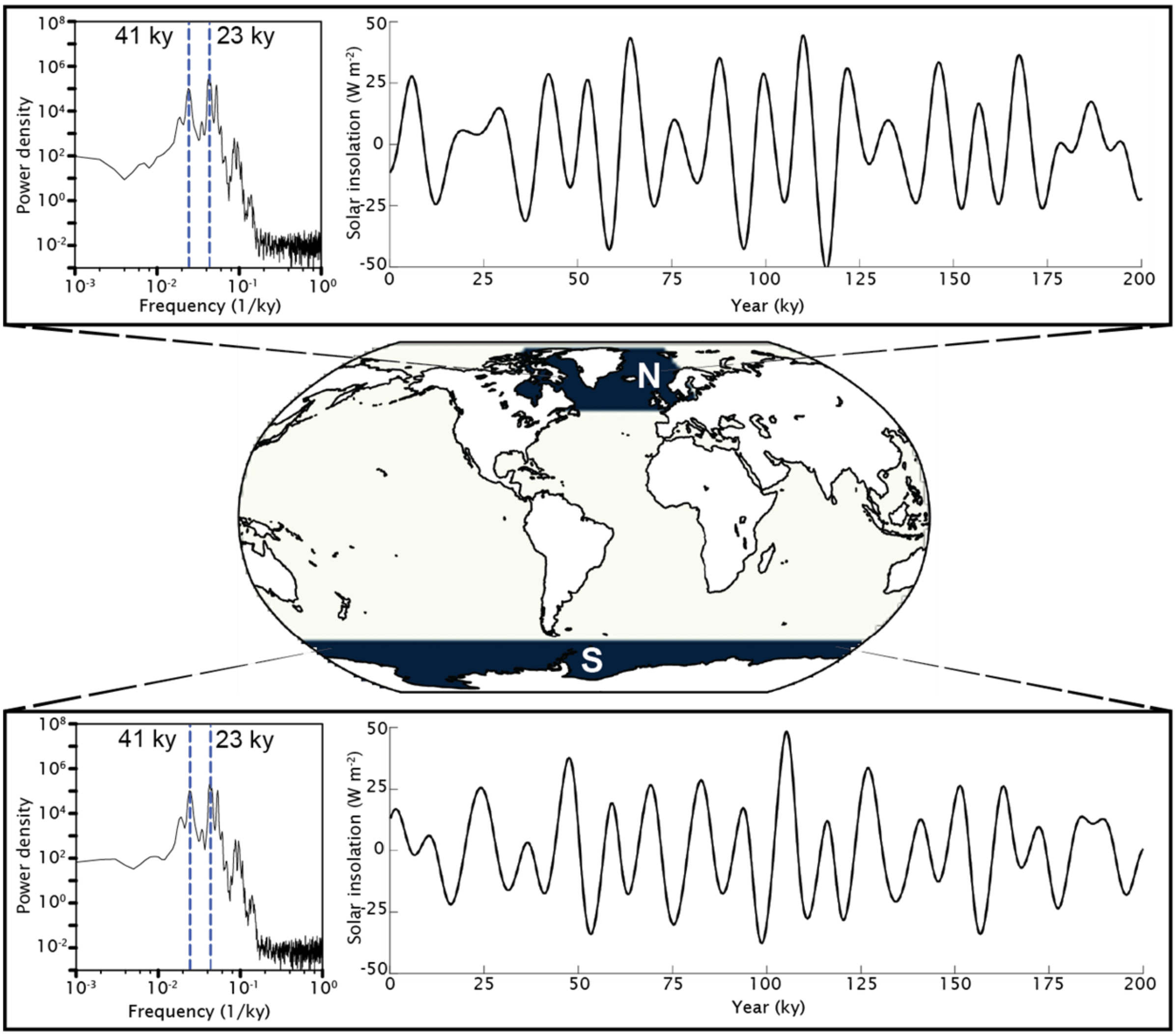


$\delta^{18}O$ records from deep-sea sediment cores show a marked contrast in dominant periodicity between the **Early (here, 2-1.2 Mya) and Late Pleistocene (here, 0.8-0 Mya)**. From variations in insolation we mainly expect obliquity (~41 ky) and precession (~23 ky) to dominate the spectrum. However, **the precessional cycle (~23 ky) is absent in Early Pleistocene records**.

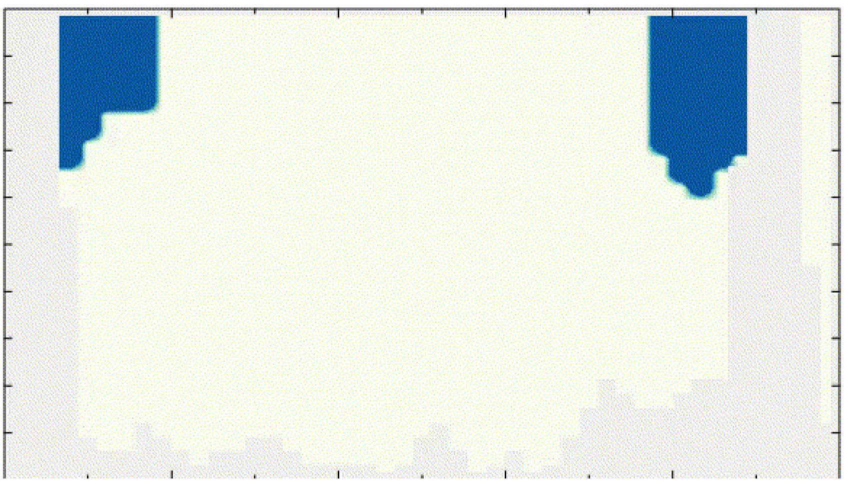
Different hypotheses have been proposed to understand this marked contrast in periodicity (the Mid Pleistocene Transition, the **MPT**). We explore the role of the cancellation of the out-of-phase hemispheric precessional signals (Raymo et al., 2006), providing **an alternative view of the MPT.**

METHODS

TMI model and Northern versus Southern boundary forcing. We applied the Total Matrix Intercomparison model (TMI; Gebbie and Huybers, 2012) for different relative end-member strengths in the Northern (N) and Southern (S) deep water formation regions (**S/N**). Solar insolation containing similar obliquity and precessional cyclic power is used as a time-varying boundary condition for the two main deep-water formation regions:



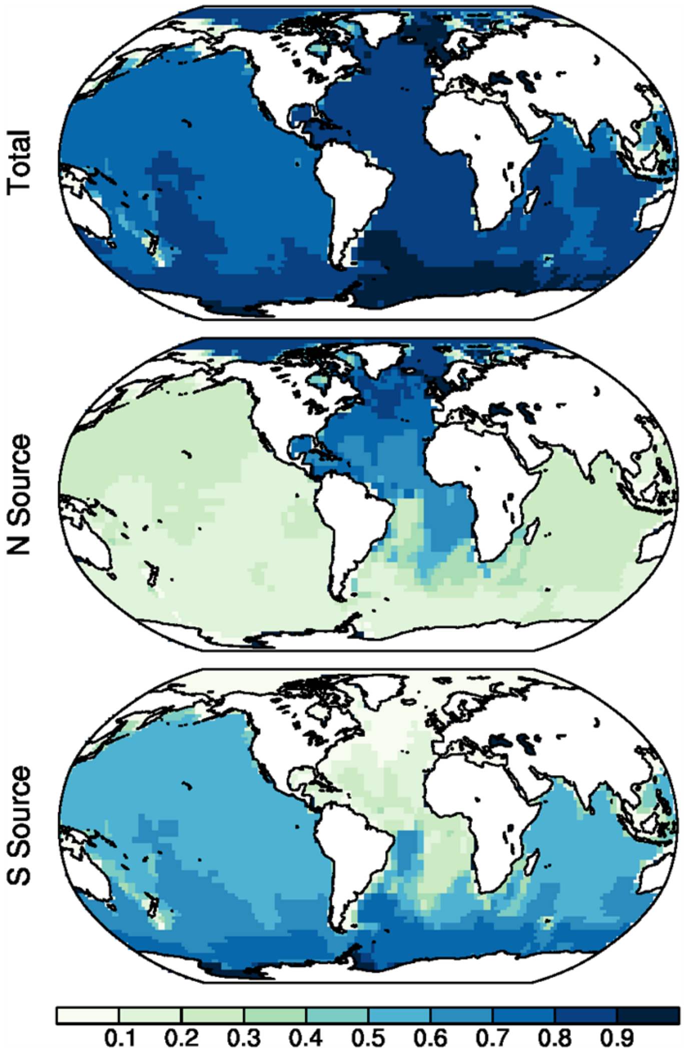
An Atlantic meridional transect showing the cyclic Northern and Southern signals entering the ocean



South North

The TMI model is representative of the contemporary ocean circulation, and we explore the effects of changes in source signal strength (S/N) for a wide range of different for S/N*.

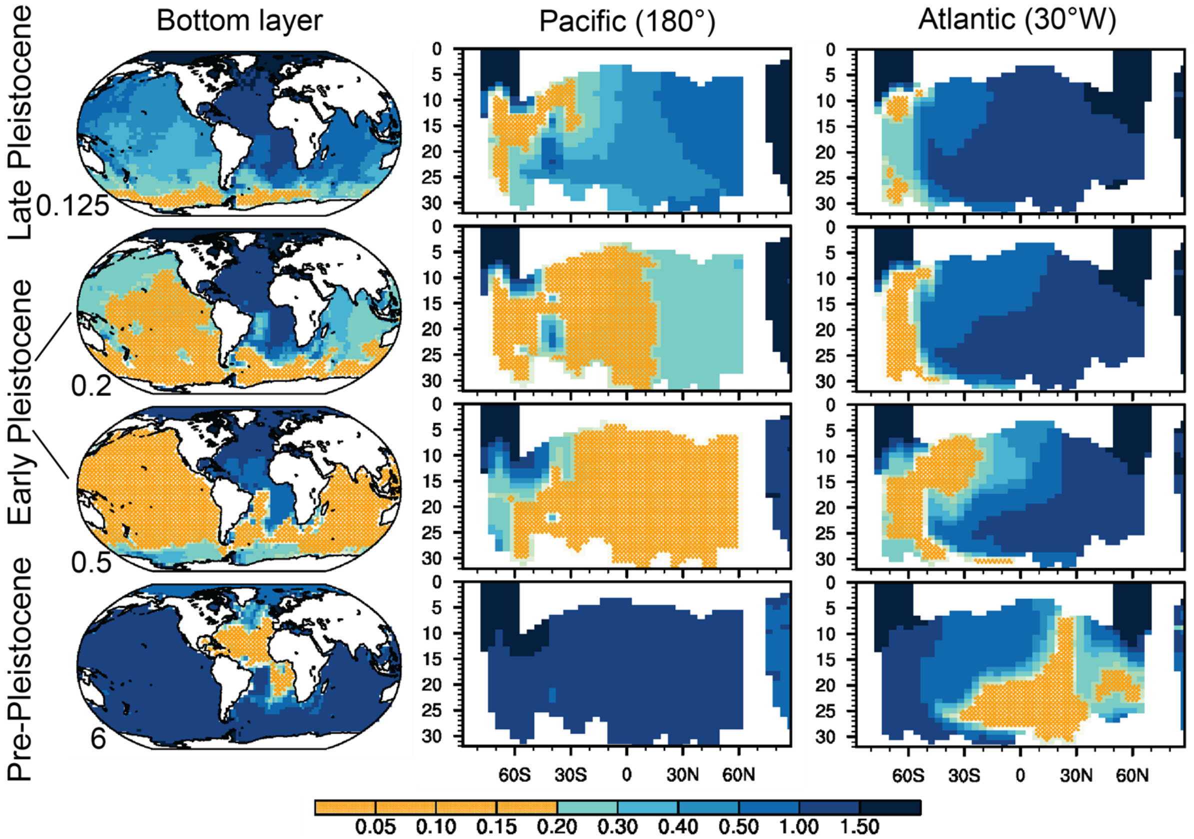
Volumetric contribution of the deep-water formation regions. The fraction of water contributed by the Northern and Southern deep-water formation regions at the sediment interface, showing the dominance of Southern end-member waters for the Pacific basin while the North-Atlantic deep waters remain relatively constrained to the North Atlantic:



* S/N = [0.125:1, 0.15:1, 0.2:1, 0.25:1,0.375:1, 0.5:1, 0.75:1, 1:1, 1.1:1, 1.2:1, 1.25:1, 1.5:1, 2:1, 2.5:1, 3:1, 3.5:1, 4:1, 5:1, 6:1].

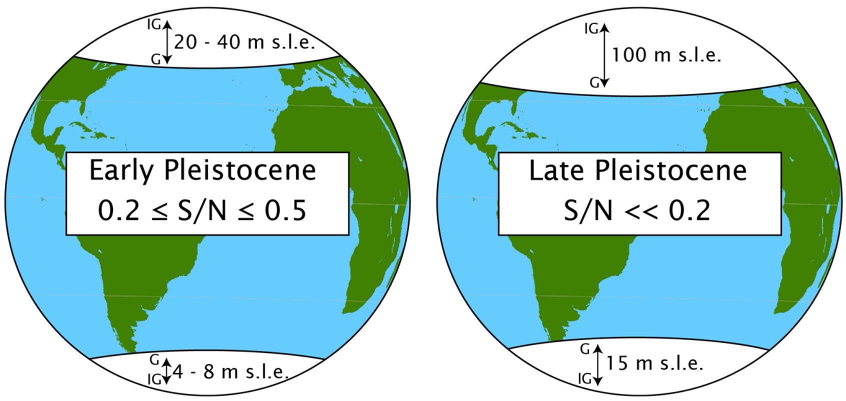
CANCELLATION OF PRECESSION

Spatial distribution. We find widespread cancellation of the precessional signal (hatched in orange) for a Southern/Northern end-member contribution representative of the Early Pleistocene (0.2≤S/N≤0.5).

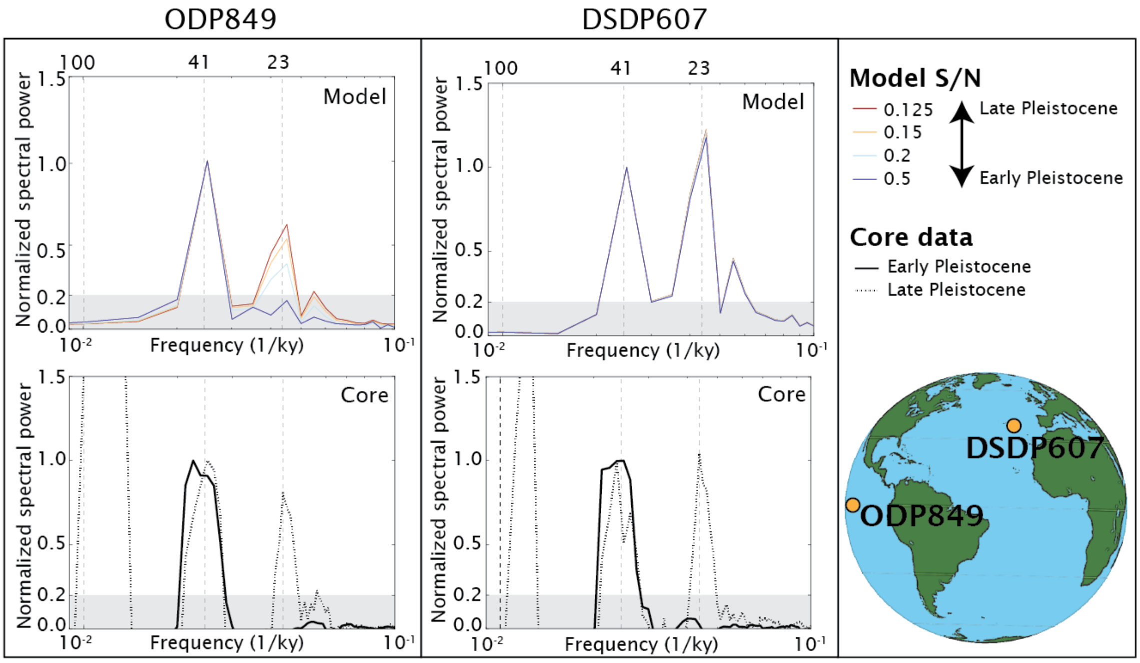


Before glaciation of the Northern Hemisphere (S/N>6), and for S/N typical of the Late Pleistocene (S/N<<0.2), cancellation is limited to a small volume of the ocean interior.

Changes in S/N. Based on reconstructions of ice sheet variability expressed in sea level equivalents (s.l.e.) for both poles, we find that S/N decreased towards the Late Pleistocene - mainly due to a relative increase in northern ice volume variability as compared to southern ice volume variability.

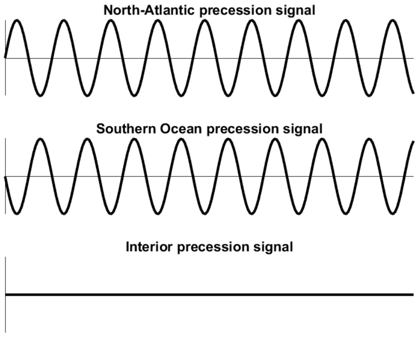


(Artificial) sediment cores. The power spectrum of the model and observational data are compared at two locations. The results show that precessional cancellation is unlikely to be important in the North-Atlantic. In the Pacific, the absence of precession is modeled for S/N typical of the Early Pleistocene.


ODP849
DSDP607
100
41
23
Normalized spectral power
1.5
1.0
0.5
0.2
0.0
Model
Core
Frequency (1/ky)
Model S/N
0.125
0.15
0.2
0.5
Late Pleistocene
Early Pleistocene
Core data
Early Pleistocene
Late Pleistocene
DSDP607
ODP849

THE ANTIPHASE HYPOTHESIS

Due to destructive interference, out-of-phase cyclic signals from the North-Atlantic and the Southern Ocean have the potential to cancel each other out.



The precessional cycle present in insolation is out-of-phase between the Northern and Southern Hemispheres for a specific season. Assuming that the Northern and Southern ice sheets archive these precessional cycles in their respective $\delta^{18}O$ signatures, these out-of-phase signals would reach the interior ocean through deep-water formation. Here, cancellation could then occur due to interference.

The actual emergence of cancellation depends on the relative strength of the Northern and Southern end-member precessional cycle and their volumetric contributions to the interior ocean (as explored in this study, see Methods).

For the Antiphase Hypothesis to explain the MPT, the cancellation needs to be an important process in the Early Pleistocene, while **not** being relevant in the Late Pleistocene).

CONCLUSIONS

- Wide-spread cancellation of the precessional cycle occurs for a relative end-member contribution typical of the Early Pleistocene;
- The deep-sea sediments, therefore, incomplete record the precessional component in $\delta^{18}O$ during the Early Pleistocene;
- More specifically, a comparison between artificial (model) and real sediment cores shows that **cancellation of precession likely was important in the Early Pleistocene Pacific basin**, while not playing a role in the North Atlantic basin due to the dominance of Northern end-member waters there.

Sorry but time is up!

CV

Profile

Enthusiastic marine biogeochemist with a broad interest across the Earth Sciences. As I want to pursue a career in academia, my current ambition is to find an inspiring postdoc environment where I can build on my previous experience with biogeochemical and physical Southern Ocean dynamics and Earth System modelling.

Scientific education

2014-now **PhD** - University of Bergen/Bjerknes Centre for Climate Research 'The Role of the Southern Ocean in Past Global Biogeochemical Cycling'. Main tasks: Global model development, execution and analysis (NorESM/ HAMOCC2s/ TMI), teaching. Focus on carbon-13 and paleo-oceanography. Supervisors: Christoph Heinze, Jörg Schwinger, Mario Hoppema. Highlights: 25% teaching position / 4-month research visit to ETH (Prof. N. Gruber) / 'Advanced Climate Dynamics Course' 2018 on Hemispheric Asymmetries / Active member of PhD research schools CHESS and ResClim / Attendance and presenting at 7 international conferences/workshops/meetings (e.g., ICDC2018, GRC2019) / Visit and seminar presentation Uni-Bern and AWI

2011-2013 **Research Master hydrology and geochemistry** - University of Utrecht, Cum laude (GPA 4.0). Focus on groundwater hydrology and biogeochemistry. Master research on global urban nitrogen and phosphorus production and discharge to surface water (Morée et al., 2013).

2007-2010 **Bachelor of Earth Sciences** - University of Utrecht With distinction (top 10%). Specialization in hydrogeology.

Publications (including submitted and in prep)

Morée, A.L., J. Schwinger, U. Ninneman, A. Jeltsch-Thömmes, I. Bethke, and C. Heinze: The Role of the Efficiency of the Biological Pump in Simulating the Last Glacial Maximum Ocean, in prep

Tjiputra, J., J. Schwinger, M. Bentsen, A.L. Morée, et al.: Ocean biogeochemistry in the Norwegian Earth System Model version 2 (NorESM2), Geoscientific Model Development, submitted to GMD.

Morée, A.L., T. Sun, A. Bretones, E.O. Straume, K. Nisancioglu, and J. Gebbie: Cancellation of the precessional cycle in benthic $\delta^{18}O$ records during the Early Pleistocene, submitted to PNAS.

Morée, A.L. and J. Schwinger: A Last Glacial Maximum forcing dataset for ocean modelling, Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2019-79, in review, 2019.

Morée, A.L. and J. Schwinger: Last Glacial Maximum minus pre-industrial anomaly fields for use in forced ocean modelling, based on PMIP3, Dataset, Norstore, https://doi.org/10.11582/2019.00011, 2019.

Morée, A.L., J. Schwinger, and C. Heinze: Southern Ocean controls of the vertical marine $\delta^{13}C$ gradient – a modelling study, Biogeosciences, 15, 7205-7223, https://doi.org/10.5194/bg-15-7205-2018, 2018.

Morée, A.L., A. H. W. Beusen, A. F. Bouwman, and W. J. Willems: Exploring global nitrogen and phosphorus flows in urban wastes during the twentieth century, Global Biogeochem. Cycles, 27, 836– 846, doi:10.1002/gbc.20072, 2013.

ABSTRACT

Deep-sea $\delta^{18}O$ records show a pronounced difference in Milankovitch periodicity between the Early and Late Pleistocene. $\delta^{18}O$ is interpreted as a proxy for ice sheet volume and temperature, which led to the conclusion that glacial-interglacial cycles considerably changed their rhythm during the mid-Pleistocene. This transition is referred to as the Mid-Pleistocene Transition (MPT). Specifically, the precessional component of the Milankovitch cycles is absent in Early Pleistocene $\delta^{18}O$ records, despite its continuous presence in solar insolation forcing to the ice sheets. Climate feedbacks involving (sea) ice, geological processes and carbon and nutrient cycling have been proposed as causes of this marked change. We, however, show that the absence of an Early Pleistocene precession signal in deep-sea $\delta^{18}O$ records could be the result of destructive interference of the precessional cycle in the interior ocean. Such cancellation is caused by the anti-phasing of the precessional cycle between the North Atlantic and Southern Ocean deep-water sources (see Figure). We explore the potential for cancellation in the transient setup of the Total Matrix Intercomparison model for a wide range of source signal strengths. Our results show that cancellation can cause the absence of the precessional signal due to cancellation in the interior South-Atlantic, Indian and Pacific basins. Cancellation is especially widespread for a relative end-member contribution typical for the Early Pleistocene. We, therefore, conclude that the precessional component is likely incompletely archived in Early Pleistocene $\delta^{18}O$ records, and appears as an actual change in Milankovitch periodicity across the MPT. Proxies not susceptible to cancellation of precession (such as those currently retrieved across the MPT from Antarctica) would be able to verify to what extent deep-sea $\delta^{18}O$ correctly represents Pleistocene climate.

REFERENCES

This poster describes a paper under review at PNAS (Morée, A.L., T. Sun, A. Bretones, E.O. Straume, K. Nisancioglu, and J. Gebbie: Cancellation of the precessional cycle in benthic $\delta^{18}O$ records during the Early Pleistocene).

G. Gebbie, P. Huybers, The Mean Age of Ocean Waters Inferred from Radiocarbon Observations: Sensitivity to Surface Sources and Accounting for Mixing Histories. Journal of Physical Oceanography 42, 291-305 (2012).

M. E. Raymo, L. E. Lisiecki, K. H. Nisancioglu, Plio-Pleistocene Ice Volume, Antarctic Climate, and the Global δ 18 O Record. Science 313, 492-495 (2006).

SWITCH TEMPLATE