180213PC31A

- **PC31A** Meridional Overturning Circulation Dynamics in Past Warm and Cold Climates I

- *Oregon Convention Center*
- *- Oregon Ballroom 204*

The meridional overturning circulation (MOC) is a key component of the global climate system, as it modulates the transport and storage of both heat and carbon. Changes in deep-ocean circulation are thought to have played a key role in past climatic transitions, such as between glacial and interglacial periods. However, reaching a quantitative understanding of the dynamics that contributed to these changes, remains a major challenge in climate research. The MOC's response to current climate trends is also an unknown when assessing future global ocean-climate-carbon cycle interactions. Investigating how the MOC varied in the past can provide crucial information on the mechanisms and drivers of its variability, as well as on the possible impacts of future circulation changes. This multidisciplinary session will facilitate discussions between the modeling and data communities, with the aim to explore both the transient and equilibrium response of the MOC to different forcing scenarios. We welcome contributions from both proxy-based studies to reconstruct past changes, and those exploring these dynamics from a mechanistic perspective, spanning from theoretical approaches to fully-coupled numerical modeling efforts. We especially encourage combined model-data analyses, as well as studies investigating past periods that could be viewed as analogues for future climates.

Wednesday, February 14, 2018

08:00 AM - 10:00 AM

- *Oregon Convention Center*
- *- Oregon Ballroom 204*

Primary Chair

- Alice Marzocchi
  - *University of Chicago*

Co-Chairs

- Benoit Thibodeau
  - *The University of Hong Kong*
- Juan Muglia
  - *Oregon State University*
- Andrea Burke
  - *University of St Andrews*

    - 08:00 AM**PC31A-01** How CO_2, ice sheets and astronomical forcings conspire to alter the strength of the AMOC, volume of NADW, and ocean carbon storage: Expectations from a coarse resolution model***Eric D Galbraith**, ICREA Catalan Institution for Research and Advanced Studies, Barcelona, Spain, Casimir de Lavergne, UNSW, School of Mathematics and Statistics, Sydney, Australia and Sarah Eggleston, Empa, Laboratory for Air Pollution & Environmental Technology, Duebendorf, Switzerland*
    - It has been suggested that the volume transport of the Atlantic Meridional Overturning Circulation (AMOC) varied over ice ages, with sudden pronounced weakenings during stadial events, most clearly during Heinrich stadials. In addition, evidence suggests that the contribution of North Atlantic Deep Water (NADW) to the global ocean was reduced during the Last Glacial Maximum (LGM), although the AMOC strength may have been similar to pre-industrial. Here, we show a matrix of equilibrium simulations with the GFDL coarse resolution coupled model CM2Mc, that appear to be consistent with these observations, and reveal important interacting roles for CO2, the Laurentide ice sheet, and orbital forcing. We find that, despite myriad interacting factors, the volume contribution of Antarctic vs. North Atlantic polar waters to the deep ocean consistently scales with the relative density of Antarctic vs. North Atlantic deep water formation sites. The relative density of Antarctic water increases at low CO2 and low obliquity as it becomes very salty, and the sequestration of salt by Antarctic bottom waters causes the North Atlantic to become so fresh that its ability to form dense waters is threatened. It thus becomes susceptible to spontaneous overturning disruptions, forced only by

internal climate variability. Meanwhile, a large Laurentide ice sheet steers atmospheric circulation so as to strengthen NADW formation and transport, but cools the Southern Ocean remotely, enhancing Antarctic sea ice export and leading to still denser and more voluminous Antarctic waters. Thus, the ice sheet effect could have contributed to a relatively strong AMOC during the LGM, even as it caused the volume contribution of NADW to diminish. Finally, we find that major increases in disequilibrium carbon storage are driven by increased volume contributions of Antarctic waters to the deep ocean, while the meridional overturning is more closely related to global soft tissue pump carbon storage.

- 10.5194/cp-12-1663-2016
- 08:15 AM**PC31A-02** The AMOC's response to global temperature change on time-scales from decades to millennia.***Malte Jansen**, University of Chicago, Chicago, IL, United States*
- Climate model simulations typically suggest a weakening and shoaling of the Atlantic Meridional Overturning Circulation (AMOC) over the course of the 21st century, although a significant change cannot yet be confirmed by observations. In lack of a direct observational confirmation, our confidence in climate predictions can be strengthened by data from past climates that can serve as analogs, and/or by a solid physical understanding of the responsible mechanisms. While proxy data for past warm climates are limited, a more substantial record exists for the Last Glacial Maximum (LGM). Interestingly, the proxies suggest that the AMOC was shallower and possibly weaker during the cold LGM, which may appear at odds with the expectation of a weaker and shallower AMOC also in a warmer climate. The presented work argues that the apparent discrepancy can be explained by the difference between the transient versus equilibrium response of the AMOC to surface temperature change.
- Idealized numerical simulations suggest that the ocean's equilibrium response to global cooling is associated with a shoaling and weakening of the AMOC (consistent with proxy evidence for the LGM), while warming results in a deepening and strengthening of the AMOC. However, the transient response is reversed, with surface warming causing a shoaling and weakening of the AMOC (consistent with results from coupled climate simulations). The initial shoaling, which is attributed to

a rapid warming of northern-sourced deep water, occurs on decadal time-scales and lasts for centuries. The eventual recovery and strengthening of the AMOC instead is argued to be associated with diffusive adjustment of the abyssal ocean and continues for many millennia. The results highlight the necessity to distinguish between the transient versus equilibrium response of the ocean circulation to changes in the climate, which is of particular importance when attempting to use past climates as analogs for the coming decades or centuries.

- 08:30 AM**PC31A-03** Ocean Density Changes and LGM-to-Modern Sealevel Rise***Geoffrey Gebbie**, Woods Hole Oceanographic Inst., Woods Hole, MA, United States, Alexander Simms, University of California Santa Barbara, Santa Barbara, CA, United States and Lorraine E Lisiecki, University of California Santa Barbara, Earth Science, Santa Barbara, CA, United States*
- Estimates of sea-level rise from the Last Glacial Maximum (LGM) to the modern-day are not balanced by the estimated amount of ice melted. This “missing ice” accounts for about 15 m of global sealevel rise but ignores the potentially important contribution from ocean expansion by seawater density change. Here we provide an estimate of this contribution to sealevel rise by using a 3D global gridded field of glacial temperature and salinity that takes into account benthic foraminiferal observations and water-mass geometry changes due, in part, to the glacial meridional overturning circulation. The large amount of meltwater added to the ocean during the deglaciation has a primarily eustatic signal, as expected, with steric contributions being an order of magnitude smaller. However, we find that the thermosteric, halosteric, pressure loading, and nonlinear effects can be a meter or greater over the deglacial timescale. It is often supposed that the thermosteric effect dominates the halosteric effect, but here we find that the halosteric effect is competitive on the regional scale due to the redistribution of salinity in the glacial ocean. Two effects that are often neglected in modern-day steric height calculations, pressure loading by meltwater and nonlinear effects due to ocean mixing, are as large as the thermosteric effect

and they have the opposite sign (i.e., ocean contraction). Thus, ocean density changes fall short of balancing the sea-level budget at the LGM, suggesting that either an LGM ice sheet has yet to be discovered or current estimates of the known ice sheets are too small.

- 08:45 AM**PC31A-04**
- Reconstructing carbon cycle and overturning changes since the LGM using benthic $\delta^{13}C$***Carlye Peterson**, University of California Riverside, Earth Sciences, Riverside, CA, United States, Lorraine E Lisiecki, University of California Santa Barbara, Earth Science, Santa Barbara, CA, United States and Geoffrey Gebbie, Woods Hole Oceanographic Inst., Woods Hole, MA, United States*
- Here we present a compilation of 118 time series $\delta^{13}C$ records from *Cibicides wuellerstorfi* spanning the last deglaciation (20-6 kyr). The age model for this $\delta^{13}C$ compilation are constrained by planktic radiocarbon records from Stern and Lisiecki (2014). The $\delta^{13}C$ records are stacked within nine regions, then combined using volume-weighted averages to create intermediate, deep, and whole ocean $\delta^{13}C$ stacks. Deglacial benthic $\delta^{13}C$ stacks can be used to reconstruct mean changes in the size of the terrestrial biosphere, and deep ocean carbon storage. A proxy for deep ocean carbon storage, the $\delta^{13}C$ gradient between the intermediate and deep stacks resembles the atmospheric CO_2 record from ice cores and reproduces several millennial-scale features of deglacial CO_2 change. This suggests these $\delta^{13}C$ records have sufficient spatial coverage and time resolution to reconstruct large-scale changes in ocean carbon storage. Similarly, results from PCA on the same $\delta^{13}C$ time series records reveals the dominant mode of variability is consistent with deglacial CO_2 change and the vertical $\delta^{13}C$ gradient while the second mode of variability is consistent with millennial scale changes in deep ocean circulation. Changes in whole-ocean $\delta^{13}C$ are quite different from the vertical $\delta^{13}C$ gradient, gradually increasing from 19-6 ka and likely recording the expansion of the terrestrial biosphere throughout this time. This four-dimensional $\delta^{13}C$ record compilation is well-suited for comparison to isotope-enabled carbon cycle model simulations and 3D visualizations.
- 09:00 AM**PC31A-05** Dynamical controls on the depth of the boundary between bottom and deep waters in the Last Glacial Maximum Atlantic***Daniel E Amrhein**, University of Washington, Oceanography / Atmospheric Sciences, Seattle, WA, United States,*

Carl Wunsch, Harvard University, Cambridge, MA, United States and Luanne Thompson, University of Washington Seattle Campus, Oceanography, Seattle, WA, United States

- Proxy measurements of ocean tracers at the Last Glacial Maximum (LGM, ca. 23-19 ka) suggest that the western Atlantic Ocean was filled dominantly by Antarctic Bottom Water (AABW), with a lesser role for North Atlantic Deep Water (NADW) relative to the modern. Proposed explanations for a shoaled NADW-AABW boundary (NAB) include changes in the strength and/or structure of the Atlantic meridional overturning circulation (AMOC), possibly driven by some combination of changes in surface buoyancy forcing, wind stress, and abyssal mixing. Given the complexity of the AMOC – which is incompletely understood in the modern ocean, let alone in the geologic past – it remains unclear which (if any) process is most important for setting NAB depth in the glacial Atlantic. Improving our knowledge of these dynamics is important for our understanding of the climate system, as glacial reservoirs of nutrient-rich AABW could explain glacial-interglacial changes in carbon dioxide.
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  This work uses the adjoint capability of the MITgcm ocean model to infer how changes in wind stress, surface air temperature, and precipitation contribute to shoaling the equilibrium NAB position (defined as the depth of the 50% isopleth of a tracer released south of 60S) by 500 m in the western Atlantic Ocean between 45 S and 45 N. Integrating the model forward under inferred patterns of wind and buoyancy forcing changes illustrates dynamical pathways by which NAB position can be adjusted. We find that equatorial wind stress changes suggestive of a migration in the intertropical convergence zone lead to a reduction in deep western boundary current transport that in turn reduces the export of NADW and decreases the presence of associated water properties in the Atlantic basin. We also report on ongoing experiments investigating NAB sensitivity to changes at high northern and southern latitudes, including mediating effects from a fully coupled sea ice model.

- 09:15 AM**PC31A-06** 'Overturning Circulation and Atmospheric CO_2 Variations Under Varying Southern Ocean Climate and Geometrical Setups'***Jonathan Baker**, Andrew J. Watson and Geoffery Vallis, University of Exeter, Exeter, United Kingdom*

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Over the past one million years, atmospheric CO_2 and Antarctic temperatures covaried over several glacial cycles, with the overturning circulation as forced by the climate over the Southern Ocean implicated as a causal factor. Here we investigate the structure of the ocean's global overturning circulation during the glacial cycles and its importance in causing the associated changes in atmospheric CO_2.

A semi-analytical single basin ocean-atmosphere model has been used to examine the effects of changes in solar irradiance and ocean surface buoyancy fluxes on the overturning circulation. It has been shown that changes in salinity caused by variations in sea-ice extent and export must be crucial in causing the variations in the overturning circulation, with a weakening and shoaling of the mid-depth cell when salinity fluxes are increased in the Southern Ocean.

However, the single basin representation of the ocean does not account for possible inter-basin exchanges, which may have an effect on the overturning circulation and carbon cycle in either or both present and past climates. The impact of changes in Southern Ocean buoyancy fluxes and wind forcing on the circulation, and consequently atmospheric CO_2 in both idealized single- and multi-basin setups is investigated using a general circulation model with simple biogeochemistry, and the significance of inter-basin exchanges on the overturning circulation structure and carbon cycle under different climate regimes is illustrated. Results are also compared with the results from the semi-analytical model.

09:30 AM**PC31A-07** Abyssal ocean overturning shaped by seafloor distribution***Casimir de Lavergne***[1], *Madec Gurvan*[2], *Fabien Roquet*[3], *Ryan Holmes*[4,5] *and Trevor J McDougall*[5], *(1)UNSW, School of Mathematics and Statistics, Sydney, Australia, (2)Sorbonne Universités (UPMC, Univ Paris 06)-CNRS-IRD-MNHN, LOCEAN Laboratory, IPSL, Paris, France, (3)Bolin Centre for Climate Research, Stockholm, Sweden, (4)University of New South Wales, Climate Change Research Centre, ARC Centre of Excellence for Climate System Science and School of Mathematics and Statistics, Sydney, NSW, Australia, (5)University of New South Wales, Sydney, NSW, Australia*

The abyssal ocean is broadly characterized by northward flow of the densest waters and southward flow of lighter waters above. Understanding what controls the strength and structure of these inter-hemispheric flows, referred to as the abyssal overturning circulation, is key to quantifying the ocean's ability to store carbon and heat on timescales exceeding one century. Here we show that, north of 32S, the depth distribution of the seafloor compels dense southern-origin waters to flow north below about 4 km depth and to return south predominantly deeper than 2.5 km. In the absence of a northern surface source of deep water, as observed in the modern Indian and Pacific oceans, a shadow zone of comparatively weak mean meridional flow forms at the overlying mid-depths (1-2.5 km). Backed by a new analysis of historical radiocarbon measurements, the findings imply that the geometry of the Pacific, Indian and Atlantic basins places a major external constraint on the overturning structure.

- 09:45 AM**PC31A-08** An Atlantic-Pacific Seesaw in Overturning Circulation and Biogeochemistry***James William Buchanan Rae***[1]*, David Thornalley*[2]*, Louisa I Bradtmiller*[3]*, Andrea Burke*[1]*, Holger Gebhardt*[4]*, William Robert Gray*[1]*, Rhian Laura Rees-Owen*[5] *and Michael Sarnthein*[6]*, (1)University of St Andrews, School of Earth and Environmental Sciences, St Andrews, KY16, United Kingdom, (2)University College London, London, United Kingdom, (3)Macalester College, Saint Paul, MN, United States, (4)Geologische Bundesanstalt, Vienna, Austria, (5)University of St Andrews, School of Earth and Environmental Sciences, St Andrews, United Kingdom, (6)Univ Kiel, Kiel, Germany*

- **PC33A** Meridional Overturning Circulation Dynamics in Past Warm and Cold Climates II
- *Oregon Convention Center*

- *- Oregon Ballroom 204*
  - 02:00 PM**PC33A-01** Stable Isotope Evidence for North Pacific Deep Water Formation during the mid-Pliocene Warm Period***Heather L Ford****, University of Cambridge, Earth Sciences, Cambridge, United Kingdom, Natalie Burls, George Mason University Fairfax, Fairfax, VA, United States and David A Hodell, University of Cambridge, Godwin Laboratory for Palaeoclimate Research, Cambridge, United Kingdom*
  - Only intermediate water forms in the North Pacific today because of a strong halocline. A recent climate modeling study suggests that conditions during the mid-Pliocene warm period (~3 Ma), a time interval used as pseudo-analogue for future climate change, could have supported a Pacific Meridional Overturning Circulation

(PMOC) in the North Pacific. This modeled PMOC is of comparable strength to the modern Atlantic Meridional Overturning Circulation. To investigate the possibility of a mid-Pliocene PMOC, we studied a depth transect of sites between ~2400 to 3400 m water depth on Shatsky Rise by measuring $\delta\delta^{18}O$ and $\delta\delta\delta^{13}C$ of *Cibicidoides wuellerstorfi* and comparing these new results with previously published records. Today, the vertical $\delta\delta^{13}C$ gradient has lower values at mid-depths because of the presence of aged water at the "end of the ocean conveyor belt." We find that the vertical $\delta\delta\delta^{13}C$ gradient was reduced, and slightly reversed during the Pliocene interval on Shatsky Rise relative to modern. This $\delta\delta\delta^{13}C$ data supports the modeling results that there was deep water formation in the North Pacific. On the Shatsky Rise, the mid-depth $\delta\delta^{18}O$ values are high relative to the deep site and other high-resolution records in the Equatorial Pacific. This suggests the PMOC water mass was colder and/or had a more enriched seawater δ than the surrounding waters. Planned future work includes minor and trace element analyses to determine the temperature and ΔCO_3^{2-} characteristics of the PMOC water mass. Our results suggest a ventilated North Pacific during the globally warm mid-Pliocene.

- 02:15 PM**PC33A-02** North Pacific Deep water formation and a Pacific Meridional Overturning Circulation (PMOC) during the warm Pliocene***Natalie Burls***, *George Mason University Fairfax, Fairfax, VA, United States, Alexey V Fedorov, Yale Univ, New Haven, CT, United States, Daniel Mikhail Sigman, Princeton University, Princeton, NJ, United States, Sam Jaccard, University of Bern, Bern, Switzerland, Heather L Ford, University of Cambridge, Earth Sciences, Cambridge, United Kingdom, Ralf Tiedemann, AWI Bremerhaven, Bremerhaven, Germany and Gerald Hermann Haug, ETH Swiss Federal Institute of Technology Zurich, Zurich, Switzerland; Max Planck Institute for Chemistry, Mainz, Germany*
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The Atlantic meridional overturning circulation (AMOC), which depends on deep water formation in the northern high-latitude Atlantic, is a critical element of modern ocean circulation and climate. A comparable overturning circulation is, however, absent in the

Pacific, the world's largest ocean, where relatively fresh surface waters inhibit North Pacific deep convection. We present complementary measurement and modeling evidence that the warm, ~400 ppmv CO_2 world of the Pliocene supported subarctic North Pacific deep-water formation and a Pacific meridional overturning circulation (PMOC) cell. In Pliocene subarctic North Pacific sediments, we report orbitally paced maxima in calcium carbonate accumulation rate, with accompanying pigment and total organic carbon measurements supporting deep ocean ventilation-driven preservation as their cause. Together with high accumulation rates of biogenic opal, this requires vigorous bi-directional communication between surface waters and interior waters down to ~3 km in the western subarctic North Pacific, implying deep convection. Redox-sensitive trace metal data provide further evidence of higher Pliocene deep ocean ventilation prior to the 2.73 Ma transition. This observational analysis is supported by climate modeling results demonstrating that atmospheric moisture transport changes, in response to the reduced meridional sea surface temperature gradients of the Pliocene, were capable of eroding the halocline, leading to deep-water formation in the western subarctic Pacific and a strong PMOC.

02:30 PM**PC33A-03** Elucidating Global Meridional Overturning Circulation in Real and Fake Worlds***Andy Ridgwell**, University of California, Riverside, Department of Earth Sciences, Riverside, CA, United States and Sandra Kirtland Turner, University of California Riverside, Riverside, CA, United States*

Questions abound surrounding the large scale circulation of the ocean in the past, from whether warm climates imply sluggish overturning (and hence weak ocean ventilation), what controls where the sources of deep water form (and hence the sign of the dominant meridional overturning), to whether we can even ever actually 'know' anything about past circulation states.

Here we present an idealized brute-force exploration of the potential controls of the meridional overturning circulation, by generating a populous 'zoo' of possible alternative worlds. In this, we randomize the location of the main cratonic blocks that form the present-day continents, creating a series of fake paleo geographies that encapsulate a variety of differences in ocean basin size, shape, and connectivity (aka gateways). We parse these possible worlds alongside differing assumptions regarding solar constant and greenhouse forcing (hence generating cold through warm climate states) plus wind stress strength, through the GENIE Earth system model. The resulting steady circulation patterns are then analyzed, and statistical relationships between the properties of ocean meridional overturning circulation and tectonic and climate boundary conditions extracted. From this, we aim to derive a generalized framework for understanding the nature of and controls on past ocean circulation. Finally, we also briefly, but critically, assess a selection of both real and fake world circulation states projected by the GENIE model against other models as well as some illustrative constraining paleo proxy data.

02:45 PM**PC33A-04** A transient simulation of the last deglaciation***Ruza F Ivanovic***, *University of Leeds, Leeds, LS2, United Kingdom, Paul J Valdes, University of Bristol, Bristol, BS8, United Kingdom, Lauren J Gregoire, University of Leeds, School of Earth and Environment, Leeds, United Kingdom and Andrew D Wickert, University of Minnesota Twin Cities, Minneapolis, MN, United States*

We present the latest results from a fully transient simulation of the early last deglaciation (21-15 ka) using the Hadley Centre Climate model, HadCM3. In line with the Palaeoclimate Model Intercomparison Project Phase 4 (PMIP4) core experiment design, this simulation uses the ICE-6G_C ice sheet reconstruction with the land-sea mask and bathymetry updating every 500 years, and the height of the ice sheet evolving smoothly through the simulation. We have performed a pair of simulations starting from 23 ka, with and without additional routed fresh water fluxes from the melting of the ice sheets to investigate the impact on Atlantic Meridional Overturning Circulation (AMOC) and climate, and to evaluate the role of freshwater in preconditioning the glacial ocean. Thus, we are able to highlight the contrasting importance of the evolution of the ice sheets and meltwater. In addition, we have also investigated the impact of performing "snapshot" simulations of the Last Glacial Maximum (LGM) by taking our transient simulation at 21 ka and running it out to equilibrium. The results show that the traditional PMIP assumption of the LGM being in equilibrium with the forcing is reasonable for surface climates and overturning circulation. At 21 ka, the transient simulations compare very well with the equilibrium runs. Furthermore, glacial meltwater alone cannot drive the observed AMOC slowdown and related North Atlantic cooling of the Heinrich Stadial period (~18.5-15 ka).

- 03:00 PM**PC33A-05** Asynchronous warming and $\delta^{18}O$ evolution of deep Atlantic water masses during the last deglaciation***Jiaxu Zhang***, *Los Alamos National Laboratory, Los Alamos, NM, United States; University of Wisconsin Madison, Madison, WI, United States, Zhengyu Liu, Ohio State University Main Campus, Columbus, OH, United States; Univ*

Wisconsin Madison, Madison, WI, United States, Esther C Brady, National Center for Atmospheric Research, Boulder, Boulder, CO, United States, Delia Oppo, WHOI, Geology and Geophysics, Woods Hole, MA, United States; Woods Hole Oceanographic Institution, Woods Hole, MA, United States, Peter U Clark, Oregon State University, Corvallis, OR, United States, Alexandra Jahn, University of Colorado at Boulder, Atmospheric and Oceanic Sciences and INSTAAR, Boulder, CO, United States, Shaun A Marcott, University of Wisconsin-Madison, Department of Geoscience, Madison, WI, United States and Keith T Lindsay, NCAR, Boulder, CO, United States

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The large-scale reorganization of deep-ocean circulation in the Atlantic involving changes in North Atlantic Deep Water (NADW) and Antarctic Bottom Water (AABW) played a critical role in regulating hemispheric and global climate during the last deglaciation. However, changes in the relative contributions of NADW and AABW and their properties are poorly constrained by marine records, including $\delta^{18}O$ of benthic foraminiferal calcite ($\delta^{18}O_c$). Here we use an isotope-enabled ocean general circulation model with realistic geometry and forcing conditions to simulate the deglacial water mass and $\delta^{18}O$ evolution. Model results suggest that in response to North Atlantic freshwater forcing during the early phase of the last deglaciation, NADW nearly collapses while AABW mildly weakens. Rather than reflecting changes in NADW or AABW properties due to freshwater input as suggested previously, the observed phasing difference of deep $\delta^{18}O_c$ likely reflects early warming of the deep northern North Atlantic by ~1.4°C while deep Southern Ocean temperature remains largely unchanged. We propose a thermodynamic mechanism to explain the early warming in the North Atlantic, featuring a strong mid-depth warming and enhanced downward heat flux via vertical mixing. Our results emphasize that the way ocean circulation affects heat, a dynamic tracer, is considerably different than how it affects passive tracers like $\delta^{18}O$, and call for caution when inferring water mass changes from $\delta^{18}O_c$ records while assuming uniform changes in deep temperatures.

Plain Language Summary

The reorganizations of deep Atlantic water masses are widely thought to regulate glacial-interglacial climate changes. However, the pattern of reorganizations and their impact on ocean tracer transport remains poorly constrained by marine proxies. Our modeling study, which simulates the coevolution

of water masses and oxygen isotopes during the last deglaciation, suggests that deglacial meltwater input causes both northern- and southern-sourced deepwater transports to decrease. This reorganization pattern leads to asynchronous warming between the deep North and South Atlantic, which might have caused the observed deglacial phasing difference in deepwater oxygen isotope records between these ocean basins. We further propose a new mechanism to explain the early warming in the northern North Atlantic.

- 03:15 PM**PC33A-06** Assessing the stability of the Atlantic Meridional Overturning Circulation during the last deglaciation***Wei Liu****, University of California Riverside, Earth Sciences, Riverside, CA, United States*
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Based on a transient simulation by a fully coupled climate model (NCAR CCSM3), we explore the stability of the Atlantic Meridional Overturning Circulation (AMOC) during the last deglaciation. We find that, although CCSM3 successfully simulates an AMOC collapse during Heinrich event 1 and a subsequent rapid recovery during Bølling-Allerød warming, the model shows a linear AMOC response to the exerted meltwater forcing. This linear response suggests a mono-stable AMOC, which is opposite to paleo-evidence that indicates abrupt AMOC change as a transition between multiple equilibria of the AMOC. We assess the AMOC stability using a generalized AMOC stability indicator (L) that is defined as the dependence of AMOC-induced freshwater transport across the Atlantic on AMOC strength. We find that L is positive in the CCSM3 transient simulation, indicating a negative basin-scale salinity advection feedback and, in turn, a mono-stable deglacial AMOC. A further analysis of L shows that the mono-stable AMOC is primarily caused by a salinity bias along 34°S at the Last Glacial Maximum (LGM), which is associated with a commonly existing double Intertropical Convergence Zone (ITCZ) problem in coupled climate models. By eliminating the salinity bias in CCSM3, we correct the AMOC to be bi-stable and simulate an AMOC collapse under either meltwater or CO_2 forcing. Our results suggest that the AMOC is potentially biased to be mono-stable in climate models, which is a critical issue to paleo-climate simulations.

03:30 PM**PC33A-07** Influence of the Freshwater Forcing Pathway on the AMOC during 8.2k Event in a High Resolution Coupled Model***Aixue Hu***[1]*, Bette L Otto-Bliesner*[2]*, Justin Small*[1]*,*

Carrie Morrill[3], Cecilia M Bitz[4] and Nan A Rosenbloom[5], (1)National Center for Atmospheric Research, Boulder, CO, United States, (2)National Center for Atmospheric Research, Climate and Global Dynamics Laboratory, Boulder, CO, United States, (3)NOAA's National Centers for Environmental Information, Boulder, CO, United States, (4)University of Washington, Seattle, WA, United States, (5)NCAR/CGD, Boulder, CO, United States

The collapse of the proglacial lakes of Agassiz and Ojibway and the discharge of the lake water into the Hudson Bay were identified as the cause of the cold event occurred around 8.2 thousand years before present day (8.2ky BP). This event has been widely studied using coupled climate models by adding freshwater forcing into the subpolar North Atlantic (NA). However, the pathways of the discharged freshwater from the coarse resolution coupled models differ from that of a high resolution forced standalone ocean model simulation. Here we use a state-of-art fully coupled high-resolution climate model (CESM1) with 0.1°horizontal resolution for the ocean and sea ice, and 0.25° for the atmosphere and land components to study the influence of the freshwater forcing to the Atlantic Meridional Overturning Circulation (AMOC) during 8.2k event. In these simulations, 2 Sv freshwater is added into NA along a narrow band of west Baffin Bay to North of Labrador Sea for two years, then the freshwater forcing is switched off or 0.1Sv weak forcing continues. Results show that AMOC weakens by over 30% within the first 10 years, and gradually recovers afterwards. The added freshwater were partly transported into the subpolar NA, partly into the subtropical gyre and a portion travelling along the US coast southward. The freshwater entering the subtropical gyre was carried by Gulf Stream back into the subpolar North Atlantic about 20 years later which keeps the AMOC from fully recover. Thus, our results partially agree with previous coarse resolution model simulation and partly agree with the previous high-res simulation. The southward penetration of the freshwater along the US coast is associated to the wind stress anomalies corresponding to the cooling in the Labrador Sea caused by the freshwater forcing there.

- 03:45 PM**PC33A-08** Proxy surrogate reconstructions of Common Era Atlantic meridional overturning circulation***Casey Saenger**, Univ of Washington-JISAO, Seattle, WA, United States, Michael N Evans, University of Maryland College Park, College Park, MD, United States, Allegra N. LeGrande, Columbia University, NASA/GISS, New York, NY, United States, Stephanie Pennington, University of Maryland College Park, United States, Julia Claire Tindall,* *University of Leeds, School of Earth and Environment, Leeds, United Kingdom, Martin Werner, AWI, Bremerhaven, Germany and Kaustubh Thirumalai, Brown University, Department of Earth, Environmental, and Planetary Sciences, Providence, RI, United States*

- Centennial-timescale variations in Atlantic meridional overturning circulation (AMOC), and their effects on climate are poorly constrained by brief observational records and low resolution marine paleoclimate datasets, adding uncertainty to the interpretation of modern trends and climate change projections. Here we seek to extend the instrumental record of AMOC by generating quantitative reconstructions of its variation during the Common Era. We develop proxy surrogate reconstructions (PSRs) that combine information from coupled ocean-atmosphere general circulation model (AOGCM) simulations, paleoclimatic proxy system models, and the observations themselves. Specifically, we use Common Era sea Mg/Ca and oxygen isotope records, compiled as part of the PAGES Ocean2K and PAGES2k v2.0 databases, to reorder realistically forced isotope-enabled AOGCM simulations that have been observationally mapped via marine carbonate proxy system modeling, such that spatiotemporally local misfit to the paleoclimate observations are minimzed. We evaluate the uncertainties in the PSR results that arise from methodological choices, data type, observing network, and observational error, in part through pseudo-proxy experiments. PSR ensembles with significant calibration and validation skill will be compared with independent estimates of past North Atlantic Circulation change. The results will be used to diagnose AMOC variations and develop a baseline for interpreting modern AMOC observations on timescales comparable to those over which projected changes are expected in the next several centuries.

- **PC34B** Meridional Overturning Circulation Dynamics in Past Warm and Cold Climates III Posters

- *Oregon Convention Center*

- *- Poster Hall*

  - **PC34B-0627** Coupling the overturning circulation to sea ice in the Southern Ocean: Variability from seasons to millennia(Invited) ***Andrew F Thompson**[1], Harrison Alexander Parker[1] and Emily Rose Newsom[2], (1)California Institute of*

Technology, Pasadena, CA, United States, (2)California Institute of Technology, Division of Geological and Planetary Sciences, Pasadena, CA, United States

- Climate variability occurs over a range of time scales, such as the large seasonal cycle in Antarctic sea ice extent or the reorganization of the overturning circulation across glacial-interglacial periods. We briefly introduce how the coupled response of the ocean's low-latitude stratification and the surface distribution of density in the Southern Ocean can reproduce both the hemispheric asymmetry and the Southern Hemisphere multi-centennial lag of Dansgaard-Oeschger (DO) events using an idealized, time-dependent isopycnal box model with fixed surface forcing. However, this model will break down over time scales where the coupling between the overturning circulation and changes in sea-ice extent become important.

- A time-dependent, but idealized numerical model is used to explore the interaction between the global overturning circulation, including both meridional and zonal components, and sea ice extent surrounding Antarctica. The model determines the low-latitude stratification in Atlantic and Indo-Pacific basins as well as the surface density distribution and isopycnal slopes in an ACC-like Southern Ocean channel. The model's reduced order permits multi-millennial simulations and a survey of parameter space. The surface buoyancy forcing and water mass modification that support the overturning circulation are determined by evolving sea-ice extent and thickness using an energy balance model (EBM). The EBM allows for meridional variations in surface heating, heat transport between the interior Southern Ocean and the mixed layer, and lateral heat transport in the atmosphere and ocean. Heat and freshwater transport to the Southern Ocean mixed layer is also influenced by changes in the low latitude stratification and water mass distribution. We show the response of the overturning circulation and sea ice distribution to perturbations in the formation rate of North Atlantic Deep Water, the Southern Ocean surface wind stress and background insolation.

- **PC34B-0628** Sea Ice Control on the Depth of the Atlantic Meridional Overturning Circulation.***Louis-Philippe Nadeau**, University of Quebec at Rimouski UQAR, Rimouski, QC, Canada, Raffaele M Ferrari, MIT, Cambridge, MA, United*

States and Malte Jansen, The University of Chicago, Geophysical Sciences, Chicago, IL, United States

- Changes in deep ocean circulation and stratification have been argued to contribute to climatic shifts between glacial and interglacial climates by affecting the atmospheric carbon dioxide concentrations. Recently, two hypotheses have suggested that changes in deep ocean circulation and stratification during glacial times are linked to changes in Antarctic sea ice: an increased extent of Antarctic sea ice (Ferrari et al. 2014) and an increased rate of Antarctic sea ice formation and export (Jansen Nadeau 2016). Both mechanisms rely on the upward shift of the Atlantic Meridional Overturning Circulation (AMOC) above depths where diapycnal mixing is strong (above 2000 m), thus decoupling the AMOC from the abyssal overturning circulation. Here, we test these two hypotheses using a series of OGCM simulations in an idealized configuration using two basins connected by a channel to the south. In order to investigate independently the effect of an increased ice extent from the effect of an increased ice formation and export, sea ice is parameterized as a latitude strip over which the buoyancy flux is negative. The results suggest that both mechanisms can effectively decouple the two cells of the MOC, and that their effects are additive. In order to illustrate the role of Antarctic sea ice in decoupling the AMOC and the abyssal overturning cell, we estimate the age of deep water masses. Both an increased ice extent and increased sea ice formation yield a dramatic increase in water mass age at depth. The key role of vertical mixing is highlighted by comparing results using different profiles of vertical diffusion. While a large increase in water mass age is observed using a realistic bottom enhanced profile of vertical diffusion, no significant increase in water mass age is observed using a constant averaged vertical diffusion. The implications of an increase in water mass ages for storing carbon in the deep ocean will be discussed.
- **PC34B-0629** Antarctic Sea Ice Control on Circulation Changes and Decreased Ventilation in the Glacial Deep Ocean***Alice Marzocchi*** *and Malte Jansen, University of Chicago, Geophysical Sciences, Chicago, IL, United States*

Transitions between glacial and interglacial climates are closely linked to shifts in atmospheric CO_2 concentrations. Since the abyssal ocean represents the largest carbon reservoir, atmospheric CO_2 fluctuations are likely to be connected to changes in deep-ocean circulation and global water masses distribution. Paleoceanographic reconstructions of the Last Glacial Maximum (LGM, ~21 ka) indicate a shoaling of the Atlantic Meridional Overturning Circulation (AMOC) and increased deep-ocean stratification, which may have resulted in a larger, poorly ventilated, abyssal water mass. Idealized LGM ocean simulations suggest that the inferred circulation and stratification changes can be attributed to increased sea-ice formation – and thus buoyancy loss – around Antarctica. Moreover, it has previously been suggested that increased sea-ice cover during glacials would have inhibited CO_2 outgassing, once again pointing towards a pivotal role for Antarctic sea ice in glacial-interglacial transitions. This study quantifies the effect of Antarctic sea-ice changes on deep-ocean ventilation, considering both the direct effect of sea ice on air-sea gas exchanges and the indirect control via rearrangements in deep-ocean circulation. Using an age tracer with a sea-ice-dependent surface restoring, we find substantially older simulated LGM ventilation ages, consistent with reconstructions from deep sea cores. The increased deep water mass ages are explained by an isolated abyssal cell, which outcrops at the surface only under sea ice around Antarctica. The isolation of abyssal water masses from the surface is likely a key factor in promoting carbon accumulation in the deep-ocean rese

PC34B-0629 Antarctic Sea Ice Control on Circulation Changes and Decreased Ventilation in the Glacial Deep Ocean***Alice Marzocchi*** *and Malte Jansen, University of Chicago, Geophysical Sciences, Chicago, IL, United States*

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- **PC34B-0630** Does Southern Ocean Surface Forcing Shape the Global Ocean Overturning Circulation?***Shantong Sun***, *Scripps Institution of Oceanography, La Jolla, CA, United States, Ian Eisenman, University of California San Diego, Scripps Institution of Oceanography, La Jolla, CA, United States and Andrew Stewart, University of California Los Angeles, Atmospheric and Oceanic Sciences, Los Angeles, CA, United States*
- Paleoclimate proxy data suggests that the Atlantic Meridional Overturning Circulation (AMOC) was shallower at the Last Glacial Maximum (LGM) than its preindustrial (PI) depth. Previous studies have suggested that this shoaling necessarily accompanies Antarctic sea ice expansion at the LGM. Here the influence of Southern Ocean surface forcing on the AMOC depth is investigated using Community Earth System Model (CESM) ocean-only simulations with surface forcing specified from the output of previous coupled PI and LGM simulations. In contrast to previous expectations, we find that applying LGM surface forcing in the Southern Ocean and PI surface forcing elsewhere causes the AMOC to shoal only about half as much as when LGM surface forcing is applied globally. We show that this occurs because diapycnal mixing renders the Southern Ocean overturning circulation more diabatic than previously assumed, which diminishes the influence of Southern Ocean surface buoyancy forcing on the depth of the AMOC. We develop a scaling relation that determines the AMOC depth as a function of the surface forcing, diapycnal mixing, and isopycnal upwelling in the Southern Ocean. We use this relation to attribute the AMOC depth changes in the CESM simulations to differences in diapycnal mixing and isopycnal slopes in the Southern Ocean,

along with minor contributions from changes in isopycnal upwelling driven by North Atlantic surface forcing changes.

- **PC34B-0631** The impact of Last Glacial Maximum tidal dissipation changes on global ocean circulation***Sophie-Berenice Wilmes***[1], *Andreas Schmittner*[1] *and Mattias Green*[2], *(1)Oregon State University, College of Earth, Ocean, and Atmospheric Sciences, Corvallis, OR, United States, (2)Bangor University, School of Ocean Sciences, Menai Bridge, United Kingdom*
- Tides dissipate approximately 1 TW of energy in the deep ocean at present day (PD), approximately half of the energy necessary to sustain the global meridional overturning circulation (MOC) through diapycnal mixing. During the Last Glacial Maximum (18,000 – 21,000 years BP; LGM) it is thought that tidal dissipation in the open ocean roughly tripled, due to the 120 - 130 m global mean sea-level drop. However, most investigations into LGM climate and ocean circulation assume present-day tidal mixing. Here, using an intermediate complexity climate model we investigate how the increase in tidal dissipation would affect the global MOC, focussing on the Atlantic MOC (AMOC). PD and LGM tides (tidal constituents M2, S2, K1 and O1) are simulated using the tide model OTIS accounting for LGM bathymetric uncertainties and used as input to the climate model UVic. The tide model results suggest that the LGM energy supply to the internal wave field was 1.8 - 3 times larger than at PD and was highly sensitive to Antarctic and Laurentide ice sheet extent. The LGM climate model simulation forced with PD tides shows a weak but stable AMOC. Including realistic LGM tide forcing to the LGM climate simulations leads to a large increase in Atlantic diapycnal diffusivities and a strengthening and deepening of the AMOC to nearly PD levels. The increased input of tidal energy leads to a greater drawdown of North Atlantic Deep Water and mixing with Antarctic Bottom Water altering temperature and salinity distributions throughout the glacial Atlantic. Our results go against the prevailing view of a more sluggish glacial AMOC but are in line with more recent reconstructions. This work has important implications for the modeling of past and future climates as it suggests that changes in tidal dissipation need be accounted for in the climate simulation setup as they can lead to large differences ocean mixing and, subsequently, in the global MOC.

- **PC34B-0632** The Sensitivity of the AMOC to Decreasing Greenhouse Gas Concentrations with Glacial and Modern Ice Sheets***Marlene Klockmann**, Uwe Mikolajewicz and Jochem Marotzke, Max Planck Institute for Meteorology, Hamburg, Germany*
- Coupled simulations of the Last Glacial Maximum show a large spread in the Atlantic Meridional Overturning Circulation (AMOC), and many of the simulated AMOC states are inconsistent with reconstructions. We study the equilibrium response of the AMOC to decreasing greenhouse gas (GHG) concentrations and its dependence on the prescribed continental ice sheets in the coupled model MPI-ESM in order to identify the mechanisms which determine the AMOC state in a glacial climate.
- We find that a GHG reduction causes a weakening and a shoaling of the upper overturning cell, regardless of the prescribed ice sheets. However, the magnitude of this response is strongly non-linear, depending on the absolute GHG concentrations and the prescribed ice sheets. With prescribed glacial ice sheets, the overturning strength decreases almost linearly with decreasing radiative forcing when the pCO2 is lower than 284 ppm. A shoaling occurs only when the pCO2 is lower than 230 ppm. With prescribed modern ice sheets, there are two distinct AMOC modes; in the first mode the upper cell is strong and deep, and in the second mode it is weak and shallow. The transition between the two modes occurs abruptly between 230 and 185 ppm. In both ice-sheet cases, the key process driving the shoaling of the upper cell is a salinity increase in the Southern Ocean through brine release and shelf convection, which increases the density of Antarctic Bottom Water sufficiently to replace North Atlantic Deep Water in the deep North Atlantic. The weak AMOC mode is not found with prescribed glacial ice sheets. The glacial ice sheets enhance the salt transport into the North Atlantic and increase the density gain in the deep-water formation sites in the North Atlantic, thereby increasing the AMOC strength also at low GHG concentrations. With glacial ice sheets, the AMOC is therefore far away from the bifurcation point beyond which a transition to the weak AMOC mode would occur.
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- **PC34B-0633** Glacial ocean carbon maximized by weak circulation and high nutrient utilization***Juan Muglia***[1]*, Luke Skinner*[2] *and Andreas Schmittner*[1]*, (1)Oregon State University, College of Earth, Ocean, and Atmospheric Sciences, Corvallis, OR, United States, (2)Department of Earth Sciences, Univ. of Cambridge, Cambridge, United Kingdom*
- Atmospheric CO2 concentrations were lower during glacial periods than during interglacials. This difference has been attributed to higher glacial ocean carbon storage, due to changes in circulation and/or organic matter export to the deep ocean. However, three-dimensional, quantitative reconstructions of the glacial ocean constrained by multiple proxies from glacial sediments remain lacking. Here we use a physical-biogeochemical model to explore effects of different overturning circulation configurations and Southern Ocean iron fertilization on the distributions of carbon (δ13C and ∆14C) and nitrogen (δ15N) isotopes and ocean carbon stor-age. We find that models that are consistent with sediment reconstructions are characterized by a weak, shallow Atlantic overturning and enhanced Southern Ocean nutrient utilization. This combination maximizes ocean carbon storage, and represents an important advance in the quantitative, three-dimensional reconstruction and understanding of the glacial ocean and its carbon cycle.
- **PC34B-0634** Benthic 14C ages record upper deep-water formation in the Norwegian Sea during late LGM and Heinrich Stadial 1***Michael Sarnthein****, University of Kiel, Kiel, Germany, Kevin Küssner, Alfred-Wegener-Institute for Polar and Marine Research, Bremerhaven, Germany, Pieter M Grootes, Christian Albrechts Univ, Kiel, Germany and Ralf Tiedemann, AWI Bremerhaven, Bremerhaven, Germany*
- We present high-resolution paired 14C records of monospecific planktic
- (N. pachyderma s) and benthic foraminifera (Cassidulina teretis) from a
- core site on the Voering Plateau (1727 m w.d.) in the Norwegian Sea,
- where sedimentation rates are 30-60 cm/ky. Local glacial-to-deglacial
- planktic 14C reservoir ages derived by means of the 14C plateau-tuning
- technique ranged from 500 to 800 yr during the LGM and rose up to
- 2,000 yr during HS-1. Benthic 14C ventilation ages that each tally the

- planktic reservoir age and the paired benthic-planktic 14C age
- difference were generally much lower than the planktic 14C reservoir
- ages, hence suggest (seasonal) upper deep-water formation active
- immediately near to the core site over glacial-to-deglacial times. This
- record is opposed to deep-water ventilation ages of ~3,500-10,500 yr
- reported by Thornalley et al. (2015; Science 349, 706) for a lowsedimentation
- rate site at 2700 m w.d. in the western Nordic Seas. The
- contrast was possibly due to an extreme, possibly oblique-vertical
- deep-water stratification on top of an old Arctic deep-water mass and
- has major implications for glacial-to-deglacial Atlantic MOC. Details of
- circulation geometries, however, are little understood yet.
- **PC34B-0635** Mg/Li-derived Intermediate Water Temperatures Record Atlantic Meridional Overturning Circulation Variability During the Last Deglaciation***Shannon Valley***[1], *Jean Lynch-Stieglitz*[1] *and Thomas M Marchitto Jr*[2], *(1)Georgia Institute of Technology Main Campus, Earth and Atmospheric Sciences, Atlanta, GA, United States, (2)Univ Colorado, Boulder, CO, United States*
- A new, high resolution Mg/Li-derived intermediate seawater temperature record spanning the last 34,000 years was reconstructed from the benthic foraminifera *Hoeglundina elegans* in a sediment core from the Florida Straits (546 m depth). Application of the promising Mg/Li temperature proxy allows for expanded reconstructions of the interior ocean, as benthic applications of Mg/Ca have been less reliable for paleothermometry. The reconstructed glacial-interglacial temperature difference is near 3.3 °C, with mean glacial temperatures near 3.7 °C and mean Holocene temperatures near 7 °C. The Holocene reconstruction is within 1°C of modern observations. Periods of abrupt warming over the deglaciation are consistent with previous circulation proxy studies from the same core that show evidence of weakened upper branch Atlantic meridional overturning circulation (AMOC) during the Younger Dryas and early Heinrich Stadial 1. Higher temperatures in Florida Current are expected to accompany weakened upper

branch AMOC due to 1) relaxing of cross-basin isopycnals that are strongly tilted in the modern, strong AMOC regime, 2) the greater ratio of warmer, gyre-sourced water relative to colder, southern-originating waters in the Florida Straits, and 3) accumulation of surface heat. However, temperatures remain persistently cold over Heinrich Stadials 2 and 3, which also agrees with previous studies showing little AMOC variability around these fully glacial-aged events. This supports evidence for a markedly different circulation regime during the most recent glaciation, in which circulation was more stable amid high-latitude freshwater input.

- **PC34B-0637** Variability in the Nordic Sea stratification during past interglacials: Any relevance to AMOC?***Benoit Thibodeau****, The University of Hong Kong, Earth Sciences and SWIMS, Hong Kong, Hong Kong, Henning A Bauch, Academy of Sciences, Humanities, and Literature, Mainz, Germany, Adina Paytan, UCSC-Inst Marine Sciences, Santa Cruz, CA, United States, Thomas F Pedersen, University of Victoria, Victoria, BC, Canada and Andreas Schmittner, Oregon State University, College of Earth, Ocean, and Atmospheric Sciences, Corvallis, OR, United States*
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The Nordic Seas (Greenland, Iceland, and Norwegian Seas) are a site of open ocean convection that play an essential role in the Atlantic Meridional Overturning Circulation (AMOC), which profoundly affects surface heat transfer in the Northern Hemisphere, deep-ocean ventilation, and the global climate. Despite its global importance to Earth’s climate, the fate of open-ocean convection is still unresolved, especially regarding the potential effects of freshwater inputs from the demise of the Greenland ice sheet. While it is generally accepted that freshwater would drastically decrease the surface water density, thus preventing convection, there are still gaps in our understanding of the sensitivity of this system to freshwater input. By coupling sedimentary $\delta^{15}N$ measurement with planktic foraminiferal abundance we highlighted that decreased nutrient utilization during past interglacials (MIS 5e and 11) where concurrent to colder condition at around 50-150 m depth in the water column compared to the Holocene. Since these periods are thought be generally warmer and characterized by an active AMOC we hypothesized that the colder condition at sub-surface were indicative of freshwater input, probably linked with the demise of ice-sheet from the preceding glaciations, which are generally thought to be larger than MIS 2. This hypothesis is coherent with the isotopic composition of alkenones used to reconstruct salinity, which suggest the presence of freshwater in the sub-surface layer. To explain both d^{15}N and foraminiferal assemblages we thus suggest the presence of a thick summer mixed-layer of meltwater origin that limited nutrient utilization. Thus, variation in Nordic Seas upper-ocean stratification between the three last interglacials highlights the sensitivity of the summer mixed-layer to large freshwater input. However, our results also raise questions about the exact link between upper-ocean stratification and convection in the Nordic Seas.

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- **PC34B-0638** The Atlantic deep water circulation during the last interglacial***Yiming Luo***[1], *Jerry Tjiputra*[2]*, Chuncheng Guo*[3]*, Zhongshi Zhang*[2] *and Jörg Lippold*[4]*, (1)University of Bergen, Geophysical Institute, Bergen, Norway, (2)Bjerknes Centre for Climate Research, Bergen, Norway, (3)Geophysical Institute, University of Bergen, Bergen, Norway, (4)Heidelberg University, Heidelberg, Germany*
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  - Understanding how the Atlantic Meridional Overturning Circulation (AMOC) evolved during crucial past geological periods is crucial in order to decipher the interplay between ocean dynamics and global climate change. Previous research, based on geological proxies, has provided invaluable insights into past AMOC changes. However, the causes of the changes in water mass distributions in the Atlantic during different periods remain mostly elusive. Using a state-of-the-art Earth system model, we show that in the deep South Atlantic the bulk of Northern Component Water (NCW) migrated from the western basins at 125ka to the eastern basins at 115ka, although the strength of AMOC stayed unchanged. This result, in concert with shallower a North Atlantic Deep Water (NADW) overturning cell and colder southern sea surface temperature at 115ka, is consistent with proxy records. Future research should, thus, look at water-mass distributions in different basins, in order to give more comprehensive interpretations of sediment records.
  - **PC34B-0639** Modelling the onset of North Atlantic Deep Water formation across the Eocene-Oligocene Transition***David Karel Hutchinson***[1], *Agatha M De Boer*[1]*,*

Helen Coxall[2], Rodrigo Caballero[1] and Johan Nilsson[3], (1)Stockholm University, Stockholm, Sweden, (2)Stockholm University, Department of Geological Sciences, Stockholm, Sweden, (3)Stockholm University, Department of meteorology, Stockholm, Sweden

- Geological evidence suggests that North Atlantic Deep Water (NADW) first formed around the Eocene-Oligocene Transition (EOT), a climate transition 34 Ma ago when semi-permanent ice sheets on Antarctica first formed. In earlier periods, deep water is thought to have formed in the Southern Ocean and possibly the North Pacific. Here we investigate possible causes of this reorganization of the deep circulation. We present novel simulations of the coupled climate model GFDL CM2.1 using late Eocene paleogeography to model the EOT climate transition. Using this paleogeography, we find that the North Atlantic becomes very fresh and prevents NADW formation. Instead sinking occurs in the North Pacific and Southern Ocean in agreement with Eocene circulation proxies. We test the role of greenhouse forcing by varying the CO_2 to values of 400, 800 and 1600 ppmv. We find that under cooler conditions the high latitudes of the North Atlantic become saltier due to a weakening of the hydrological cycle, but this effect is not large enough to destabilize the strong North Atlantic halocline and induce sinking. We further test the effect of closing the Arctic-Atlantic gateway. This experiment is motivated by geological data that suggest that the Arctic Ocean became isolated at the EOT. The gateway closure shuts off freshwater export from the Arctic to the Atlantic. This change enables a strong salinification of the North Atlantic that triggers the onset of NADW production. Closing the Arctic-Atlantic gateway also alters the salt advection feedback in the Pacific basin, causing deep water formation to shut down in the North Pacific.

- **PC34B-0640** Stalagmite records and model simulation indicating wet conditions in northwestern Madagascar during the 8.2 ka event***Ny Riavo Gilbertinie Voarintsoa**[1,2], Ilkka Seppo Olavi Matero[3], Lauren J Gregoire[4], L. Bruce Railsback[1], Julia Claire Tindall[4], Louise C Sime[5], Hai Cheng[6], R. Lawrence Edwards[7], George A. Brook[8], Gayatri Kathayat[6], Xianglei Li[6], Amos Fety Michel Rakotondrazafy[9] and Marie Olga Madison Razanatseheno[9], (1)University of Georgia, Department of Geology, Athens, GA, United States, (2)The Hebrew University of Jerusalem, Institute of Earth Sciences,* *Jerusalem, Israel, (3)University of Leeds, School of Earth and Environment, Leeds, LS2, United Kingdom, (4)University of Leeds, School of Earth and Environment, Leeds, United Kingdom, (5)Ice Dynamics and Paleoclimate, British Antarctic Survey, Cambridge, United Kingdom, (6)Xi'an Jiaotong University, Institute of Global Environmental Change, Xi'an, China, (7)University of Minnesota, Department of Earth Sciences, Minneapolis, MN, United States, (8)University of Georgia, Department of Geography, Athens, GA, United States, (9)Université d'Antananarivo, Sciences de la Terre et de l'Environnement, Antananarivo, Madagascar*

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The 8.2 ka event is an abrupt cooling event of the early Holocene, known to have influenced the Atlantic Meridional Overturning Circulation (AMOC). It is a well-known cooling event in the Northern Hemisphere, but is poorly understood in the Southern Hemisphere, including Madagascar. Stalagmite proxies from NW Madagascar suggest wet conditions during the 8.2 ka event, with the following characteristics: (1) $\delta^{18}O$ and $\delta^{13}C$ show similar changes to the Greenland ice core records, (2) two distinct excursions are observed at ca. 8.37 and at ca 8.23 ka BP, which seem to reflect the two cooling/freshening occurrences observed in the subpolar North Atlantic, (3) the double peak/plunging structure within the prominent 8.2 ka event reported in Brazil, China, and Oman is also noted in the Stalagmite ANJB-2 records, which suggests that the Malagasy Monsoon was in phase with the South American Summer Monsoon, but it was antiphase with the Asian Monsoon. The wet conditions in NW Madagascar during the 8.2 ka event are also seen in climate simulations, which suggest 10 to 25% (~100–200 mm per year) increase in precipitation. Being the key component of the global climatic system, weakening of the AMOC due to the abrupt 8.2 ka cooling event must have been strongly felt in Madagascar.

- **PC34B-0641** 30 kyr Indian summer monsoonal record from Sri Lanka***Nadee Uthpala Nanayakkara**, Geological Survey and Mines Bureau Sri Lanka, Pitakotte, Sri Lanka and Pradeep N Ranasinghage, Department of Oceanography and Marine Geology, University of Ruhuna,, Matara, Sri Lanka*

    - Indian monsoon plays vital role in determining climate events in the Asian region. Sri Lanka is situated at an ideal location with a unique geography to isolate Indian summer monsoon record from Indian winter monsoon, present study was carried out to build up continuous long term summer monsoonal variability record. Although there are many Summer Monsoon records from different parts of the region there is no sufficient work in Sri Lanka to fully understand how the summer monsoonal variability affected Sri Lanka during the quaternary.

- For this purpose a 1.82 m long gravity core, extracte from western continental shelf off Colombo, Sri Lanka was used. Particle size, chemical composition and colour reflectance were measured using laser particle size analyzer , X-Ray Fluorescence spectrometer and color spectrophotometer respectively. Radio carbon dating of foraminifera tests yielded the sediment age. Principal component analysis of XRF and color reflectance (DSR) data was performed to identify groups of correlating elements and mineralogical composition of sediments. Particle size results indicate that Increasing temperature and strengthening monsoonal rainfall after around 18000 yrs BP, at the end of last glacial period, enhanced chemical weathering over physical weathering. Proxies for terrestrial influx and upwelling and nutrient supply driven marine productivity indicate that strengthening of summer monsoon started around 15000 yrs BP and maximized around 10000 yrs BP after a short period of weakening during Younger Dryas. monsoon was weekend till around 2000 yrs BP. Marine productivity increasing throughout the Holocene indicating monsoonal wind-driven upwelling also followed the same.