Meeting AMOC Observation Needs in a Changing Climate

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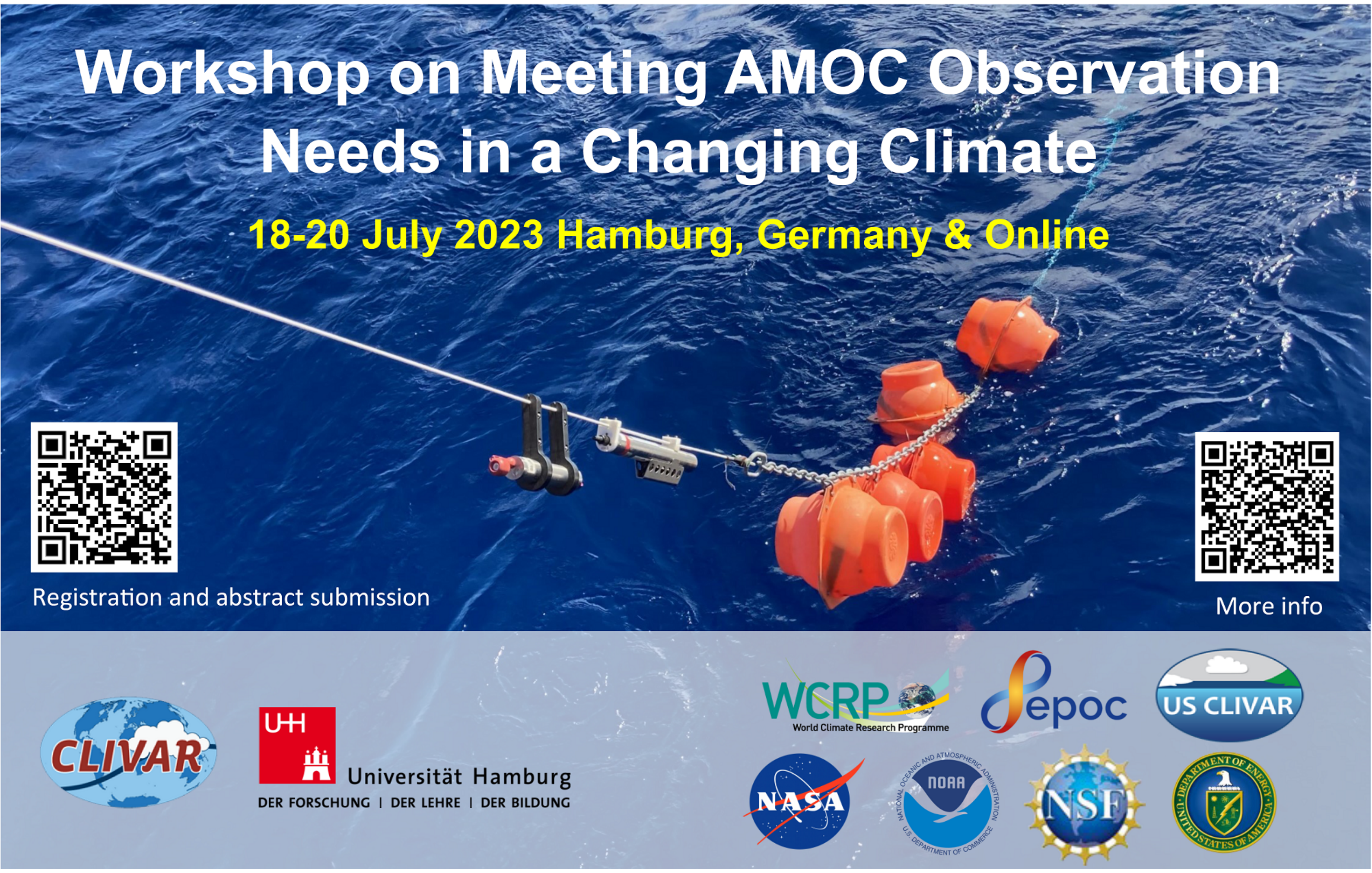
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An updated analysis of the Freshwater Transport by the Atlantic Meridional Overturning Circulation at nominally 34.5ºS

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The freshwater transport (Mov) by the Atlantic Meridional Overturning Circulation (AMOC) across 34.5ºS is computed using observations from 49 eXpendable BathyThermograph (XBT) AX18-lines between 2002-2019. The Mov is used as an indicator of the AMOC stability at 34.5ºS. XBT data present a negative Mov mean of -0.15±0.09 Sv, indicating a bi-stable AMOC regime. Results are complemented with data from Argo floats, numerical ocean models, and coupled models. The Mov estimation is very sensitive to the dataset used, with some coupled models estimating positive Mov. To clarify the causes of the opposite sign of the Mov, we have investigated the differences in the vertical profiles obtaining fresher upper and saltier deep waters in models with positive Mov. Moreover, we have investigated the time variability and correlation between Mov, MOC, and meridional heat transport (MHT), estimating a strong linear relationship between them. Finally, we have studied the seasonal variability of the South Atlantic Meridional Fluxes from all the datasets used, suggesting a more negative Mov and a stronger MOC and MHT from April to August at 34.5ºS in the South Atlantic Ocean.

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Overturning Pathways Control AMOC Weakening in CMIP6 Models

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Future projections indicate the Atlantic Meridional Overturning Circulation (AMOC) will weaken and shoal in response to global warming, but models disagree widely over the amount of weakening. We analyse the overturning pathways in 27 CMIP6 models to assess their impact on this weakening. The branch of the AMOC that returns through upwelling in the Indo-Pacific, but does not later upwell in the Southern Ocean, is particularly sensitive to warming, in part, because shallowing of the deep flow prevents it from entering the Indo-Pacific via the Southern Ocean. The present-day strength of this Indo-Pacific pathway provides a strong constraint on the projected AMOC weakening, explaining 81% of the variance in AMOC weakening across the CMIP6 ensemble in the SSP5-8.5 scenario. However, estimates of this pathway using four observationally-based methods imply a wide range of AMOC weakening under this scenario of 29% to 61% by 2100. Our results suggest

that improved observational constraints on this pathway would substantially reduce uncertainty in 21st century AMOC decline. This could be achieved through the implementation of an Indo-Pacific Ocean array at 34.5°S, analogous to the existing SAMBA array in the South Atlantic. This would allow for monitoring of the Indo-Pacific and global-integrated MOC at 34.5°S and thus for estimation of the present-day MOC pathways.

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Weakening of the Atlantic Meridional Overturning Circulation Abyssal Limb in the North Atlantic

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The abyssal limb of the Atlantic Meridional Circulation (AMOC) redistributes heat and carbon northward as it carries Antarctic Bottom Water (AABW) from the Southern Ocean to the subtropical North Atlantic Ocean. Using primarily mooring observations from different AMOC observing arrays and hydrographic data from multiple sources, we show that northward flowing AABW is mainly constrained below 4500 m with a mean volume transport of 2.40±0.25 Sv at 16°N. During 2000-2020, the northward transport of abyssal waters into the North Atlantic subtropics weakened by approximately 0.35±0.13 Sv, corresponding to a 12±5% decrease. This weakening of the AMOC's abyssal cell likely results from the circulation adjustment to the reduction of AABW formation rates since the 1960s due to anthropogenic climate change and is associated with abyssal warming observed throughout the Atlantic Ocean. Specifically, in the tropical and subtropical North Atlantic, we estimate that the warming of the AABW layer is, on average, 1 m°C/year in the last two decades due to the downward heaving of abyssal isopycnals resulting in a contribution to the increase of the abyssal heat content and, hence, sea-level rise of the North Atlantic. Finally, this warming trend is approximately half of the AABW trends in the South Atlantic and parts of the Southern Ocean, indicating a dilution of the signal as the AABW crosses the Equator.

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Enhancing observational mooring arrays for next generation biogeochemical measurements

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The AMOC is key to the North Atlantic (NA) being a sink for carbon dioxide (CO2) from the atmosphere, through both surface cooling of waters advected polewards (making them more soluble to CO2) prior to sinking at high latitudes, and through northwards nutrient delivery that sustains strong subpolar biological production (that drives down CO2 levels). As atmospheric CO2 levels have increased, the NA has played an outsized role in mitigating their rise, accounting for ~30% of all global CO2 uptake from the atmosphere and 25% of the global anthropogenic carbon inventory, despite making up only 15% of the ocean surface.

However, current climate models however significantly underestimate the current ocean uptake of CO2 (by up to 20%) and disagree widely in future projections (particularly in subpolar regions), limiting our ability to assess the effects of emissions reduction policies. The main source of uncertainty is attributed to how the models represent the magnitude of and balance between ocean carbon transports and regional carbon uptake in mid-to-high latitudes, which determine how much carbon accumulates in the ocean interior. Current observations are insufficient to constrain these processes, lacking both the temporal and spatial coverage necessary to quantify both NA carbon/nutrient transport convergence, and deconvolve the anthropogenic component of air-sea CO2 fluxes.

Here we present new initiatives to improve our knowledge of the movements of carbon and nutrients into and out of the Atlantic - and the surface carbon fluxes that result - through the instrumentation of transport mooring arrays with biogeochemical sensors and autonomous water samplers. They will help us better understand how the ventilation and overturning systems interact, the mechanisms that drive the current NA carbon sink (thermal / biological), and the fate of carbon exported to depth.

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Eight years of continuous Rockall Trough transport observations from moorings and gliders

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The Rockall Trough (RT) is a key pathway for warm and salty water flowing northward, a process which plays a key role in dictating the western European climate. The picture of the mean circulation and variability in the RT is still emerging, as the record of continuous transport observations has only recently been extended to eight years. Here, for the first time, we present the temporally extended record of RT volume, heat and freshwater transports. An important feature of the RT circulation is the European Slope Current (ESC) which is poorly constrained by ship-based, mooring, and satellite observations. To tackle this, we gathered around 150 glider transects over 3 years which capture the ESC velocity field in unprecedented detail. The data are sufficient to characterise both the mean state and the emergent seasonal variability of the ESC and reveal the year-round presence of a southward countercurrent at depth. Variability in the strength and structure of this previously unstudied feature modulates net northward transport in the eastern boundary current system.

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Thirty years of GO-SHIP and WOCE data: Atlantic overturning of mass, heat, freshwater, and anthropogenic Carbon transport

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The Atlantic Meridional Overturning Circulation (AMOC) plays a vital role in global climate, redistributing heat, freshwater and anthropogenic CO2 (Canth) meridionally and in depth. Accurately monitoring AMOC strength with observations has inspired a number of dedicated observing systems in the Atlantic since the 2000s. However, no consensus has been reached on whether the slowdown of the AMOC and its associated heat, freshwater and Canth transports is occurring. Hydrographic data and biogeochemical measurements from zonal sections across the Atlantic for 30 years that predate and overlap the era of AMOC observations were employed to build three inverse models, one for each of the last decades. The results show no changes in the AMOC for all sections analyzed over the whole Atlantic for the last 30 years. The change in time in the net transports of Canth appears to be mainly due to modifications in the transport of upper layers. The lower layer of the AMOC maintain more consistent transports in time. Vertical advection plays an important role in the North Atlantic, exporting Canth from upper to deeper layers. The strong gradient in Canth concentration at the interphase between upper and deeper layers results in a strong vertical diffusion.

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Nature run for AMOC investigations: What are the minimum requirements?

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Nature runs are state-of-the-art numerical simulations that are as close as possible to reality that can be used as reference for design of observational arrays and/or data assimilation. We will review the current status of basin-scale to global-scale AMOC modeling and define the minimum requirements that a numerical model should be able to reproduce (mean transport and water mass characteristics of upper and lower NADW, mean DWBC depth and pathways, overflow representation, interannual variability, latitudinal coherence, etc.).

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Energetic overturning flows, dynamic interocean exchanges, and ocean warming observed in the South Atlantic

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Since the inception of the international South Atlantic Meridional Overturning Circulation initiative in the 21st century, substantial advances have been made in observing and understanding the Southern Hemisphere component of the Atlantic Meridional Overturning Circulation (AMOC). Here we synthesize insights gained into overturning flows, interocean exchanges, and water mass distributions and pathways in the South Atlantic. The overturning circulation in the South Atlantic uniquely carries heat equatorward and exports freshwater poleward and consists of two strong overturning cells. Density and pressure gradients, winds, eddies, boundary currents, and interocean exchanges create an energetic circulation in the subtropical and tropical South Atlantic Ocean. The relative importance of these drivers varies with the observed latitude and time scale. AMOC, interocean exchanges, and climate changes drive ocean warming at all depths, upper ocean salinification, and freshening in the deep and abyssal ocean in the South Atlantic. Long-term sustained observations are critical to detect and understand these changes and their impacts.

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Sustaining Subpolar North Atlantic Basin-Wide Observations of the Strength and Structure of the Atlantic Meridional Overturning Circulation (OSNAPi)

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Since 2014 the OSNAP array has provided monthly estimates of the subpolar AMOC strength, structure and associated heat and fresh-water fluxes. A specific objective from the outset was to determine from the observations "the configuration of an optimally efficient long-term AMOC monitoring system in the North Atlantic subpolar gyre". OSNAP is a huge international programme of 29 Principal Investigators from 14 institutes. Observations are made on over 60 heavily instrumented moorings, including glider measurements at the eastern boundary. Biennial moorings cruises also contribute trans-basin hydrography and biogeochemistry measurements. We aim to test a radical reduction in observing effort to ~12 moorings and demonstrate that this new array is sufficient for long-term monitoring. We use the German mooring array at the western boundary measuring the transport of upper water and the Deep Western Boundary Current out of the Labrador Sea. In the east we use the UK moorings from the Iceland basin to Scotland, measuring the warm water path of the North Atlantic Current. We will compare results from this line directly to OSNAP in observations and models. The western boundary array data began in 1996 and monitoring of the eastern boundary began in 1974 with 71 hydrographic sections completed to the beginning of the OSNAP array in 2014.

We therefore plan to extend the overturning timeseries back to 2004 (and possibly earlier) matching the RAPID array which began in 2014. Looking forward to new observing techniques, in 2022 we deployed FETCH AZA zero drift bottom pressure recorders at the western and eastern boundaries and are planning for 2024 further deployments in the Iceland Basin.

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Labrador Sea Process Studies Linked to AMOC

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Canadian researchers have been making observations in the winter dynamics of the Labrador Sea with a focus on the links between convection, restratification and gas exchange with the atmosphere. These studies have been conducted with a mix of platforms including ships, gliders and fixed moorings, including one mooring system -Seacycler- with a profiling instrument package. This work has led to new understanding of the processes regulating oxygen uptake and the links to convection. Interesting questions are raised linked to the OSNAP program results which show that the connection between convection and deep circulation is perhaps more subtle than previously considered. Much of this work was carried out through the research efforts of the Ocean Frontier Institute, that has now been refunded to support a program entitled Transforming Climate Action. In this talk, some results of the earlier work will be reviewed and presented, together with consideration of the technological advances - both in terms of sensors and platforms. Plans for the new program will also be offered together with consideration of opportunities for renewed and new collaboration.

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Multi-decadal Records of the South Atlantic Meridional Overturning and Heat Transport Derived from in-situ and Satellite Observations and Recent Applications

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The South Atlantic Meridional Overturning Circulation (SAMOC) observing system has evolved tremendously since 2007, and has substantially improved our understanding of the dynamics and variability of the upper, deep, and abyssal South Atlantic circulation from daily to interannual timescales. However, the SAMOC daily time series derived from moored arrays are still relatively short and are only available at 11°S and 34.5°S. To expand the SAMOC time series in space and time, we derived monthly zonal trans-basin temperature (T) and salinity (S) sections since 1993 at four latitudes (20°S, 25°S, 30°S, and 34.5°S) based on historical relationships between T, S, and satellite sea level. The resulting meridional overturning circulation (MOC) and meridional heat transport (MHT) estimates at 20°S, 25°S, and 30°S are significantly correlated with each other at near zero lag, however correlations with the estimates at 34.5°S are somewhat lower. Although the overturning contribution dominates changes in the MHT at all four latitudes, the gyre contribution increases southward, reaching 30% of the explained MHT variability at 34.5°S. These 30-year monthly records indicate that the dominant mechanism controlling the MOC/MHT variability alternates between wind forcing and internal ocean dynamics. Therefore, both mechanisms must be monitored to fully capture changes in the MOC/MHT. These estimates demonstrate a linkage between the tropical Pacific forcing and heat content changes in the subtropical South Atlantic, as well as the impact of the MOC/MHT on extreme weather events, and provide context for measurements obtained from the SAMOC moored arrays.

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Array: SAMBA

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Cross-shelf exchanges between the East Greenland shelf and interior seas

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Increasing freshwater fluxes from the Greenland ice sheet and the Arctic have the potential to lead to a dampening of deep convection in the subpolar north Atlantic by increasing stratification in deep convection regions. In turn, this could affect deep water formation and the Atlantic Meridional Overturning Circulation (AMOC). However, it is unclear where and how much freshwater is exported from the Greenland shelf where it first enters the subpolar north Atlantic, to the interior seas where deep convection occurs. In particular, there is still little understanding of exchange processes east of Greenland, while overturning east of Greenland has been shown to be particularly important for the total subpolar AMOC.

Using drifter data, satellite altimetry data and winds from an atmospheric reanalysis, we identify areas favourable to cross-shelf exchanges and investigate the respective role of winds, eddies and the mean circulation in these exchanges. Using drifters deployed in 2020 and 2021 at the east Greenland shelfbreak, we further investigate exchange processes in two regions: Cape Farewell and the Blosseville Basin. At the Blosseville Basin, drifters are brought off-shelf towards the Iceland Sea and into the interior of the basin. As they flow downstream, they re-enter the shelf and most are driven towards the coast. At Cape Farewell, drifters round the Cape offshore of the shelfbreak, and part of them enter an eddy, but they all re-enter the shelf west of Greenland. How much of the freshwater signature is lost during these exchanges is not clear and will need further study.

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Western Boundary Overturning Estimation: Past and Future Studies

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Based on geostrophy, the zonally-integrated mass transport at a given depth is simply the difference between the pressure on the boundaries at that depth. Thus, to measure the overturning streamfunction, in depth space, only measurements of pressure are theoretically required. Presently, only high-frequency pressure anomalies can be reliably measured directly at constant depth in the ocean.

Instead, oceanographers typically use measurements of temperature and salinity on vertical moorings (referred to as "dynamic height moorings") and derive the pressure from the hydrostatic relation. However, this technique only measures the transport between vertical moorings, and so the sectional areas between potentially sloping boundaries and moorings are not included. To resolve this issue, the gap on the western boundary is typically addressed by deploying current meters that measure transport directly in this intermediate space such as for the western boundary wedge east of the Bahamas for the Rapid-MOCHA-WBTS array at 26N. A proposed alternative method, known as the step method, is to measure bottom velocity and density along the sloping boundary, which can be used to calculate a downslope pressure gradient. This pressure gradient can in turn be integrated with depth in order to obtain a relative western or eastern boundary contribution to the overturning meridional transport within the depth layer of integration. In this talk I will briefly review past studies of the AMOC based on the step method and describe future plans for using this technique at the 26N Rapid array.

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AMOC change in recent time-Model and observation perspective

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The Atlantic Meridional Overturning Circulation (AMOC) has been a key factor in the modulation of climate change both locally and globally in the past decades. However, in recent time the evolution of AMOC seems not clear. The degree of agreement between the state of AMOC depicted in the new simulations from the sixth Coupled Model Intercomparison Project (CMIP6) and observation dataset is not well understood. Furthermore, the timescale for AMOC evolution in these datasets still remains debateable. If the result of these datasets differs reasonably, this could lead to bias in projected long term climate knowledge.

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The importance of the subpolar continental shelves to the large-scale overturning circulation

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The continental shelves around the subpolar North Atlantic are important conduits of volume and freshwater transports. The Greenland and Labrador Shelves are deep (150-400 m), the Labrador Shelf is wide (200 km), and they each sustain coastal currents that reach 1-2 Sv of volume transport in the mean. Resolving these volume transports in AMOC monitoring lines is critical if an assumption of net zero mass balance is applied. In addition, the low salinity of the coastal currents makes the freshwater transports notable: the Labrador Coastal Current alone is likely responsible for about one-third of the total southward freshwater transport across the OSNAP array. Finally, shelf mooring arrays promote a process-based understanding of AMOC forcing mechanisms across a wide range of time scales from those directly resolved by the moorings to paleo time scales that rely on mechanisms of freshwater release along the subpolar boundaries. As AMOC arrays pare down their moorings for cost-cutting purposes, retaining this mooring infrastructure on the shelf is vital. It is also essential to invest in mooring technology that can sample surface salinities near sea ice and icebergs. In this poster, I will review the literature on the shelf mooring arrays, and provide information about future planned work on the Labrador Shelf.

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Explaining and Predicting the Ocean Conveyor

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EPOC will generate a new conceptual framework for the Atlantic meridional overturning circulation, to understand how it functions in the Earth system, and how it impacts weather and climate. The AMOC is a key component of the climate system, responsible for ocean heat and freshwater transport, associated with the ventilation of anthropogenic carbon, and anticipated to experience or drive climate tipping points. However, the link between ocean transport, ventilation and tipping points relies on the common conceptual view of the AMOC as a 'great ocean conveyor' which was developed to explain very long timescale (glacial-interglacial) fluctuations in climate. The conveyor belt schematic conflates millennial timescales with human timescales (days to 100 years), leading to misconceptions by the observing and modelling communities, and misplaced expectations about the AMOC's role in climate.

EPOC will capitalise on new understanding about the AMOC variability and coherence from two decades of AMOC observations and advances in ocean observing technology and climate modelling in order to develop new tools and approaches to quantify and explain past AMOC change and how its connectivity (or lack thereof) imprint on the Earth system. Through joined-up observational and model experiments, focussing on next generation high resolution coupled models, machine learning techniques and critical re-assessment of paleo proxies, EPOC will generate a new conceptual framework for the AMOC, its meridional connectivity, feedbacks and the relationship between ventilation and overturning on human timescales. This will lead to better predictions of the AMOC and related climate evolution, including the risk of rapid change.

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A Lagrangian study on the structure and pathways of the Irminger Current

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The Irminger Current (IC), located over the western flank of the Reykjanes Ridge, is a contributor to the northward volume transport related to the Atlantic Meridional Overturning Circulation.

Previous studies showed that the IC is associated with a region of enhanced eddy kinetic energy. Using high-resolution mooring data from 2014 – 2020 combined with satellite altimetry, a strong intensification in volume transport of the IC in August 2019 could be attributed to the presence of mesoscale eddies in the vicinity of the moorings. At this time, altimetry showed an anticyclone lingering next to a cyclone in the mooring array, which intensified northward velocities within the IC. This example shows that mesoscale variability can directly impact the transport variability of the IC.
Further research presented here uses the high-resolution model POP (Parallel Ocean Program, 1/10°) to investigate the pathways of the IC up- and downstream of the mooring array. Here, the focus lies on determining the origin of waters feeding the IC and the role of mesoscale eddies in shaping the current and its pathways using Lagrangian particle tracking with the Ocean Parcels software. First results from a backtracking experiment reveal different origins for the water masses feeding the respective cores of the IC. Waters of the eastern core mostly originate from the eastern side of the Reykjanes Ridge. The western core appears to contain a substantial amount of waters from the interior Irminger Sea that partly recirculate from the Labrador Sea.

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Deep Western Boundary Current variability in the Labrador Sea and its link with sea surface height variability

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The subpolar North Atlantic plays an important role in connecting the upper and the lower branches of the Atlantic Meridional Overturning Circulation. The Labrador Sea is part of this system. By means of repeat hydrographic sections and a mooring array, the Deep Western Boundary Current (DWBC) system is measured at the southern exit of the Labrador Sea with help of the 53°N Observatory since 1996. DWBC variability is operating on various time scales and comprises signals of a couple weeks, associated with topographic waves, to several decades and connected with the NAO forcing (Zantopp et al., 2017).

Here we use satellite altimetry to (1) improve reconstruction of the DWBC transport from sparse moored arrays and considering high resolution synoptic surveys and (2) better constrain the transport for connecting it to potential drivers.

We find that the width of the DWBC at the surface estimated from satellite altimetry relates to the horizontal and vertical structure of the flow which in turn enables an improved reconstruction of the flow and its transport. Applying Multivariate Empirical Orthogonal Function analysis of sea level anomaly (SLA) and moored instrument velocity data, as well as composite analysis, reveals states of more barotropic and more baroclinic DWBC, as well as variations in current velocity.

Further analysis in the coming weeks will focus on determining the impact of varying the spatial extent of SLA and mooring data on the multivariate EOF modes, as well as identifying possible mechanisms that generate the observed the co-variability.

References
Zantopp, R., Fischer, J., Visbeck, M., and Karstensen, J.: From interannual to decadal: 17 years of boundary current transports at the exit of the Labrador Sea, J. Geophys. Res.-Oceans, 122, 1724–1748, https://doi.org/10.1002/2016JC012271, 2017.

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Interannual variability of the subpolar MOC and OSNAP array reduction experiment

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The Overturning in the Subpolar North Atlantic Program (OSNAP) array, consisting of an OSNAP West section covering the Labrador Sea and an OSNAP East section covering the Irminger and Iceland basins, has continuously observed the MOC and meridional heat and freshwater transports (MHT and MFT, respectively) since 2014. The OSNAP observations have contributed substantially to the understanding of the mean state and sub-seasonal to seasonal variability of the subpolar MOC. We present here the latest OSNAP observational results covering 2014-2022 and investigate interannual variability of the subpolar MOC with respect to water mass transformation in the Labrador Sea and eastern subpolar basins. We propose an optimized observational design that employs a less densely instrumented array for continuing OSNAP beyond the first decade. We show that the reduced OSNAP array can capture over 90% of the MOC, MHT and MFT variability across the full OSNAP section.

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Upper Ocean Transport in the Anegada Passage from Multi-Year Glider Surveys

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Caribbean through-flow accounts for two-thirds of the Florida Current and consequently is an important conduit of heat and salt fluxes in the upper limb of the Atlantic Meridional Overturning Circulation (AMOC). While high-latitude sinking and interior mixing processes have a first order control on the magnitude of the AMOC, low-latitude wind-driven processes determine and modify the subsurface density structure of the water masses flowing through the Caribbean Sea. Considering there is evidence that up to one-half of the Florida Current originates as South Atlantic Waters (SAW), determining the distribution of SAW throughout the Caribbean Island passages is important as this constitutes the major pathway for cross-equatorial AMOC return flow. Ship-based observations in the 1990's revealed the Windward Island passages as a dominant SAW inflow pathway. However, there is still a substantial amount of SAW that is taking an unknown, alternate route northward. The Anegada Passage (AP) is a major location for subtropical gyre inflow and suggested to be an alternate SAW inflow pathway. Here, we will present the first co-located observations of temperature, salinity, and subsurface velocity in the AP in nearly 20 years. Through an isopycnal water mass analysis the total transport (-4.8 Sv) and the transport of SAW through the AP (-2.79 Sv) is shown to be larger than previously estimated. This result indicates that the AP may be an important pathway for cross-equatorial AMOC return flow. This study has added to the growing body of literature supporting the use of gliders as an effective component of the global ocean observing system. The maturity that glider platforms have now reached make them uniquely well suited to collect the evolving maps of subsurface variables needed for sustained climate monitoring.

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High resolution ocean circulation models to understand processes and guide observations

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Progress in information technology has driven exponential growth in the number of global ocean observations and the fidelity of numerical simulations of the ocean in the past few decades. The growth has been exponentially faster for ocean simulations, however. The present cutting-edge ocean circulation models running on the latest supercomputers can cover the globe with resolutions of a few kilometers. Regional simulations on the same machines use resolutions of less than one kilometer; at these scales non-hydrostatic, submesoscale dynamics can dominate. These virtual ocean datasets are increasingly realistic, and provide insight into processes at scales that are inaccessible with conventional observations.

This talk will explain these trends and their implications. The specific focus is on opportunities and challenges to exploit high-resolution ocean circulation model simulations to understand Atlantic Meridional Overturning Circulation (AMOC) processes, and to guide observations. Examples are given of model predictions related to the AMOC lower limb in the subpolar North Atlantic, including sources and fates of the Denmark Strait Overflow and East Greenland continental shelf exchange with the deep ocean.

Lightning poster / 24

Mechanism on the short-term AMOC variability

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The continuous moored observation revealed significant variability in the strength of the Atlantic Meridional Overturning Circulation (AMOC). Cause of such AMOC variability is an extensively studied subject. This study focuses on the short-term variability, which ranges up to annual and interannual timescales. A mechanism is proposed from the perspective of ocean water redistribution by layers. Being able to explain four phenomena of AMOC variability in the subtropical and tropical oceans (seasonality, the meridional coherence, the layered-transport compensation at 26.5°N, and the 2009/2010 downturn at 26.5°N), this mechanism suggests at least the short-term variability of AMOC strength is dominated by an adiabatic process and therefore its observed variation so far is predominantly a reversible process. That is, AMOC may recover itself from a short-term weakening in a rapid and complete manner. The same mechanism was used to explain the seasonal variability of the meridional overturning circulation in the Indian Ocean in a former study of the author (Han, 2021 JPO).

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Simulation-based approaches for quantitative observing system design

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The North Atlantic Ocean circulation is the result of a range of physical processes, from large-scale gyre circulation (subtropical and subpolar), associated Ekman transports, fluctuations of the gyre boundaries, westward intensification that gives rise to the Gulf Stream, watermass transformation at high latitudes along continental boundaries and in the interior, complex ("return") flows at depth, Arctic sub-Arctic exchanges, efficient communication between the tropics and mid-to-high latitude through wave propagation along eastern boundaries, westward traveling Rossby waves, geostrophic eddies, and submesoscale processes, to name but a few. Interactions with the atmosphere and topography set crucial boundary conditions on the flow. For historical reasons, much of that circulation has been subsumed under a metric called the Atlantic Meridional Overturning Circulation (AMOC), which provides a heavily space (and time)-averaged depiction of the circulation.
Understanding the role that the different elements, which make up the circulation, play, has involved a diverse and heterogeneous stream of observations (satellite and in-situ), which, taken together constitute a sparse, eclectic observing system. Arguably, a rigorous way to combine the knowledge reservoir offered by the available, yet incomplete observations with the knowledge reservoir that is encapsulated in the governing equations of motion, rendered in the form of numerical models, is through formal ocean state and parameter estimation. The adjoint-based effort pursued by the Estimating the Circulation and Climate of the Ocean (ECCO) consortium has produced state estimates that have provided valuable insights into the AMOC in a number of studies. Beyond the use of the adjoint for state estimation, the tool has proven powerful in causal, dynamical attribution studies of subtropical and subpolar North (and South) Atlantic MOC. Furthermore, use of the adjoint and Hessian are enabling rigorous studies of quantitative observing system design within the framework of uncertainty quantification.
This talk provides an overview of how the adjoint-based modeling framework has supported studies of AMOC variability and observing system design. It is meant to set the stage for more detailed presentations these subjects.

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Lessons learnt from Observing System reviews and perspectives on next steps

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In the early 2000s while we were building the sustained observing system (out of WOCE and TOGA), the global community was focused on filling in the dots on the map. Once we had a basic global ocean observing system the focus had had to become more nuanced of augmenting, reviewing and evolving the observing system, while there is a continued need to provide guidance on priorities for investment. We need to continually demonstrate that we are observing the ocean smarter and delivering more for investment particularly in light of a) a system primarily funded by research, and b) expanding observation requirements. This talk will draw on;
* Experiences in planning and prioritising a system from scratch (IMOS),
* International planning through GCOS and GOOS
* Lessons from other observing system reviews (e.g. TPOS 2020 and other regional reviews) – what worked/didn't work (consideration of multiplatform design, links to models, associated needs for process studies/pilots to evolve design and improve models).
* Experience in engaging with G7 (and other) funders.
* UK future planning – Future Marine Research Infrastructure.
* Key messages: recommendations and next steps. Framing/designing observing system reviews, what triggers a review, shaping actionable recommendations.

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Social and economic impacts of changes in the Atlantic Merid-

ional Overturning Circulation

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People living in coastal zones, islands and continents surrounding the Atlantic Ocean experience weather, climate and marine conditions that are directly impacted by the Atlantic Meridional Overturning Circulation (AMOC). Changes in the strength of the AMOC can have serious environmental, social and economic impacts on timescales of years to decades. The ability for communities to plan mitigation and adaptation to future change in the AMOC depends on reliable projections and good knowledge of the chains of physical, chemical and biological processes that lead to societal and economic impacts. The ocean research community has collaboratively implemented a sparse AMOC observing system that provides the only accurate source of information of the present-day currents and their evolution over the past 20 years. However, the challenge for planning is that future scenario projections were given a 'low confidence' rating by the Intergovernmental Panel for Climate Change in 2021 because of model inconsistencies with observations. Furthermore, knowledge about ways in which the AMOC affects society-relevant environmental conditions is scattered throughout academic literature and can be difficult or even impossible for potential users to access. Here we present a summary of the state of knowledge about AMOC-led environmental change that directly affects people and their livelihoods, highlighting priority areas for research and for the provision of actionable knowledge.

Lightning poster / **27**

Mid-20th Century Atlantic Circulation informed by Modern Observations and Models

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The Atlantic Meridional Overturning Circulation (AMOC) is a driving force in the redistribution of heat on our planet and has a particularly large impact on the climate of the Northern Hemisphere and Europe. Since the 1980s, it has been predicted that the anthropogenic increase in atmospheric CO_2 concentration will weaken the AMOC. This change in AMOC intensity will lead to changes in European climate and extreme weather events. It is therefore essential to understand how AMOC responds to climate change.

In order to study the variations of AMOC during the 20th century, we have developed simple layered models based on a limited number of time series. These models take into account the Ekman transport and the Florida Strait, as well as the density time series of the Thermocline, Antarctic Intermediate Waters (AAIW), Upper North Atlantic and Lower North Atlantic Deep Waters (UNADW, LNADW). These models, using the deep AMOC branches, are trained with modern RAPID measurements at 26N and compared to each other.

Since lack of prior data can occur for the reconstruction, it is important to identify the crucial layers or data for the AMOC reconstruction. In this study, we investigate the importance of each layer of the models in the reconstruction of AMOC strength over time. Our goal is to provide, with direct observations, an answer to the drivers of the short- and long-term variability of the AMOC.

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Biogeochemical observations on AMOC moorings – results from oxygen measurements on the 53N array

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The Labrador Sea is a key region for ocean ventilation, as it is one of the few places globally where deep water formation can transport atmospheric oxygen and anthropogenic carbon to the deep ocean. The newly formed Labrador Sea Water (LSW) is then exported out of the basin, spreading the biogeochemical signal set in the formation region to the rest of the ocean. While this general picture has been well known for some time, ocean sensor technology has only recently reached a point where ocean biogeochemistry can be continuously measured *in situ* and thus linked to the underlying physical forcing.
In this talk, we will present results from the 53N moorings in the Labrador Sea's boundary current, which are part of the OSNAP array, and have been equipped with oxygen sensors since 2016. The data reveal a pronounced seasonal cycle in oxygen concentration at 600m depth, indicating a preferential export of LSW in the months following the deep convection period. We estimate the annual oxygen transport out of the basin driven by the addition of LSW to the outflowing boundary current to be 1.6 Tmol, about half of the annual uptake in the interior.
Our results highlight two benefits of adding biogeochemical sensors to existing AMOC observing infrastructure: Using the measurements as a tracer to better understand the underlying dynamics, and obtaining estimates of biogeochemical fluxes associated with the AMOC.

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Understanding the decreasing transport of the Deep Western Boundary Current within a steady AMOC

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The Overturning in the Subpolar North Atlantic Program (OSNAP) has monitored the Atlantic Meridional Overturning Circulation (AMOC) across the entire northern North Atlantic since 2014. The OSNAP record now includes the longest continuous measurements of the furthest upstream observations of the Deep Western Boundary Current near Cape Farewell, Greenland. Since the OSNAP record began, the Deep Western Boundary Current ($\sigma\theta$ > 27.8 kg m-3) has decreased in transport by 25% while the AMOC transport as calculated by OSNAP has remained relatively steady. Given that the Deep Western Boundary Current is the primary component of the lower limb of the AMOC, it is surprising that these results are so divergent. This presentation will explain the reasons behind these transport differences and how that may inform future observations of the AMOC and the Deep Western Boundary Current.

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Validating and Testing Methods of Measuring Geostrophic Ocean Transports

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Most observational arrays that study the AMOC rely on the geostrophic method, by which a (small) number of measurements at endpoints of a section are used to infer the flow across the section. This is a necessity because measuring everywhere along the section is cost-prohibitive. Here, we will study a few different examples how the results from such applications have been validated using independent data. This helps identify and quantify the "weak spots" of the method, and supports a better understanding of overall measurement uncertainty.

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Array: Update from the MOVE Array at 16 N

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This is a quick lightning talk presenting the latest results from the MOVE array at 16 N. Data are now available through fall 2022, which is the time when the moorings were last serviced.

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AMOC exchanges in the Iceland-Scotland Ridge region

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The exchanges across the Greenland-Scotland Ridge compose the northernmost part of the Atlantic Meridional Overturning Circulation (AMOC), with the warm Atlantic inflow in the upper limb transporting heat towards the Arctic while the returning deep overflows provide density for the deep limb of the AMOC further south. Since the mid-1990s, the Faroe Marine Research Institute (FAMRI) has monitored the overflow through the Faroe Bank Channel (FBC), which transports one third of the total overflow, and the Faroe Current (FC), which is the main Atlantic inflow branch. Both the FC inflow and FBC overflow volume transports remained relatively stable through the monitoring period, although with interannual variabilities and a weak positive trend in the FC transport. Increased AW temperatures have resulted in increased heat transports towards the Arctic, and the FBC overflow have also become slightly warmer. In addition, a rapid freshening of AW occurred around 2015-2017, with a potential to impact the overturning circulation. Together with colleagues in Scotland, FAMRI has also monitored the inflow branch through the Faroe-Shetland Channel and have observed the overflow across the Iceland-Faroe Ridge (IFR). Historical estimates of the IFR overflow of about 1 Sv are not based on direct observations. Recent observations by FAMRI indicate, for the first time,

persistent overflow across the central parts of the ridge, and based on this finding the possibility of sustainable monitoring of the IFR overflow is presently scrutinized. In-situ data have been combined with satellite altimetry which allows for an extension of the time series of the AW inflow north and south of the Faroes back to the beginning of the satellite era in 1993. This has also allowed for a reduction of the observational effort along the monitoring section, making the monitoring more sustainable. Comparisons between our temporally and spatially comprehensive current observations on the Iceland-Scotland Ridge and ocean reanalysis products have identified strengths and weaknesses in such products within this key region. Understanding the flow across the ridge and the processes involved is important for improving ocean models to achieve better climate predictions.

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The Atlantic meridional overturning circulation at 35N from deep moorings, floats, and satellite altimeter

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From 2004 to 2014, the Line W moorings measured a 0.7 Sv/yr slowing of the Deep Western Boundary Current (DWBC) offshore of Cape Cod. Here, we combine these deep mooring observations with float and satellite altimeter data and find that this DWBC change corresponded to a slowing of the cross-basin Atlantic Meridional Overturning Circulation (AMOC) of about 0.3 Sv/yr. Our AMOC transport time series corresponds well with the ECCO state estimate, particularly when the Line W mooring data influences our volume closure. We compare our 35N time series with a similar time series at 41N as well as the 26N RAPID AMOC, and find AMOC declines across datasets from 2004 to 2014. However, when we extend our analysis to 2004-2019, there are no significant trends at any latitude. These observations suggest that AMOC decadal variability is meridionally coherent from 26N to 41N and that the DWBC may reflect this variability. In this presentation I will highlight the value of direct DWBC measurements as well as the value of comparing multiple datastreams.

Lightning poster / 65

The weakening AMOC under extreme climate change

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We examine changes in the Atlantic Meridional Overturning Circulation (AMOC) in the quadrupled CO_2 experiments conducted under the sixth Coupled Model Intercomparison Project (CMIP6). The increase in CO_2 triggers extensive Arctic warming, causing widespread melting of sea ice. The resulting freshwater spreads southward, first from the Labrador Sea and then the Nordic Seas, and proceeds southward along the eastern coast of North America. The freshwater enters the subpolar gyre north of the separated Gulf Stream, decreasing the density contrast across the current. The current weakens in response, reducing the inflow to the deepwater production regions. The AMOC cell weakens in tandem, first near the North Atlantic Current and then spreading to higher and lower latitudes. This contrasts with the common perception that freshwater caps the convection regions stifling deep water production; rather, it is the inflow to the subpolar gyre which is suppressed. Changes in surface temperature have a much weaker effect, and there are no consistent changes in local or remote wind forcing among the models. Thus an increase in freshwater discharge, primarily from the Labrador Sea, is the precursor to AMOC weakening in these simulations.

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Can we trust projections of AMOC weakening based on climate models that can't reproduce the past?

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The Atlantic Meridional Overturning Circulation, a crucial element of the Earths' climate system, is projected to weaken over the course of the 21st Century which could have far reaching consequences for the occurrence of extreme weather events, sea level rise, monsoon regions and the marine ecosystem. The latest IPCC puts the likelihood of such a weakening as "very likely". As our confidence in future climate projections depends largely on the ability to model the past climate, we take an in depth look at the difference in the 20th Century evolution of the Atlantic Meridional Overturning Circulation based on observational data (including direct observations and various proxy data) and model data from climate model ensembles. This shows that both the magnitude of the trend in the Atlantic Meridional Overturning Circulation over different time periods and often even the sign of the trend differs between observations and climate model output, with this difference becoming even greater when looking at the CMIP6 ensemble compared to CMIP5. We discuss possible reasons for this observation-model discrepancy and question what it means to have higher confidence in future projections than historical simulations.

Lightning poster / 20

Observing the oxygenation of the Denmark Strait Overflow Water in the Irminger Basin

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Direct observations of dissolved gases in the Subpolar North Atlantic are scarce, particularly during the winter and along boundary current systems. Consequently, current understanding of the physical processes governing the sequestration of dissolved oxygen into the deep North Atlantic is limited. One proposed pathway through which oxygen-enriched waters enter the deep ocean is the Denmark Strait Overflow Water (DSOW). Formed from buoyancy loss in the Nordic Seas, DSOW spills over the sill of the Denmark Strait into the Irminger Basin, feeding the lower limb of the Atlantic Meridional Overturning Circulation (AMOC). While DSOW is thought to entrain Arctic-origin, Atlantic-origin, and Labrador Sea Waters (LSW) near the sill, the proportions of water masses that become entrained into the overflow plume and their variability over seasonal and interannual timescales remain unclear. Here we use an optimum multiparameter (OMP) framework to investigate the water-mass composition of DSOW in the western boundary current of the Irminger Basin.

BGC-Argo float data will be used to constrain the properties of source DSOW in the Nordic Seas and additional end-member water types in the Irminger Basin. OMP analysis will be performed on the OSNAP mooring array along the western boundary current region of the Irminger Basin, where oxygen sensors were recently deployed in summer 2020. This study underscores the importance of *in situ* oxygen measurements to understand entrainment processes in the Subpolar North Atlantic and its role in the uptake and storage of biogeochemically important gases.

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Adjoint-based Assessment of Ocean Observing Network Design in the Subpolar North Atlantic

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A large ensemble of adjoint-based sensitivity experiments within the Arctic and Subpolar gyre sTate Estimate (ASTE) is used to interrogate the constraint provided by continuous monitoring at the Overturning in the Subpolar North Atlantic Program (OSNAP) array. Each ensemble member is designed to expose ocean adjustments impacting the hydrography sampled at an individual mooring within the array backbone. Sensitivity pattern correlations across the ensemble quantify the coherence between propagating signals sequestered in individual mooring time series. Low coherence results from strong sensitivity to local wind-stress curl, suggesting low data redundancy across much of the array. Larger coherence is found, however, on repeating this analysis using sensitivities shared by OSNAP observed quantities and remote heat transports across the Greenland-Scotland Ridge and Fram Strait, due to strong transport dependence on larger-scale wind stress variations along topographic waveguides upstream from these sections. Our approach complements traditional withholding experiments in identifying which observations constrain modelled transports most effectively. With the added advantage that this assessment is accompanied by a clear dynamical explanation, our work encourages further use of adjoints for ocean observing system assessment and design.

Lightning poster / 19

How good should the initial conditions for decadal climate predictions be in terms of the Atlantic meridional overturning circulation?

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Atlantic meridional overturning circulation (AMOC) is one of the mechanisms for long-term predictability and one of the properties that decadal climate predictions (DCP) are attempting to predict.

Yet, verifying the AMOC performance from the DCPs is problematic due to the short observational record as well data assimilation procedures for DCPs struggle to reconstruct the AMOC initial conditions from the historical period (1960-present).

To initialize DCPs, the widespread practice is to introduce separate ocean and atmosphere-only reanalyses (data assimilation products) into a coupled climate model through nudging and then to begin DCPs from the nudged states. Possible inconsistencies that may lead to initialization shocks from introducing external uncoupled reanalyses into ocean and atmosphere components of a prediction system is a known and long-established issue in the seasonal and decadal climate prediction communities. Initialization shocks that result from the following inconsistencies: 'between reanalysis and the prediction system' and 'between ocean reanalysis and atmosphere reanalysis' might lead to the loss of prediction skill at longer lead times. For example, it is known that full-field initialization can result in the disruption of the AMOC cell leading to multiple maxima in the overturning cell structure. However, how critical such AMOC issues are at the assimilation step for the prediction skill, e.g., at the surface of the ocean, has not been fully understood yet.

This study concerns with deriving a coupled reanalysis as a source of coupled ocean and atmosphere initial conditions for DCPs that are dynamically consistent between themselves and the prediction system. The reanalysis is based on the coupled adjoint method with the regularization scheme in the atmosphere designed for the Earth System Model of intermediate complexity CESAM (Centrum für Erdsystemforschung und Nachhaltigkeit Erdsystem Assimilations-Modell). From the test versions of the coupled reanalysis, it is obvious that different settings of the assimilation affect the behaviour of the AMOC. In a model-consistent approach, the study attempts to compare the initialization of the AMOC based on the coupled reanalysis and based on the coupled nudging toward the separate ocean and atmosphere reanalyses, which are also external to the prediction system as well as they are uncoupled. We also analyse the AMOC from the multi-model CMIP6 DCP experiments to identify whether possible flaws in the AMOC assimilations could be linked to the issues with the prediction skill for the important climate indices. The results of this study aim to guide future initialization developments for DCPs with the comprehensive Earth System Models.

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The Seasonal cycle of the eastern boundary currents of the North Atlantic Subtropical Gyre

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For the first time, four dedicated hydrographic cruises – one in each season – took place in 2015 around the Canary Islands to determine the seasonality of the flows at the eastern boundary of the North Atlantic Subtropical Gyre. The Canary Current (CC) is the eastern boundary current of the North Atlantic Subtropical Gyre and links the Azores Current with the North Equatorial Current. The CC shows a seasonal behavior in its path and strength, flowing on its easternmost position in winter (3.4±0.3 Sv), through the Canary Islands in spring (2.1±0.7 Sv) and summer (2.0±0.6 Sv) and on its westernmost position in fall (3.2±0.4 Sv). At the Lanzarote Passage (LP), the dominant flow is southward except in fall, where a northward transport is observed at the surface (1.1±0.3 Sv) and intermediate (1.3±0.2 Sv) layers. Combining all the available transport estimations a historical composite observational seasonal cycle is constructed and fits the 2015 seasonal cycle. The LP seasonal cycle and seasonal amplitude match the seasonal cycle of the Atlantic Meridional Overturning Circulation (AMOC) measured by the RAPID-MOCHA data array.

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South Atlantic Meridional Overturning Circulation in the LENS2 Simulations

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The Atlantic Meridional Overturning Circulation (AMOC) is essential for the distribution of heat, salt, and carbon dioxide, so it is a fundamental part of understanding climate change and its ocean's role as a mitigator of those changes. Focusing on the South Atlantic, this work aims to understand the AMOC upper and lower branch changes in the SSP3-7.0 scenario compared to the present climate. We rely on simulations performed as part of the Community Earth System Model, version 2, Large Ensemble Project (LENS2). Our results show that LENS2 represents the AMOC stream function well from the comparison we made with other models and observations. According to LENS2, The AMOC upper branch intensified between the years ~1850 and ~2000. However, after ~2000, the AMOC weakened mainly due to the reduced formation of North Atlantic Deep Water, evidenced by the decreased mixed layer depth. However, the lower branch of the AMOC will be intensified by the end of the century, evidenced by a likely intensification of bottom water transport. The intensification of this lower branch may act as a compensatory mechanism of mass transport due to the weakening upper branch. This result indicates that it is crucial that observational systems can monitor volume transport at different depths from the surface to the bottom, as distinct mechanisms may drive the AMOC upper and lower branches in different ways.

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Zonal Circulation in the North Atlantic Ocean at 52ºW from WOCE-WHP and CLIVAR sections: 1997, 2003 and 2012

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The A20 line is a meridional hydrographic section located at 52ºW that cuts through the western North Atlantic Subtropical Gyre (NASG). It encloses the main paths of the Atlantic Meridional Overturning Circulation (AMOC). Using data from three A20 hydrographic cruises carried out in 1997, 2003 and 2012 together with Acoustic Doppler Current Profiler data and the velocities from an inverse box model, the circulation of the western NASG is estimated. The Gulf Stream is the main poleward path of the AMOC, carrying 155.3±11.1, 102.7±13.5 and 181.1±14.9 Sv in 1997, 2003 and 2012, respectively (1 Sv = 106 m3/s ~ 109 kg/s). In opposite direction, the Deep Western Boundary Current crosses the section at the northern/southern boundaries with a mass transport of -21.2±8.9/29.0±9.1,

-14.4±10.8/14.2±8.1 and -37.9±10.2/44.5±9.8 Sv in 1997, 2003 and 2012, respectively. A net heat exchange from the ocean to the atmosphere is estimated to be -0.7±0.1 PW and -0.6±0.1 PW in 1997 and 2012, respectively, but is negligible in 2003 (0.1±0.1 PW). The freshwater flux is significantly lower in 2003 (0.3±0.1 Sv) than in 1997 (0.6±0.1 Sv) and 2012 (0.6±0.1 Sv). Ocean numerical models such as ECCO, GLORYS and MOM are used to address the interannual variability between the three surveys, but only the GLORYS output roughly agrees with the hydrographic data. GLORYS suggests a heat transport from the ocean to the atmosphere throughout the year and a net freshwater flux supported by precipitation plus river runoff higher than evaporation in all seasons except the spring.

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Enhanced array for AMOC observation in the South Atlantic

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The South Atlantic Meridional Overturning Circulation (SAMOC) is a scientific program aiming to investigate and promote the progress of the knowledge regarding the AMOC through the Atlantic basin. The installation and maintenance of the SAMOC Basin-wide Array (SAMBA) along the latitude of 34.5ºS was an accomplishment that involved institutions and scientists from Argentina, Brazil, South Africa, France, South Africa, and the United States, among others. The observational backbone on the western side includes measurements from pressure sensor inverted echosounders (PIES) and the realization of periodical maintenance cruises.

In this study we show the analysis from two CPIES instruments (with an integrated currentmeter) moored at 31ºW and at 18ºW (sites E and F along the SAMBA-West line, respectively at the western flank of the Rio Grande Ridge and at the western side of the Mid-Atlantic Ridge). The time series span the period from 2019 to 2023, a unprecedented continuous sampling of the thermohaline structure of the ocean's interior which will contribute to resolve the basin-wide transport variability. These two sites represent an important extension of the original SAMBA-West and they also helped us to capture details of the lower layer water mass structure and circulation. These in-situ measurements allowed us to improve the accuracy of the AMOC and the variability of the transport contribution from that sector of the South Atlantic. Fluctuations from intra-annual to interannual in the geostrophic transport between E and F are compared to previous estimates from the SAMBA-West and the whole array.

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Overturning in the Nordic Seas

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A substantial portion of the dense water in the lower limb of the AMOC originates in the Nordic Seas, including the densest component. The volume of the water overflowing the Greenland-Scotland

Ridge doubles through entrainment in the subpolar North Atlantic. As such, dense-water formation in the Nordic Seas is crucial for sustaining the AMOC. In this talk, I will highlight recent observational studies advancing our understanding of the overturning in the Nordic Seas. As a consequence of climate change, open-ocean convection in the interior gyres of the western Nordic Seas is subsiding. Observations demonstrate that dense waters formed in the Nordic Seas have become lighter, and descending isopycnals imply a decrease of the dense-water reservoir. This may affect the future supply of dense water to the overflows. Concurrently, new areas of dense-water formation are opening. In the Iceland Sea, the locus of dense-water formation is shifting westward along with the ice edge. Furthermore, the East Greenland Current has recently become ice-free in winter, and water that previously had been isolated from the atmosphere may now be further ventilated and densified on its southward transit. An extensive field campaign in 2024-2026 will help quantify the water-mass transformation and elucidate this potential mechanism for resilience of the overturning in the Nordic Seas. A similar effect of along-stream water-mass transformation due to sea-ice retreat is expected in the Atlantic Water boundary currents in the Arctic Ocean. Understanding the changing processes of dense-water formation at the northern extremity of the AMOC is imperative, as these headwaters to the lower limb of the AMOC affect the variability and potential predictability of the AMOC farther south and may sustain the AMOC even as overturning south of the Greenland-Scotland Ridge weakens in a warming climate.

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Variability of the Atlantic Meridional Overturning Circulation in the subtropical Atlantic and the design of the RAPID 26°N observing array

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The time series of the Atlantic Meridional Overturning Circulation (AMOC) at 26°N has been extended to December 2020 and is now almost 17 years long. During the period from 2004 to 2008 the AMOC was about 2.5 Sv stronger than in the following years. Since then, there has been significant interannual variability, but the AMOC has remained relatively weak compared with the first four years of observations. The design of the array was changed in 2020 so that continuous measurements are no longer made over the mid-Atlantic Ridge and in the deep eastern basin. Here, the extended time series is presented and the impact of the design change on the accuracy of the RAPID timeseries is examined. Other possible design changes are considered too. It is found that, although the mid-Atlantic ridge measurements have been important in determining the mean structure of the overturning streamfunction, the impact upon the variability of the streamfunction maximum is small. It is hoped that these changes will enable the measurement of the AMOC at 26°N to be sustained in the future.

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Variability of Subpolar Mode Water in the Subpolar North Atlantic

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Subpolar Mode Water (SPMW) represents a variety of near-surface waters that occupy a large volume in the upper 1000 m of the Subpolar North Atlantic (SPNA) water column. Originating in the eastern and northeastern SPNA through late winter water mass formation, SPMW acts as a precursor to forming the North Atlantic Deep Water, an important ingredient of the Atlantic Meridional Overturning Circulation (AMOC). This study addresses spatial and temporal changes in the SPMW layer thickness and volume. We relate these changes to variability in the water mass formation estimated both through a thermodynamic approach (focusing on the direct effect of air-sea interactions) and through a kinematic approach, the latter involving the estimation of volume transport from the mixed layer to the interior of the ocean due to subduction and to the entrainment/detrainment of the mixed layer itself. We use two observation-based gridded 3D products from the Copernicus Marine Environmental Monitoring Service (CMEMS), i.e., the ARMOR3D and the OMEGA3D datasets. The first one provides 3D temperature and salinity fields and is available on a weekly 0.25° regular grid from 1993 to the present. The second one provides observation-based quasi-geostrophic vertical and horizontal velocity fields with the same temporal and spatial resolution as ARMOR3D but for the period 1993 to 2018. This is the first time that thermodynamic and kinematic approaches are applied to observation-based data in the North Atlantic. Our results show that formation of SPMW is characterized by large interannual variability in terms of volume and spatial distribution. Most importantly, the differences in the kinematic and thermodynamic estimates of SPMW yearly formation rates suggest a substantial role of diapycnal mixing in diluting the waters formed by air-sea fluxes towards the range of SPMW densities.

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Array: OSNAP

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Overturning, Freshwater and Carbon Sequestration in the Subpolar North Atlantic

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The Atlantic Meridional Overturning Circulation (AMOC) is an important player in Earth's climate system on a wide range of timescales and with a correspondingly long list of potential societal impacts. The drivers of its variability are still debated and climate models give diverging projections for AMOC change over the 21st century. Sustained AMOC observations are, therefore, needed to inform interpretation of past variability and improve future projections. While the AMOC can be

measured in different regions in the Atlantic, the Subpolar North Atlantic (SPNA) offers the opportunity of linking AMOC variability with two additional, interconnected, and changing components of our climate system. First, variability of the poleward heat transport through the SPNA, in part associated with the AMOC, is implicated in the loss of Arctic sea ice and Greenland land-ice. The resulting ice loss, in turn, has the potential to impact the AMOC via a freshening of the surface ocean. Second, the SPNA is the largest anthropogenic carbon dioxide sink (per unit area) and a key region for carbon sequestration via the warm to cold water transformation that is part of the AMOC. The rate of future carbon uptake, however, is still debated in part because of uncertainties tied to future AMOC variability.

The Overturning in the Subpolar North Atlantic Program (OSNAP) is an international observing system that has provided continuous measurements of the meridional transports of heat, freshwater and mass in the SPNA from 2014 to present. Its two-line structure offers the opportunity of separating AMOC contributions from different water transformation regions and of capturing distinct overflow and freshwater pathways. As such, in addition to providing a measure of the structure and variability of the AMOC, OSNAP has offered insight into the mechanisms that contribute to the observed variability. Here we show, via recent studies that leveraged OSNAP, that OSNAP is also ideally positioned and constructed to address linkages between the AMOC, the melting Arctic cryosphere and the anthropogenic carbon uptake in the high latitude North Atlantic. Examples include tracking Greenland meltwater and the most recent Great Salinity Anomaly, quantifying the fraction of Arctic freshwater export that participates in overturning, and providing an infrastructure for GOHSNAP measurements (Gases in the Overturning and Horizontal circulation of the SPNA). Based on this motivation, we argue that continuation of OSNAP, albeit in a reduced and cost-effective form, is key not just to understanding and projecting AMOC variability but also its connection to the Arctic cryosphere and carbon uptake by the North Atlantic.

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Hydrographic properties of the Denmark Strait Overflow

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Meridional Connectivity of a 25-year Observational AMOC Record at 47°N

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The Atlantic Meridional Overturning Circulation (AMOC) plays a vital role in the climate system of Europe and the Arctic by redistributing heat and freshwater in the Atlantic. Since climate model studies project a decline of the AMOC in the 21st century, monitoring AMOC changes remains essential. While on longer than decadal timescales AMOC variability is expected to be coherent across latitudes, connectivity on inter-annual and seasonal timescales is less clear. Model studies and observational estimates disagree on the regions and timescales of meridional connectivity and AMOC observations at multiple latitudes are needed to study its connectivity. We calculate basin-wide AMOC volume transports (1993-2018) from measurements of the North Atlantic Changes (NOAC) array at 47°N, combining data from moored instruments with hydrography and satellite altimetry. The mean NOAC AMOC is 17.2 Sv, exhibiting no long-term trend. We find substantial variability on monthly timescales, while the variability on longer timescales is similar to the RAPID-MOCHA-WBTS AMOC at 26°N. Both the unfiltered and low-pass filtered NOAC AMOC show a significant correlation with the RAPID AMOC when the NOAC AMOC leads by about one year. Our findings highlight the importance of long-term observations to evaluate model results and study the physical processes responsible for meridional connectivity.

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A tale of two perspectives on AMOC observing needs: historical gravity and altimetry satellite missions and future Earth system simulations

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This presentation will be a tale of two perspectives that come together to inform AMOC observing needs in a changing climate. First, I will share some results from NASA's gravity and altimetry satellite science teams that highlight how these NASA assets contribute to monitoring and understanding AMOC. Second, I will present highlights from my own analysis of future Earth system simulations, in which I seek to understand how AMOC variability and change influence North Atlantic Ocean biogeochemistry and biological productivity as global warming intensifies. I will conclude by discussing my perception of how both perspectives might guide future AMOC observing priorities and design.

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Enhancing AMOC Observing Strategies and Interpreting Observations through Process

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The spatial scales of key AMOC processes are typically larger than the deformation radius and, thus, its variations are likely governed by lower order dynamics that acts on complex bathymetry. It is expected that a large portion of observed AMOC variations can be modeled and explained in simple models. In this study, we employ a 3-layer process model with realistic bathymetry and wind-stress forcing to simulate AMOC variations. The model exhibits excellent agreement with observational data from the RAPID array at 27°N and ECCO4 ocean state estimate across latitudes. Topography, particularly the mid-Atlantic Ridge and continental slope, plays a crucial role in shaping AMOC responses to atmospheric forcing and influencing the propagation pathways of AMOC variability. By comparing process model simulations with ECCO4 and satellite-observed ocean bottom pressure, we identify key processes responsible for observed AMOC variations and main propagation pathways and examine contributions from barotropic and baroclinic processes. The simplicity and transparency of dynamics make process models particularly useful for helping to interpret observed AMOC changes and planning future observing strategies.

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Understanding multidecadal AMOC variability and associated impacts

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The Atlantic Ocean is crucial for many regional climate phenomena through its linkage with the AMOC. For example, modeling studies suggest that the AMOC and associated Atlantic heat transport can affect multidecadal Arctic sea ice variability. Coherent multidecadal changes among the AMOC fingerprint and inverted vertical wind shear over the main development region of Atlantic hurricanes have been found in both observations and a coupled model control simulation, supporting an important role of the AMOC in multidecadal changes of Atlantic major hurricane frequency. The decadal AMOC decline directly observed from the RAPID program is consistent with that inferred from the observed AMOC fingerprint. Multidecadal AMOC variability is underestimated in many climate models. Understanding the mechanism of multidecadal AMOC variability and the causes of its underestimation in climate models are crucial for improving simulated AMOC-related climate impacts. Recent reconstructions of the long-term mean AMOC structure reveal that the Arctic Ocean is the northern terminus of the AMOC and the density-space AMOC across the OSNAP section is linked to the section's west-east density contrast through both thermal wind and horizontal gyre contributions across sloping isopycnals. Across the OSNAP section, the directly observed mean AMOC strength over the recent period is similar to the reconstructed long-term mean AMOC strength over the past several decades. A simple conceptual model, which is calibrated by the OSNAP observations and includes two-way Atlantic-Arctic interactions through the oceanic advection and the AMOC-induced atmosphere-ocean (or ice-ocean) coupled freshwater feedback, illustrates the multidecadal AMOC delayed oscillator mechanism. It suggests an important role of the Arctic salinity anomaly and associated delayed negative feedback in multidecadal AMOC variability. The underestimation of multidecadal AMOC variability and associated impacts in climate models is likely related to their underestimation of multidecadal Arctic salinity changes. Monitoring the potential propagations of Arctic salinity anomalies along the boundary outflow would be valuable for predicting the timing and amplitude of future AMOC changes.