School and Workshop on Polar Climates: Theoretical, Observational and Modelling Advances | (SMR 3960)

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P01

Ocean Circulation and the Southern Ocean Carbon Sink

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The Southern Ocean is a key component of the global carbon cycle and an important regulator of global climate, through the uptake of excess carbon and heat. A substantial contribution to the Southern Ocean carbon sink is provided by the biological carbon pump. The biological carbon pump exports carbon into the ocean interior through sinking organic matter, which is subsequently remineralised, and finally returns to the surface ocean through circulation. Remineralisation depth significantly affects the duration for which the remineralised carbon is stored for - carbon remineralised in poorly ventilated waters is stored for a greater amount of time, whereas the opposite occurs in well-ventilated waters. Despite the importance of this interaction between remineralisation and circulation in the Southern Ocean, a critical gap remains in our understanding of the structure of remineralisation in the region. In particular, there is uncertainty around the amount of remineralisation occurring within the various water masses in the Southern Ocean, and the associated carbon storage times. We investigate this problem using observations from autonomous profiling floats (Biogeochemical-Argo floats), in combination with simulations from the ocean general circulation model MITgcm. Decreases in dissolved oxygen over the productive period are used as a proxy for remineralisation [1] and estimates for remineralisation in the different water masses are calculated. Direct observations of sinking particles from a subset of BGC-Argo floats provide a potential additional method for estimating remineralisation. The BGC-Argo observations are compared with MITgcm simulations, ran with various remineralisation profiles [2], with the aim of determining which remineralisation profile accurately represents the biological carbon pump in the Southern Ocean.

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[2] Lauderdale, J. M. & Cael, B. B. Geophysical Research Letters **48**, e2020GL091746 (2021).

P02

The Response of the East Greenland Current to Sea-Ice Decline and a Changing Climate

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In the Arctic, the atmosphere, ocean and sea-ice are strongly coupled. Sea-ice variability impacts local atmospheric and oceanographic processes and dynamics. As Arctic sea-ice declines due to anthropogenically forced warming, air-sea interactions are also changing, with near-surface wind speeds increasing in regions of new sea-ice loss, which influences the surface-forced upper ocean.

Ocean circulation systems are crucial in regulating the global climate. The response of these ocean circulation systems to a changing climate is an important but poorly understood problem. The East Greenland Current is the main conduit for the waters of the Arctic Ocean and Nordic Seas to the North Atlantic, carrying cold fresh surface water southwards from the pole.

In this study, we use a CMIP6 global coupled high-resolution model to consider the future of the East Greenland Current. We study how the East Greenland Current is predicted to change in the future and why. We also explore the projected downstream impacts of these changes, particularly on the complex interaction of ocean pathways in the Denmark Strait.

P03

Dynamics of the Southern Hemisphere zonally asymmetric circulation and its impacts on the Antarctic climate.

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We study the zonally asymmetric circulation of the Southern Hemisphere using Complex Empirical Functions cEOF1[1] and by separating the Southern Annular Mode into its zonally symmetric (S-SAM) and asymmetric (A-SAM) component [2]. We computed the Complex Empirical Orthogonal Functions (cEOFs) of the 200 hPa and 50 hPa geopotential height zonal anomalies, which enabled us to characterise the amplitude and phase of the main variability patterns of the zonally asymmetric circulation.
The first cEOF (cEOF1) represents the zonal wave 1 variability in the stratosphere and is associated with a Southern Annular mode (SAM)-like pattern in the troposphere and significant stratospheric ozone anomalies. The second cEOF (cEOF2) represents a wave 3 pattern with maximum amplitude in the Pacific region mainly in the troposphere with a weaker signal in the stratosphere. This mode is related to Pacific-South American mode (PSA)-like spatial patterns and an SAM-like annular pattern.
Both cEOFs are associated with significant 2-m temperature anomalies over western Antarctica. The location and sign of the impacts of the cEOF2 in particular depend heavily on its phase, which is influenced by tropical Pacific Sea Surface Temperatures (SSTs), making the cEOF2 a very useful description to understand the relationship between tropical and polar variability.
On the other hand, by splitting the SAM into the S-SAM and A-SAM we identify that the positive trend in boreal summer SAM is only evident in its symmetric component and that the correlation between it and ENSO is only explained by the asymmetric component. The relationship between SAM and 2-m temperature over and around Antarctica can also be similarly assigned to the SAM's components. The S-SAM is associated with cold anomalies over eastern Antarctica and the A-SAM is associated with warm anomalies over the Ross Sea, the Antarctic Peninsula and the Weddell sea and cold anomalies over the Amundsen-Bellingshausen.

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[2] Campitelli, E., Díaz, L. B., & Vera, C. (2023). Revisiting the zonally asymmetric extratropical circulation of the Southern Hemisphere spring using complex empirical orthogonal functions. *Climate Dynamics*.

Abstract for the Workshop on Polar Climates

Large-scale destratification in the Eurasian Basin thermocline and consequences on the Atlantic Water shoaling

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The stratification in the upper layers of the Arctic Ocean is a key indicator of climate change in the Arctic [1]. Warm and saline Atlantic Waters are separated from sea ice by a cold, salt-stratified layer called the halocline, which limits vertical heat fluxes. While freshwater has accumulated in the Amerasian Basin over the past 30 years, increasing the stratification [2], an opposite trend has been observed in the Eastern Eurasian Basin since the mid-2000s [3]. There, both a shoaling of the Atlantic Water upper limit and a reduced sea ice cover have been observed, allowing for enhanced wind impacts and mixing, which reduced the stratification, increased local vertical heat fluxes and slowed down winter sea ice formation.

Using available in situ data since the 1980s, we implemented a clustering algorithm to divide the Eurasian Basin into several regions with coherent temperature, salinity and stratification profiles. This approach provides new insights on the evolution of the stratification across the basin, in particular in regions where few long-term studies are available like the Amundsen Basin. We show that the salinity in both the Nansen and Amundsen Basin has significantly increased above the Atlantic Waters up to the base of the halocline, causing a vertical migration of the associated isopycnals over the study period. In these layers, the stratification is found to have decreased by 50% in 40 years in both basins, enhancing salt and heat fluxes up to the base of the halocline and potentially contributing to a basin-wide Atlantic Water shoaling.

[1] Polyakov, I., Pnyushkov, A., and Carmack, E. Stability of the arctic halocline: A new indicator of arctic climate change. Environmental Research Letters **13,** 125008 (2018).

[2] Morison, J., Kwok, R., Peralta-Ferriz, C. *et al.* Changing Arctic Ocean freshwater pathways. *Nature* **481**, 66–70 (2012).

[3] Polyakov, Igor et al., Greater role for Atlantic inflows on sea-ice loss in the Eurasian Basin of the Arctic Ocean. Science **356**, 285-291 (2017).

P05

Investigating Antarctic Sea Ice Anomalies Through CMIP6 Simulations

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Antarctic sea ice cover experienced an abrupt decline in 2016, transitioning from a record maximum state to a record minimum state, a status it maintained until 2024[1]. However, the drivers of this rapid retreat are currently not well understood. Therefore, it is difficult to determine whether this signals the start of a long term melting trend, as has been long anticipated by climate models, or is an isolated episode of internal climate variability. In this study, we utilise the CMIP6 pre industrial control simulations to understand if internal climate variability could be responsible for this Antarctic sea ice anomaly, and if so what the primary atmospheric and oceanic drivers are. This involves examining composites of the tropical teleconnections, subsurface ocean heat content, and high latitude atmospheric variability preceding extreme Antarctic sea ice anomalies in CMIP6 simulations. The primary objective is to elucidate the multifaceted factors influencing these extreme events, specifically addressing the 2016-2017 sea ice retreat, with lessons for 2023's extreme Antarctic sea ice state. Initial results indicate that such events are possible in the absence of anthropogenic emissions in some climate models, although the occurrences are considered rare. Moreover, the climates systems in the Tropical Pacific plays an important role preceding the drop in Antarctic sea ice in terms of surface temperatures and winds. On the other hand, we do not find evidence of a build-up of subsurface ocean heat in the Southern Ocean within the models as documented in observational records by Purich & Doddridge. [2] We also show that that using the limited observed record alone will underestimate the interannual variability of the Antarctic sea ice cover and therefore overestimate how rare such an anomaly would be. In fact, if we extend the observed record further back using statistical reconstructions [3], rapid declines of sea ice extent may have occurred in the early and mid 20th century. Our results highlight the importance of internal climate variability in the Southern high latitudes and advance our understanding of the drivers and predictability of Antarctic sea ice changes. Lastly, we discuss the implications of this work for 2023's record Antarctic sea ice anomaly.

[1] Turner, John, et al. "Unprecedented springtime retreat of Antarctic sea ice in 2016." Geophysical Research Letters 44.13 (2017): 6868-6875.
[2] Purich, Ariaan, and Edward W. Doddridge. "Record low Antarctic sea ice coverage indicates a new sea ice state." Communications Earth & Environment 4.1 (2023): 314.
[3] Fogt, R. L., M. N. Raphael, and M. S. Handcock. "Seasonal Antarctic Sea Ice Extent Reconstructions, 1905-2020, Version 1." (2023).

P06

The impact of Antarctic Sea Ice on simulated Southern1 Ocean water mass

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The Southern Ocean plays a crucial role in the absorption of oceanic heat and carbon, primarily owing to the occurrence of the most substantial deep-water upwelling in this region[1]. The ventilation between deep water and atmosphere facilitates the anthropogenic heat and carbon absorption by the ocean. The heat and carbon in the surface ocean are sequestrated back into the deep ocean after water mass transformation. Sea ice forming and melting act like the pump, transforming the surface water mass into higher and lower density water by salinificate and freshening[2]. Here, we analyse the sea ice impact on the Southern Ocean water mass transformation and provide a concise summary of the relationship between water mass transformation and sea ice in CMIP6. The surface air-sea flux transforms surface upwelling into 9.75 ± 5.05 Sv denser water and 46.89 ± 14.14 Sv lighter water, of which sea ice freshwater flux contributes 91% densification and 57% lightening.

[1] T. L. Frölicher, J. L. Sarmiento, D. J. Paynter, J. P. Dunne, J. P. Krasting, and M. Winton, "Dominance of the Southern Ocean in Anthropogenic Carbon and Heat Uptake in CMIP5 Models," *Journal of Climate*, vol. 28, no. 2, pp. 862–886, Jan. 2015, doi: 10.1175/JCLI-D-14-00117.1.
[2] R. P. Abernathey, I. Cerovecki, P. R. Holland, E. Newsom, M. Mazloff, and L. D. Talley, "Water-mass transformation by sea ice in the upper branch of the Southern Ocean overturning," *Nature Geosci*, vol. 9, no. 8, Art. no. 8, Aug. 2016, doi: 10.1038/ngeo2749.

P07

GREP reanalysis captures the evolution of the Arctic Marginal Ice Zone across timescales

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The recent development of data-assimilative reanalyses of the global ocean and sea ice enables a better understanding of the polar region dynamics and provides gridded descriptions of sea ice variables without temporal and spatial gaps. Here, we study the spatiotemporal variability of the Arctic sea ice area and thickness using the Global ocean Reanalysis Ensemble Product (GREP) produced and disseminated by the Copernicus Marine Service (CMS). GREP is compared and validated against the state-of-the-art regional reanalyses PIOMAS and TOPAZ, and observational datasets of sea ice concentration and thickness for the period 1993-2020. Our analysis presents pan-Arctic metrics but also emphasizes the different responses of ice classes, marginal ice zone (MIZ) and pack ice, to climate changes. This aspect is of primary importance since the MIZ has been widening and making up an increasing percentage of the summer sea ice as a consequence of the Arctic warming and sea ice extent retreat. Our results show that the GREP ensemble provides reliable estimates of present-day and recent past Arctic sea ice states and that the seasonal to interannual variability and linear trends in the MIZ area are properly reproduced, with ensemble spread often being as broad as the uncertainty of the observational dataset. The analysis is complemented by an assessment of the average MIZ latitude and its northward migration in recent years, a further indicator of the Arctic sea ice decline. There is substantial agreement between GREP and reference datasets in the summer. Overall, the GREP ensemble mean is an adequate tool for gaining an improved understanding of the Arctic sea ice, also in light of the expected warming and the Arctic transitions to ice-free summers.

P08

Increased Rotational Coupling between Antarctic Sea Ice and the Atmosphere Over the Last 30 Years

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Antarctic sea ice has been characterized by high temporal and spatial variability since the inception of reliable satellite records. The complex mechanisms driving this variability, involving oceanic and atmospheric influences, present ongoing challenges in determining their respective contributions. In this study, we examine the rotation dynamics within the sea ice and overlying atmosphere at daily timescales from 1991 – 2020. A two-dimensional pattern similarity comparison between the sea-ice and atmospheric vorticity fields demonstrated a noteworthy increase in similarity over the past three decades, despite the absence of discernible trends in rotation within either medium over the same period. This escalating coupling suggests an increasing susceptibility of sea ice to atmospheric forcing, a phenomenon observed across all regions of the Southern Ocean and independent of sea ice extent. Notably, the Weddell Sea experienced a sudden regime shift after 2001, marked by a sharp decline in the intensity of sea ice rotation, persisting in this weakened state from 2002 onwards. Furthermore, an investigation into the Southern Annular Mode's impact on atmospheric vorticity revealed no distinct differences during positive or negative phases, explaining the lack of relationship with sea ice rotation dynamics. Our findings underscore the predominant role of the atmosphere in driving rotation within Antarctic sea ice, while highlighting a knowledge gap regarding ocean-related influences on ice dynamics.

P09

Advancements in developing a seasonal to interannual projection tool of Arctic sea ice state.

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Our project aims to develop a seasonal to interannual projection tool dedicated to the study and prevent of rapid Arctic sea ice loss events. The initial conditions for EC-Earth medium-term projections will be derived from NEMO simulations into which observations describing the sea ice state are assimilated. The assimilation method uses a Kalman filter (EnKF). The focus will be on assimilating original variables describing sea ice conditions, such as melt pond area or snow depth for instance, in addition to sea ice concentration. This will provide an advanced sea ice state medium-range forecasting tool.

Data assimilation through a Kalman filter requires an estimate of the variables involved in the model and their errors. This means knowing their distribution. This will be estimated by generating an ensemble of sea ice and ocean states based on the ERA5 reanalysis. The ensemble is created by perturbing ERA5, preserving the correlations between variables in time and space. At the end of this first preliminary step, a dataset statistically similar to ERA5 (25 members) will be available, enabling a NEMO simulation ensemble forced by this set of perturbed reanalyses over recent times. The NEMO-ERA5 ensemble will then be used as the initial state for assimilation.

In addition to improving the projection capabilities of the model, the extended assimilation of observations in NEMO is also intended to improve the representation of sea ice in general and to claim an Arctic sea ice reanalysis product.

P10

CMIP6 models rarely simulate Antarctic winter sea-ice anomalies as large as observed in 2023

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In 2023, Antarctic sea-ice extent (SIE) reached record lows, with winter SIE falling to ~2.5Mkm^2 below the satellite era average. With this multi-model study, we investigate the occurrence of anomalies of this magnitude in latest-generation global climate models. When these anomalies occur, SIE takes decades to recover: this indicates that SIE may transition to a new, lower, state over the next few decades. Under internal variability alone, models are extremely unlikely to simulate these anomalies, with return period>1000 years for most models. The only models with return period<1000 years for these anomalies have likely unrealistic interannual variability. In the multi-model ensemble, the return period is reduced from 2650 years under internal variability to 580 years under a strong climate change forcing scenario.

P11

Variability of the Weddell Sea Deep Waters in GLORYS12v1 Reanalysis

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Antarctic Bottom Water (AABW) play a crucial role in the intensity and variability of the Global Overturning Circulation (GOC) by supplying its lower limb. Changes in AABW have far-reaching implications for the stability of the GOC. Therefore, understanding the variability of deep water mass varieties forming AABW is crucial for projecting changes in ocean circulation and assess potential risks for the global climate. The study of Antarctic deep water masses and AABW formation processes has been challenging due to limited observational data products and the numerical complexities of integrating processes at different scales. However, recent high-resolution oceanic products offer a promising opportunity to improve our understanding about this region. Here, we investigate the structure and variability of deep water masses in the Weddell Sea using the Global Ocean Physics Reanalysis 1/12° (GLORYS12V1) product provided by the Copernicus Marine Environment Service (CMEMS) spanning from 1993 to 2020. Results from GLORYS12v1 indicate an almost decadal variability in Warm Deep Water (WDW), characterized by a warmer phase from 1993 to 2004 followed by a colder phase from 2005 to 2020. GLORYS12v1 highlights potential temperature increases in Weddell Sea Deep Water (WSDW) and Weddell Sea Bottom Water (WSBW) in the 2000s, resulting in less dense AABW varieties. New analyses are under development in order to understand the variability observed in these deep water masses and their connections with external forcings variables, such as winds and sea ice concentration. The anticipated findings are expected to contribute to an enhanced understanding of Weddell Sea circulation, providing insights to inform and constrain the potential implications for global circulation.

P12

Abstract template for School and Workshop on Polar Climates: Theoretical, Observational and Modelling Advances

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Satellite-derived datasets have been widely used to study snow cover and sea ice variability, which both exert strong forcing on the polar climate through their contributions to the planetary albedo [1]. However, concerns linger regarding the temporal stability of these datasets. We focus on a long-term record -- the NOAA Climate Data Record of Snow Cover Extent (NOAA CDR) -- which is widely used but controversial due to its representation of positive snow cover trends from September to November and [2]. These positive trends oppose other trend estimates [3]. We produce benchmark estimates of historical snow cover variability and trends with reanalysis-forced offline snow modeling (described in [4]). Using three forcing datasets, multi-decadal trends are derived which add a new line of evidence that snow cover has decreased over the Northern Hemisphere across all winter months. To reproduce the trends of the NOAA CDR with the historical snow cover data, we must systematically reduce the SWE threshold that defines snow cover. This result is consistent with an internal trend in the NOAA record which could be attributed to improved detection algorithms and resolution over time. We use the last ten years of data from the NOAA CDR to calibrate and produce a merged SCE dataset for 1980-2020. Improving monthly trend estimates will help us advance our understanding of the coupled climate system by providing updated information for model validation.

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[3] R. Brown and C. Derksen, Environ. Res. Lett. **8**, 024006 (2013).
[4] A. Elias Chereque, P. Kushner, L. Mudryk, C. Derksen, C. Mortimer, The Cryosphere [preprint] (2024).

P13

Exceptional sea ice loss leading to anomalously deep winter convection north of Svalbard in 2018

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An important question is will deep convection sites, where deep waters are ventilated and air-gas exchange into the deep ocean occurs, emerge in the Arctic Ocean with the warming climate. As sea ice retreats northward and as Arctic sea ice becomes younger and thinner, air-sea interactions are strengthening in the high-latitude oceans. This includes new and extreme deep convection events. We investigate the associated physical processes and examine impacts and implications. Focusing on a region near the Arctic gateway of Fram Strait, our study confirms a significant sea ice cover reduction north of Svalbard in 2018 compared to the past decade, shown in observations and several numerical studies. We conduct our study using the regional configuration Arctic and North Hemisphere Atlantic of the ocean/sea ice model NEMO, running at 1/12° resolution (ANHA12). Our numerical study shows that the open water condition during the winter of 2018 allows intense winter convection over the Yermak Plateau, as more oceanic heat is lost to the atmosphere without the insulating sea ice cover, causing the mixed layer depth to reach over 600 m. Anomalous wind prior to the deep convection event forces offshore sea ice movement and contributes to the reduced sea ice cover. The sea ice loss is also attributed to the excess heat brought by the Atlantic Water, which reaches its maximum in the preceding winter in Fram Strait. The deep convection event coincides with enhanced mesoscale eddy activity on the boundary of the Yermak Plateau, especially to the east. The resulting substantial heat loss to the atmosphere also leads to a heat content reduction integrated over the Yermak Plateau region. This event can be linked to the minimum southward sea ice volume flux through Fram Strait in 2018, which is a potential negative freshwater anomaly in the subpolar Atlantic.

P14

Water masses transformation along Nares Strait from 2002-2020: a numerical model study.

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Nares Strait is one of the main pathways connecting the Arctic Ocean to the North Atlantic. The southward transport of sea-ice and freshwater through the strait plays an important role in the mass balance of Arctic sea-ice and influences the climate of the North Atlantic region [1]. In the last two decades the strait has gone through some significant hydrographic changes. Given the significance of the region, we use an eddy-permitting configuration of the NEMO ocean model to explore water masses transformation along Nares Strait, from 2002 to 2020. The model is coupled with the Louvain-la-Neuve sea-ice thermodynamic and dynamic numerical model and is forced by the Canadian Meteorological Centre's Global Deterministic Prediction System Reforecasts.

Model data indicates that north of the Kane Basing sill, the strait has become fresher, and the overall temperature has decreased by ~0.2°C. These changes are more prominent below 100 m depth. This increasing freshwater signal may reflect changes in circulation and ice formation that contributes to an increased flow of relatively fresh waters from the Arctic Ocean into Nares Strait. The southern portion of the strait, on the other hand, has become warmer. This warming is more pronounced between 100-350 m depth. However, no significance changes in salinity have occurred. This would be consistent with an influx of warmer Atlantic Origin Water, as proposed by previous modelling results [2,3]. These changes could impact the formation and stability of the southern ice arch, posing a potential risk for the formation and maintenance of the North Water Polynya.

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P15

Abstract template for School and Workshop on Polar Climates

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The densest component of the AMOC, originating in the Nordic Seas, is primarily formed in the Greenland Sea and flows across the Greenland-Scotland Ridge [1,2]. The upstream pathways of these dense overflows are not well known but are important for understanding the connections between dense water formation regions and export pathways. Here we use Argo floats drifting at intermediate depths (1000 – 1500 m) to provide an overview of this circulation, in particular the interbasin exchange, which has not been well documented in the past. We found the highest velocities along the boundaries and in the Norwegian Sea along steep topography, while the velocities in the interior basins are lower. Increased wintertime velocities, especially in the boundary current system, are associated with enhanced large-scale wind stress curl. Floats generally remain within the basin they were deployed in, unless they are entrained by the boundary current. This occurs primarily when the interior gyre circulation is close to the boundary, or where steep topography can cause instabilities in the boundary current. The exchanges across submarine ridges show certain preferred interbasin pathways, except for the crossings between the Greenland and Lofoten Seas.

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P16

On the role of barotropic and baroclinic flows in forming a Taylor Cap at Maud Rise, Weddell Sea

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In several locations around the global ocean Taylor Caps are found above seamounts. Taylor Caps originate from the flow's impingement on the seamount and subsequent formation of an almost stagnant area above the seamount in a stratified water column. The Cap isolates water properties and weakens the stratification around it. Our focus is the Taylor Cap at Maud Rise in the Weddell Sea, as this is a region prone to open-ocean polynya formation. While many studies looked at the Taylor Cap in a barotropic case, little work under baroclinic conditions more relevant to the real-world ocean has been done. We study the behavior of Taylor Caps in response to the ambient stratification and inflow conditions in an idealized model set-up.

Our study explores scenarios ranging from a barotropic ocean to a simplified exponentially-decaying stratification associated with thermal wind. In the stratified case, we determine the relative roles of the barotropic (depth-independent) flow and the baroclinic (depth-dependent) flow components, and investigate the local response of the stratification. Our results show that the Taylor Cap is primarily generated by the barotropic flow, and that the baroclinic component only generates a Taylor Cap if the velocity at the depth of the seamount is sufficiently large. The baroclinic flow is, however, more effective at producing the doming of isopycnals over the seamount than the barotropic component. Lastly, we show that higher inflow velocities lead to a shoaling of isopycnals and reduction of upper-ocean stratification over the seamount.

P17

Projection of Sea Ice Condition in Nunatsiavut (Labrador)

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The ongoing changes in global climate patterns have significant implications for sea ice conditions, impacting local Inuit communities, including those in Nunatsiavut, Labrador. This study focuses on forecasting the future of sea ice conditions along the Labrador coast by examining historical and projected changes in sea ice extent and thickness. Observed data from the Canadian Ice Service, with a resolution of 10 km covering the period 1990-2020, and simulated data from the High-Resolution Community Earth System Model (HR-CESM) with a 0.1-degree spatial resolution covering the period 1850-2100, were used for a comprehensive analysis of past trends and future projections. Results show a very slow decline in the maximum sea ice extent in March followed by a rapid transition to winter ice-free conditions around 2060 when the Arctic Ocean becomes seasonally ice free and no longer advect sea ice south through the Nares Strait along the Labrador coastline. Also of interest is the gradual decline in the length of sea ice season and maximum thickness until the end of the 21st century. Additionally, later freeze-up and faster breakup of sea ice are expected to affect the marine ecosystem and wildlife over the Labrador coast, with an increase in open water areas. These shifts present potential challenges for the Inuit communities, with significant socio-cultural and economic implications, particularly regarding traditional practices and livelihoods. These results can inform the development of mitigation and adaptation programs, emphasizing the urgent need for proactive measures to ensure the sustainability and resilience of the Inuit communities in Nunatsiavut and other affected regions in the face of the evolving sea ice landscapes.

P18

Mechanisms and variability of the Arctic overturning circulation

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The Arctic overturning circulation involves the production of water masses that are key to the global ocean circulation. The Arctic climate is, however, rapidly changing, and it is currently not known how the Arctic overturning circulation is responding. Previous modeling efforts have identified the emergence of new areas of deep convection in the Arctic Ocean as a source of Arctic overturning changes, but the interactions with the Atlantic Water Boundary Current (AWBC) have not been resolved in these models. It is therefore not known how the Arctic overturning circulation will respond to changes in Atlantic water modification and associated dense waters along the AWBC.
Here, we use the high-resolution ocean reanalysis GLORYS12 to quantify the mean state and variability of the Arctic overturning circulation (ArMOC) between 1993 and 2021. The ArMOC is quantified by calculating the density-space overturning divergence over the Arctic Ocean, bounded by the Bering Strait, Davis Strait, Fram Strait, and the Barents Sea Opening. The mean overturning streamfunction shows three overturning cells, where the lowest (densest) cell represents the transformation of Atlantic water into denser waters. The role of surface forcing in driving overturning variability is then estimated by calculating the surface forced water mass transformation. The difference between the ArMOC and its surface-forced component estimates the importance of interior mixing.

P19

Air-sea heat fluxes exchange at the Southern Ocean

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The Southern Ocean (SO) and the Southwest Atlantic Ocean (SWA) present a great relevance to studies of ocean-atmosphere interaction, especially due to their dynamic and thermodynamic characteristics, which modulate the exchange of mass and energy and influence the weather and climate of South America [1]. Although important, ocean-atmosphere fluxes have been scarcely studied in the SO and SWA, compared to other regions of the planet (e.g. equatorial region), and there is still a critical need for systems designed return high-quality measurements in all seasons and ocean conditions [2]. Understanding and quantifying the exchange of heat between the ocean and the atmosphere is therefore extremely important for the proper management of natural resources and reducing risks for vulnerable populations [3]. The fluxes calculations are made using two methods to have more reliable results, and they are Bulk parameterization, and Eddy Covariance. The *in situ* data were collected along the scientific cruises during the Brazilian Antarctic Operation for the years 2018, 2019, 2020 and 2022. The aim of this study is to obtain heat transfer coefficients that will allow a better estimation of heat fluxes in the SO and SWA. We will combine these two methods to reduce the uncertainties about these processes and generate more reliable results. We will use Artificial Intelligence techniques to estimate new coefficients adapted to the southwestern and southern parts of the Atlantic Ocean. To achieve this, we will use a turbulent database already collected in situ, combined with remote sensing data and atmospheric and oceanic reanalyses. By obtaining these transfer coefficients, we hope to advance our knowledge, especially from a dynamic and thermodynamic point of view, of the SO and SWO.The turbulent fluxes that occur between the ocean-atmosphere interface are of great importance for understanding climate dynamics. These heat exchanges influence both atmospheric and ocean temperatures, affecting the climate in the study region. Turbulent flows in the SO and SWA still need to be extensively explored and are of utmost importance for understanding the climate of this region and the globe, as well as the marine ice/melt regime influenced by them.

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Abstract template for a Talk

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The Nordic Seas are key to the formation of the dense, deep water that drives the thermohaline circulation. Strong air-sea heat loss drive the formation of deep water by triggering convection. This dense water is then stored in the deep areas of the Nordic Seas. The Iceland-Scotland Ridge topographically prevents this flow of moving southward. At the western side of the ridge, Denmark Strait (DS) is a narrow path between Iceland and Greenland where this dense water overflows the ridge, forming the Denmark Strait Overflow Water (DSOW). This deep flow forms the lower limb of the Atlantic Meridional Overturning Circulation (AMOC) and thus it plays a determining role in the planet’s climate. The FAR-DWO project is an interdisciplinary project that aims to understand the formation, propagation, and seafloor impact of dense water overflows in the DS and also in the Cap de Creus submarine canyon in the Mediterranean Sea, where cascading of dense waters also occur. In summer 2023, a high-resolution hydrographic cruise took place between 64.5ºN and 67.5ºN. This study describes the large-scale circulation from the DS to roughly 200km downstream and shows exchanges between the Greenland continental shelf and the deep Irminger Basin.

P21

Characterizing the biological pump in regions of natural iron fertilization in the Southern Ocean

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Phytoplankton growth is the cornerstone of the oceans' biological carbon pump – an important mechanism for transporting carbon into the deep ocean [1]. In the Southern Ocean, this pump is weakened by low levels of dissolved iron – an essential nutrient for photosynthesis [2]. However, there are several regions that experience natural iron fertilization, where large scale phytoplankton blooms are frequently observed. These include island wakes such as downstream in the Antarctic Circumpolar Current where the presence of islands enhances the availability of nutrients and iron in the surrounding waters, leading to increased primary productivity [3]. Further, iron released by hydrothermal vents contributes to this process. Combined with upwelling events induced by bathymetry or fronts, this benthic source can be transported to the euphotic zone, where it supports primary production [4]. Closer to Antarctica, the seasonal ice zone is another region where chlorophyll blooms are being observed. Iron in sea-ice has been found to be especially bioavailable [5]. However, global warming may alter sea-ice dynamics in the future.

Biogeochemical (BGC) Argo floats offer a promising avenue to investigate the fate of biogenic material produced in the euphotic zone in regions previously inaccessible for in-situ observations. We apply BGC Argo based methods to quantify the characteristics of the biological carbon pump to the different regions identified as naturally iron fertilized and explain the impact of the physical environment on the productivity and the degree of iron-driven enhancement relative to the surrounding HNLC iron-limited waters. Understanding how and why the regions differ in carbon export will be crucial to target questions regarding the expected adjustments due to climate change.

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P22

Dataset of Arctic Ocean water masses from 40 years of hydrographic observations

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The Arctic Ocean plays a crucial role in the Earth's system. The sinking of cold, dense water is a key process in the global transport of heat, carbon, and other-climate critical traces. Arctic sea ice cover sustains a fundamental global climate feedback through its influence on Earth's planetary albedo. All these processes are changing significantly and rapidly in a warming climate. To monitor these changes, it is useful to classify the Arctic Ocean into water masses containing waters of the same origin and histories and similar physical and biogeochemical properties. However, there are significant barriers to water mass classification for the Arctic Ocean: observations of seawater properties are sparsely and inhomogeneously sampled in space and time, and traditional water mass classification methods rely on extensive oceanographic knowledge of water mass characteristics and circulation and mixing. Here, we propose a data-driven framework for quantifying Arctic Ocean water masses from observations that semi-automates a traditional water mass classification method. The framework includes a synthesis of 40 years of temperature, salinity, and dissolved oxygen observations, and a supervised machine learning model to estimate fractions of Arctic Ocean water masses (0-1) from basic hydrographic data. This framework allows for up-to-date water mass estimates as new Arctic observations become readily available. We anticipate this framework to be useful for answering open and urgent questions related to Arctic climate change and the capacity of models to accurately represent Arctic Ocean properties.

P23

The role of subglacial sediments on ice shelf basal melting from idealised simulations.

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Abstract

The Antarctic Ice Sheet has been experiencing increased mass loss in recent decades, which has been mainly driven by basal melting. Changes in the grounding zone, where the grounded ice sheet transitions to a floating ice shelf, are of primary importance to this volume loss. While subglacial freshwater in the grounding zone can enhance basal melting, the effects of sediments transported by this outflow on the ice shelf cavity dynamics are poorly known. The sediment distribution responds to the vertical stratification of the water column, which is also affected by the tidal mixing. To understand the role of subglacial water outflow, sediments, and tides on ocean circulation and basal melting, we analyse a range of experiments in an idealised cavity forced by an ocean warming forcing, representative of a warm shelf regime. Results show simulated basal melt rate is reduced by $1.55\pm$ 0.15 m/year in the presence of sediment, and $6.15\pm$ 0.45 m/year at the grounding zone. The sediment-laden plume not only increases the local bulk density but changes the bedrock topography and weakens the intrusion of warmer waters into the grounding zone, which is independent of the tidal forcing in these simulations.

P24

Analyzing Antarctic Sea Ice Dynamics: Exploring Advance and Retreat Patterns Within a Traditional and Invariant Annual Cycle

Frida A. Perez [1] **, Marilyn Raphael**[1]

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Sea ice dynamics in the Antarctic play a pivotal role in shaping the region's climate system. Understanding the timing of sea ice advance and retreat, referred to as its phase, is essential for comprehending sea ice variability. This study undertakes a comprehensive circum-Antarctic examination of daily sea ice phase. We achieve this by juxtaposing the traditional annual cycle of sea ice extent (SIE) with an invariant annual cycle. Recent research underscores the significance of top-of-atmosphere (TOA) insolation as the primary driver for the short-term and longer-term advance periods of sea ice [2]. Leveraging this understanding, we compute an invariant annual cycle across space to elucidate the influence of external (TOA) forcings on phase dynamics. Unlike the traditional annual cycle calculation, which overlooks day-to-day fluctuations, our newly proposed invariant cycle offers a more nuanced depiction of phase variations.

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Defining the Sea Ice Advance in a Changing Arctic: The Arctic Turnaround Period

Jaynise M. Pérez Valentín[1], Michael Steele[1], Peter Gaube[1], Jim Thomson[1], Seth Zippel[2]

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The Arctic summer season is dominated by strong inputs of solar radiation melting sea ice and warming up the ocean surface through open water areas. By late summer, shortwave radiation decreases, and then in early autumn the heat stored in the ocean mixed layer begins to be released into the atmosphere. This air-sea exchange is modulated by turbulent air-sea fluxes and mixing in the upper ocean. As our planet warms, progressively less sea ice survives the summer, resulting in thinner winter ice packs. This creates a positive feedback increasing heat fluxes from ocean to atmosphere which can affect sea ice advance over the winter. By the same token, sea ice growth (or lack of) is tightly coupled to heat fluxes from the ocean to the atmosphere as it is determined by the energy balance at the lower boundary of the ice. For an increasingly dynamic Arctic, a new way to define the summer to winter transition without the use for sea ice is proposed. Surface radiative and turbulent heat fluxes are used from reanalysis data to define the Arctic turnaround as the time when the upper ocean and lower atmosphere are at a mean thermal balance. We analyze a suite of surface meteorological parameters together with the dynamical (advective) and thermodynamic (heat) oceanic response from the PIOMAS (Arctic Sea Ice Volume) model during this period to understand the predetermined conditions for sea ice formation (or lack of). A study case is developed for the 2022 Arctic turnaround period (ATP) using data collected during the NASA-sponsored Salinity and Stratification at the Sea Ice Edge (SASSIE) field experiment in the Beaufort Sea.

P26

Abstract template for a poster presentation at the School and Workshop on Polar Climates (ICTP)

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Towards modeling the 3D evolution of the world's largest glaciers

Glaciers outside the ice sheets are important contributors to sea-level rise. Indeed, the worldwide ca. 200,000 glaciers remain key contributors, responsible for about 25-30% of the observed 3.5-4 mm/year sea-level rise [1]. Most of the global glacier volume, and thus potential sea-level contribution, is located in a limited amount of glaciers. For example, the largest 1% of the glaciers outlined in the Randolph Glacier Inventory [2] contain more than 80% of the total glacier ice volume.

The goal of my PhD is to model the temporal evolution of the world's largest glaciers. Most of these large glaciers, which cover the underlying landscape and are commonly referred to as ice caps, are located in polar areas. Here, I will highlight some of the first steps that we are undertaking to realistically model the evolution of these ice masses:

- **3D modeling** : To date, large-scale glacier models treat ice caps as a series of independent subglaciers through flowline modeling or other simplified approaches [3]. Here, ice caps are modeled in 3D as single entities as opposed to considering ice caps as a series of non-connected glaciers. We will try to properly simulate the migrating boundaries between subglaciers while modeling several dynamical processes in a more accurate way.

- **Over long time scale** : Based on our knowledge from ice sheet modeling, where future projections strongly depend on how the model is calibrated to match past observations [4], we anticipate projected future glacier changes to substantially change when being calibrated to match observations over longer timescales. In our work, we will specifically focus on the long-term evolution of glaciers, both in the past and in the future.

- **Atmosphere-glacier surface interactions** : We will work towards a better representation of the polar atmosphere and climate over glaciers surfaces, and how this affects surface mass balance processes.

This presentation will be the opportunity to share some of the first modeling results from my PhD.

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P27

Intrahalocline eddy in the central Arctic from distributed observations during the MOSAiC winter

Alejandra Quintanilla-Zurita [1] **, and Benjamin Rabe** [1]

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Hydrographic observations from the Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition (2019-2020) show the existence of several eddies in the upper halocline in the central Arctic Ocean, particularly in winter time when the biggest eddies cross the Distributed network. February eddy was observed with two different Ice tethered profilers (ITP), microstructured (MSS), CTD from the ship, and three different ADCP simultaneously. This eddy is an intrahalocline anticyclonic with a radius close to 15 km, extending vertically from the base of the mixed-layer (~20 m) to ~120 m depth, and showed horizontal velocities of up to 3.0 m/s

P28

Interannual Variability of basal melt rates in the eastern Amundsen Sea

Ole Rieke[1] , **Paul Spence**[1] , **Bea Pena-Molino**[2], **Maxim Nikurashin**[1], **Laura Herraiz-Borreguero**[2], **and Matthis Auger**[1]

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Ice discharge in the Amundsen Sea is among the highest around Antarctica due to unrestricted access of relatively warm Circumpolar Deep Water to the continental shelf and the ice shelf cavities resulting in large melt rates at depth [1]. Several previous studies have emphasized the link between atmospheric forcing, inflow of Circumpolar Deep Water, changes in thermocline depth and basal melt rates. In this study we find very high correlation (>0.8) between satellite-observed basal melt rates in the Amundsen Sea (1992-2017) and temperature variability from a global ocean-sea ice model, ACCESS-OM2, consistent across different cycles from the model. Temperature variability is dominated by a local vertical displacement of the thermocline due to changes in zonal surface stress. Reduced easterlies are associated with isopycnal heaving and hence warming, and higher melt rates. A secondary effect comes from wind-related changes in the inflow of Circumpolar Deep Water on the continental shelf that is then advected towards the ice shelves. As there is some delay in this response, atmospheric forcing leads the total temperature variability. The atmospheric forcing of both these processes indicates a limited role of internal ocean variability and provides the potential for predictability of future melt rates.

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P29

Quantifying Ice-Ocean-Atmosphere-Driven Fluxes

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The Southern Ocean plays a crucial role in global climate regulation, serving as a major driver of oceanic and atmospheric circulation [1], [2]. Salinity variability of water masses in this region is influenced by sea ice formation and atmospheric interactions. As a fundamental parameter in terms of vertical mixing throughout the ocean, salinity is intimately linked with ice sheet and sea ice dynamics, as well as atmospheric drivers like wind [3], [4], [5], [6]. Understanding the causes and consequences of salinity fluxes in the Southern Ocean is not only essential for understanding changes in regional climate dynamics but also implications the changes have on the global climate system. We aim to conduct a comprehensive analysis of salinity fluxes in the Southern Ocean by investigating the relationships between ice, ocean, and atmosphere. The objective is to quantify the impact of ice sheet and sea ice dynamics on Southern Ocean salinity investigating spatial and temporal changes in Antarctic Bottom Water (AABW) and Antarctic Intermediate Water (AAIW) salinity fluxes. Stable seawater isotopes and noble gases serve as tracers for understanding the impact of melting ice on ocean properties [7], [7], [8], [9], [10], [11], [12], [13]. We will utilize a novel database of stable isotopes and noble gases to assess the influence of ice masses on salinity changes. To achieve these objectives, this project will use in-situ measurements of salinity and water isotopic properties, remote sensing data to analyse ice sheet and sea ice dynamics, and climate reanalyses to simulate the complex interactions between ice, ocean, and atmosphere.

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P30

Study of the Life Cycle of Ice Bridges and Their Variability in the Canadian Arctic Archipelago

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An ice bridge forms when sea ice becomes completely landfast between two land masses. The ice is held in place by its ability to resist wind and current stresses by redistributing the load onto land or grounding points. Consequently, the occurrence and location of ice bridges depend largely on local geography. The concave shape of the free edge of a bridge takes the form of an arch, which is an indicator of the dynamic equilibrium between the internal resistance of sea ice (rheology) and external forces [1]. The formation and long-term stability of many ice bridges in the Canadian Arctic Archipelago (CAA) contribute to form the North Water Polynya (*Pikialasorsuaq*). It is the largest and most studied polynya in the Arctic, as it supports many northern communities and a highly productive ecosystem [2]. Understanding what drives the life cycle of ice bridges is key to predict how the ecosystem might evolve in a changing climate.

The multidecadal variability of ice arches of the eastern high Arctic is assessed through a visual analysis of weekly regional ice charts from 1968 to present. These observations form a database indicating the presence or absence of ice bridges, as well as the type of polynya (closed, semi-closed or open) based on ice concentration downstream of the arch. From this database, the formation and break-up dates of each event are extracted at a weekly frequency for each ice year defined from September 1st (week 36 or 37) to August 31st of the following year [3]. An attempt is then made to determine the correlation between the timing of events with environmental indicators such as the cumulative number of freezing degree days (FDD). Geometric properties of arches as well as the wind are extracted for a few break events to estimate cohesion using the hypothesis of static equilibrium of an arch and the Mohr-Coulomb theory, as described by Sodhi [4].

The objective is to better understand what controls the shape and life-cycle variability of ice arches. More specifically, we want to determine how much of these observable characteristics can be attributed to prevailing environmental conditions, and how much to the stochastic nature of the plastic-brittle-granual material sea ice is.

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P31

Box modelling of the Bistable Dynamics of Ocean Circulation under Antarctic Ice Shelves

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Ice shelves are floating extensions of ice sheets grounded on the Antarctic continent. The resistance ice shelves provide against the flow of grounded ice into the sea decreases when they thin. Increasing basal melting of ice shelves, i.e., melting by the ocean, may thus lead to faster sea-level rise. Recent modelling studies have shown that ice shelf cavities currently filled with cold water may experience suddenly warm water conditions under climate change scenarios [1,2]. However, the dynamical drivers and time scales of such regime changes are poorly understood, such that the impacts of ocean cavities tipping from cold to warm conditions on sea levels and global ocean circulation are not considered in current climate projections.

Some recent studies [2,3] have used conceptual box models to propose a mechanistic explanation for tipping point from a high melt rate (as a result of warm deep water filling the cavity) to a low melt rate (cold saline surface water filling the cavity) in specific ice-shelf cavities. Furthermore, [1-3] emphasized that cold katabatic winds coming from the South are expected to play a key role, as they induce strong surface freezing at coastal polynyas and hence brine releases that can trigger vertical convection.

Here, we propose a similar but generic theoretical framework. We include a box for cavity waters adjacent to ice-shelf base in addition to a box for surface waters near the ice-shelf front and a box for deep waters already present in [2,3]. The melting physics at the ice-shelf base is computed with the so-called "two-equations" parametrization of ice-ocean boundary layers. Salinity and temperature balances are implemented in each box, making it possible to monitor the dynamics of both tracers, whereas box temperatures are often fixed at constant levels in previous models. By solving the resulting dynamic system, we can show that bistable dynamics is possible, with hysteresis behavior induced by competition between brine discharge at the surface and heat flux inputs via deep waters. This result is in line with the conclusions of [2,3] and it is possible to recover the conceptual model of J. E. Hazel and A. L. Stewart [2] under certain assumptions. The addition of a cavity box makes our model more generic to study the melt rates at the base of ice-shelves. Thus, we aim to discuss –within the idealized framework of dynamical systems– the conditions under which an ice-shelf can be subject to bistability and the time scales associated to the tipping dynamics.

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P32

The Impact of Polar Stratospheric Clouds When Modelling the Future Recovery of the Ozone Layer.

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Polar stratospheric clouds (PSCs) play a fundamental role in depleting stratospheric ozone. They increase the concentration of active chlorine that can catalytically destroy ozone and prolong ozone depletion by denitrifying and dehydrating the stratosphere. Vertically propagating mountain waves can induce negative stratospheric temperature anomalies that lower the temperatures below the threshold for PSC formation – making them a crucial source of PSCs. However, parametrisation of PSC formation and mountain-wave-induced temperature fluctuations are poorly included in global chemistry-climate models due to the course resolution of models and complexity of the microphysical processes of PSC particle formation. This restricts our ability to project the future recovery of the Antarctic ozone hole and the resulting climate impacts. Since both the ozone hole and increasing greenhouse gas concentrations have contributed to an increase in summertime westerlies in the Southern Hemisphere, future ozone recovery could result in a reverse in the tropospheric circulation changes, despite continued increasing greenhouse gas concentrations influencing surface climate, sea ice, and ocean circulation [1]. Accurately predicting the timing of ozone recovery is therefore critical for mitigation and adaptation policies.

In my PhD project I am working with the Unified Model – United Kingdom Chemistry Aerosol (UM-UKCA) chemistry climate model to investigate the impact of a realistic representation of PSCs on model projections of twenty-first century stratospheric polar ozone levels and climate in both hemispheres. To achieve this, I am improving the representation of PSCs in UM-UKCA by refining the particle formation schemes and coupling with a novel mountain-wave-induced temperature fluctuation scheme [2]. As a first step, I have implemented a kinetic parameterisation for nitric acid trihydrate (NAT) formation [3]. This allows Type Ia PSC particles to grow and evaporate over multiple timesteps, enabling persistence and advection into regions where temperatures are too warm for formation, as has been observed in the Antarctic Peninsula. It also alters the uptake of gaseous HNO_3 by NAT which will be important for the next step of including supercooled ternary solution droplets – crucial PSC particles for the heterogeneous chlorine activation. Here I will present some preliminary results of my work, and particularly the impacts of the new PSC scheme on the representation of stratospheric ozone, stratospheric large-scale circulation and temperature, tropospheric westerlies, as well as surface climate.

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P33

Effects of ice shelf basal melting on sea ice production around the Antarctic Peninsula

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The cold and fresh waters from the melting of ice shelves have strong impacts on the sea ice [1], [2], [3]. Along with other atmospheric parameters (e.g., air temperature, surface winds, precipitation), they contribute to the increase of sea ice production, especially over the regions near the ice shelves. In contrast, the sea ice production also affects the ice shelf basal melting. The sea ice modulates the intensity of the ocean-atmosphere interaction. When sea ice decreases or creates polynyas near the ice shelves, the heat exchange between the ocean and ice shelf is modified due to changes in the water masses properties and distribution [4]. To investigate these processes, we conducted two experiments using the Regional Ocean Model System (ROMS), to simulate the dynamic and thermodynamic mechanisms across the Antarctic Peninsula region with and without the meltwater effects from ice shelves in the domain. Control (CTRL) and sensitivity (SENST) experiments were conducted simulating the ocean between 2002 and 2020. In SENST, the salt and heat fluxes representing the freshwater fluxes from melting were set to zero. An increase in sea ice production (average increase of 0.1m in thickness) in the coastal region was observed in CTRL, due to the extremely cold freshwater plumes resulting from ice shelf basal melting. The CTRL and SENST experiments do not show a significant difference in the sea ice extent, but differences are present in concentration (sea ice concentration – SIC). The differences along the coast are on the order of 2% of SIC along the West Antarctic Peninsula (WAP) and very near the shelves, with the main parts showing larger concentration in the CTRL experiment. Over the Weddell Gyre, we have the highest differences in SIC, mainly during the summer/autumn. The strong katabatic winds from the continent and the westerly winds along the latitudes lower than 60°S, as well as the topography, including continental boundaries and seabed structures, guide the sea ice to the middle of the Weddell Gyre, increasing thickness. The increasing sea ice layer at the surface, in consequence, works as a barrier between the ocean and atmosphere, reducing the movement of heat and wind stress over the water column. Therefore, the currents under the sea ice are reduced, and they increase along the borders where the exchange occurs more easily.

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Better understanding the Double Estuarine Arctic Circulation

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Climate predictions show an increase of oceanic heat transport into the Arctic despite an observed slow down of the Atlantic Meridional Overturning Circulation (AMOC). This counterintuitive result indicates the need to better understand the mechanisms controlling ocean dynamics in the Arctic. Meridional overturning cells are usually computed as a function of latitude. In the Arctic, this definition is inadequate since the geometry of latitude circles does not permit the full extent of the Arctic basin. To remedy this problem, we instead choose an alternate path connecting the North Atlantic to Bering Strait for diagnosing the Arctic Overturning Circulation. With this new approach, we observe the double estuarine circulation previously described in literature. This circulation is characterized by two superimposed cells going in opposite directions. We also note a strong seasonal cycle during which the cells alternately occupy the majority of the Arctic basin. We hypothesize on the mechanisms controlling the dynamics of this system, whether locally through surface buoyancy forcing or remotely through in depth variations of the in the Nordic Seas or the North Atlantic circulation. Finally, we introduce future analysis that we will realize to characterize the contribution of multiple forcing mechanisms on the Double Estuarine Arctic Circulation.

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Antarctic ice-mass loss impacts on sea ice and climate: results from the SOFIA multi-model experiment

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The impact of mass loss from the Antarctic continent on Antarctic sea ice, the Southern Ocean, and global climate was examined in a new multi-model ensemble experiment called "SOFIA": the Southern Ocean Freshwater Input from Antarctica Initiative. SOFIA is an international model intercomparison, in which freshwater is added to the ocean surrounding Antarctica to simulate the otherwise missing ice-sheet mass loss. This unique suite of models allows us compare the response to Antarctic mass loss across climate models, identify reasons for model discrepancies, and quantify the potential impact of the absence of increasing Antarctic ice-mass loss on Antarctic sea ice and climate. We will give an overview of the SOFIA initiative including the experiment design and participating models. We will present results from the "antwater" experiment outlined in the SOFIA protocol in which a constant freshwater input of 0.1 Sv is distributed evenly around the Antarctic continent at the ocean surface in an experiment with pre-industrial control forcing. We show that there is a spread of up to a factor of 3 in the Antarctica sea ice area response to identical freshwater forcing. There are also substantial differences in the spatial pattern of the sea ice response depending on the model used. We explore the dependence of the response on the mean state of Antarctic sea ice and the Southern Ocean in the pre-industrial control run, as well as the response of the stratification and oceanic deep convection in the models. We also explore the seasonality of the sea ice and oceanic response.

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Observed Interannual Variability of Antarctic Winter Water Drives Mixed Layer Warming and Preconditions Sea Ice Melt Events

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Antarctic Winter Water (WW) is a water mass in the Southern Ocean that lies below the summertime mixed layer, which acts as a potential energy barrier between the ocean interior and the surface layer. WW forms in the wintertime mixed layer south of the Antarctic Polar Front; it becomes subsurface in summertime following the restratification of the mixed layer and is characterised by a subsurface temperature minimum. Deep waters upwell to below WW around the Southern Ocean, which are naturally warm and rich in carbon dioxide. Therefore, WW modulates summertime mixed layer exchanges with upwelled deep waters, influencing mixed layer content of heat and carbon dioxide. Using 18 years of quality controlled Argo, MEOP, SOCCOM, glider and ship-based hydrographic profiles, we investigate the interannual variability of WW properties and their relationship with the mixed layer. We find spatial heterogeneity in the observed interannual variability of WW across different ocean basins as well as around topographic features: there is higher variability of WW properties upstream of large topographic features, whilst downstream displays less interannual variability. Furthermore, we indicate that thin summertime WW layers are associated with positive Southern Annular Mode years and lead to anomalously warm wintertime mixed layers through prolonged contact with warm subsurface waters. Consequently, wintertime sea ice conditions are potentially effected but are not necessarily observable in sea ice extent observations. We find that WW plays an important role in arresting deep waters from mixing with the surface layer such that heightened summertime thinning of WW potentially precondition sea ice melt events.

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Abstract for School and Workshop on Polar Climates: Theoretical, Observational and Modelling Advances.

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The decline in summer Arctic sea ice extent that has been underway for several decades is set to continue until summer Arctic sea ice disappears completely by the middle of the century, according to the latest climate projections. Based on observations and these climate model projections, the rate at which sea ice is retreating is not linear: the decrease in the Arctic sea ice cover is marked by periods of abrupt sea ice decline. Specifically, it has been suggested that these rapid ice loss events (RILEs) will become a frequent phenomenon in the coming decades. The causes of such events remain poorly understood and we are still unable to reliably predict their evolution. Furthermore, investigations are needed to gain a better understanding of the possible impacts of Arctic RILEs. The rate and manner of sea ice decline affect the ability of ecosystems and societies to adapt to these rapid changes. It is critical to improve the understanding of the conditions favoring rapid losses of Arctic sea ice. Therefore, we conduct an inventory of these events using the latest available climate projections from the CMIP6 database. Our results show that while RILE occurrence persists year-round in model simulations, differences in timing and persistence occur between winter/spring and summer/fall. Highlighting the difference in the influence of forcing factors between seasons but also emphasizing that model uncertainty significantly impacts the probability and characteristics of RILEs for winter/springs events. In addition, characteristics of these events reveal that while RILEs onset in both years and sea ice extent differ consequently between September and March due to sea ice extent mean state difference, the initial sea ice volume is similar for both of these two months emphasizing the role of sea ice thickness as a preconditioning factor. Our study stresses the importance of improving prediction for summer months, given projections of a seasonally ice-free Arctic, potentially accelerated by RILEs in the near future. Additionally, the probability of RILEs in winter and spring underscores the importance of emission reductions. This inventory guides future investigations into RILE mechanisms and development of a warning system to predict the possibility of RILEs for better Arctic management.

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Community-based Sea Ice Monitoring in Kaipokok Bay (Nunatsiavut)

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Nunatsiavut, a land claim area located in northern Labrador, experiences seasonal ice cover along its coastline, which serves as a habitat for a diversity of marine species and sympagic fauna and is an integral part of Labrador Inuit life [1]. Rapid changes to the sea ice environment are being observed throughout all Arctic communities as a consequence of anthropogenic climate warming [2], including sea ice loss, shorter ice seasons, and more unpredictable ice conditions. The extreme winters of 2010 and 2021 in Nunatsiavut are notable examples, with each ice season about 2 weeks shorter than average and with notably less ice coverage and thickness than any other year in lived memory. Extreme years such as these significantly restrict people's access to the landfast ice for travel and subsistence hunting and fishing, leading to adverse effects on their quality of life including food security and mental health. The drivers of extreme years and interannual variability are poorly understood, mainly due to the lack of long-term in-situ observations. We present our methods and preliminary results from a new community-based sea ice monitoring program in coastal Nunatsiavut. In January 2024, we launched an "ice monitoring site" on the landfast sea ice in Kaipokok Bay, located near the community of Postville, Nunatsiavut, Labrador. The site includes a suite of ice-tethered scientific instruments set to collect data on the sea ice, ocean, and atmosphere over the 2024 ice season (January to April 2024). In addition, local team members visit the site each week to supplement the monitoring site with in situ ice thickness measurements and under-ice CTD casts and to incorporate local knowledge on weather and ice conditions. The project's central focus is to examine the heat balance between ice, ocean, atmosphere, and rivers, and the role each component plays in yearly ice conditions. Our methodology emphasizes ongoing collaboration with community members from inception to completion. Through this approach, we can obtain a more detailed and holistic understanding of the local sea ice environment.

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P39

Interannual variations in Antarctic sea ice thickness (from ICESat-2): Insight into recent extreme changes

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Antarctic sea ice has a significant role in the Earth's climate and ocean systems, for example by influencing surface water mass transformation and the global overturning circulation [7], as well as determining surface albedo [6]. From 1979 to 2016, Antarctic sea ice extent underwent a small, yet steady, increase [1], despite increasing global mean surface temperatures. However, multiple dramatic reductions in sea ice extent have occurred since 2016, including record lows in 2023. The lowest sea ice extent in the observational record and the lowest wintertime sea ice extent occurred on February 19, 2023 and September 10, 2023, respectively, [5]. Most explanations for these events have focused on sea ice concentration or extent [5, 3], yet sea ice extent does not fully capture changes in oceanic processes related to sea ice growth and melt rates. Sea ice volume provides a clearer perspective on these mechanisms. Used as a proxy for sea ice volume, which requires knowledge of both thickness and areal extent, sea ice thickness can be obtained from remote sensing observations [2, 4].

This project examines inter-annual variations in sea ice thickness at both regional and pan-Antarctic scales, using both observational data as well as observationally constrained model output from the ECCO ocean state estimate. We analyze five years of sea ice thickness data from ICESat-2 observations, extending earlier sea ice thickness estimates, e.g. Kacimi and Kwok (2020), to study the relationship between sea ice extent, thickness, and volume. Both pan-Antarctic and regional time series analyses and spatial maps of sea ice extent and thickness, extending from October 2018 to the present, are performed to evaluate temporal and spatial sea ice changes. Furthermore, the connection between ocean conditions and ice thickness changes is explored through the analysis of mixed layer heat and freshwater budgets from the ECCO V4r5 solution. A mechanistic understanding of recent changes in Antarctic sea ice thickness and volume is needed to accurately represent sea ice in coupled climate models and improve future projections of ocean heat and carbon uptake.

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