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P01

Impact of atmospheric forcing on wintertime sea-ice lead patterns in the Southern Ocean

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Sea-ice leads are narrow, linear fractures in sea ice, and are an important basis for understanding the mechanism of the atmosphere-sea ice-ocean system in the Southern Ocean. We use monthly sea-ice lead frequencies based on satellite thermal imagery with 1 km2 grid resolution to investigate potential causes for the observed spatial and temporal variabilities of sea-ice leads during wintertime (April-September), 2003-2023, using ERA5 winds and sea level pressure, as well as climate indices El Niño–Southern Oscillation (ENSO) and Southern Annular Mode (SAM). The presented investigation provides evidence for correlations between mean monthly lead frequency and monthly wind divergence, as well as monthly sea level pressure across the majority of the circum-Antarctic regions (significantly in the Weddell Sea, Ross Sea and Amundsen & Bellingshausen Sea). Furthermore, our investigation evaluates the influence of wintertime ENSO and SAM on sea-ice lead patterns in the Southern Ocean. Results reveal a positive correlation between sea-ice leads and SAM, in the Weddell Sea and specific regions of the Ross Sea. Moreover, a positive correlation is found between sea-ice leads and ENSO, particularly in the Ross Sea, Western Pacific Ocean, and certain portions of the Indian Ocean. While the driving mechanisms for these observations are not yet understood in detail, the presented results can contribute to opening new hypotheses on atmospheric forcing and sea-ice interactions. The contribution of atmospheric forcing to regional lead dynamics is complex, and a more profound understanding requires detailed investigations in combination with considerations of ocean processes. This study provides a starting point for further research into the detailed relationships between sea-ice leads and atmosphere, ocean, combined effect of ENSO-SAM, respectively in the Southern Ocean.

P02

Abstract for Workshop on the Role of Sea Ice and its Variability in the Climate System

from July 29th – 31st 2024

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Two RAFOS-enabled APEX floats (AWI-9223 and AWI-9224) were deployed at 8°W in the Antarctic Slope Current, on the 2200m and 2600m isobaths, in the context of the Hybrid Antarctic Float Observing System (HAFOS) in the Weddell Sea. Though both floats drifted westward at 800m depth, the float deployed in shallower waters (AWI-9223) propagated towards the Stancomb-Wills Iceshelf where it stayed for approximately two months, while float AWI-9224 propagated directly to the edge of the Filchner trough. Hydrography and trajectory data show that float AWI-9223 was captured by an anticyclonic eddy prior to moving under the iceshelf. We postulate that the eddy was generated by baroclinic instability on the shoreward side of the Antarctic Slope Current due to variable bathymetry and floating ice shelves. The anticyclonic eddy, with a core of fresh and cold Eastern Shelf Water, propagated westward along the slope and ultimately became trapped under the Stancomb-Wills Iceshelf. While under the iceshelf the eddy spun down as a result of ocean-iceshelf stresses, in accordance with timescales suggested by the linear model [1]. We use hydrography from both floats to investigate the role of the eddy in modifying water properties under the iceshelf, as well as cross-slope exchange at the iceshelf edge. A simple box model is fitted to observations to explore the role of eddies under the iceshelf, in relation to an 'Eddy-Ice-Pumping' mechanism [2]. Evidence of subsurface freshening due to the Eastern Shelf Water core can be found downstream at the edge of the Filchner Trough three months later. Since water at the Filchner Trough feeds FRIS, any changes in water mass properties can affect basal melting [3], dense water production [4] and potentially connectivity between the Weddell Sea and the Western Antarctic Peninsula [5]

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P03

Machine learning as a tool to predict and understand Arctic sea-ice variability.

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This work focuses on using statistical models to predict and understand rapid sea-ice loss events in the Arctic. While sea-ice extent in the Arctic has shown a downward trend for all seasons since 1979, the summer trajectory exhibits rapid, non-linear fluctuations with large interannual variability [1]. Recent advances in machine learning (ML) have shown promise for making predictions of sea ice on daily to seasonal timescales [2, 3]. We employ a data-driven approach with the aim of creating statistical models that can make reliable predictions of the evolution of summer sea-ice extent and forecast the probability of extreme sea ice reductions on seasonal to interannual timescales. We begin by building a transfer operator that makes interannual predictions of sea-ice extent based on historical statistical year-to-year state transitions [4]. Preliminary results show that the model is skillful at reproducing internal variability but has difficulty capturing extreme sea-ice minima. We are working on training the model with additional inputs to improve its overall reliability and ability to predict these extreme events. Additionally, future work will employ other types of ML models that can capture information about non-linear and non-local interactions between the sea ice, atmosphere, and ocean. Explainable machine learning (XML) methods will be applied to these models to understand the physical mechanisms of sea-ice predictability and variability of sea ice extent in the Arctic [5].

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P04

Constraining Projections of Antarctic Sea Ice Area Decay

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The dramatic recent reductions in sea ice area (SIA) in the Antarctic [1] point to the urgency of understanding how sea ice will evolve under anthropogenic greenhouse gas emissions. Climate models project a substantial decline in SIA in forthcoming decades, but projections from different climate models differ widely from one another, so that it is not evident how one should combine these projections to make inference about what might happen in the real climate. Moreover, models have biases in their sea ice mean states and other aspects of sea ice representation, which might be expected to affect the fidelity of their predictions.

We have previously used an emergent constraint method to demonstrate a relationship between historical climatological mean sea ice cover and centennial scale change in sea ice [2], especially in summer. If we understand the cause, this can partially account for biases and reduce uncertainty in future projections. Part of the cause of this relationship was found in the 'no ice limit' that restricts the possible sea ice loss for a low-biased model, yet this only applies for time slice projections once this limit has been reached.

Therefore, we wish to extend this approach to allow examination of the time evolution of sea ice over the 21st century. To this end, this study proposes a simple three parameter emulator model for SIA decay that can represent both linear and exponential decay, and therefore accounts for the 'no sea ice' limit. The model provides good fits to 36 CMIP6 model simulations of February SIA for 1950-2100 when forced with the ssp585 projection scenario. The initial SIA and the rate of linear decay (two of the parameters from the model) are found to exhibit a strong positive correlation across the model fits, implying the relationship shown in [2] was not solely due to the no-ice limit. This emergent relationship can be usefully exploited to make a more certain inference about how SIA is likely to decline. Furthermore, the model can also be applied to other seasons and forcing scenarios, as well as to decay as a function of temperature rather than time, which sheds light on some of the mechnisms involved.

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P05

Generation of the Internal Pycnocline in the Subpolar Southern Ocean by Wintertime Sea Ice Melting

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The ocean's internal pycnocline is a layer of elevated stratification that separates the well-ventilated upper ocean from the more slowly renewed deep ocean. Despite its pivotal role in organizing ocean circulation, the processes governing the formation of the internal pycnocline remain little understood. Classical theories on pycnocline formation have been couched in terms of temperature and it is not clear how the theory applies in the high-latitude Southern Ocean, where stratification is dominated by salinity. Here we assess the mechanisms generating the internal pycnocline at southern high latitudes through the analysis of a high-resolution, realistic, global sea ice–ocean model. We show evidence suggesting that the internal pycnocline's formation is associated with sea ice-ocean interactions in two distinct ice-covered regions, fringing the Antarctic continental slope and the winter sea-ice edge. In both areas, winter-persistent sea-ice melt creates strong, salinity-based stratification at the base of the winter mixed layer. The resulting sheets of high stratification subsequently descend into the ocean interior at fronts of the Antarctic Circumpolar Current, and connect seamlessly to the internal pycnocline in areas further north in which pycnocline stratification is determined by temperature. Our findings thus suggest an important role of localized sea ice-ocean interactions in configuring the vertical structure of the Southern Ocean.

P06

Antarctic Sea Ice changes over the past decade

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The Antarctic Sea Ice is changing rapidly, representing one of the most extreme alterations in the Earth's system observed over recent decades (potentially the most extreme, considering a retreat of the size of Greenland). Unprecedented changes have been observed since 2016, including reductions in sea ice cover and the emergence of offshore polynyas not seen since the 1970s. Various hypotheses aim to explain these extreme changes. Some studies argue that these changes are driven by atmospheric processes, such as variability in winds and atmospheric rivers, while others suggest that oceanic drivers, such as upwelling, could potentially be the cause. These studies mostly rely on atmospheric reanalysis data or in situ oceanic measurements. However, the scarcity of measurements in this region adds an additional degree of uncertainty to these analyses. Here, we use satellite sea surface salinity (SSS) derived from SMOS (Soil Moisture and Ocean Salinity) observations to help elucidate what has occurred over the past decade. We combine this SSS dataset with sea ice observations from satellites, as well as with in situ observations and models, to demonstrate that both atmospheric and oceanic processes are involved in the observed changes, highlighting the complexity of the ice-ocean-atmosphere system in the Southern Ocean.

P07

Interhemispheric Teleconnections as Drivers of the Southern Hemisphere Response to Spontaneous Dansgaard-Oeschger-type Events

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Dansgaard-Oeschger (DO) events are the most iconic mode of millennial-scale variability of glacial climate. First observed in the Greenland ice core record [1], these events manifest as quasi-periodic abrupt warmings in the range of 5-16°C within decades [2], followed by gradual cooling over centuries. DO events are believed to originate from millennial-scale variability in the Atlantic Meridional Overturning Circulation (AMOC). The variations in the AMOC are thought to be linked also to the transmission of the DO signal to the Southern Hemisphere (SH) through the bipolar seesaw, explaining the lagged and muted temperature response observed in the Antarctic isotope record, known as the Antarctic Isotope Maxima (AIM). However, recent ice core-based reconstructions have found a synchronous response superimposed on the AIM signal, suggesting an additional contribution by atmospheric teleconnections to the propagation of DO events [3]. Here, we study the propagation of DO-type signals from the North Atlantic to the Southern Hemisphere in a set of simulations with the general circulation model HadCM3, including an isotope-enabled run [4]. The simulations show spontaneous DO-type oscillations under glacial boundary conditions, which allows studying the interaction of atmospheric and oceanic processes under a continuously varying background state. Consistent with the ice core record, we find a muted and anti-phased temperature response over Antarctica that lags the North Atlantic by ~300 years, in agreement with the bipolar seesaw. Additionally, we identify a robust SH mode in phase with the North Atlantic. This mode is associated with hydroclimate changes in the tropical Pacific, which modulate the SH atmospheric circulation, and, thereby, impact Antarctic temperatures. Notably, the dominant millennial-scale circulation pattern exhibits zonal asymmetries that do not resemble the leading modes of inter-annual variability. Preliminary analyses indicate a good agreement of the simulated millennial-scale variability in oxygen isotopes with speleothem and ice core records.

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