INTERNATIONAL SYMPOSIUM ON POLAR OCEAN AND GLOBAL CHANGE

PHYSICAL AND ECOLOGICAL PROCESSES IN THE SOUTHERN OCEAN UNDER A CHANGING CLIMATE

ABSTRACT

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Contents

Keynote Lectures

Abyssal ocean overturning slowdown and warming driven by Antarctic meltwater

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The abyssal ocean circulation is a key component of the global meridional overturning circulation, cycling heat, carbon, oxygen and nutrients throughout the world ocean. The strongest historical trend observed in the abyssal ocean is warming at high southern latitudes, yet it is unclear what processes have driven this warming, and whether it is linked to a slowdown in the ocean's overturning circulation. Furthermore, future change in the abyssal overturning remains uncertain, with the latest CMIP6 projections not accounting for dynamic ice-sheet melt. In this talk I will present new transient forced high-resolution coupled ocean – sea-ice model simulations to show that under a high emissions scenario, abyssal warming is set to accelerate over the next 30 years. We find that meltwater input around Antarctica drives a contraction of Antarctic Bottom Water (AABW), opening a pathway that allows warm Circumpolar Deep Water greater access to the continental shelf. The reduction in AABW formation results in warming and aging of the abyssal ocean, consistent with recent measurements. In contrast, projected wind and thermal forcing has little impact on the properties, age, and volume of AABW. These results highlight the critical importance of Antarctic meltwater in setting the abyssal ocean overturning, with implications for global ocean biogeochemistry and climate that could last for centuries.

Southern Ocean heat uptake and El Niño variability under greenhouse warming

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Planet Earth is unique in our solar system where three forms (states) of water (vapor, liquid, and solid) co-exist. In the present-day climate, the three states are in a quasi-equilibrium with regular seasonal cycles, despite perturbations from inter-annual (such as El Niño/La Niña) and interdecadal (such as the Atlantic Multidecadal Variability) variability. Greenhouse warming is projected to drastically disrupt the equilibrium because of the increase in radiative heating, for example, the associated ocean warming, whereby Southern Ocean heat uptake is a key process, is projected to accelerate melt of Antarctic ice sheet/shelf, leading to a global sea level rise; high temperatures will increase evaporation intensifying climate extremes particularly during strong El Niño/La Niña events, which are themselves projected to increase in amplitude and frequency. In this talk, I will provide modelling evidence showing that the projected increase in El Niño/La Niña could substantially affect the Southern Ocean warming structure, likely accelerating Antarctic ice sheet/ice shelf.

Perspectives on the Ross Sea Ecosystem studies and monitoring

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The Ross Sea is a focus on regional ecosystem shifts caused by climate change and human activities and in turn potential impacts of these shifts on climate. A number of studies in the Ross Sea supported by the Nature Science Foundation of China have been undertaken to examine variations of polynyas and warm Circumpolar Deep Water (CDW) intrusions onto the shelf vs. the Southern Annular Mode (SAM), the correlation of variations between the Shelf Slope Current (SSC) and westerly, sources of trace metals, and seasonal-long term variations of community structures. Significant advances have been made for understanding water mass formations, on- and off-shelf exchanges of water masses, ice shelf and sea ice dynamics, nutrient-trace metal cycling, and seasonal-long term changes of ecosystem structures. However, as climate modellers eagerly ask us to provide process rates of links between ecosystem components, there are significant knowledge gaps on uncertainties of some key links between components and causes of these uncertainties associated with nature change and human impacts. For examples, how are biomass flows between winter foodweb components set and in turn, how do these winter processes reset the initial conditions for spring, how do mesopelagic fish and benthic organisms mediate biomass flows and carbon sequestration, and what kinds of ecosystem gradients will be found across edges of ice shelves? Because these studies cannot be done by a single country, there is a great interest for scientists to form consortiums taking holistic approaches to address basic processes in different seasons and to monitor long-term changes over decades.

Asian cooperation in strengthening the Antarctic governance: towards 2026 ATCM in Japan

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My presentation will focus on the Antarctic Treaty and its Environmental Protocol, and how the Asian Consultative Parties (CPs), namely China, India, Japan, Republic of Korea, along with other Asian Treaty Parties can strengthen the Antarctic governance by reaffirming the fundamental concept of "Antarctica as a natural reserve, devoted to peace and science".

・As the three Asian CPs will be hosting the ATCMs in the next four years (India 2024, Japan 2026, Korea 2027), it is very timely to highlight the role of Asian countries in such an endeavour.

・My presentation touches upon, as a few specific examples, the following topics where Asian members can cooperate to contribute in strengthening the Antarctic governance:

(1) Effective law-making: entering into force of Annex VI on Environmental Liability;

(2) Consensus decision-making under the legal principle of cooperation; and

(3) Re-invigorating the science-based decision making in Antarctic environmental protection

Session: Southern Ocean Heat Uptake and Its Climatic Impacts

Mechanisms of poleward heat transport in the Antarctic Circumpolar Current

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The circumpolar currents of the Southern Ocean are barriers to poleward movement of heat, allowing waters around Antarctica to remain close to freezing. Southward-flowing warm and salty Circumpolar Deep Water must first cross the frontal barriers of the Antarctic Circumpolar Current (ACC) and Antarctic Slope Current before reaching Antarctica's continental shelf and ice shelves. These frontal barriers break down in regions where currents encounter steep bathymetric features. In these locations, meanders form and enhanced eddy activity drives heat and other properties through the frontal barriers at rates 100 times greater than elsewhere around Antarctica.

In response to strengthening and poleward shifting westerly winds, ocean eddy kinetic energy has increased by nearly 5% per decade in eddy-rich regions of the ACC, potentially enhancing the rate of poleward heat and salt transport. Glacial melt by Circumpolar Deep Water intruding on the underside of ice shelves has been shown to have accelerated. Antarctic melt has already contributed 12% of total sea-level change (2006-2015) and by 2300 the IPCC could not rule out 15m of sea level rise from high-impact, low-confidence ice shelf collapse. Ocean salt fluxes are a vital component of the global freshwater cycle and are crucial for the formation of Antarctic Bottom Water and the ocean's overturning circulation.

Despite the critical need to quantify the time-varying poleward movement of heat and salt, we lack the means to monitor eddy fluxes with the global satellite and in situ ocean observing array. Our work diagnoses physical mechanisms that enable poleward ocean heat and salt transport using finescale observations and high-resolution models. This talk highlights recent observations of eddy dynamics in the ACC and describes our efforts to fuse satellite observations of sea surface height variability with subsurface Argo measurements to enable near-real time, circumpolar estimates of poleward eddy fluxes in the Southern Ocean.

Evolution of the subantarctic mode water in the Southern Ocean

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Powerful westerlies drive the Antarctic Circumpolar Current (ACC), the northward Ekman flow, and the associate upwelling of the deep waters in the Southern Ocean. Upon reaching the north side of the Subantarctic Front (SAF), the waters transported by northward Ekman flow undergo intensive vertical mixing driven by cooling of the atmosphere in winter, forming the Subantarctic Mode Water (SAMW) with vertically homogenous properties. The SAMW is then transported eastward with the ACC and northward with the subtropical gyre, completing the ventilation of the Southern Hemisphere oceans. As a part of the upper limb of the Southern Ocean overturning circulation, the SAMW plays essential roles in the heat, freshwater, carbon, oxygen, and nutrient budgets both regionally and globally. Changes in its physical properties also provide good indications of global climate change. Under global warming, research has presented different conclusions regarding changes in its volume and properties, hindering our further understanding of its climate impacts.

By analyzing gridded Argo observations in the past decades and future warming simulation from the Coupled Model Intercomparison Project (CMIP), we found that the volume of the SAMW is generally decreasing. This volume decreasing is mainly determined by the change in surface buoyancy flux. The volume of the SAMW slowly increases after the radiative forcing stabilized in the future warming simulation. We also found there is an opposite change in volume between different density layers, representing changes in properties of the SAMW. The opposite volume change is mainly determined by the change in the depth and position of the winter deep mixed layer. Meanwhile, the observed average temperature and salinity of the SAMW in the South Indian Ocean are increasing. But the freshening in the formation area and the southward shift of the isopycnal surfaces weaken the trend of the average temperature and salinity increase of the SAMW. In future warming simulations, the cooling and freshening on the isopycnal surfaces cause the minimum warming and strong freshening in the depth of SAMW in the Southern Ocean, weakening the warming of this part of the ocean. These conclusions deepen our understanding of the evolution of the SAMW in the Southern Ocean and its underlying physical mechanisms, providing a new perspective on the climate response and impact of water masses in the Southern Ocean.

Buoyancy and wind driven effects on recent changes of the Subantarctic Mode Water

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The Subantarctic Mode Water (SAMW) is a thick low-stratified subsurface water mass located north of the Antarctic Circumpolar Current, and it is important for heat uptake. How the SAMW has changed and what drives that change remain to be quantified? By synthesizing observations, eddy-resolving ocean model hindcasts and climate model simulations, we show that the SAMW has become warmer, fresher, lighter, and weaker in recent decades. As revealed by partially coupled model experiments, the SAMW core has remained at a constant depth since 2004 due to a balance between the enhanced wind stress curl, which deepens the SAMW core, and the buoyancy gain, which shallows the core. The lightening and weakening of the SAMW mainly result from the increased surface buoyancy gain due to climate warming, while the enhanced westerlies play a secondary role in slowing this trend. As greenhouse warming continues, the increased stratification will keep weakening the SAMW.

Observing Antarctic Marginal Ice Zones with Satellite Altimetry Synergy – A Case Study of the Indian Ocean Sector during July, 2017

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Marginal Ice Zone (MIZ) is an integral part of the Antarctic sea ice and associated with intensive air-ice-ocean interactions. Wave-affected MIZs form due to the wind wave/swell propagation into the ice pack, the ice breaking, the intensified ocean mixing, as well as the potential positive feedbacks on the sea ice cover. However, great challenges exist for the satellite-based observation of MIZs, mainly due to the small temporal and spatial scales of the MIZs. In this talk we introduce recent advances in remote sensing of MIZs with radar altimeters. The retrieval of circumpolar Antarctic MIZs is carried out through the synergy of multiple satellite campaigns, with 2017-July as the sample period of study. We show that, the wave-affected MIZ can be effectively retrieved with radar altimeters, and the synergy of multiple campaigns greatly improves the temporal and spatial representation of the MIZ retrievals. Hot-spots of MIZs are revealed around the Antarctic, especially around Ross/Amundsen Sea and Weddell/Riiser-Larsen Sea. Related topics, including the swell attenuation in the MIZ, are also discussed.

Key role of Southern Ocean water masses in global heat uptake using Argo measurements

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The global ocean plays a major role in moderating atmospheric temperature rise, thereby buffering climate change. Amongst the various oceanic regions undergoing warming, the Southern Ocean is a primary heat sink in the climate system. Subantarctic Mode Water (SAMW) and Antarctic Intermediate Water (AAIW) are the dominant water masses in the upper Southern Ocean, and play a fundamental role in ocean ventilation and the uptake of heat and carbon into the ocean interior. This talk will first focus on understanding the geographic variability in the formation of SAMW and AAIW in the Southern Ocean based on a volume budget analysis, using observationally based hydrographic and eddy diffusivity datasets. Our results suggest that the distribution of SAMW and AAIW is set by their formation due to subduction and mesoscale and small-scale turbulent mixing, which shows strong regional variability with hotspots of large subduction and water-mass transformation. We further find that total warming (volume effects removed) of SAMW and AAIW in the Southern Ocean is estimated to account for ~36% of the global upper 2000-m ocean warming over the Argo era. To better understand how and where the anthropogenic heat is stored in the world ocean, we further analyzed the warming of a set of regional mode and intermediate waters over the subtropical oceans and in the Southern Ocean. Warming of these mode and intermediate waters explains nearly half net global ocean warming during the Argo era, despite occupying just 24% of the total ocean volume. These water masses in the subtropical Pacific and Atlantic Oceans, as well as in the Southern Ocean, are responsible for a large fraction of total heat uptake, with important implications for understanding ongoing ocean warming, sea-level rise, and climate impacts.

Origins and pathways of the Antarctic Intermediate Water

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Antarctic Intermediate Water (AAIW), occupying a vast area of the southern hemisphere oceans, is important for heat and freshwater redistribution in the global ocean. But questions remain regarding to its sources and pathways to the intermediate depths. This study applies a new metric, which can distinguish similar water parcels, to answer these questions. The results show that the massive AAIW originates from the limited regions only, including near the Subantarctic Front in the southeast Pacific and the Falkland Plateau in the southwest Atlantic. Circulating with the Antarctic Circumpolar Current and the subtropical gyres, waters from these limited regions slowly gain salt and density through diapycnal mixing with surrounding waters, eventually sinking and becoming AAIW with different physical properties in the three southern hemisphere oceans.

Reversal of surface temperature trend pattern over Antarctic continent in 21st century

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During the second half of the 20th century, the Antarctic Surface Air Temperature (SAT) trends are characterized by fast warming over West Antarctica but mild cooling over East Antarctica. However, after 2000, the warming over several stations in the Antarctic Peninsula slowed down, whereas the South Pole experienced fast warming. The Antarctic SAT trends show strong regionality and seasonality, together with large uncertainty and disagreement among different observational and reanalysis datasets, which makes it difficult to achieve a comprehensive understanding of the multi-decadal Antarctic SAT trend and its reversal. In this study, we try to extract the most coherent modes of the Antarctic SAT trends among six reanalysis datasets and 26 station-based observations using the Combined Maximum Covariance Analysis (CMCA) method. Results reveal a. reversal of the SAT trends before and after 2000, especially for austral spring and summer. For austral spring, the reversal of the west-warming-east-cooling pattern over Antarctica is closely related to the changes of thermal advection induced by the anomalous circulation center over the Antarctic Peninsula – Weddell Sea region. For summer, the post-2000 reversal of the Antarctic Peninsula-warming-East Antarctic-cooling is attributed to the stratospheric ozone recovery over the Antarctic, and the associated adjustment of the southern annular mode.

Roles of surface forcing in shaping the Southern Ocean rapid warming

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While the relatively short Argo record displays considerable interannual-to-decadal variations, the enhanced warming in the mid-latitude Southern Ocean (30°-55°S) seen over the past several decades has been largely attributed to increasing greenhouse gases and projected to continue in the future with ongoing climate change. It has been of great interest to understand drivers and mechanisms that are involved in the Southern Ocean rapid warming resulting from the anthropogenic climate change. In this study, specifically designed numerical perturbation experiments based on a global ocean-sea ice model were conducted to distinguish different contributions from surface heat flux, freshwater flux, and wind stress forcing to the Southern Ocean warming patterns at the doubling of CO2 under transient climate change. We first examine the simulated Southern Ocean temperature changes, including those seen at depth levels, on density surfaces (termed as the spiciness component), and due to the vertical displacements of density surfaces (termed as the heave component), in response to different surface flux forcing. We then proceed further to analyze multiple processes, including model resolved versus parameterized, overturning versus horizontal gyre, and their relative roles in driving the latitudinal distributions of the Southern Ocean warming and changes in meridional ocean heat transport.

Role of seasonal energy transfer mechanism in the Antarctic Warming and its inter-model spread in CMIP6

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Under the background of global warming, the Arctic region has warmed faster than the Antarctic, which is referred to as asymmetric Arctic and Antarctic warming. The new generation of model simulations from the CMIP6 offers an opportunity to identify the major factors contributing to the asymmetric warming and its inter-model spread. In this study, the pre-industrial and abrupt-4 × CO2 experiments from eighteen CMIP6 models are examined to extract the asymmetric warming and its inter-model spread. A climate feedback-response analysis method is applied to reveal the contributions of external and internal feedback processes to the asymmetric warming and its inter-model spread, by decomposing total warming into the partial temperature changes caused by individual factors. It is found that a seasonal energy transfer mechanism (SETM) dominates in both polar warmings. In summer sea ice melts and retreats and the oceans absorb and store more heat from the solar radiation, while in cold months heat is released by sensible and latent heat fluxes resulting in stronger warming than in summer. However, the background oceanic circulation in the Southern Ocean, namely the Antarctic Circumpolar Current, continually transports energy equatorward, resulting in a suppressed SETM and surface warming in the Antarctic. The key factor that accounts for inter-model spread in the asymmetric warming is that models vary in the strength of SETM. The poleward atmospheric transport and water vapor feedback also contribute to the inter-model spread slightly.

The relative role of the subsurface Southern Ocean in driving negative Antarctic sea ice extent anomalies in 2016-2021

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The low Antarctic sea ice extent (SIE) following its dramatic decline in late 2016 has persisted over a multiyear period. However, it remains unclear to what extent this low SIE can be attributed to changing ocean conditions. Here, we investigate the causes of this period of low Antarctic SIE using a coupled climate model partially constrained by observations. We find that the subsurface Southern Ocean (SO) played a smaller role than the atmosphere in the extreme SIE low in 2016, but was critical for the persistence of negative anomalies over 2016-2021. Prior to 2016, the subsurface SO warmed in response to enhanced westerly winds. Decadal hindcasts show that subsurface warming has persisted and gradually destabilized the ocean from below, reducing SIE over several years. The simultaneous variations in the atmosphere and ocean after 2016 have further amplified the decline in Antarctic SIE.

Climate change in the Southern Ocean: the rising temperature and enhanced zonal velocity

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The Southern Ocean (>30°S) has taken up a large amount of anthropogenic heat north of the Subantarctic Front (SAF) of the Antarctic Circumpolar Current (ACC). Poor sampling prior to the 1990s and decadal variability have heretofore masked the ocean's dynamic response to this warming. Here we use the lengthening satellite altimetry and Argo float records to show robust acceleration of zonally-averaged Southern Ocean zonal flow at 48°S-58°S. This acceleration is reproduced in a hierarchy of climate models, including an ocean-eddy-resolving model. Anthropogenic ocean warming is the dominant driver, as large (small) heat gain in the downwelling (upwelling) regime north (south) of the SAF causes zonal acceleration on the northern flank of the ACC and adjacent subtropics due to increased baroclinicity; strengthened wind stress is of secondary importance. In Drake Passage, little warming occurs and the SAF velocity remains largely unchanged. Continued ocean warming could further accelerate Southern Ocean zonal flow.

Session: Sustainability Use of Antarctic Marine Living Resources and Antarctic Governance

Legal Implementation of Madrid Protocol in China

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The Madrid Protocol and its six Annexes provide for the conservation of resources in the entire Antarctic region. The Madrid Protocol, which is the most comprehensive Antarctic environmental protection treaty in the ATS, reflects a shift in the core Antarctic governance concept from resource utilization to environmental protection. All the measures taken and instruments used at the domestic level are beneficial to the achievement of the objectives of Madrid Protocol. In order to achieve the environmental protection objectives of the Protocol, China has incorporated the main provisions of the Protocol into domestic laws in recent years. China has adopted the approach of transformation rather than incorporation to implement the Madrid Protocol. As a responsible and accountable ATCP, China realized provisions with obligations for governments of Contracting Parties or individuals need to be incorporated into the domestic law. For the purpose of incorporate enforcement obligation, domestic Regulations implementing the Protocol need to be upgraded from the Divisional Regulations to a comprehensive and coherent piece of law made by the Standing Committee of NPC.

Challenges for the Antarctic Treaty System in its Seventh Decade

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The Antarctic Treaty System (ATS) is widely regarded as one of the key successes of international law in that it has provided effective international order of the Antarctic region based on key values of peaceful use, scientific cooperation, environmental protection, and conservation. However, as the ATS moves into its seventh decade, it is facing significant biophysical and political challenges sourced from events and activities occurring well outside the Antarctic region. Firstly, on the biophysical front, global environmental problems such as climate change and ocean acidification, are negatively impacting the biophysical environment of the Antarctic region. Secondly, geopolitical tensions in the wider international system, such as the armed conflict in Ukraine, are spilling over into forums of the Antarctic Treaty System and have the potential to further constrain consensus decision making on key issues. Some voices within academia and civil society have therefore questioned whether the ATS is now 'fit for purpose' and even argued for alternative approaches to ordering the region, such as the proposed 'Declaration for the Rights of Antarctica', based on recognition of intrinsic value and rights for the region. In response, this paper argues that over the past six decades the ATS has shown the significant ability to respond to difficult issues, and if realistic ambition for the system and goodwill of the parties are maintained, it is still well placed to manage the above challenges.

Antarctic blue carbon protection under the framework of Antarctic Treaty System

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In recent years, with the continuous development and extension of the meaning and scope of blue carbon captured by marine organisms, the importance of blue carbon protection has attracted widespread attention from the international community. The ocean is the largest carbon pool on Earth. The Southern Ocean absorbs 40% of the global marine carbon dioxide, and is forming the world's largest blue carbon sink. It is a key region in the global effort to achieve carbon neutrality and address climate change. Through in-depth analysis of the mechanism of Antarctic blue carbon cycle, three new pathways for the formation of Antarctic blue carbon are found, including sea ice melting, ice shelf calving and glacier retreat, which would further stimulate the potential of Antarctic blue carbon to cope with global climate change. Based on the international law framework of Antarctic Treaty System, it is proposed to realize the protection of Antarctic blue carbon through the establishment of Non-Market Approach framework, Antarctic Specially Protected Area, and Antarctic Marine Protected Area. However, there are many governance dilemmas to be faced from international law, scientific evidence, economic rights and geopolitics. Therefore, it is suggested that China should strengthen the research on key scientific issues, participate in the formulation of rules, establish Antarctic protected areas, promote international cooperation, and eventually build an all-dimensional, multi-layered and multi-dimensional protection system for Antarctic blue carbon based on the framework of international law.

Governance of Antarctic marine ecosystem conservation, a hot potato or a cool lodestar?

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Designating a large portion of marine area as a protected zone is a conservation tool as well as an initiative gathering global attention. Southern Ocean is no exception, rather there has been a significant history of such practice and successful cases supported by international instruments such as the Convention on Conservation of Antarctic Marine Living Resources (CCAMLR). Fundamentally different views and stances exist, for example, many Parties vehemently advocate sufficient size and coverage of the protected areas and the timeliness and speed of the related processes while others accord great importance to the completeness and thoroughness of the proposals. This resulted in a slow progress and a number of applications waiting for endorsements. Both strong precautionary measures and cautiousness against an easy thumb-up are valid tenets from the prospective of respective proponents. It is also a reality that each stance has a range of practical reasons and considerations behind. Recently, a historic agreement aiming to place 30% of the seas into protected areas by 2030 has been reached. As for elsewhere, management of large marine ecosystems in the Antarctic is a joint product of highly developed yet customized science and policy decisions. Governance of Antarctic marine ecosystem conservation is facing a new opportunity to become a touchstone and reference for the globe, however sticky the deal between science and national propositions will be. Pursuit of solid and pertinent scientific evidence and reasoning should assume the highest priority in any case.

Integrating Mesopelagic Fish into the assessment of marine protected areas under climate change scenarios

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Climate change is having an increasingly significant impact on ocean ecosystems worldwide, prompting the proposal of Marine Protected Areas (MPAs) to safeguard crucial regions of the Southern Ocean (SO). Recognized as both key predators and prey in this ecosystem, mesopelagic fishes play an important role in the SO. However, their integral ecological role and capacity for adaptation to climate change are infrequently taken into account when designing MPAs. To address this gap, our study utilized an ensemble model approach (MAXENT, random forest, and boosted regression tree models) to predict the habitat of nine common mesopelagic fishes. We projected the distribution of these mesopelagic fishes under two Representative Concentration Pathways (RCP4.5 and RCP8.5) for future periods between 2006-2055 and 2050-2099. All the mesopelagic fishes were consistently projected to experience a poleward shift in habitats. Lanternfishes from the Myctophidae family were predicted to migrate poleward to a greater extent than high-Antarctic species (Paralepididae, Nototheniidae, Bathylagidae, and Gonostomatidae). Our projections suggest that with climate change, lanternfish would increase their area in the eastern SO while losing area in the western SO, while high-Antarctic species would experience the opposite. To ensure proper ecological representation in established and proposed MPAs, we defined Important Areas (IAs) of mesopelagic fishes using a top 5% threshold. These IAs were primarily distributed in the Antarctic Peninsula and East Antarctica, with proposed MPAs covering only 23% of these IAs. Looking ahead to the future (RCP8.5, 2050-2099), 38% of IAs are predicted to be covered by proposed MPAs, particularly as a result of the shift of IAs to the Weddell Sea. Our findings lay out a framework for the development of new MPAs that incorporate climate change adaptation strategies for MPA management.

The Area 48 Krill Fishery: The difficult pace of upgrading the management system

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The rapid growth of krill resource development has led to the attention of Antarctic Treaty Consultative Parties to the issue of biological resources in the Southern Ocean. This has triggered the negotiation of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). The negotiation ended in 1980, and in 1982, CCAMLR was established in accordance with the requirements of the Convention.

The management of the krill fishery cannot be separated from the population assessment of krill and upstream and downstream populations. The impact of climate change should also be fully discussed. However, the relevant scientific foundation for Antarctic krill is still insufficient. CCAMLR has temporarily adopted a passive, preventive management approach as a transition. Feedback management aims to improve the spatial pattern of krill fisheries and the unreasonable distribution of fishing effort. This will actively respond to changes in ecosystem structure and function.

The discussions at the 2022 meeting revealed that at least the following challenges must be faced to increase the fishing quota of the krill fishery in the Area 48 cautiously: first, the scientific basis for increasing the quota; second, the simultaneous improvement of management measures; third, the response to other risks; fourth, the magnitude of the increase in fishing quotas.

The prerequisite for enhancing the krill catch in the Area 48 is a more refined management, it includes more robust scientific support and stricter management measures. It's like a bridge that can only allow the trunk less than 10 tons to pass, may be designed to carry 20 tons, but if a 20-ton trunk does pass this bridge, it may be necessary to further test and strengthen the bridge, and also to ensure that the trunk is really only 20 tons.

Session: Antarctic Shelf-basin Exchanges and Ice-ocean Interactions

Vulnerability of East Antarctic Ice Shelves to ocean processes and change

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The East Antarctic Ice Sheet (EAIS) was long thought to be stable because it was believed to rest on bedrock mostly above sea level and to be isolated from warm ocean waters. Recent observations have challenged both assumptions. Satellite-based estimates show the EAIS has contributed about 30% of the total Antarctic contribution to sea level rise since 1979. Most of the EAIS contribution to date has come from the Totten and Denman Glaciers, the primary drainages of the Aurora Subglacial Basin, which holds a marine-based ice volume equivalent to 5 m of global sea level rise. Oceanographic measurements show that warm water spreads along the sea floor to reach the cavities beneath the Totten and Denman ice shelves. The ocean heat flux entering the cavities is sufficient to drive rapid rates of basal melt, as also observed in satellite data. These results highlight that the EAIS, like the WAIS, is vulnerable to thinning or weakening of ice shelves by ocean-driven melt.

The factors that control how much ocean heat reaches East Antarctic ice shelves are not yet understood. Increased melt has been linked to a poleward shift of warm waters. In addition, recent work shows that heat transport to ice shelf cavities depends on the competition between salinification by sea ice formation, which acts to destabilise the water column and vent ocean heat, and glacial melt, which acts to stabilise the water column and protect warm water at depth from heat loss to the atmosphere. A key research question is whether increased glacial melt can shift East Antarctic ice shelves from their present state, characterised by moderate thermal forcing, to "warm cavity" conditions typical of the more rapidly melting ice shelves of West Antarctica.

Sensitivity of the relationship between Antarctic ice shelves and iron supply to projected changes in the atmospheric forcing

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Previous studies showed that correlations of satellite-derived estimates of chlorophyll a in coastal polynyas over the Antarctic continental shelf with the basal melt rate of adjacent ice shelves are a result of upward advection or mixing of iron-rich deep waters due to circulation changes driven by ice shelf melt, rather than a direct influence of iron released from melting ice shelves. In this study, the effects of projected changes in winds, precipitation, and atmospheric temperatures on this relationship were examined with a 5-km resolution ocean/sea ice/ice shelf model of the Southern Ocean with different simulated dissolved iron sources and idealized biological uptake. The atmospheric changes are added as idealized increments to the forcing. Inclusion of a poleward shift and strengthening of the winds, increased precipitation, and warmer atmospheric temperatures resulted in doubling of the heat advected onto the continental shelf and an 83% increase in the total Antarctic ice shelf basal melt. The total dissolved iron supply to the surface waters over the continental shelf increased by 62%, while the surface iron supply due just to basal melt driven overturning increased by 48%. However, even though the ice shelf driven contribution becomes less important to the total iron supply on average (29% of total), the ice shelf involvement becomes relatively even more important in some locations, such as the Amundsen and Bellingshausen Seas. The modified atmospheric conditions also produced a reduction in summer sea ice extent and a shoaling of the summer mixed layers. These simulated responses to projected changes suggest relief of light and nutrient limitation for phytoplankton blooms over the Antarctic continental shelf and perhaps an increase in annual production in years to come.

Ice-Shelf Meltwater Overturning in the Bellingshausen Sea

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Hydrographic data are analyzed for the broad continental shelf of the Bellingshausen Sea, which is host to a number of rapidly thinning ice shelves. The flow of warm Circumpolar Deep Water (CDW) onto the continental shelf is observed in the two major glacially carved troughs, the Belgica and Latady troughs. Using ship-based measurements of potential temperature, salinity, and dissolved oxygen, collected across several coast-to-coast transects over the Bellingshausen shelf in 2007, the velocity and circulation patterns are inferred based on geostrophic balance and further constrained by the tracer and mass budgets. Meltwater was observed at the surface and at intermediate depth toward the western side of the continental shelf, collocated with inferred outflows. The maximum conversion rate from the dense CDW to lighter water masses by mixing with glacial meltwater is estimated to be 0.37 ± 0.1 Sv in both depth and potential density spaces. This diapycnal overturning is comparable to previous estimates made in the neighboring Amundsen Sea, highlighting the overlooked importance of water mass modification and meltwater production associated with glacial melting in the Bellingshausen Sea.

Recent reduced abyssal overturning and ventilation in the Australian Antarctic Basin

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Dense water formed near Antarctica, known as Antarctic Bottom Water (AABW), drives ocean circulation and supplies oxygen to the deep ocean. Observations show that AABW has freshened and contracted since the 1960s, yet the drivers of these changes and their impact remain uncertain. Here, using observations from the Australian Antarctic Basin, we show that AABW transport reduced by 4.0 Sv between 1994 and 2009, during a period of strong freshening on the continental shelf. An increase in shelf water salinity between 2009 and 2018, previously linked to transient climate variability, drove a partial recovery (2.2 Sv) of AABW transport. Over the full period (1994 to 2017), the net slowdown of -0.8 ± 0.5 Sv decade−1 thinned well-oxygenated layers, driving deoxygenation of -3 ± 2 μmol kg−1 decade−1. These findings demonstrate that freshening of Antarctic shelf waters weakens the lower limb of the abyssal overturning circulation and reduces deep ocean oxygen content.

Ice-ocean interactions sea-ice formation and break-out near ice shelves

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Antarctic ice-mass loss from ice sheets and ice shelves is increasing and projected to increase further. Fresh water entering the Southern Ocean due to this ice-mass loss increases ocean stratification, thereby inhibiting vertical transport of warmer, deeper water to the surface. This results in surface cooling and increased sea ice growth. Though this increased Antarctic ice-mass loss is expected to impact climate, it is absent from almost all models in the current Coupled Model Intercomparison Project (CMIP6), which typically enforce that the continent remain in mass balance. Further, previous non-CMIP6 model experiments that include changing Antarctic ice-mass loss suggest that the climate response depends on the model used; the reasons for this model dependence are not clear. In our modelling efforts, we use the HadGEM3-GC3.1 model to contribute to the Southern Ocean Freshwater release model experiments Initiative (SOFIA), an international model intercomparison, in which freshwater is added to the ocean surrounding Antarctica to simulate the otherwise missing ice-mass loss. We will give an overview of the SOFIA project and present preliminary results from the "antwater" experiment 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 forcing. Our observational and process-modelling research focusses on influences of fresher water from ice shelf basal melt on land-fast sea ice. Ice Shelf Water (ISW) in some Antarctic locations reaches the surface; in addition to the stratification effect discussed above, this leads to platelet ice formation. We will present an overview of our observation research that shows that platelet ice enhances sea-ice growth rates, thickness, and extent. We will also present preliminary work on how the presence of platelet ice can affect sea ice breakout.

Impacts of Grounding Icebergs on Sea Ice, Polynyas and Circulation in Prydz Bay, Antarctica

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Based on satellite remote sensing and numerical modeling, we investigated the impacts of grounding icebergs on sea ice, polynyas and circulation in Prydz Bay, Antarctica. Four recurrent polynyas were identified in eastern Prydz Bay from remote sensing positive microwave data during 2002 – 2011. The components of their ice barriers were identified through comparison of satellite remote sensing visible images and synthetic aperture radar images. All types of fast ice, including landfast ice, offshore fast ice and ice fingers serving as ice barriers for these polynyas are anchored by an assemblage of small icebergs and have an approximately year-round period of variations that also regulates the variability of polynyas. The movement and grounding of giant icebergs near the polynyas significantly affects the drifting of sea ice and development of the polynyas. The effects of grounding icebergs D15 and B15 on the circulation in Prydz Bay were investigated with a three-dimensional numerical model of the summer circulation in the Prydz Bay region. The results indicate that these giant grounding icebergs substantially affect the flows into and within the bay, which may differ with the different grounding locations. As grounding iceberg D15 is located close to the southwestern part of the West Ice Shelf (WIS), it cuts off the coastal current along the outer edge of the WIS, and the Antarctic Slope Current (ASC) can only enter Prydz Bay from the west side of iceberg D15. The relatively small iceberg B15 entered Prydz Bay from 2007 to 2009 and grounded on the southwestern section of the Four Ladies Bank. The numerical experiments indicate that iceberg B15 guides the ASC flowing into the bay around its west side and reduces the width of the inflow on the eastern side of the Prydz Bay Channel. The results of this study illustrate the important impact of grounding icebergs on fast ice, wind-driven polynyas and circulation in Prydz Bay.

The influence of snow cover on landfast sea ice thickness in Prydz Bay, East Antarctica

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The observed snow depth and ice thickness on landfast sea ice in Prydz Bay, East Antarctica, were used to determine the role of snow in (a) the annual cycle of sea ice thickness at a fixed location (SIP) where snow usually blows away after snowfall and (b) early summer sea ice thickness within the transportation route surveys (TRS) domain farther from coast, where annual snow accumulation is substantial. The annual mean snow depth and maximum ice thickness had a negative relationship ($r=-0.58$, $p < .05$) at SIP, indicating a primary insulation effect of snow on ice thickness. However, in the TRS domain, this effect was negligible because snow contributes to ice thickness. A one-dimensional thermodynamic sea ice model, forced by local weather observations, reproduced the annual cycle of ice thickness at SIP well. During the freeze season, the modeled maximum difference of ice thickness using different snowfall scenarios ranged from 0.53–0.61 m. Snow cover delayed ice surface and ice bottom melting by 45 and 24 days, respectively. The modeled snow ice and superimposed ice accounted for 4–23% and 5–8% of the total maximum ice thickness on an annual basis in the case of initial ice thickness ranging from 0.05 to 2 m, respectively.

Deep and shallow warm water intrusion on the continental shelf off East Antarctic coasts

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The Antarctic and surrounding Southern Ocean are changing. Acceleration of ice mass loss and warming of the coastal region in West Antarctica have substantial impacts on the global climate system. In East Antarctica, which has been considered to be stable, interactions among climate subsystems and temporal variations on the various time scales from subseasonal to millennium have been revealed. Off Sabrina Coast, access of warm water has been discovered underneath the Totten Glacier Ice Shelf. In the Lützow-holm Bay off Enderby Land, presence of warm water was reported. Both of the two regions correspond to the eastern boundary of the subpolar "gyres". Sea ice formation in Cape Darnley Polynya result in production of Dense Shelf Water and lead to the export of bottom water. Despite the global impact of these coastal variabilities, investigations of the mechanisms and variabilities in East Antarctica are insufficient. During 2016-2022, we made intensive, interdisciplinary observations for the three typical regions.

In the Lützow-holm Bay the warm water supply and ice-ocean interaction has been clarified. In front of Shirase Glacier, our hydrography has detected the warmest modified-Circumpolar Deep Water (mCDW) inflow and subsequent meltwater outflow. Off Sabrina Coast, bathymetric survey with multi-narrow beam were effective and described detailed features of glacier-carved valleys and deep basin. Hydrographic measurements revealed the ubiquitous presence of mCDW, with its temporal change from days to years scales. For the region off Cape Darnley Polynya, in-situ observations revealed that the minimum of sea ice cover in 2017 has provided the excessive heat in Antarctic Surface Water to melt the Amery Ice Shelf from below. The meltwater anomalously freshened the Cape Darnley Polynya and delayed the onset of dense water formation. Significant sea ice loss in the future might result in relative increase of basal melting by the shallow warm water intrusion.

Poleward shift of Circumpolar Deep Water threatens East Antarctic Ice Sheet

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Future sea-level rise projections carry large uncertainties, mainly driven by the unknown response of the Antarctic Ice Sheet to climate change. During the past four decades, the contribution of the East Antarctic Ice Sheet to sea-level rise has increased. However, unlike for West Antarctica, the causes of East Antarctic ice-mass loss are largely unexplored. Here, using oceanographic observations off East Antarctica (80–160° E) we show that mid-depth Circumpolar Deep Water has warmed by 0.8–2.0 °C along the continental slope between 1930–1990 and 2010–2018. Our results indicate that this warming may be implicated in East Antarctic ice-mass loss and coastal water-mass reorganization. Further, it is associated with an inter- decadal, summer-focused poleward shift of the westerlies over the Southern Ocean. Since this shift is predicted to persist into the twenty-first century, the oceanic heat supply to East Antarctica may continue to intensify, threatening the ice sheet's future stability.

Topography-mediated transport of Warm Deep Water across the continental shelf slope, East Antarctica

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Warm Deep Water intrusion over the Antarctic continental shelves threatens the Antarctic ice-sheet stability by enhancing the basal melting of ice shelves. In East Antarctica, the Antarctic Slope Current (ASC), along with the Antarctic Slope Front (ASF), acts as a potential vorticity barrier to prevent the warm modified Circumpolar Deep Water (mCDW) from ventilating the cold and fresh shelf. However, mCDW onshore transport is still observed within certain shelf regions, such as submarine troughs running perpendicular to the continental shelf. This study focuses on the dynamic mechanisms governing mCDW intrusion within a submarine trough over the fresh shelf regions, East Antarctica. Based on an idealized eddy-resolving coupled ocean-ice shelf model, two high resolution process-oriented numerical experiments are conducted to reveal the mechanisms responsible for the mCDW onshore transport. Three dynamic mechanisms governing cross-slope mCDW intrusion are identified: 1) the bottom pressure torque, 2) the topography beta spiral, and 3) the topography Rossby waves. These three mechanisms simultaneously govern the mCDW intrusion together. The bottom pressure torque plays a leading role in driving the time-mean onshore flow whose vertical structure is determined by the topography beta spiral, while the topography Rossby waves contribute to the high-frequency oscillations in the onshore volume and heat transport. The simulated spatial distribution and seasonality of mCDW intrusion qualitatively coincide with the observed mCDW intrusion over fresh shelf regions, East Antarctica. Both the topography beta spiral and the ASC play an important role in governing the seasonality of mCDW intrusion.

Intrusion of warm modified circumpolar deep water and its impact on dense shelf water formation

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Warm modified Circumpolar Deep Water (mCDW) from the Southern Ocean is able to intrude onto the continental shelf in many regions around Antarctica. These intrusions transport great amounts of heat to the continental shelves, affecting basal melting of ice shelves and sea ice formation in coastal polynyas. In Prydz Bay, the largest embayment in East Antarctica, the strongest intrusion of mCDW over the inner continental shelf in March-July is significantly associated with the variability of westerly winds north of the shelf break in January-May. This is the period when the westerly winds over the Southern Ocean move southward, driving the mCDW to become shallower near the shelf break and allowing more warm water to access the inner shelf. Deep convection in winter can entrains sensible heat of this intruded mCDW at mid-dephts into the surface layer, reducing 45% of the potential sea ice production in the coastal polynya. Our findings provide insight into how seasonal variability of atmospheric forcing in the open ocean will affect warm water inflow and heat transport onto continental shelves, and indicate potential impacts on the Antarctic Bottom Water formation.

The salinity budget of the Ross Sea continental shelf, Antarctica

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Towards understanding the trend and variability in the bottom water salinity in the Ross Sea, this study focuses on the seasonality of the salinity budget over the Ross Sea continental shelf, using a new coupled regional ocean-sea ice-ice shelf model. Owing to the sea ice production, the upstream advection, and the glacial melting, the Ross Sea continental shelf is characterized by the relatively saltier water on the western shelf than on the eastern shelf, with the saltiest water in the Terra Nova Bay Polynya. During the early freezing season (March-April), there is remarkable sea ice production over the broad continental shelf, which makes a significant contribution to the production of High Salinity Shelf Water (HSSW). The brine rejection in the polynyas leads to the salinification and deepening of the mixed layer, yet the upstream advection acts to decrease the salinity below the mixed layer until the deep convection is fully developed throughout the water column. The seasonal cycle of the salinity budget in the Ross Sea continental shelf is largely determined by the formation/melting of sea ice, the intrusion of modified Circumpolar Deep Water, and the outflow of HSSW, while the contribution of the Ross Ice Shelf melting is relatively small.

Effects of projected wind changes caused by the Amundsen Sea low on the high salinity shelf water formation in the Ross Sea

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The Ross Sea is an important formation site of the Antarctic Bottom Water (AABW), which supplies the lower limb of the meridional overturning circulation. Climate variability in the Ross Sea is significantly modulated by the Amundsen Sea Low (ASL). In this study, the CMIP6 multi-model ensemble simulation is used to project the future changes in the ASL strength and location by 2050 and 2100, and obtain the future changes of wind fields associated with the ASL variation over the Ross Sea and the Amundsen Sea on interdecadal time scales. Using a high-resolution sea ice-ocean-ice shelf model, we quantified the influence of the projected ASL-induced wind changes in different regions of the Ross Sea and Amundsen Sea on the formation of High Salinity Shelf Water (HSSW) — the precursor of AABW. Results show that the projected deepening of ASL will lead to increased meridional wind over the Ross Sea, which will enhance sea ice production on the continental shelf and the HSSW formation. Over the western Amundsen Sea, the future southward shift of the ASL will weaken the easterlies, which will reduce the transport of ice shelf meltwater from the Amundsen Sea to the Ross Sea, resulting in increased HSSW formation. In the eastern Amundsen Sea, the southward shift of the ASL will strengthen the westerly wind over the slope dramatically, and enhance the intrusion of the Circumpolar Deep Water (CDW) by affecting the undercurrents, increasing the basal melting rates of the Amundsen Sea ice shelves. Meanwhile, the enhanced westerly also reduces the barotropic meltwater transport westward and finally results in an increase in the HSSW formation in the Ross Sea. The processes above overall contribute to an increase of ~12% in the HSSW volume in the Ross Sea by 2100.

Interannual Variability of Winter Water in the Indian Ocean Sector of the Southern Ocean and Its Causes

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Multiple studies have confirmed the long-term property change of water columns from the bottom to the sea surface at the Southern Ocean and pointed out that it is closely related to the changes of large-scale external forcing. Nevertheless, the higher frequency interannual variability of the water masses and its causes are still poorly understood, including the Winter Water (WW), the most vulnerable water to external forcing near the sea surface. Based on repeated hydrographic observations along 110 ° E in Januaries 2011 to 2020 and meteorological reanalysis datasets, this study estimated interannual variability of WW in the Seasonal Ice Zone (SIZ) and its possible causes over ten years. Results show that WW properties have significant temporal and spatial variability in this region. There is a significant positive correlation between the temperature anomaly at WW core and the last year Antarctic Oscillation (AAO) index anomaly (R = 0.69), and a negative correlation between the AAO index and the turning latitude of the local zonal wind component (R = − 0.61), indicating that a larger (smaller) AAO index corresponds to a southward (northward) shift of the divergence zone, and an increase (decrease) of the WW core temperature in the SIZ. A negative correspondence between the local net precipitation anomaly and the WW core salinity anomaly indicates the negative net precipitation anomaly (less freshwater input to the ocean) after 2016 contributes to an increase in the WW core salinity anomaly. Meanwhile, the local eddy kinetic energy anomaly is negatively correlated with the WW thickness anomaly (R = − 0.70), which supports the idea that the enhancement (decrease) in the intensity of persistent cyclonic eddies in this region may strengthen (weaken) the upward pumping to shoal the depth of the circumpolar deep water, and further affect the WW thickness.

The New Golden Era of Polar Research and Exploration with Autonomous Systems

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As climate change becomes humanity's greatest existential crisis, the race is on to convince the world to take urgent action. A key factor in motivating this action is a clear understanding of how the global climate system works and specifically our ability to monitor its current state and model its future. Polar regions are at the same time critical components of this system and some of the most poorly observed, due to the extreme polar conditions and challenging logistics. This has resulted in persistent data and knowledge gaps - gaps that have existed for decades and continue to negatively impact climate action through the uncertainty they inadvertently feed. Robots, or autonomous systems, present more than just an exciting and innovative 'tool' for Antarctic science – they are quite possibly the only chance we have to fill these critical gaps and improve the accuracy of vital metrics such as the impact of polar melting on global sea-level rise. But simply adding robots to polar research expeditions doesn't make all your problems go away – if anything, your challenges will increase. Nonetheless, a new golden era of polar exploration awaits those groups with the courage and expertise to utilise autonomous systems in this high risk/high reward research field. In this talk I'll discuss the great progress made this century with polar autonomous systems, some of the lessons learnt and how we need to work together as scientists and engineers, within and across national borders, to observe, monitor and protect our precious polar regions.

Session: Marine Biodiversity and Biogeochemical Cycles in the Southern Ocean

Dissolved Organic Carbon Cycling in the Antarctic Seas Based on Radiocarbon Analysis

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Radiocarbon results of dissolved organic carbon (DOC) in the ocean have been mainly obtained from the open oceans. Main findings include that oceanic DOC is 4000-6000 years in C-14 age and that DOC in the water column is a mixture of modern/labile and old/refractory components. Radiocarbon results around Antarctica have revealed some interesting features that are different from the oceanic ones. Results from the Amundsen Sea revealed consumption of the refractory component of DOC in the productive shelf environment. Other results from the Little America Basin of the Ross Sea show the lowest radiocarbon content in the surface water suggesting the source of very old radiocarbon in the surface.

Strong transport of anthropogenic carbon from the Antarctic shelf to deep Southern Ocean triggers rapid acidification

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Flows of dense shelf water are an efficient way for pumping CO2 to deep ocean along the continental shelf-slope, particularly around the Antarctic Bottom Water (AABW) formation area where much of the global bottom water is formed. However, the contribution of the formation of AABW to sequestering anthropogenic carbon (Cant) and its consequence are unknown. Here, using an integrated observational dataset, we find that the CO2 sink at Antarctic coastal regions reaches 44 Tg C yr-1, accounting for 22% of the global coastal CO2 uptake, which is twice higher than previous estimates. Moreover, we show that the strong CO2 uptake is attributed to the AABW-formation-driven mechanism, which transports Cant towards the deep sea (>2000 m) in the Pan-Antarctica. As a consequence, such transport would accumulate Cant in deep-water and trigger rapid acidification, i.e., pH declines at 0.0007±0.0002 yr-1, far faster than that of any other open ocean deep waters (<0.0002 yr-1). Our findings elucidate the prominent role for AABW in controlling the Southern Ocean carbon uptake and storage to mitigate climate change, whereas its side effects also warrant more attentions.

Isotopic constraints on sources and cycling of Nitrate in Polar Sea Ice

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Sea ice exerts major control in the structuring of polar marine ecosystems. Nitrogen (N) in the sea ice is an essential nutrient to the marine production and biogeochemical cycle. Nitrate (NO3-) is a relatively stable physical and chemical form of N, preserving biogeochemical fingerprints of sea ice N. But NO3- cycling processes and sources of polar sea ice are largely unknown, and simultaneous observations of sea ice NO3- cycle would be significant for a better understanding marine N budget in Polar regions. Thus, this study investigates the sources and cycling process of NO3- in polar sea ice with nitrogen and oxygen isotopes of NO3-. The one-year and the multi-year sea ice cores were collected in November 2019 in Prydz Bay, East Antarctica, and August 2018 in the Arctic, respectively. Sea ice, seawater, snow, and atmospheric samples were analyzed for NO3- isotopes of (δ15N, δ18O, and Δ17O) using the bacterial denitrifier method at Environmental Stable Isotopes Laboratory (ESIL), East China Normal University (ECNU). The δ15N-NO3- and δ18O-NO3- sea ice values in Antarctica increased with depth, while NO3- concentrations decreased, indicating NO3- depletion inside sea ice. The atmospheric deposition contributes 10% and 40% to total sea ice NO3- in the Antarctic and Arctic, respectively, while the rest of NO3- is from nitrification and seawater. The δ15N-NO3- and δ18O-NO3- were enriched in sea ice at a ratio of 1:1, indicating that nitrate assimilation in sea ice is strong. The fractionation effect Δ(15-18) in Antarctic sea ice suggests that the nitrification process decreased isotope values. A large amount of NO3- accumulated at the bottom of the Antarctic sea ice, and the maximum was about six times larger than seawater, revealing the coupling between assimilation consumption of inorganic dissolved nitrogen and organic nitrogen remineralization. Denitrification is not significant in sea ice.

Role of zooplankton in the Southern Ocean biogeochemical cycles

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Zooplankton, mainly krill and copepods, play great roles in polar ocean ecosystems. They serve as trophic links that transfer carbon and energy from phytoplankton to higher trophic levels. Meanwhile, they also contributed in determining the efficiency of the biological carbon pump of polar oceans via passive sinking of moults, carcasses, feacal pellets and via activities such as grazing on phytoplankton, diel vertical migration and respiration. The polar ocean is undergoing rapid climate change (e.g. warming, changes in extent of sea ice) with contrasting rates and directions among different sectors of the Southern Ocean. These changes have had and would have profound impacts on the distribution, phenology, community of zooplankton and their role played in structure, function and service of polar ocean ecosystems. This report provides an overview of the role of zooplankton in the Southern Ocean biogeochemical cycles and potential responses of the key zooplankton species to a changing Southern Ocean.

A study on the role of sea ice in the N_2O cycle in the Prydz Bay, Antarctica

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Continuous observation of N_2O in surface water was conducted for the first time at a station in Prydz Bay, Antarctica, from November 31 to December 10, 2016. The results showed that the decrease in N_2O in surface water corresponded to the salinity trend due to water dilution from melting sea ice. The extremely low N_2O concentration of ~2 nmol L-1 in sea ice meltwater confirmed our hypothesis that the N_2O dilution in the surface water was caused by melting ice water during the melting season. Artificial sea ice formation was simulated in a tank placed in a refrigerator in the lab; the results showed that for 10 cm of sea ice growth, approximately 70% N_2O (69.3%±2.4%) in the surface water was rejected into the underlying seawater with brines, approximately 20% N_2O (18.1% ± 4.0%) remained in the ice, and a small fraction (12.6% ± 3.2%) was released into the atmosphere during sea ice formation. These results suggested that sea ice formation in the Polar Ocean can induce the export of N_2O to certain depths and that sea ice melt can dilute the surface water and cause a N_2O sink.

Does reactive iron contribute to the long-term preservation of marine organic carbon in the Antarctic sediment?

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The preservation of organic carbon (OC) in marine sediments by reactive iron (FeR) has the potential to act as a long-term carbon sink. However, the preferential preservation mechanism of FeR-bound OC (OC-Fe) during transport is not well understood. Here we conducted a study on surface sediments in the East Antarctic Ocean. The results show that the proportion of OC-Fe to total organic carbon (fOC-Fe) in the central shelf is 9.59% ± 7.27%, which is lower than the 18.97% ± 5.86% found in the open ocean and the 20% observed in global surface sediments. The low fOC-Fe in the central shelf may be attributed to the combined effect of high total organic carbon (TOC) input and low FeR content. Additionally, the molar ratio of OC-Fe to FeR (43.24 ± 29.59 in the shelf and 230.79 ± 135.06 in the open ocean) in sinking particles is higher than the highest known value in sediments (~30). This suggests that OC-Fe in sinking particles are influenced by upper ocean biological processes, and the controlling factors of fOC-Fe may vary among different types of sediments. The properties of OC-Fe in sinking particles from both the shelf and open ocean regions exhibit similarities, as evidenced by fOC-Fe, fTHAA-Fe, Δδ13C, and ΔΔ14C. The OC-Fe properties of shelf sediments are comparable to those of sinking particles, indicating that in shallow water shelf regions, the OC-Fe in sediments is primarily derived from marine organic matter in the upper water column and is relatively stable. However, the OC-Fe properties of open ocean sediments differ greatly from those of sinking particles, suggesting that in deep ocean regions, the OC-Fe in sediments is primarily derived from terrestrial sources, either produced in situ or transported from the continent, and the marine-derived OC-Fe is completely decomposed during the long-term sedimentation process. This understanding highlights the significant differences in the fate of OC-Fe in the East Antarctic shelf and open ocean, which is crucial for a deeper comprehension of the mechanisms that promote long-term burial of OC through FeR. The estimated amount of buried OC-Fe in the Antarctic shelf is approximately 1.78 ± 1.42 Mt/yr, accounting for 10.4% of the global shelf/slope OC-Fe burial. As the glacier melting accelerates, the contribution of OC-Fe to Antarctic OC burial may increase.

A novel ATP dependent dimethylsulfoniopropionate lyase identified in Antarctic bacteria

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Dimethylsulfoniopropionate (DMSP) is an abundant and ubiquitous organosulfur molecule in marine environments with important roles in global sulfur and nutrient cycling. Diverse DMSP lyases in some algae, bacteria and fungi cleave DMSP to yield gaseous dimethyl sulfide (DMS), an infochemical with important roles in atmospheric chemistry. In this study, we screened DMSP-catabolizing bacteria from Antarctic samples, and obtained a strain Psychrobacter sp. D2 that grew on DMSP and produced DMS. Genetic and biochemical work showed that Psychrobacter sp. D2 possesses a novel DMSP lyase termed DddX for DMSP catabolism. DddX is an acyl-CoA synthetase superfamily enzyme and is distinct from the eight other known DMSP lyases. DddX catalyses the conversion of DMSP to DMS via a two-step reaction: the ligation of DMSP with CoA to form the intermediate DMSP-CoA, which is then cleaved to DMS and acryloyl-CoA. The novel catalytic mechanism was elucidated by structural and biochemical analyses. DddX is found in diverse marine Alphaproteobacteria, Gammaproteobacteria and Firmicutes, suggesting that this new DMSP lyase may play an important role in DMSP/DMS cycles.

Iron limitation and uneven grazing pressure on phytoplankton co-lead the seasonal species succession in the Ross Ice Shelf Polynya

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The seasonal species succession of phytoplankton from Phaeocystis antarctica to diatoms in the Ross Ice Shelf Polynya (RISP) plays a fundamental role in food webs and ecosystem functioning. Previous studies have revealed that this seasonal succession is affected by differences in light, iron demand, aggregation and subsequent sinking between these two taxa. This study further investigated the dominant process of species succession by analyzing the results of a box-ecosystem model. The mechanism of processes leading to the replacement by diatoms differs from that for triggering the initial P. antarctica bloom. Light triggered the spring bloom dominated by P. antarctica in iron-rich surface water, which is resupplied by winter convective mixing from the lower layer pool. After reaching its maximum in mid-November, the biomass of P. antarctica declined progressively due to the severe iron limitation. Seasonal species succession can be enhanced by a small amount of predation on P. antarctica by microzooplankton. The long-term iron enrichment promotes the transition by supporting diatom growth. The balance between bottom-up and top-down processes plays a critical role in shaping the phytoplankton composition and promoting the seasonal species succession in the iron-limited upper mixed layer of the RISP.

The distribution characteristics and potential roles of viruses in the Antarctic ice-edge algal blooms

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Microbial systems in Antarctic sea ice and seawater are the foundation of the Antarctic marine food chain, and play an important role in maintaining the stability of the Antarctic marine ecosystem. During spring and early summer, with the initiation of sea ice retreat, sea ice algal communities undergo exponential growth, and ice-edge phytoplankton blooms occurred. Using flow cytometry and metagenomic analysis, we researched the distributions of viral abundance and community structure in the Indian Ocean sector of East Antarctica and the Amundsen Sea of West Antarctica during the Antarctic summer melting period and their potential control factors. In the austral summer, the distributions of viral abundance and community structure were mainly controlled by the edge-blooms caused by ice-melting and upwelling of the Circumpolar Deep Water (CDW). Viruses were significantly correlated with heterotrophic prokaryotes in the ice-covered areas but more strongly correlated with autotrophic picoeukaryotes in areas associated with ice-edge blooms. Throughout the water column, nutrient supply from the upwelling of the CDW induced an increased abundance of heterotrophic prokaryotes, particularly in the meso- and bathypelagic zones of stations in the northern part of the area. High viral abundances were detected in the meso- and bathypelagic zones of stations with high abundances of virio- and picoplankton in the epipelagic zone. The results of community structure analysis showed that Phycodnaviridae and Lavidaviridae were higher in the coast, Amundsen Sea Polynya (ASP) where the blooms occurred. This study preliminarily reveals the distribution and potential roles of viruses in the edge-blooms of the Antarctica and provides a novel understanding and important reference dataset for in-depth reveal of the ecological role of climate change on the algal blooms.

Pelagic ciliate (Ciliophora) communities in the Southern Ocean: Bioindicator to water mass, habitat suitability classification and potential response to global warming

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Although the pelagic ciliate (microzooplankton) play important role in carbon flux of marine ecosystems, their ecological function, habitat suitability classification and response to global warming were poorly documented in the Southern Ocean (SO). During summer of 2020/2021, ciliate (including aloricate ciliates and tintinnids) communities in waters from surface to 1000 m were investigated in the SO. Rapid attenuation of ciliate abundance and biomass occurred at 100 m layers in most stations. According to distinctive hydrographic features, five water masses were identified in the SO with holding unique ciliate community structure. Aloricate ciliate small size-fraction (10–20 μm) was dominant in water masses ⩾200 m. Tintinnids showed distinctive regional and vertical distribution characteristics, and their habitat suitability characterized by the Bio-index exhibiting different optimum survival zones. Variations in tintinnid habitat can be regarding as indicators for future SO climate change. Correlation between environment and biota revealed that depth, Chl a and dissolved oxygen were main factors determining ciliate composition. Combining tendency of phytoplankton and meso-/macro-zooplankton to rapid global warming, pelagic ciliates may become smaller and more prominent in the future SO marine ecosystem. Our study has laid a foundation for recognizing the ciliate community and reinforcing the ideas about tintinnid indication for the change of future SO marine ecosystem.

POSTER

The Southern Ocean rapid warming and related spiciness changes

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As the emission of anthropogenic greenhouse gases increases, the Southern Ocean absorbs substantial heat from climate change and warms rapidly. In this study, we analyzed updated ocean observational datasets and found that the warming of the Southern Ocean, especially within two warming hotspots in the South Pacific and the South Indian Ocean, presents significant interannual and decadal variations. Particularly, there was a rapid warming over 2003-2012, a warming slowdown or even cooling after 2013, and another surge of warming tendency over 2020-2022 under the influences of recent triple La Nina events. We further decompose the ocean temperature change into two processes: spiciness (temperature variation along neutral density surface) and heave (vertical heave of neutral density surface). Both the long-term trend and short-term variations of the Southern Ocean warming are dominated by the heave component. The spiciness changes show long-term cooling mainly in the 200-800m layer (above the Antarctic Intermediate Water), and also display strong signals of interannual and decadal variations in the 200-500m layer. This leads to the maximum signal-to noise ratio for spiciness change in the 500-800m layer, that is, the long-term climate change signal could emerge more easily. The sources and mechanisms of the spiciness changes in Southern Ocean are currently under investigation.

Interannual variability of eddy activity in the Southern Ocean associated with the ENSO

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Using the mesoscale eddy trajectory dataset provided by AVISO, the interannual variability of the mesoscale eddies in the Southern Ocean from 1993-2019 and its associated dynamical mechanisms are studied. The results show that the relationship between Eddy Occurrence Number (EON) and Niño3.4 index has a significant negative correlation (correlation coefficient -0.42) at a lag of 11 months, i.e., EON is more in the La Niña period and less in the El Niño period. Further study shows that the interannual variability of EON in the Southern Ocean is mainly dominated by the cyclonic eddies (cEON) in the Pacific sector of the Southern Ocean, and there is a significant negative correlation between the cyclonic eddies (cEON) and Niño3.4 index in the Pacific sector of the Southern Ocean (correlation coefficient of -0.56). The mechanism analysis indicates that the interannual variability of EON in the Southern Ocean is modulated by the wind stress curl, and the ENSO process influences the interannual variability of EON by acting on the wind stress curl in the Southern Ocean through the Pacific–South American (PSA) pattern. The negative wind stress curl in the Pacific sector of the Southern Ocean during La Niña is beneficial to the generation and maintenance of cyclonic eddies, resulting in an increase in cEON, while the opposite is observed during El Niño. Our study contributes to deepening the connection between tropical large-scale ocean-atmosphere interaction processes and the subpolar mesoscale eddies.

The observed enhancement of eddy from stress in the standing meanderings of the Antarctic Circumpolar Current

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The transport of the Antarctic Circumpolar Current (ACC) is known to be insensitive to changes in wind stress, the so-called "eddy saturation" phenomenon. Recent studies highlighted the importance of local topographic features for the eddy saturation process. When the surface westerlies are increased, the isopycnal becomes steeper and the ACC is accelerated. As a result, the standing meanders excited by the local flow-topography interactions are adjusted to promote the efficiency of downward momentum transfer by the eddy from stress (EFS). Finally, the downward momentum is balanced by the topographic form stress and frictions, so that the increased westerlies do not enhance the ACC transport. However, the proposed mechanism has not been well tested by observations. In this study, we construct the Southern Ocean (SO) three-dimensional eddy-resolved (0.1 ° × 0.1 °) climatological temperature, salinity, and density fields based on the long-term (1998-2022) Argo profiles, and then estimate the EFS in the SO. The estimated EFS in the ACC are all positive, indicating downward momentum transfer, consistent with the proposed physical process. Furthermore, the EFS along the ACC is significantly enhanced in the local standing meanders. On average, the EFS in the standing meanders exceeds 90% of the total EFS in the ACC. The observations suggest that "eddy saturation" results from the adjustment of the local standing meanders by the winds.

The ocean response leaves behind a footprint in the Antarctic Intermediate Water heat content

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The climate changes lead to the Southern Ocean warming and leaves behind a significant footprint in the Antarctic Intermediate Water (AAIW) heat content (HC), the primary water masses in Southern Ocean. Observation and reanalysis datasets are adopted to explore the AAIW HC changes and analyse the attributions to the remarkable regional differences. We find that the conspicuous warming occurred in Indian AAIW is attributed to the poleward meridional heat advection by the southward Polar Front which also contributes to mild warming in Atlantic AAIW. Comparatively, Pacific AAIW shows opposite and significant cooling due to the thinning mainly and the increasing northward cold-water transport partly. The results reveals that atmospheric forcing and water masses behaviours play a more and more important role in modulating ocean heat content.

Bird feathers as non-invasive bio-indicators of metals and pesticides in the Southern Ocean

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Bird feathers have been used in the monitoring of various contaminants. This study aims to study the feasibility of feathers as bio-indicators for metals and pesticides in the environments. We obtained feather samples from Adélie penguins and snow petrels based on the Chinese Antarctic Scientific Expedition Platform. Eight metals (As, Cd, Cr, Cu, Ni, Pb, Zn, and Hg) and 164 pesticides (25 organochlorine pesticides (OCPs), 83 organophosphorus pesticides, 43 organonitrogen pesticides, and 13 pyrethroids) were analyzed. The results showed that the total concentration of metals was 155 ± 1.52 ug/g dw in Adélie penguin feathers and 194 ± 1.50 ug/g dw in snow petrel feathers. The most abundant metals were Zn and Cr, accounting for 79% in Adélie penguins and 86% in Shearwaters, respectively. The total concentration of pesticides was 42.7 ± 0.917 ng/g dw in Adélie penguin feathers and 45.1 ± 0.543 ng/g dw in snow petrel feathers. It is noticed that all eight metals were detected in both species, demonstrating the long-term existence of metals in the Antarctic environment. 13 of the 164 pesticides were detected in both species, but the compounds detected were not identical. Hexachlorobenzene (HCB), hexachlorocyclohexane (HCHs), mevinphos, dimethoate, fenchlorfos, famphur, carbofuran, oxadiazon, mefenacet, fenpropathrin were detected in both species, suggesting more attention should be paid to the variation of their concentrations in the Antarctic environment in future studies. Only HCB and HCHs were detected in OCPs, and they were also the most abundant pesticides in the feathers of both species, accounting for 61% in Adélie penguins and 61% in snow petrels, respectively. This indicated that there was still an exposure risk to OCPs in the Antarctic. In conclusion, feathers are good bio-indicators of metals and pesticides in the environments. This study also provided a reference method for conducting contaminant monitoring in the Antarctic.