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A CHANGING ARCTIC OCEAN: DRIVERS, IMPACTS AND PROJECTIONS

ABSTRACT

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Contents

Keynote Lectures

Linkage of Arctic Amplification to the Change in Land-Ocean Warming Contrast in Boreal Winter

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Global warming is spatially uneven on a planetary scale, with the Arctic warming faster than other regions (so-called the Arctic Amplification, AA) and the surface air temperature warming faster over land than over the ocean (so-called land-ocean warming contrast, LOWC). AA has been a focus of research in the context of global warming. However, it is still unclear whether AA and LOWC are connected. In this study, based on observations over recent decades, we find a weakening trend of LOWC that significantly impacts AA during the boreal winter. We show that the trend of stationary zonal wave-2 component at mid-high latitudes in the lower troposphere is well related to the LOWC trend. A poleward shift of the sea level pressure in the stationary zonal wave-2 component over recent decades resulted in an increased heat transport to the Arctic, which contributes not only to the spatial distribution of AA but also to about 31% of the warming over the Barents Sea, where the most prominent warming occurs. This study provides a new mechanism which in favour of the AA formation.

Changes in the Arctic Ocean circulation impact the marine environment in a boundary region of Atlantic-origin and Pacific-origin waters

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The Arctic Ocean is undergoing dramatic environmental and ecosystem changes. In this context, an international multi-ship survey project, the Synoptic Arctic Survey (SAS), was undertaken in 2020 to provide up-to-date baseline data. During the Japanese R/V Mirai cruise in collaboration with the SAS project, unusually low dissolved oxygen and acidified waters were found in a high seas fishable area of the western Arctic Ocean. Combining the data from the SAS multi-ship expeditions, it was suggested that the Beaufort Gyre shrunk east of an ocean ridge and formed a front between the water within the gyre (Pacific-origin water) and the water from the eastern Arctic (Atlantic-origin water). This phenomenon triggered a frontal flow northward along the ocean ridge. This current is likely to transport the low oxygen and acidified water to the fishable area of the high seas; similar biogeochemical properties had previously been observed only on the shelf-slope north of the East Siberian Sea (ESS). The transport of the low oxygen water along the ocean ridge from the ESS shelf-slope was well simulated by a physical sea ice – ocean general circulation model. These findings were reflected in the implementation plan of the Joint Program for Scientific Research and Monitoring (JPSRM) of the Central Arctic Ocean Fisheries Agreement (CAOFA) by proposing a most urgent monitoring site in the Agreement Area, which is threatened by ocean deoxygenation and acidification for the marine ecosystem. Japan is currently building a new icebreaker for Arctic science (named Arctic Research Vessel (ARV) Mirai II), which will be delivered to JAMSTEC in 2026. The vessel will be equipped with a fish-finding echosounder and advanced onboard instruments capable of withstanding extreme low-temperature conditions, and is expected to contribute to scientific surveys related to the CAOFA. In addition, the ARV Miral II is expected to contribute to the second SAS (SAS II) project, which is planned to be implemented in or around 2030.

Late Cenozoic changes in Arctic ice sheets, sea ice and organic-carbon burial: Past, Present and Future

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Due to complex feedback processes (collectively known as “polar amplification”), the Arctic is both a contributor of climate change and a region that will be most affected by global warming. That means, the Arctic Ocean and surrounding areas are (in real time) and were (over historic and geologic time scales) subject to rapid and dramatic change. When talking about the (global) climate system and its driving processes, the organic carbon (OC) cycle plays a key role, i.e., production on land and in the oceans, storage/burial in the ocean and sediments, diagenesis/degradation, and release of greenhouse gases to the atmosphere. During glacial climate cooling and times of extended circum-Arctic ice sheets and lowered sea-level, huge amounts of OC-rich soils, sediments and rocks might be eroded and transported by glacigenic processes across the shelf edge, and buried in deep ocean sediments, thus acting as an important geological CO2 sink and storage. Well-dated detailed records dealing with such glacigenic and oceanographic processes, sediment discharge and rates of OC burial in the central Arctic Ocean during late Quaternary glacial stages, however, are quite limited and mainly restricted to the last climate cycle. Here, new data from a well-dated deep-sea sediment core are presented that allow for the first time to reconstruct in detail the interrelationship between ice-sheet dynamics and organic-carbon (OC) burial in the Eurasian Basin during the last 430 kyr, and to correlate marine and terrestrial records of the Eurasian Ice Sheet (EIS) history. Using a multi-proxy approach, it is demonstrated that within pulses of EIS advance and retreat during glacial to subsequent deglacial times, erosion of ancient (petrogenic) OC-rich sedimentary rocks and soils deliver sediments, further supplied onto the shelf and beyond. Down-slope and long-distance transport of the fine-grained OC-rich suspension by turbidity and contour currents cause elevated burial of terrestrial OC and anoxic sedimentary conditions in the deep Eurasian Basin that allow preservation of labile (marine and sea-ice) algae-type OC.

Mechanisms for the response of midlatitude surface temperature variance to climate warming: A moist energy framework approach

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Understanding the dynamics of surface temperature variance under global warming is crucial for predicting changes in surface temperature extremes. Previous studies have emphasized an eddy mixing length theory that links surface temperature variance to meridional temperature gradients, yet the role of moist processes is not well understood. Here, we present a framework based on the variance budget of moist static energy (MSE).

We begin by simplifying the vertically integrated energy transport to surface energy transport, resulting in an approximate balance between the temperature variance generated by surface energy transport and the variance dissipated by net energetic forcing to the atmosphere. Particularly, the total effects of longwave radiation and surface sensible heat flux absorbed by the atmosphere are interpreted as the dry damping of surface temperature variance, whereas surface latent heat flux corresponds to the moist damping of temperature variance. This approach yields an estimate of surface temperature variance from the combination of eddy heat flux, the MSE gradient, and the Clausius-Clapeyron (CC) factor for evaporative cooling.

We apply this analysis to midlatitude surface temperature variability in an idealized aquaplanet model and the CESM2 Large Ensemble (LENS2) under climate warming. It is found that this framework captures the spatial features of changes in surface temperature variance, indicating a dominant role of eddy heat flux produced by horizontal advection. These results highlight the MSE variance framework as a physical tool for understanding changes in surface temperature variance in a warming climate.

Modelling snow and sea ice thermodynamics along the MOSAiC drift trajectory

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Properties of snow are crucial for snow and sea ice modelling at the physical process level. During MOSAiC winter-spring period (October–May), the impact of snow density and precipitation on the thermal regime of sea ice was examined using a numerical snow and sea ice model (HIGHTSI), when snow was dry. The constant snow density of 308 kg/m³ was derived from linear regression of snow water equivalent (SWE) versus snow depth, using samples collected during the winter-spring observation period. Several snow density schemes produced mean snow densities consistent with MOSAiC observations; however, none adequately captured the observed temporal variability. The HIGHTSI-modelled mean surface temperature and ice thickness showed a linear relationship with snow density, whereas the modelled mean in-snow and in-ice temperatures exhibited an inverse linear relationship with snow density. The impacts of time-dependent snow density on snow and ice thermodynamic regimes were stronger than in the model runs using constant snow density. Model sensitivity experiments revealed contrasting responses of the snow and ice system to changes in snow density and precipitation. Increased snow density decreased snow and ice temperatures, promoting ice growth, while increased precipitation led to warmer snow and ice temperatures and reduced ice thickness. Snow depth and ice thickness along one SIMBA ice mass balance buoy drift trajectory between 29 Oct 2019 and 14 Aug 2020 were also modelled by updated HIGHTSI, and the results are interpreted.

Session

Arctic Amplification and Extreme Events

An analytic theory for the degree of Arctic Amplification

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Arctic Amplification (AA), the amplified surface warming in the Arctic relative to the globe, is a salient feature of climate change. While the basic physical picture of AA has been depicted, how its degree is determined has not been clearly understood. Here, by deciphering atmospheric heat transport (AHT), we build a two-box energy-balance model of AA and derive that the degree of AA is a simple nonlinear function of the Arctic and global feedbacks, the meridional heterogeneity in radiative forcing, and the partial sensitivities of AHT to global mean and meridional gradient of warming. The formula captures the varying AA in climate models and attributes the spread to models' distinct feedback parameters and AHT physics. The formula clearly illustrates how essential physics mutually determine the degree of AA and limits its range within 1.5-3.5. The formula can also be applied to understand the degree of AA under idealized forcing and feedbacks. Our results articulate AHT as both forcing and feedback to AA, highlight its fundamental role in forming a baseline AA that exists even with uniform feedbacks, and underscore its partial sensitivities instead of its total change as key parameters of AA. The lapse-rate feedback has been widely recognized as a major contributor to AA but its effect is fully offset by the water-vapor feedback.

Impact of tropical oceans on surface mass balance trends in West Antarctica

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The surface mass balance of the Antarctic Ice Sheet is a critical factor in influencing global mean sea level rise and has substantial implications for future projections of sea level rise. In recent decades, the Antarctic Ice Sheet surface mass balance trends show pronounced regional disparities, marked by an increase over the western part but a decrease over the eastern part of West Antarctica. Through a synthesis of ice core records and five reanalysis datasets, as well as atmospheric dynamics analysis and numerical model simulations, we demonstrate that the multi-decadal trends in tropical sea surface temperature are key drivers of the dipole-like surface mass balance trends in West Antarctica. Specifically, the eastern tropical Pacific cooling associated with the phase changes of the Interdecadal Pacific Oscillation (IPO) and the tropical Atlantic warming associated with the Atlantic Multi-decadal Oscillation (AMO) stimulate Rossby wave trains propagating to the West Antarctic, resulting in the contrasting moisture divergence and precipitation changes between the western and eastern parts of West Antarctica. In particular, the statistical analysis and model simulation clarify the seasonality of these teleconnections. Both the Pacific and Atlantic contribute to the dipole-like surface mass balance pattern during austral spring and autumn, while the Pacific is the major contributor during austral summer. Our findings have broad implications for understanding the recent observed surface mass balance trends as well as the projecting future changes in the Antarctic surface mass balance and consequent global sea level.

An abrupt shift in the Arctic Ocean warming due to increased extremes

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Arctic sea ice has been shrinking since 1980s, and a sudden shift from thicker, deformed ice to thinner, more uniform ice occurred in 2007. The impacts remain unclear. Here we uncover a sudden 0.8°C rise and a doubling of sea surface temperature variability within the marginal ice zone (MIZ), pinpointing 2007 as a critical point of abrupt transition. Following a rapid expansion of the MIZ post-2007, Arctic marine heatwaves (MHWs) have intensified, accelerating sea ice melt and solar heat accumulation. Our analysis uncovers an intensified positive feedback between MHWs and Arctic Ocean warming. With continued greenhouse warming, destabilizing Arctic sea ice is expected to further intensify MHWs, exacerbating Arctic Ocean warming. Our findings underscore the critical role of climate extremes in triggering climate transitions.

Atmosphere-Ocean-Ice interactions in high latitudes and the role of weather events

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Cold air outbreaks (CAOs) play a key role in air-sea interactions in high latitudes. Modeling air-sea interactions near the ice edge, in the marginal ice zone, and through leads poses a major challenge due to of the vast range of scales and physical processes involved. During CAOs, also low-level atmospheric convergence zones often emerge over relatively warmer seas downstream of coastlines, sea ice edges, and mountains. These can give rise to the development of polar lows, which can yield extreme weather conditions. Air-sea interactions due to CAOs also cause wintertime water mass transformations in the Nordic Seas that play a crucial role for the Atlantic meridional overturning circulation.

Using idealised experiments with the WRF model, we investigate how the transformation of a cold air mass moving across the marginal ice zone and lead-fractured sea ice depends on sea ice distirbution and model resolution. We show how the integrated and local sensible and latent heat fluxes depend on the model resolution, as well as the distribution of the sea-ice concentration in the marginal ice zone.

We also investigate the formation mechanism of such convergence zones using idealized numerical experiments and analytic theory. The numerical simulations show that varying the angle of a kink in the coastline as well as changing the height of a mountain cause a difference in the fetch (traveling distance over sea) of the cold airmass and thus form a warm wedge downstream. Hydrostatically, this results in a trough, inducing convergence. We also present an analytic model, where theoretical estimates of the pressure trough and convergence agree well with the results of the numerical experiments.

Investigating the response in the ocean mixed layer during a CAO, we show noticeable spatial variability. While interior seas with weak lateral oceanic transport are dominated by a response to the air-sea heat exchanges, regions in the ocean with strong current feature a much more complex response due to the large horizontal heat transport in the ocean.

Session

Processes and Driving Mechanisms of Biogeochemical Cycling in the Arctic Ocean

Terrestrial organic matter transport, degradation and burial in the Arctic Ocean

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The Arctic warms more rapidly than the rest of the world, leading to drastic changes in permafrost stability and rapid glacier retreat. As a consequence, strongly pre-aged or ancient organic matter may be mobilized and delivered to the ocean from thawing permafrost or through glacier melt. If remineralized, this organic matter could potentially constitute an additional source of fossil carbon emissions to the atmosphere. It remains, however, incompletely understood which processes govern permafrost organic matter mobilization and transport to the ocean, which fraction of the pre-aged organic matter is degraded following mobilization, and how much is simply buried in marine sediments. Studying sediment records covering the last deglaciation, an interval of drastic climate warming, allows inferences on the most important controls on this part of the Arctic carbon cycle.

In this presentation I will summarize findings from several studies that have been conducted using Arctic marine sediments and samples from permafrost landscapes to enhance our understanding of these open questions. Using combined analyses of bulk sediment characteristics, organic biomarkers, stable isotopes and radiocarbon (both on the bulk level and on specific compounds), insights and quantitative estimates on degradability and the fraction buried of terrestrial materials can be obtained. Studies of marine sediments cores covering the last deglaciation reveal that sea-level rise, sea-ice retreat, meltwater discharge and inland warming contributed to the supply of terrestrial organic matter to the ocean.

Sea ice changes and its impact on organic carbon sources in the Chukchi Sea over recent centuries: New insights from lipid biomarkers

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The drastic decline of Arctic sea ice due to global warming and polar amplification of environmental changes in the Arctic basin profoundly alter primary production with consequences for polar ecosystems and the carbon cycle. However, pelagic and sympagic sourced OC remains difficult to discriminate in the Arctic Ocean, particularly in regions of high sympagic productivity. Only a limited number studies has explored sea ice variability over the past centuries. None have attempted to link sedimentary organic carbon source with seasonal sea ice changes since the beginning of the Industrial Era. Here, Bulk organic parameters (total organic carbon, total nitrogen, δ13Corg, and δ15N) and molecularorganic biomarkers (e.g., sterols and highly branched isoprenoids–HBIs) are combined to distinguish between sympagic, pelagic, and terrestrial OC sources and their evolution over last two centuries under changing sea ice conditions to improve our understanding of the ongoing alteration of the OC cycle. We found a major increase of pelagic and sympagic OC in response to shifts in primary production as a result of sea ice recession in the northern Chukchi Sea over the last 200 years highlighting the role of phytoplankton in mitigating CO2 increase in the atmosphere.

Pigment evidence of phytoplankton community shifts driven by rapid changes in the Arctic Ocean, 2008-2018

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Rapid warming in the Arctic have influenced the ecological and biogeochemical systems in the Arctic Ocean, particularly the phytoplankton community that plays a fundamental role in food webs and carbon flow. Our 10-year study (2008–2018) found an abrupt change in the phytoplankton community in the western Arctic Ocean basin after 2012. This shift involved the replacement of nanoplanktonic prymnesiophytes with picoplanktonic prasinophytes. This change was closely associated with a sudden deepening of both the nitracline (from an average depth of 38±17 to 45±10 m) and the chlorophyll maximum layer (from an average depth of 47±16 to 57±10 m) after 2012, driven by thickening of the relatively fresh surface layer (S<31) in the western Arctic Ocean basin. The northwestward movement and intensification of the Beaufort Gyre may have exacerbated this surface freshening of the western Arctic Ocean by regulating freshwater redistribution, thereby driving changes in the phytoplankton community.

Quantitative estimates of Younger Dryas freshening from lipid δ2H analysis in the Beaufort Sea

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The Younger Dryas (YD) cold event is thought to have been triggered by a weakening of the Atlantic Meridional Overturning Circulation, driven by an influx of freshwater into the North Atlantic Deep Water formation region. Determining the source, timing, and magnitude of this freshwater input is critical for understanding the associated climate change. In this study, we analyzed the hydrogen isotopic composition of various lipids in a sediment core from the Canadian Beaufort Sea to investigate these hydrological changes. Our results show that terrestrial leaf wax lipids and microalgae lipids recorded distinct freshwater signals during the YD, allowing for a better constraint on the source and magnitude of this freshening. Using an established empirical relationship between lipid hydrogen isotopes and sea surface salinity, we estimated that surface waters in the Canadian Beaufort Sea experienced a substantial salinity reduction of approximately 15–24 during the YD. This significant decrease was likely caused by a combination of a freshwater outburst and the Laurentide Ice Sheet (LIS) melting water discharge. Following the LIS retreat, the δ2Hlipid indicates that the region likely experienced a shift toward a drier climate during the mid-to-late Holocene (~8–0 cal. kyr BP).

Session

Physical Processes of a More Dynamic Arctic Ocean

Recent variation of physical property in the Chukchi Borderland, Pacific Arctic region

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The Korea Polar Research Institute (KOPRI) has carried out the government-funded project 'Korea-Arctic Ocean Warming and Response of Ecosystem' (K-AWARE) to monitor the Arctic Ocean warming and changes in the marine ecosystem, and to suggest future conditions of the Arctic Ocean. As a part of the project, we have performed the Arctic Ocean expeditions every summer using the Korean ice-breaking R/V Araon to investigate marine environmental changes in the Pacific Arctic region. We present the preliminary results that we found from the Pacific Arctic region by analyzing the physical ocean data (CTD and ocean moorings) obtained from 2017. We found the sustained intrusion of Atlantic-derived cold saline water in the specific transects around the East Siberian shelf slope and shoaling of the boundary between Atlantic-origin waters and Pacific-origin waters at certain stations. We propose that the horizontal distribution of the Pacific-derived waters is likely to be affected by that of the Atlantic-derived cold saline water. Moreover, we suggest that recent change in atmospheric circulation in the Arctic and intensification of atlantification modify the intensity and direction of clockwise Beaufort Gyre which influences on the distribution of water masses in the Chukchi Borderland. We will further discuss on possible biochemical property change induced by the variation of physical property.

Two-dimensional Numerical Simulations of Mixing under Ice Keels

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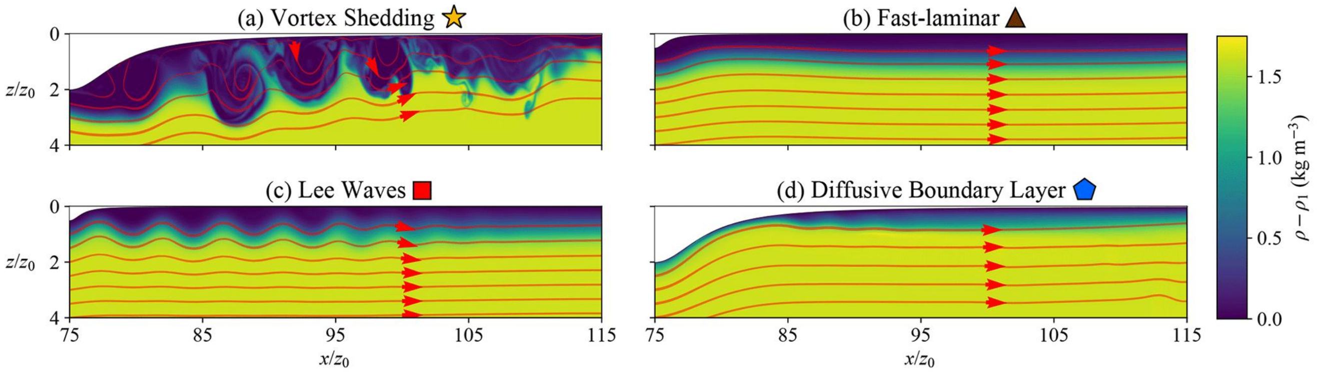
Changes in sea ice conditions directly impact the way the wind transfers energy to the Arctic Ocean. The thinning and increasing mobility of sea ice is expected to change the size and speed of ridges on the underside of ice floes, called ice keels, which cause turbulence and impact upper-ocean stratification. However, the effects of changing ice keel characteristics on below-ice mixing are difficult to determine from sparse observations and have not been directly investigated in numerical or laboratory experiments. Here, for the first time, we examine how the size and speed of an ice keel affect the mixing of various upper-ocean stratifications using 16 two-dimensional numerical simulations of a keel moving through a two-layer flow. We find that the irreversible ocean mixing and the characteristic depth over which mixing occurs each vary significantly across a realistic parameter space of keel sizes, keel speeds, and ocean stratifications. Furthermore, we find that mixing does not increase monotonically with ice keel depth and speed but instead depends on the emergence and propagation of vortices and turbulence. These results suggest that changes to ice keel speed and depth may have a significant impact on below-ice mixing across the Arctic Ocean and highlight the need for more realistic numerical simulations and observational estimates of ice keel characteristics.



Why the Nordic Seas overturning circulation resists weakening in a warming climate

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The overturning circulation in the Nordic Seas involves transformation of warm Atlantic Water (AW) to cold, dense overflow water, which constitutes the densest component of the lower branch of the Atlantic meridional Overturning Circulation (AMOC). While models consistently project a weakening of the AMOC under anthropogenic warming, the Nordic Seas overturning circulation exhibits remarkable stability, or even strengthening, in response to climate change. The mechanisms driving this divergence remain poorly understood. Using climate model simulations for the 21st century, we demonstrate that changes in the Nordic Seas overturning are fundamentally tied to horizontal gyre circulations, rather than vertical density-driven processes like the AMOC. As such, high-latitude warming does not destabilize the Nordic Seas overturning circulation because its dynamics are insensitive to local density changes. Instead, the inflow of AW, modulated by atmospheric circulation in the North Atlantic basin, ensures a resilient relationship between inflow and overflow rates in the Nordic Seas. This explains why the Nordic Seas remain a consistent source of dense water even as subpolar convections weaken in a warming climate. These findings highlight a critical distinction in climate responses between regional overturning systems and suggest limited future weakening of the AMOC.

Modeled and observed upper-ocean under a transitioning ice cover in the Canada Basin

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The Arctic Ocean's Beaufort Gyre is experiencing rapid, anthropogenic change as evidenced by numerous observations including sea ice loss, a more stratified upper ocean, and ocean warming. Climate models struggle to simulate observed changes to the sea ice cover and ocean stratification, raising the possibility of significant biases in the upper-ocean heat storage. Here, we examine how accurately near-surface ocean heat signatures from local solar absorption and the Pacific Ocean are represented in 35 climate model simulations in comparison to ORAS5 ocean reanalysis. We find that 85\% of the models do not reproduce the heat signature associated with Pacific Water typically found in observed temperature profiles. This bias causes the models to have 62\% (23\%) less heat than observed in the top 100m in March (September) on average. Our results suggest that this bias may be closely related to unrealistically deep vertical mixing in the Beaufort Gyre, causing the surface to be too salty and weakening the lateral density gradient necessary for the subduction of Pacific Water. This model bias implies that heat, which would otherwise be stored in the ocean, is instead lost to the atmosphere and to the sea ice and thus has direct implications for simulated Arctic climate in response to climate change.

Weaker seasonal variation in potential energy anomaly in the upper Beaufort Gyre favors the upward release of subsurface heat

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The stability of the upper ocean is crucial for the exchange of momentum, heat, and salt between sea ice and subsurface warm water in the Arctic Ocean's Beaufort Gyre (BG) region. Here, based on multiple in-situ observations, the shifting phases of the BG during 2003-2023 are objectively defined. We find that the potential energy anomaly (PEA) in the upper 55 m decreased from 130.9±2.3 J/m^3 during 2006-2012 with BG intensification to 90.3±2.0 J/m^3 during 2013-2019 with BG relaxation. Further, the mixed layer became saltier and deeper across all seasons. Decreasing PEA indicates an overall weaker stratification in the upper water column which promotes stronger vertical entrainment. We also find that the mixed layer heat content increased across nearly all seasons, except during July to September (summer). Our analysis using a Price–Weller–Pinkel model suggests that the cause of this warming was not atmospheric heat fluxes from above, but rather subsurface heat entrainment upward. The key mechanism is the seasonal amplitude of PEA is smaller during 2013-2019 when the BG relaxes, thereby allowing mixing to greater depths under the same surface salt flux as in 2006-2012. This is important for the future evolution of the sea ice melting and oceanic vertical mixing if the BG relaxes further.

Session

Arctic Sea Ice Observation Techniques and Modelling

Upscaling of ICESat-2 Sea Ice Freeboard Measurements by Sentinel-1 Synthetic Aperture Radar

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Satellite altimetry serves as the backbone of measuring sea ice elevation and producing basin-scale climate record of sea ice thickness in polar regions. Although modern altimeters such as ICESat-2 provide highly precise freeboard measurements, its spatial representation is inherently limited due that scanning only covers the nadir of the satellite's pass. Consequently, measurements within a month are used to compile basin-scale maps, which is a compromise between coverage, spatial and temporal representation, as well as matching end users' needs. In this talk we explore the statistical upscaling of the sea ice topography as measured by ICESat-2 by collocating backscatter maps by the C-band synthetic aperture radar of Sentinel-1. By using Operation IceBridge (OIB) data and collocating Sentinle-1 maps, we construct statistically significant relationship between the total freeboard statistics (i.e., mean height, height variability) and the C-band backscatter. In particular, the scale dependency of this relationship is investigated. The relationship is rooted in the different backscatter mechanisms among various sea ice types/ages. Besides, this relationship is also found to be localized, varying with both the sea ice conditions and the observational geometry. We further utilize this relationship to build a prototype algorithm to upscale the spatially limited ICESat-2 measurements with SAR images to larger scales. As a result, the spatial representation of the freeboard measurements is much improved, which potentially allows more effective synergy with other payloads such as SMOS. Collaterally, the temporal representation of basin-scale freeboard maps can be achieved: weekly basin-scale maps are generated instead of monthly. Initial results of the upscaled total freeboard dataset based on ICESat-2 and Sentinel-1A/B for recent winters are also discussed.

Incidence angle dependence of SAR polarimetric characteristics over sea ice

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Arctic sea ice is a pivotal indicator of global climate change. Synthetic aperture radar (SAR) is the most widely used instrument for sea ice monitoring in the harsh and unpredictable Arctic environment, owing to its capability for all-weather, day-night, and continuous observations. There are more than seventy SAR parameters have been used for sea ice monitoring. However, there is no system comparison among these parameters to determine the optimal parameters for sea ice classification. Meanwhile, the SAR parameters are incidence angle dependent. Therefore, it it is necessary to study the incidence angle dependence of optimal parameters for different types of sea ice.

In the study, we will identify an optimal subset of seven polarimetric parameters from 70 possible parameters, to achieve fine sea ice classification for distinguishing different types of first year sea ice and open water, using random forest methodology. The incidence angle dependence of the optimal seven sea ice classification SAR parameters will be investigated using the slope of parameters versus incidence angles. The separability index is used to evaluate the sea ice classification capabilities of these parameters with different incidence angles. Finally, the optimal incidence angle range for effective sea ice classification using these optimal parameters are presented. These results will throw new light on radar instrument design and sea ice monitoring operation application.

Physical and optical characteristics of sea ice in the Pacific Arctic Sector during the summer of 2018

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The reduction in Arctic sea ice in summer has been reported to have a significant impact on the global climate. In this study, Arctic sea ice/snow at the end of the melting season in 2018 was investigated during CHINARE-2018, in terms of its temperature, salinity, density and textural structure, the snow density, water content and albedo, as well as morphology and albedo of the refreezing melt pond. The interior melting of sea ice caused a strong stratification of temperature, salinity and density. The temperature of sea ice ranged from –0.8°C to 0°C, and exhibited linear cooling with depth. The average salinity and density of sea ice were approximately 1.3 psu and 825 kg/m3, respectively, and increased slightly with depth. The first-year sea ice was dominated by columnar grained ice. Snow cover over all the investigated floes was in the melt phase, and the average water content and density were 0.74% and 241 kg/m3, respectively. The thickness of the thin ice lid ranged from 2.2 cm to 7.0 cm, and the depth of the pond ranged from 1.8 cm to 26.8 cm. The integrated albedo of the refreezing melt pond was in the range of 0.28–0.57. Because of the thin ice lid, the albedo of the melt pond improved to twice as high as that of the mature melt pond. These results provide a reference for the current state of Arctic sea ice and the mechanism of its reduction.

Research progress and applications of polar sea ice products based on multi-source remote sensing payloads of Fengyun Satellites

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Fengyun satellites have now developed the capability to retrieve multiple polar sea ice parameters based on active and passive microwave payloads. This includes the operational production and release of four types of polar sea ice products, including the FY-3 MWRI radiometer sea ice concentration, the FY-3E WindRAD scatterometer sea ice edge and type, and the FY-3 GNOS-R sea ice thickness. The monitoring capabilities of Fengyun satellites in the polar regions are continuously improving. This study will systematically introduce the inversion and validation of polar sea ice parameters mentioned above. The release and application of operational sea ice parameter products from Fengyun satellites can further enhance the polar sea ice monitoring capabilities and provide a scientific and reliable new data source for research related to polar and global climate change, such as climate numerical models and the monitoring of extreme climate events.

Melt Pond Evolution along the MOSAiC Drift: Insights from Remote Sensing and Modeling

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Melt ponds play a crucial role in the melting of Arctic sea ice. Studying the evolution of melt ponds is essential for understanding changes in Arctic sea ice. In this study, we used a revised sea ice model to simulate the evolution of melt ponds along the MOSAiC drift at a resolution of 10 m. A novel melt pond parameterization scheme simulates the movement of meltwater under the influence of gravity over a realistic sea ice topography. We evaluated different melt pond parameterization schemes based on remote sensing observations. The absolute deviation of the maximum pond coverage simulated by the new scheme is within 3%, while differences among parameterization schemes exceed 50%. Errors were found to be primarily due to the calculation of macroscopic meltwater loss, which is related to sea ice surface topography. Previous studies have indicated that sea ice with a lower surface roughness has a larger catchment area, resulting in larger pond coverage during the melt season. This study has identified an opposing mechanism: sea ice with lower surface roughness has a larger catchment area connected to the macroscopic flaws of the sea ice surface, which leads to more macroscopic drainage into the ocean and thereby a decrease in melt pond coverage. Experimental simulations showed that sea ice with 46% higher surface roughness, resulting in 12% less macroscopic drainage, exhibited a 38% higher maximum pond fraction. The presence of macroscopic flaws is related to the fragmentation of sea ice cover. As Arctic sea ice cover becomes increasingly fragmented and mobile, this mechanism will become more significant.

Improvement of sea ice drift extraction based on feature tracking in Sentinel-1 Imagery

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Monitoring sea ice drift (SID) is critical for safeguarding Arctic shipping and advancing understanding of global climate dynamics. This study proposes an enhanced methodology for estimating SID vectors using Sentinel-1 Synthetic Aperture Radar (SAR) imagery. Three feature detection algorithms—Scale-Invariant Feature Transform (SIFT), Oriented FAST and Rotated BRIEF (ORB), and Accelerated KAZE (AKAZE)—were systematically evaluated for their ability to extract spatially representative features. Results demonstrate that AKAZE achieves feature point densities comparable to ORB while improving spatial coverage by approximately 20% relative to both SIFT and ORB, with significantly enhanced distribution uniformity ($p<0.05$). To address limitations in traditional feature matching, including computational inefficiency and high false-match rates, a Grid-Based Motion Statistics (GMS)-based matching algorithm was developed. Quantitative analysis reveals the proposed GMS method reduces matching errors by 40% compared to the brute-force SIFT matcher and by 5–10% relative to Fast Library for Approximate Nearest Neighbors (FLANN), while reducing computation time by 32% on average. The integrated workflow combining AKAZE detection, GMS matching, and locally consistent (LC) flow field filtering was applied to 27 Sentinel-1 scenes from the East Siberian Sea (2019–2021). The derived SID vectors exhibit distinct seasonal patterns: winter velocities averaged 2.8 km/day ($\sigma=0.6$) with predominant transpolar drift, while summer motion slowed to 1.2 km/day ($\sigma=0.3$) with increased rotational components. Validation against buoy data shows a mean absolute error of 0.4 km/day in speed and 12° in direction. These findings provide operational benefits for Northeast Passage navigation risk assessment and contribute to parameterizing ice dynamics in climate models. The methodology's computational efficiency (processing 500×500 km^2 scenes in <8 minutes) demonstrates feasibility for near-real-time monitoring applications.