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ISPOGC

INFLUENCE OF ARCTIC RAPID CHANGE ON OCEANIC TRANSPORT OF MATTER AND ENERGY

ABSTRACT

中国海洋大學
OCEAN UNIVERSITY OF CHINA

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Contents

Keynote Lectures

Subsea Permafrost and Methane Evasion: The East Siberian Arctic Ocean

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1 Stockholm University and the Royal Swedish Academy of Sciences, Sweden

2 The International Siberian Shelf Study (ISSS) Team

The East Siberian Arctic Ocean (ESAO) is the target area because of its vast, yet poorly constrained stores of potentially vulnerable organic matter and methane in subsea permafrost, hydrates and thermogenic reservoirs. The ESAO is the largest yet shallowest shelf of the World Ocean, being a seaward extension of the Siberian tundra that was flooded during the Holocene transgression 7-15 kyr ago and has been warming up even since.

The presentation will focus on the current state and composition of subsea permafrost, the dynamics of the spatially extensive methane evasions, and preliminary results on the isotope fingerprinting of the subsea sources of the methane escaping to the overlying water column and atmosphere.

Drilling campaigns of the Laptev Sea subsea permafrost reveal that temperature profiles of the PF underneath the coastal waters is much higher and close to zero, compared to nearby still on-land permafrost. Several sites that were drilled 30 years ago were recently re-drilled, which revealed that the thaw horizon has been moving down by several meters in just a few decades. There is thus both a potential for degradation of the organic matter (including to methane) in this subsea PF as well as an increasing permeability for pre-formed methane to penetrate toward the surface.

Methane in the ESAS water column is over extensive scales present at concentrations much above what would be predicted from equilibrium with overlying atmospheric mixing ratios. The water column to atmosphere transfer of methane is affected both by the relative importance of diffusive exchange of dissolved methane and through ebullition. The relative contributions of different subsea compartments to the methane fluxes is also approached through isotopes. We are exploring triple isotope fingerprinting of bottom water methane to apportion its sources.

Changes in the upper Arctic Ocean since 2007: Atlantic Water Entrance, Freshwater Distribution and Pathways

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The presentation synthesizes recently published papers (see below) on changes in the Upper Arctic Ocean since 2007. Results were obtained combining unique in situ measurements and modeled fields from high resolution Mercator Ocean operational model PSY4. We first focused on changes in the Atlantic Water (AW) circulation and properties at its entrance to the Arctic via Fram Strait (Artana et al., 2022, Athanase et al., 2021). AW progressed further north following new pathways, over the Northern Yermak Plateau and further east above the 3,800 m isobath. The AW flow featured significantly enhanced mesoscale activity. We then examined how the freshwaters, which isolate the sea-ice from the heat stored at depth, have seen their distribution, pathways and exports changed over the last 14 years over the deep Basins (Bertosio et al. 2022a, 2022b). After 2012 the Beaufort gyre extended northward and increased the freshwater content in the Makarov Basin, near the North Pole. Coincidentally, the freshwater content decreased along the East Siberian slope, along with the AW shoaling, and the Transpolar Drift moved from the Lomonosov Ridge to align with the Mendeleev Ridge. These changes in freshwater distribution were followed in 2015 by a marked change in the export of freshwater from the Arctic Ocean with a reduction in Fram Strait (−30%) and an increase in the western Canadian Archipelago (+16%).

Sea ice Studies and Their Linkages to the Atmosphere and Ocean During the MOSAiC Expedition in 2019/20

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Year-round observations of the physical snow and ice properties and processes and their interaction with the atmosphere and the ocean were studied during the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition in the Arctic Ocean from October 2019 to September 2020. The overall aim of the snow and sea ice observations during MOSAiC was to comprehensively characterize the physical properties of the snow and ice cover in the central Arctic over an entire annual cycle. This objective was achieved by detailed observations of physical properties, and of energy and mass balance of snow and ice. The measurements cover all seasons and thus all stages of sea ice and snow evolution over one year. We found large spatial variability in snow metamorphism and thermal regimes impacting sea ice growth, prompting the need to better understand snow-related feedback processes in the future. The ice pack revealed rapid transformation and motion along the drift in all seasons, driven by atmospheric conditions, indicating more similarities across scales than classically assumed.

Ecosystem Dynamics in the Pacific Arctic: Key Drivers of Biological Change in the Context of Climate Warming

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Warming seawater and reduced sea ice have changed the status of the marine ecosystem in the northern Bering and Chukchi Seas. Variations in upper-ocean hydrography, light penetration, primary productivity, lower and upper trophic levels, pelagic-benthic coupling and carbon cycling are being evaluated through the Distributed Biological Observatory (DBO). This international cooperative venture was initiated in 2010 in the Pacific Arctic to facilitate multiple process research cruises by cooperating countries. The DBO emphasizes annual standardized sampling by researchers on an international suite of ships occupying agreed-upon transect lines to measure the current ecosystem status as well as developing environmental trends. Continuous data are also obtained through mooring measurements, satellite observations, and autonomous glider sampling. The first decade of DBO sampling has revealed that seasonal and interannual hydrographic changes are driving shifts in species composition, distribution and abundance, with northward range expansions into Arctic waters for some temperate species and negative impacts for some ice dependent species. The seasonal timing of phytoplankton growth influences food exported to the underlying sediments that are then used by epi- and infaunal benthic animals, which are important prey for benthic-feeding marine mammals and seabirds. The sediments are also indicators of changing organic carbon cycling that provides seasonal and interannual records of water column biological events. This presentation will highlight findings from studies of biological change, the use of sediment chemistry to understand ecosystem status, and key physical drivers for these observed changes. It will also discuss the ongoing development of the DBO concept to the Atlantic sector and Davis Strait/Baffin Bay, bordering Greenland and Canada.

Session 1

Variability of Arctic Ecosystems Due to Arctic Rapid Change

Assessment of Arctic Marine Ecosystem with Integrated Acoustic Systems

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Climate change has profoundly affected marine ecosystems across the globe, including the polar oceans, from plankton to predators. Understanding the mechanisms by which climate variability impacts multiple trophic levels is critical for determining the polar marine ecosystem's response to climate change. Sustained observations are key to the understanding of the causes and consequences of marine ecosystem changes related to climate change. However, most of the long-term studies in the polar marine ecosystems are limited to observing lower trophic levels (i.e. phytoplankton) by satellite remote sensing. Studies are scarce and sporadic on the spatio-temporal variability of mid to high-trophic levels, which form important links in the food web. It is still unclear how climate change affects mid to high-tropic levels in the polar oceans and trophic coupling. Thus, new strategies are required to develop further insights into how multiple trophic levels have responded to rapid environmental change. In this presentation, I would like to suggest an observation platform on the ecology of polar marine life with some expected outcomes using an integrated acoustic system with a vessel-based acoustic system, mooring-based acoustic system and unmanned mobile vehicles-based acoustic system. The aim of the research is to observe the long-term variability of mid to high-trophic levels from zooplankton to cetacean in the polar oceans through simultaneous observation using integrated acoustic systems. The systems will enable us to acquire the essential data on monitoring the marine organisms, which could give a new insight into understanding polar marine ecosystems.

The Role of Zooplankton Fecal Pellet to the Vertical Carbon Flux in the East Siberian Sea and the Chukchi Sea

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To investigate the role of zooplankton fecal pellets in the vertical carbon flux of the marine pelagic ecosystem, long-term observations were conducted using moored sediment traps in the seasonally ice-covered East Siberian Sea (ESS) and Chukchi Sea (CS). Sediment traps deployed in the ESS (115 and 335 m) and in the CS (325 m) sampled at intervals varying from 11 to 31 days from late August 2017 to early October 2019. Zooplankton fecal pellets and zooplankton collected in the traps (swimmers) were quantified, and the contribution of fecal pellet carbon (FPC) to the particulate organic carbon (POC) flux was assessed. Although FPC fluxes generally decreased during the ice season (mean sea ice concentration >80% during sampling interval), it increased when the under-ice bloom began due to enhanced grazing. The FPC flux in the ESS contributed up to 55% of the POC flux at 115 m and up to 30% at 335 m during sampling periods. In the CS, the FPC flux contributed up to 95% of the POC flux, suggesting the spatial difference compared to the former. Swimmers were mostly copepods that are often found in deeper layers, and Limacina spp. and amphipods were also abundant. While fecal pellets are known to be important in the biological pump because they can rapidly reach the deeper water layer, their contribution to the POC flux was highly variable. These FPC flux results reflect the importance of zooplankton in the regulation of the vertical carbon export in the Western Arctic Ocean.

Tight Association between Microbial Eukaryote and Giant Virus Communities in the Arctic Ocean

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Viruses are important regulatory factors of the marine microbial community including microeukaryotes. However, little is known about their role in the northern Chukchi Sea in the Arctic basin, which has oligotrophic conditions in summer. To clarify the link between microbial eukaryotic communities and viruses as well as environmental conditions, we investigated the community structures of microeukaryotes (from 3–144 μm and 0.2–3 μm size bio-particles collected from seawater) and Imitervirales (from 0.2–3 μm size bio-particles collected from seawater), a dominant group of viruses infecting marine microeukaryotes. To the best of our knowledge, no study has investigated both Imitervirales and eukaryotic communities in the Arctic Ocean. Surface water samples were collected at 21 ocean stations located in the northeastern Chukchi Sea and an adjacent area outside the Beaufort Gyre (Adjacent Sea), and at two melt ponds on sea ice in the summer of 2018. At the ocean stations, nutrient concentrations were low in most of the locations, except the shelf in the adjacent sea. The community variations were significantly correlated between eukaryotes and Imitervirales, even within the northeastern Chukchi Sea characterized by relatively homogeneous environmental conditions. The association of the eukaryotic community with the viral community was stronger than that with geographical and physicochemical environmental factors. These results suggest that Imitervirales actively infect their hosts even in the cold and oligotrophic seawater in the Arctic Ocean.

The Response of Arctic Roseobacter Bacteria to Temperature Variation

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Members of the marine Roseobacter group are ubiquitous in global oceans, but their cold-adaptive strategies have barely been studied. In a recent study, as represented by Loktanella salsilacus strains enriched in polar regions, we firstly characterized the metabolic features of a cold-adapted Roseobacter by multi-omics, enzyme activities, and carbon utilization procedures. Unlike in most cold-adapted microorganisms, the TCA cycle is enhanced by accumulating more enzyme molecules, whereas genes for thiosulfate oxidation, sulfate reduction, nitrate reduction and urea metabolism are all expressed at lower abundance when L. salsilacus was growing at 5℃ in comparison with higher temperatures. Moreover, a carbon-source competition experiment has evidenced the preferential use of glucose rather than sucrose at low temperature. This selective utilization is likely to be controlled by the carbon source uptake and transformation steps, which also reflects an economic calculation balancing energy production and functional plasticity. These findings provide a mechanistic understanding of how a Roseobacter member and possibly others as well counteract polar constraints.

Planktonic Ciliate Community Structure and its Indicator Function for Monitoring Arctic Warming

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Planktonic ciliates are an important component of microzooplankton, but there is limited understanding of their responses to changing environmental conditions in the Pacific Arctic Region. Through comparing the variations of ciliate community structure and their relationships with environmental features in the Pacific Arctic Region in the summer of 2016, 2019, 2020 and 2021, we found: 1), the abundance and biomass of total ciliate and aloricate ciliate were significantly higher in 2019 than those in 2016, while those of tintinnid were significantly lower; 2), the distribution of tintinnid species (Codonellopsis frigida, Ptychocylis obtusa, and Salpingella sp.1) in 2019 expanded by 5.9, 5.2, and 8.8 degrees further north of where they occurred in 2016; 3), The dominant aloricate ciliate changed from large size-fraction (> 30 mm) in 2016 to small size-fraction (10–20 mm) in 2019; 4), Pacific origin tintinnid species (Salpingella sp.1) had intruded into the Canada Basin and occupied the top abundance proportion in the Pacific Summer Water in summer 2020 and 2021; and 5), tintinnid species could be regarded as indicator species of each water masses in the Arcitic Basin and can monitor the Arctic Warming. These results provide basic data on the response of the planktonic ciliate community to hydrographic variations and implicate the potential response of microzooplankton to Pacification as rapid warming progresses in the Pacific Arctic Region.

Session 2

Arctic Geochemistry Process and the Controlling Mechanism

Centennial Sea-Ice Variability Influencing Organic Carbon Sources in the Western Arctic Ocean

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Arctic sea ice plays a vital role in Earth's climate system through its influence on the planetary radiation balance and ocean convection. The spatial and temporal variability of Arctic sea ice is important for understanding regional and global climate change and its ecological impacts. Recently, the Arctic has experienced marked warming and declining sea-ice cover. Ice-melt caused by Arctic warming enhancing ice algae and phytoplankton growth. Ice-free conditions have also facilitated the upwelling of nutrients from deep- to surface-waters via wind-driven mixing, further augmenting algal growth within both sea ice and open water. Changing sea-ice cover also influence the transfer of organic matters from land to sea, as terrestrial materials are incorporated into ice during its formation along the coast, and subsequently transported long distances before melting and sinking to the seafloor. In addition, terrestrial organic carbon fluxes from Arctic rivers have increased significantly over the last century in association with a 128 km3/year increase in total river discharge to the Arctic. These alterations to the Arctic Ocean organic carbon cycle represent an important feedback on global climate. Here, we use proxy-based methods to study long-term Arctic sea-ice variability and its role in organic carbon cycle. The lipid-biomarker-based sea-ice proxy PIP25 in two sediment cores on the Chukchi Sea shelf is analyzed to reflect the sea-ice coverage in the western Arctic during the past centuries. The δ13C and Δ14C data of total organic carbon were combined to estimate the fractional contribution from active layer of permofrost, ice complex deposition and marine primary production, to investigate the linkage between sea-ice conditions and sedimentary organic carbon sources and burial.

The Decadal Trends of Sea Surface pCO_2 and CO_2 sink in the Western Arctic Ocean

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While rapid climate warming and sea ice loss have induced major changes in sea surface partial pressure of CO_2 (pCO_2), long-term pCO_2 trends are unknown in the Arctic Ocean. Here, we report changes of summer pCO_2 from 1994-2017 in the western Arctic Ocean. We find the rate of increase in the Canada Basin to be more than two times the rate of atmospheric CO_2 increase, in contrast with no significant increase on the Chukchi Shelf. Warming and ice loss in the basin have enhanced CO_2 increase and amplified the pCO_2 seasonal amplitude, and resulted in a rapid decadal increase. Consequently, the summer air-sea CO_2 gradient has reduced rapidly and may become near zero within two decades. In contrast, strong and increasing biological CO_2 uptake has held pCO_2 low on the Chukchi Shelf, and thus the CO_2 sink has increased and may increase further due to the atmospheric CO_2 increase. Based on these assessments, we further quantitatively evaluated how the oceanic CO_2 sink responds to rapid sea ice loss. The air-sea CO_2 flux and the regional CO_2 sink in the western Arctic Ocean from 1994 to 2019 were examined by two complementary approaches: observation-based estimation and a data-driven box model evaluation. The pCO_2 observations and model results showed that summer CO_2 uptake significantly increased by about 1.4 0.6 Tg C decade-1 in the Chukchi Sea, primarily due to a longer ice-free period, a larger open area, and an increased primary production. However, no statistically significant increase in CO_2 sink was found in the Canada Basin and the Beaufort Sea based on both observations and simulation. The reduced ice coverage in summer in the Canada Basin and the enhanced wind speed in the Beaufort Sea potentially promoted CO_2 uptake, which was, however, counteracted by a rapidly decreased air-sea pCO_2 gradient therein.

Climate Change Drives Rapid Decadal Acidification in the Arctic Ocean from 1994 to 2020

Di Qi

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The Arctic Ocean has experienced rapid warming and sea ice loss in recent decades, becoming the first open-ocean basin to experience widespread aragonite undersaturation [saturation state of aragonite (Ωarag) < 1]. However, its trend toward long-term ocean acidification and the underlying mechanisms remain undocumented. Here, we report rapid acidification there, with rates three to four times higher than in other ocean basins, and attribute it to changing sea ice coverage on a decadal time scale. Sea ice melt exposes seawater to the atmosphere and promotes rapid uptake of atmospheric carbon dioxide, lowering its alkalinity and buffer capacity and thus leading to sharp declines in pH and Ωarag. We predict a further decrease in pH, particularly at higher latitudes where sea ice retreat is active, whereas Arctic warming may counteract decreases in Ωarag in the future.

Changes in Materials Fluxes from Arctic Ocean Margins as Traced by Radium Isotopes

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Global warming has led to dramatic changes in the Arctic Ocean environment, including along the ocean margins. Changes include increases in river discharge, permafrost thawing, coastal erosion and reduced sea ice coverage. These processes are altering the mass balances of carbon, nutrients and trace elements in this high latitude marine system. Radium (Ra) isotopes have been used for decades as tracers of sediment- and rock-water interactions in the ocean. Here, we use Ra isotopes to infer changes in material fluxes from the Arctic Ocean margins over the past two decades. Examples from published and new data will be used to support our hypothesis that reduced sea ice coverage has led to enhanced sediment-water exchange across both eastern and western Arctic shelves. These changes in turn may lead to higher productivity in this ocean basin, or in the North Atlantic Ocean, which is a major gateway for the export of Arctic Ocean surface water.

A Mesocosm Approach to Studying Arctic Ocean-Sea Ice-Atmospheric Processes under Controlled Conditions

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In this presentation I will highlight recent advances in studying the dynamic Arctic Ocean-sea ice-atmospheric (OSA) processes from two mesocosm-scale sea ice research facilities at the University Manitoba, Canada. The facilities include the Sea-ice Environmental Research Facility (SERF; operational since 2012) and Churchill Marine Observatory (CMO; partially operational since 2020). At the core of the facilities are an outdoor sea ice pool (one pool at SERF and two pools at CMO) with a movable roof, a large suite of in-situ, real-time sensors, and on-site laboratories. Sea ice is grown naturally in winter months from formulated (SERF) or natural (CMO) seawater under various controlled conditions (e.g., seawater salinity, water circulation speed and pattern, presence or absence of snow cover, natural or controlled melting) with the capacity of applying chemical, isotopic and microbiological tracers. This mesocosm approach has helped us to address numerous critical knowledge gaps in our understanding of Arctic OSA processes. Among the most significant scientific advances are 1) the application and ground-truthing of remote sensing techniques to study surface properties of sea ice and snow (e.g., surface roughness; dynamics of frost flowers; detection of oil spills on and in ice); 2) the discovery of a dramatic pH gradient of over 2–3 units within a thin layer of sea ice; 3) the dynamics of formation and dissolution of ikaite in sea ice; and 4) the recreation of Arctic spring-time boundary-layer photochemical phenomena (e.g., bromine explosion events, ozone depletion events, mercury depletion events). I will review the motivation and research capacity of SERF and CMO, highlight some of these major scientific advances, and discuss how the mesocosm approach can be integrated with field, laboratory, and modeling studies to improve our understanding of a changing Arctic Ocean and its implications.

Session 3

Circulation, Transport and Flux in a Changing Arctic Ocean

Recent Observations in the Arctic Chukchi Borderland from the Araon Summer Expeditions, 2015–2022

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We have carried out the Arctic Ocean summer expeditions using the Korean ice-breaking research vessel Araon to investigate marine environmental changes in the Pacific Arctic region in response to the Arctic climate change. In this study, we focused on spatiotemporal variations in physical properties (i.e., circulation pattern, water mass composition, stratification/mixing, etc.) in the Arctic Chukchi Borderland (CBL). We analyzed the hydrographic data (CTD, XCTD, and ocean moorings) obtained from 2015 to 2022. In 2017, the cold saline water was observed on the Chukchi continental slope, which was previously observed on the East Siberian continental slope. It occupied the depths between 70 and 150 m, corresponding to the layer between the Pacific and the Atlantic waters, and gradually moved eastward along the continental slope. The intrusion of the cold saline water had a profound influence on the shoaling of the Pacific-derived halocline layer around the CBL, implying that heat (warm summer water) and nutrient (cold winter water) were likely to be delivered to the upper layer. In addition, our results provide insights into the impact of large-scale circulation in the Pacific sector of the Arctic Ocean on the interannual variations of salinity, temperature, and water velocities obtained at certain mooring sites located on the Chukchi continental slope.

Existence of the Mendeleev Gyre and Its Role in Arctic Circulation

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On the basis of conductivity, temperature, and depth (CTD) and nutrient data obtained during the Korean R/V Araon 2012 summer Arctic cruise, a gyre-like local circulation in the Chukchi Abyssal Plain is identified as the Mendeleev Gyre (MG). Evidence supporting the existence of the MG includes uniform temperature, salinity, and density in the central plain; a cold core surrounding the plain; a bowl-like surface steric height embedded in the background field; and a lens structure appearing in the vertical section. The nitrate – phosphate (N – P) relationship in the Chukchi Abyssal Plain suggests gyre-like mixing. In an ice–ocean coupled model used to simulate the MG and its multiyear variation, a gyre-like flow pattern is shown to appear only during 2011 – 2014 corresponding to the sea ice retreat, particularly in 2011 and 2012. Therefore, the MG might be an accompaniment of sea ice retreat. Lateral entrainment is suggested as the driving factor of the MG. The eastward boundary current and the northwestward Pacific inflow provide momentum and relative vorticity by lateral turbulent friction, which facilitates the current leaving from the isobaths to generate a gyre. The inclined isopycnal interfaces from west to east are verified to facilitate an eastward slope flow along inclined isosteric height interfaces. The MG plays the role of a watershed in preventing the outflow of the shelf water and benefiting the colder and fresher shelf water transported directly to the Canada Basin.

Arctic Ocean Amplification in a Warming Climate in CMIP6 Models

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Arctic near-surface air temperature warms much faster than the global average, a phenomenon known as Arctic Amplification. The change of the underlying Arctic Ocean could influence climate through its interaction with sea ice, atmosphere and the global ocean, but it is less well understood. Here we show that the upper 2000 m of the Arctic Ocean warms at 2.3 times the global mean rate within this depth range averaged over the twenty-first century in the CMIP6 SSP585 scenario. We call this phenomenon the ‘Arctic Ocean Amplification’. The amplified Arctic Ocean warming can be attributed to a substantial increase in poleward ocean heat transport, which will continue outweighing sea surface heat loss in the future. Arctic Amplification of both the atmosphere and ocean indicates that the Arctic as a whole is one of the Earth's regions most susceptible to climate change.

Physical Observations During MOSAiC: First Results from Year-round, Basin wide and Small-scale Measurements from a Drifting Observatory

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The Arctic Ocean has been scarcely observed year-round, yet the variability in ocean state and varying processes are important to the global and regional coupled climate system. The Multidisciplinary drifting Observatory for the Study of the Arctic Climate (MOSAiC) was a year-long drift with the Arctic sea ice from autumn 2019 to late summer 2020. Physical-oceanography observations were carried out by Team OCEAN, an international consortium that planned the design, field work and analysis of detailed measurements of the Arctic Ocean system from top to bottom. Unprecedented to date, the effort has already led to advances in our understanding of small-, meso- and regional-scale processes, in a large-scale context. Interdisciplinary aspects relevant to the ecosystem, biogeochemistry and climate as a whole is an important aspect of the team's work, that marks the comprehensive approach of the whole of MOSAiC to understand the coupled climate system.

The observations were making use of different approaches: autonomous and manual measurements, from the ship, installations on the ice, autonomous ice-tethered systems in an approximately 40 km radius around the drifting ship and ice-based central observatory. Both routine measurements as well as temporary, event-focused observations formed part of the field work.

Here we present results covering the full seasonal cycle and much of the Eurasian Basin, focusing on the full-depth and regional scale as well as important local to mesoscale processes. This will include an overview of the Team OCEAN measurements as well as published results and a glimpse at ongoing studies.

Increasing Winter Ocean-to-ice Heat Flux in the Beaufort Gyre Region, Arctic Ocean

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Ocean-to-ice heat flux (OHF) is important in regulating the variability of sea ice mass balance. Using surface drifting buoy observations, we show that during winter in the Arctic Ocean's Beaufort Gyre region, OHF increased from 0.76±0.05 Wm-2 over 2006-2012 to 1.63±0.08 Wm-2 over 2013-2018. We find that this is a result of thinner and less-compact sea ice that promotes enhanced winter ice growth, stronger ocean vertical convection, and subsurface heat entrainment. In contrast, Ekman upwelling declined over the study period, suggesting it had a secondary contribution to OHF changes. The enhanced ice growth creates a cooler, saltier, and deeper ocean surface mixed layer. In addition, the enhanced vertical temperature gradient near the mixed layer base in later years favors stronger entrainment of subsurface heat. OHF and its increase during 2006-2018 were not geographically uniform, with hot spots found in an upwelling region where ice was most seasonally variable.

Variation of Pathways and Transports for the Canadian Arctic Archipelago Throughflow

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The throughflow in the Canadian Arctic Archipelago (CAA) had a significant impact on the North Atlantic Ocean with the Arctic climate change. The findings of physical mechanisms driving the transport of the CAA throughflow differed and few studies about the detailed pathways of the CAA throughflow were made. A high-resolution ice-ocean coupled Arctic Ocean Finite-Volume Community Ocean Model (AO-FVCOM) was used to examine the interannual and seasonal variability of the pathways and transports of the CAA throughflow and the mechanism of sea level pressure (SLP) in driving the variation of the CAA throughflow quantitively. The simulated volume transport through Davis Strait, Nares Strait, Lancaster Sound and Jones Sound showed consistent increasing trends over 1978−2016 and the larger flux in winter and spring than in summer and fall. The variation of volume transport through Nares Strait contributed more than Lancaster and Jones Sound to the variation through Davis Strait. Five process-oriented experiments were made to further explore the role of SLP in setting up and controlling the sea surface height (SSH) difference and thus the throughflow transport in the CAA. The SLP was a primary forcing to control the SSH difference and the outflow transport compared with the wind forcing. The upstream and downstream SLP difference, however, made a slight direct contribution to driving the volume transport of the CAA throughflow.

Session 4

Arctic Sea Ice Variation and Redistribution

Mass Balance Processes of Arctic Sea Ice: Change and Current Situation

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Sea ice is the key element that makes the atmosphere-ocean interactions in the Arctic Ocean different from other oceans. The wide area and thin thickness of Arctic sea ice make it very sensitive to atmospheric and ocean forcing. The mass balance of Arctic sea ice plays a vital role to regulate the exchanges of heat, momentum and fresh water between the ocean and the atmosphere. Based on the observation data of the sea ice mass balance buoys over the Arctic Ocean in the past 20 years, we identified the temporal and spatial changes of the Arctic sea ice mass balance, especially for the freezing and thawing processes, and its response mechanism to the atmosphere and the ocean, and revealed the differences between seasonal ice and multi-year ice. In addition, based on the MOSAiC international expedition, we constructed the most comprehensive sea ice mass balance buoy observation array in the transpolar stream region, obtaining the sea ice mass balance processes through the entire ice season for the floes with various initial thicknesses. We used the data to characterize the impacts of the winter sea ice growth on the stratification of the upper ocean, and the impacts of the snow and sea ice melting on the heat and salt exchanges between sea ice and ocean in summer. The results exhibit the new normal of the Arctic sea ice mass balance processes.

Seamless Sea-ice Forecasts with the AWI Coupled Prediction System

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A new version of the AWI Coupled Prediction System is developed based on the Alfred Wegener Institute Climate Model v3.0. Both the ocean and the atmosphere models are upgraded or replaced, reducing the computation time by a factor of 5 at a given resolution. This allowed us to increase the ensemble size from 12 to 30, maintaining a similar resolution in both model components. The online coupled data assimilation scheme now additionally utilizes sea-surface salinity and sea-level anomaly as well as temperature and salinity profile observations. Results from the data assimilation demonstrate that the sea-ice and ocean states are reasonably constrained. In particular, the temperature and salinity profile assimilation has mitigated systematic errors in the deeper ocean, although issues remain over polar regions where strong atmosphere-ocean-ice interaction occurs. One-year-long sea-ice forecasts initialized on January 1st, April 1st, July 1st and October 1st from 2003 to 2019 are described. To correct systematic forecast errors, sea-ice concentration from 2011 to 2019 is calibrated by trend-adjusted quantile mapping using the preceding forecasts from 2003 to 2010. The sea-ice edge raw forecast skill is within the range of operational global subseasonal-to-seasonal forecast systems, outperforming a climatological benchmark for about two weeks in the Arctic and about three weeks in the Antarctic. The calibration is much more effective in the Arctic: Calibrated sea-ice edge forecasts outperform climatology for about 45 days in the Arctic but only 27 days in the Antarctic. Both the raw and the calibrated forecast skill exhibit strong seasonal variations.

Arctic Sea Ice Volume Export through Fram Strait and Changes in Sea Ice Speed

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During recent decades Arctic sea ice is decreasing in both area and volume. While the majority of this retreat can be attributed to warming of the Arctic atmosphere and ocean, the contribution associated with changes in sea ice dynamics are still under discussion. If the export of sea ice is increasing this would enhance the decrease of sea ice volume in the Arctic Basin. Fram Strait is the main gate where about 90% of the sea ice export from the Arctic Basin is happening. Sea ice volume export can be derived by combining sea ice thickness, drift, and area observations. Sea ice drift and area can be obtained on a daily basis from satellite passive microwave (PMW) radiometers SSM/I and SSMIS, however, at low spatial resolution. The sea ice drift record shows a clear increase in sea ice speed starting at the beginning of the 2000s. This change in sea ice speed got more variable during recent years. Since 1990 upward looking sonars (ULS) are operated as moored instruments in Fram Strait. The ULS measure the distance to the ice underside and water surface, which allows to observe the sea ice draft and consequently to estimate the sea ice thickness. Concurrent with ice thickness in the Arctic Basin the ULS in Fram Strait observe a strong decrease in mean and modal sea ice thickness of 15% and 20%, respectively, between 1990 and 2014. The sea ice drift and area observations from satellites are combined with the ULS ice thicknesses do derive the sea ice volume flux in Fram Strait, which shows a decrease of −27%±2% per decade between 1990 and 2014. Thus, for the given time period, changes in sea ice export do not drive the sea ice volume decrease in the Arctic Basin. However, for individual years like 2007 and 2012 the ice export likely has contributed to the loss of summer sea ice.

Sea Ice in Focus - The Year of Polar Prediction Sea Ice Drift Forecast Experiment (SIDFEx)

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The Sea Ice Drift Forecast Experiment (SIDFEx) is a community effort to utilise and foster sea-ice drift forecast capabilities at lead times from daily to seasonal. We collect, process, and analyse forecasts that are made with various methods, largely for drifting sea-ice buoys of the International Arctic Buoy Program (IABP), but also for campaigns such as the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC). SIDFEx is part of the World Meteorological Organization’s Year of Polar Prediction (YOPP) and inspired by increasing research and operational needs to forecast future positions of assets drifting in Arctic sea ice. A systematic assessment of real drift forecasting capabilities is also foreseen to improve our physical understanding of sea ice and to help identify and resolve model shortcomings. Since the launch of SIDFEx in 2017, thirteen groups have been contributing drift forecasts. Some forecasts are based on free drift or on drift observed from satellites during past years, but most groups derive their days-to-seasonal-range forecasts by means of diagnostic Lagrangian tracking based on predicted drift fields of coupled or uncoupled general circulation models. The majority of submissions are in near-real time and include deterministic and probabilistic forecasts. Here we present results from more than 170,000 individual forecasts, evaluating them against the observed drift and comparing forecast skill with simple benchmarks and between forecast systems. We describe how we construct consensus forecasts and how they have been used to support the MOSAiC campaign.

Representing the Small Scale Sea-ice Dynamics in High Resolution Models

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Environment and Climate Change Canada (ECCC) uses a number of ice-ocean forecasting systems, such as the Regional Ice-Ocean Prediction System (RIOPS) that are used for an increasing number of purposes, such as the forecasting of sea ice conditions or the assessment of ice pressure hazards for navigation in Canadian waters. In these systems, the ice model component is represented by the Community Ice CodE (CICE) and the standard Elastic-Viscous Plastic rheology.

Seasonal Predictability of Summer Sea Ice in the Baffin Bay Region

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We investigate the predictability of summer seasonal sea ice in July, in the Baffin Bay region. Our focus is atmospheric forcing and pre-conditions that might occur in the preceding winter. We find that the summer sea ice is significantly affected by the preceding winter North Atlantic Oscillation (NAO) and the East Atlantic Pattern (EAP), with a "two-winter lead-time", and also has a strong linkage to preceding spring circulation modes. For example, sea ice in July 2020 has pre-conditions that link to November-December in 2018 and January-February-March in 2019. This is the "two-winter lead-time". Thus, we developed a statistical forecast model, based on empirical multiple linear regression, using NAO and EAP and preceding spring atmospheric circulation modes. With the "two-winter lead-time" for NAO and EAP, the forecast model explains about 25% of the internal variance of the observed sea ice area (SIA), and has a correlation coefficient of 0.51 compared to observations. When we use winter NAO and EAP, and the linear trend, we can develop a new model, "model 1" with a 16-month lead-time and correlation coefficient 0.72 of observations. And adding EOF4 of the SLP for the preceding spring, we can create "model 2", with a shorter 2-month lead-time, and correlation coefficient of 0.79. In forecasted SIA for July 2021, errors are about 0.8% for "model 1" and 8.6% for "model 2". We produce spatial maps of estimated sea ice concentration (SIC) and estimate the corresponding correlation coefficients and residual standard errors to be 0.6-0.7 and 0.2, respectively. We also discuss possible physical mechanisms that can dominate seasonal forecasts.