Interdisciplinary Poster Session

Monday 29th January, 17:30-19:00

1.1/Abstract 37: Shotaro Uto[1], Natsuhiko Otsuka[1]
[1]Hokkaido University, Japan

A New Framework of Naigability Assessment of Ships in Arctic Sea Routes

Arctic sea ice has been decreasing rapidly and commercial use of the Arctic Shipping Routes has been expanding in recent years. However, sea ice is still a serious hazard for arctic navigation, especially for a large merchant vessel with a low ice class. It requires special consideration for safer and greener navigation and toward the sustainable use of the Arctic Shipping Routes. In the present study, we use “Navigability” as a technical term for safe and green ice navigation. In general, the navigability of vessels in ice waters can be assessed from two perspectives: structural safety, which is determined by the strength of the hull and propulsion system, and propulsion performance, which is determined by the hull form and the output of the propulsion system. For safety assessment, AIRSS (Arctic Ice Regime Shipping System) for the Canadian Arctic and POLARIS (Polar Operational Limit Assessment Risk Indexing System) for the Arctic Ocean are the systems that evaluate navigational risks and provide safety limits for ships in ice. In these systems, risks can be evaluated based on the ice class of vessels and an encountered ice regime in which sea ice information is depicted by an ice chart. For the assessment of propulsion performance, a lot of research and development have been conducted so far. Using the same sea ice information, it would be possible to assess safety and propulsion performance more consistently. However, there were few past studies for the propulsion performance assessment using ice chart information. The authors developed the method for predicting ship resistance and propulsion power in an ice regime using ice chart information. Based on these methodologies, the authors propose a method for evaluating propulsion performance limits in an ice regime. The procedure of propulsion-performance limit assessment is demonstrated for an ice-strengthened merchant vessel. Toward realizing a more comprehensive assessment of ice navigability, the authors proposed the framework of the navigability assessment of ice-class vessels by combining POLARIS with the proposed method for evaluating propulsion-performance limits in an ice regime.

1.2/Abstract 40: Weixin Zhu[1], Shiming Xu[1], Lu Zhou[2], Siqi Liu[1], Yong Luo[1], Jianbin Huang[1]
[1]Tsinghua University, China, [2]University of Gothenburg, Sweden

Sea Ice Thickness Retrieval during the 2018 Greenland Polynya Event – A Study with CryoSat-2 and SMOS

Arctic sea ice is a vital component of the global climate system, exerting influence by the albedo effect and the modulation of air-sea interactions. It is undergoing rapid changes due to climate change, becoming younger and thinner. In the Arctic Ocean, the sea ice in northern Greenland is amongst the oldest and thickest. However, the sudden stratosphere warming (SSW) event in February 2018 caused an unusually warm southerly wind and an unusually large polynya near the northern coast of Greenland. In this study we examine the capabilities and deficiencies of various satellites for the remote sensing of sea ice thickness during the polynya event, including CryoSat2 the radar altimeter and SMOS the L-band passive radiometer.

Firstly, our focus is for the retrieval of thin ice within the polynya. Given the intricate nature of polynyas, characterized by the mixture of newly formed thin ice, leads, and thick ice floes, we analyze the uncertainties associated with CryoSat-2 products. We also perform inter-comparison of sea ice thickness retrievals using SMOS, CryoSat-2/SMOS synergy, and other methodologies. The results reveal that the existing retrieval algorithms struggle with the classification and the retracking the CS2 waveforms within the polynya, leading to challenges for the retrieval of ice thickness and sea surface height. Additionally, the sensitivity to SMOS brightness temperature (TB) to sea ice thickness is lost for the fully developed polynya. We further analyzed the retrieval of sea ice thickness and snow depth on multi-year ice to the north of the polynya. High temperatures, heavy snowfall, and significant ice deformation affect multi-year ice in this region. Numerous small sea ice features cause ambiguous CS-2 waveforms, adding complexity when combined with SMOS data. Additionally, potential penetration issues for CS2 radar signals in the snow cover during/after warming events are apparent. In the context of ongoing climate change, the retrieval challenges may be increasingly more common and should be dealt with in future development of satellite payloads and retrieval algorithm.

1.3/Abstract 63: Natsuhiko Otsuka[1], Shotaro Uto[1]
[1]Hokkaido University, Japan

Navigational hazard by sea ice convergence in the North East Passage

In parallel with the rapid retreat of Arctic sea ice, the Arctic Ocean has been attracting the maritime sector to utilize the Arctic Sea route. Following two trial voyages transferring the North-East Passage(hereinafter NEP) in 2010, commercial use of the NEP started to increase by transporting natural resources such as iron ore and gas condensate. Furthermore, Russia started year-round transport of liquefied natural gas and crude oil from the Yamal Peninsula and the Kara Sea coast. Thus far, there has been no significant maritime accident that caused environmental damage in the NEP water area. However, in early November 2021, about 20 cargo ships were beset in the East Siberian Sea and the Chukchi Sea by harsh sea ice. All of them were rescued by a Russian nuclear icebreaker, but some of them were forced to wait for rescue for more than a week in the ice-covered sea. In this way, it is important to know what state of sea ice condition would become a serious navigational hazard.

This study aims to investigate sea ice condition that causes beset incident of ice-class ship by focusing on sea ice convergence. Here, three typical beset incident cases occurred in the NEP in November 2021 were chosen for a case analysis. Ship track was retrieved from satellite AIS and sea ice condition was retrieved from TPAZ4 ocean-sea ice data assimilation system.

Among these three incidents, one cargo ship(ARC 4) sailed eastward independently about one week ahead of the rest of the two ships(ARC4 and FS-1C) and was beset in the western part of the East Siberian Sea. The rest of the two ships sailed together along almost the same route as the first one and were beset in the same water area. As a result, these three ships were ice-locked together. Then a week later, a Russian nuclear icebreaker rescued them and supported their navigation until sea ice conditions became calmer enough for them to navigate independently in the Chukchi Sea. In these incident cases, sea ice concentration was almost 100%, and ice thickness varied from 0.2m to 1.4m. And ships were unable to operate when ice thickness reached 0.5m~1.0m in the case of independent navigation. In the case of icebreaker-supported navigation, ship speed reached nearly 10 knots even though ice thickness exceeded 1.0m. On the other hand, there were many cases in which ship speed markedly slowed even thinner sea ice condition was expected.

One possibility of this might be sea ice convergence behavior. To assume sea ice convergence, authors introduced sea ice thickness and ice concentration to the prior research of sea ice convergence factor by drift speed change rate (Kimura, 2004). This new factor could be an ice volume change ratio when it becomes

negative means ice volume increases and ice convergence increases. This factor showed slightly negative when and where beset incidents occurred in the East Siberian Sea, as ice floes would tend to accumulate and make it difficult for ships to navigate.

1.4/Abstract 64: Jake Thoenen[1]
[1]United States Coast Guard Academy

Projected Sea Level Rise and Flooding of Coastal Infrastructure at Four Major Arctic Maritime Ports

Over the past century, human activities have led to changes in the Earth's climate over a relatively short period of time, resulting in sea level rise (SLR) that can impact coastal infrastructure. As the Arctic continues to become more accessible, maritime activity in the Arctic has greatly risen, leading to increased maritime development projects – especially in coastal areas. To determine if current and future infrastructure will remain intact and functional, it is essential to understand how SLR impacts will affect structures in the Arctic. The goal of this project was to identify key infrastructure with potential exposure to flooding as a result of SLR by 2050, 2100, and 2150 at four ports in the Arctic region: (1) Port of Nome, United States; (2) Port of Nuuk, Greenland; (3) Port of Sabetta, Russia; and (4) Port of Murmansk, Russia. The influence of SLR on these ports was examined with a multi-source data integration technique incorporating the publicly available Arctic Digital Elevation Model (ArcticDEM) from the University of Minnesota's Polar Geospatial Center, satellite imagery from Google Earth, ICESat-2 Light Detection and Ranging (LiDAR) datasets, and a SLR projection model from the Intergovernmental Panel on Climate Change Sea Level Projection Tool (IPCC SLPT AR-6). This analysis provides key insights into the extent to which Arctic ports will be exposed to coastal flooding due to SLR in the future. Results presented will include a combined visualization of each port based on satellite imagery, with port infrastructure highlighted, with respect to exposure to coastal flooding under different temporal scales, tidal conditions, and extreme weather events.

1,5/Abstract 113: Connor Rettinger[1], Jackie Dawson[1]
[1]University of Ottawa, Canada

A Comprehensive Content Analysis Examining Arctic Maritime Shipping Risks in the Northwest Passage (NWP)

The Canadian Arctic has seen significant changes in sea ice conditions and weather patterns since the beginning of the 21st century. This has led to summer months having ice-free days throughout many sections of the northwest passage (NWP). If global warming patterns persist, this will introduce

partial shipping seasons through areas of the NWP and increase accessibility from Europe to Asia. Previous research has examined the individual risks of maritime shipping operations through the NWP, though there has yet to be a study that examines hazards and risks in a comprehensive matter. This study is the first phase of a large-scale research risk assessment project to assess hazards and risks throughout the NWP comprehensively. Using academic literature, this research uses a wide range of sources to conduct a comprehensive content analysis of past and present-day risks of maritime shipping within the Arctic. This study uses natural language processing to identify hazards and risks to Arctic shipping operations. Keywords and phrases found within the previous step will be used to identify scholarly publications to conduct an initial risk rating to determine possible data sources, data limitations, hazard/risk severity, frequency, control measures, and direct/indirect impacts from the identified hazards and risks. The risks identified in the publication's results will be synthesized based on the hazard/risk likelihood of occurrence and severity. The study will create a list of comprehensive hazards and risks from most to least severe to aid policymakers, researchers, and maritime ship operators in prioritizing the most detrimental risks. This study will also aid future research to create risk assessment frameworks and models that address complex problems using a data-driven approach.

1.6/Abstract 122: Anita Parlow[1]
[1]Fulbright Scholar Iceland

Sustainable Innovations in the Arctic from Ancient Times

The ongoing melting of Arctic sea-ice, accompanied by a simultaneous increase in natural resource development and shipping activities, has generated an urgent need to enhance preventive action, and improve reactions. The subject of this presentation would reflect upon evolving approaches for coexistence of policy that links together two distinct Arctic philosophies: one a millennia of indigenous observations that perceives the marine ecosystem as an indivisible whole; the other, more recent, compartmentalizes environmental protections into separate categories of western science. Efforts to produce coexistence between the two philosophical approaches is improving maritime monitoring and forecasting, as co-existence is also able to diminish risks to ecosystem challenges.

Various Arctic stakeholders, including shippers, commercial fishers, tourist vessels, and governments are demonstrating a growing interest and capacity to address the interconnected challenges of hazards to shipping and marine ecosystems protections. This presentation will address the participation of indigenous peoples, their expressed priorities, and increasingly pivotal role in shaping the Arctic's marine policy and legal landscape. It would also reflect upon

efforts for greater inclusion of indigenous priorities in Arctic policy discourses.

This presentation examines the impact of the changing seasonal timing of sea-ice melt, its impact on Arctic shippers and subsistence fishers, hunters and whalers through the lens of Siberian Yup'iks who have lived on St. Lawrence Island in the Bering Sea for more than 2,500 years. My research is based in communities, such as St. Lawrence Island's Savoonga, where residents firmly maintain continuity with a millennia of observations, monitoring, and anticipating Bering Sea conditions in order to put food on the table. The central premise of this presentation is that the satellite technologies remote sensing and related methodologies when synthesized with strategies that have evolved over a millennia, demonstrably support more effective interventions to protect Arctic marine ecosystems, shipping and other challenges as sea-ice disappears earlier, faster and greater.

The presentation would reflect upon the insights, forecasts, and priorities of subsistence practitioners and Western scientists, raising questions for two ground truth realities: First, who determines the priorities for innovative design of research technologies? Second, what methods regarding indigenous priorities are included as part of the strategic design to ensure a meaningful inclusion of indigenous priorities? The distinct approaches of shippers, indigenous communities and western scientists, would be reflected upon to better understand how the "ground truths" and the distinct approaches and priorities that are being linked to enhance sustainable practices, forecasting techniques, and fulsome monitoring capabilities. The presentation will also reflect upon a key challenge for the region's innovators, a much needed integration of the two approaches to support timely and reliable oceanographic forecasts and ecosystem protections on an Arctic-wide scale,

The challenges of warming, sea-ice retreat and impacts to sustained biodiversity represents an existential threat that squarely confronts not only the Arctic, but all of humankind.

1.7/Abstract 227: Eirik Malnes[1], Malin Johansson[2], Zuzanna Swirad[3]
[1]NORCE, Norway, [2]UiT – The Arctic University of Norway, Tromsø, [3]Polish Academy of Sciences

Sea ice presence, extent and duration in Hornsund, Svalbard in 2014-2023

Coastal erosion can be prevented by sea ice protecting the coastline from wave and ocean forces. In the Hornsund area on Svalbard wave models are set up and coastal erosion is being monitored. However, to accurately estimate the forcings we need to include sea ice presence and extent in the models, and for that we need long term records of the sea ice. Synthetic aperture radar (SAR) images can

penetrate clouds and are not hindered by darkness and are therefore ideal for such monitoring. Here we establish the sea ice presence, extent, and duration the Hornsund area using SAR images from the ESA satellites Sentinel-1A/B. The entire data record from 14 October 2014 to 29 June 2023 was used in combination with a segmentation algorithm creating a time series of ice/open water maps. Every 1.57 days on average there was one new image, making the time record near daily. The maps have a resolution of 50 m and cover 9 full sea ice seasons, in addition is the long-term changes discussed using an earlier existing record using SAR and optical satellite images extending the record back to 1999/2000 providing a 22 year record.

The Hornsund area was divided into four parts, the main basin and the three major bays: Burgerbukta, Brepollen and Samarinvagen. As fast ice often forms in the bay this enabled analysis of the fast ice formation within sections of the fjord. The sea ice duration was on average 158 days of the year and was initiated by the arrival of drift ice from the west in October. Fast ice formed later in the bays and normally was this time difference 24 days. In spring (June) did the presence of drift ice disappear 20 days before the last fast ice disappeared. The sea ice extended to on average 41% of the total bay area, though the largest coverage was observed in the Samaringvagen in the south. Likely is the narrow width of the mouth and the angle of the mouth with respect to the inlet to the Hornsund area (90 degree) a major factor for the larger ice extent. The highest sea ice extent was observed in April and the coverage for the years 2019/20, 2021/22 and 2014/15 was the highest of the investigated seasons. This corresponded to the years with the longest negative air temperature years. Intern-annual seasons were observed but no gradual trend throughout the years investigated.

1.8/Abstract 237: Leigh Stearns[1]
[1]University of Kansas, USA

Dynamic behavior of icebergs observed in Greenland fjords from 2017-2021

Iceberg calving is a major source of mass loss around the Greenland Ice Sheet. Quantifying iceberg size and distribution is critical in parsing solid vs liquid ice sheet mass loss, constraining freshwater flux parameters in coupled ocean models, and providing information for maritime operators. However, until now there has not been a comprehensive iceberg dataset for all Greenland fjords. Here we show the first five-year bi-monthly time-series of iceberg distribution for all fjords in Greenland, from May 2017 to December 2021, comprised using Sentinel-1 Synthetic Aperture Radar imagery and machine learning. Our results show the dynamic behavior of icebergs in Greenland fjords, where concentrations fluctuate rapidly over bi-monthly time-frames. Importantly, we also find a major drop in total iceberg area from February to April 2018 in six out

of seven ice sheet drainage basins; the total iceberg area does not recover back to pre-February 2018 levels by December 2021 (the end of our record). Our results provide important insight into the short-term mobility of icebergs, and a possible long-term trend of reduced iceberg area.

1.9/Abstract 238: Kerry Nickols[1], David Koweek[1], Brad Ack[1]
[1]Ocean Visions, USA

Assessing possible pathways and climate interventions to stabilize Arctic sea ice

Halting emissions of greenhouse gases and carbon dioxide removal, alone or combined, are unlikely to cool the planet in time to prevent massive shifts and loss of function for critical marine ecosystems. One ecosystem at particular risk is Arctic sea ice, which in addition to habitat provision serves an important role in stabilizing the global climate through its high albedo. Ocean Visions is leading an international, multidisciplinary, multisector collaborative 'mapping' process to assess and document the current status, critical needs, and highest priorities to advance the conversation around pathways and climate interventions to stabilize and/or repair Arctic sea ice. The map reviews the current state and potential of all relevant pathways, social and environmental risks and co-benefits of these approaches, policy and governance considerations, and the knowledge gaps that need attention to further evaluate the interventions. This work is inherently multidisciplinary and international, and it is guided by an international advisory board of diverse Arctic experts. Thus far the mapping process has engaged 70 individuals from 13 countries and identified 24 pathways. These approaches span various levels of technology and societal readiness, and their impact spans from the local (e.g., thickening ice via pumped water) to the global (e.g., stratospheric aerosol injection). Once finalized, the road map will be available on an interactive web platform similar to Ocean Visions' previous road mapping efforts (www.oceanvisions.org/roadmaps). These road maps have allowed interested actors to work together on key priorities and are regularly updated and refined as advances emerge in science, technology, governance, policy, and ethics. This talk will highlight the mapping process, lessons learned, and next steps to advance critical research necessary to inform decision-making for climate interventions.

1.10/Abstract 12: Seongyeob JEONG[1], Hyunkyo SEO[2]
[1]Korea Research Institute of Ships and Ocean Engineering (KRISO), [2]Korea Polar Research Institute (KOPRI)

Current status and future of research on core technology development for eco-friendly icebreaking container ship for Arctic Sea Route

Over the last few decades, the Arctic sea ice extent has decreased sharply due to climate change. Recent research estimates that summer sea ice in this region could disappear almost entirely by the 2030s, earlier than the Intergovernmental Panel on Climate Change (IPCC) forecasts. From this point of view, melting sea ice in the Arctic Ocean could open up new international shipping lanes, such as the Northern Sea Route (NSR), and provide significant cost savings for shipping companies by decreasing the transit distance and time compared to the traditional route.

Geopolitical issues in the Arctic regions have recently increased due to the Russia-Ukraine war. However, the Arctic route is expected to become one that can compete with the Suez Canal in the future.

Moreover, sustainability has become a key area in the Arctic region, and sustainable shipping is an essential component of Arctic transport. Therefore, Smart and Eco-friendly technologies will play a significant role in the maritime sector, leading the future of shipbuilding technology. Accordingly, the Republic of Korea and other major shipbuilding countries have been mainly focused on these trends and developing new technologies in the shipping industry.

From this perspective, the Korea Arctic Research Consortium (KoARC), as a multidisciplinary cooperation platform including institutions, universities, and businesses involved in Arctic research, has conducted the planning research of an 'Eco-friendly Icebreaking Container Ship Development' for a national R&D project. The study aims to identify critical tech trends and develop a research framework with a holistic and strategic approach. First, innovative technologies, such as short- and mid- and long-term sea ice prediction, ship design and propulsion systems based on green tech, and winterization of vessels, are investigated to overcome the potential obstacles in Arctic shipping and to protect the vulnerable Arctic environment. And then, the R&D roadmap is established to achieve sustainable development in the Arctic shipping. Finally, a schematic diagram of the research is derived. These outcomes can be used to prepare and plan a research project to contribute to navigation safety and ensure sustainability, including environmental protection in Arctic shipping.

2.1/Abstract 4: Antonia Radlwimmer[1,2], Siiri Wickström[2,3], Holt Hancock[2,4], Einar Jenssen[5]
[1]Finnish Meteorological Institute, [2]University Centre In Svalbard, Norway, [3]Skred, Norway, [4]Norwegian Geotechnical University, [5]Telenor Svalbard

In situ observations of snow depths on avalanche prone slopes surrounding Longyearbyen, Svalbard

Snow avalanches are a considerable threat to many northern communities, such as Longyearbyen in Svalbard, and the future risk picture of snow avalanches is sensitive to the magnitude and timing of climate changes experienced by these regions. The expected increase of snow depths in the Longyearbyen region, in the short term, combined with more winter days with melt is expected to exacerbate the snow avalanche hazard.

In Longyearbyen, Svalbard, a deadly avalanche in 2015 initiated a wide array of avalanche prevention and mitigation measures. The in situ snow depth sensors used in the study presented here are part of this effort. The snow avalanche risk is mitigated with daily avalanche forecasts, in addition to permanent barriers. For the avalanche forecasting snow depth in the release zones is a key variable. As the snow cover is to a large extent controlled by meteorological variables - snowfall, wind transport and air temperatures - it is important to link meteorological parameters to snow depth evolution and variability.

In this work we investigate and validate available snow depth data, both modeled and measured, for Longyearbyen from an avalanche forecasting perspective in the winter seasons 2021/2022 and 2022/2023. Further we test the hypothesis of whether automatic weather station data from representative altitudes in the vicinity of the avalanche paths can be used as a proxy for snow depth changes.

Our results suggest that on regional scales snow depth forecasting models do well. But on the local scale of individual slopes and valleys, such as the one Longyearbyen is situated in, in situ measurements are the most valuable source of real time information. Further, precipitation, though the most intuitive source of snow for any given point, does not serve well as a predictor of snow depths around Longyearbyen. Still, as precipitation will determine the total amount of snow that can be distributed over the region, it remains a good regional proxy of snow input.

On avalanche path scales wind is the most important meteorological determiner of changes in snow depth. We show that the challenge in translating precipitation amounts to snow depths stems from the high local variability in snow depth, driven by wind variability due to complex terrain and local topographic features. Our results demonstrate the added value of in-situ snow depth monitoring of avalanche prone slopes.

2.15/Abstract 20: Elena Popova[1,2], Victor Bogin[1,2], Sergei Malyshev[1,2], Georgii Ovanesyan[1,2]
[1]Gramberg All-Russian Research Institute of Geology and Mineral Resources of the World Ocean (VNIIO), [2]Arctic and Antarctic Research Institute, Russian Federation

New vessel / drifting ice station 'Severny Polyus': science onboard it during the 'North Pole-41' expedition, marine geology example

Perennial sea-ice cover is one of the most prominent features of the central Arctic Ocean which is still a desired study area for many researchers, both in fundamental and applied science. Drifting in the ice is one of the solutions – this is why the new vessel 'Severny Polyus' has been built. In its first expedition, the 'North Pole-41' by the Arctic and Antarctic Research Institute several research groups were studying water, atmosphere, biota, ice, ice-ship interaction, earth physics, and ocean bottom: here some aspects of the marine geologists' work are covered and some results are given. Such large geomorphological features as Lomonosov Ridge, Amundsen Basin, Gakkel Ridge, and Nansen Basin were studied, the work area spans over 83-88.5°N. A giant box corer and a 6 m long gravity corer were used to obtain cores: the gears entered the water through a hole in the ice astern that required often ice removal. Sediment composition was studied in smear slides and coarse fraction (≥63 mkm) wet-sieved samples. Cores have been sampled onboard so that many types of analyses such as grain-size, mineralogical, macrofaunal, magnetostratigraphic, and others could be performed in laboratories later on the land. Some geochemical analysis was performed onboard using a gas chromatograph and a spectrofluorimeter. Profiler PARASOUND P70 ICE (Teledyne Marine, USA) allowed to receive continuous ocean sub-bottom profile during the whole drift. Particles ≥10 mm (considered to be ice-rafted debris) were studied in detail onboard. The material of the box corer was divided according to lithology (up to five layers were described with about 50 cm recovery in general) and wet-sieved, then the psephites were picked. The large volume of the material allowed us to make both qualitative and quantitative analyses of IRD in a profile across the Lomonosov Ridge (83°N) near the Eurasian margin. The size was measured in three axes, the roundness degree was determined, and the rocks and minerals composition were studied using a binocular microscope, 1-3 N hydrochloric acid was used to distinguish carbonate rocks. The preliminary age model was made by correlating lithology and the MS curve with a core PS87/079-1 (see report). Carbonate sedimentary rocks dominate with 38%, igneous, terrigenous sedimentary, and metamorphic rock debris follow with 18-22%, and ferromanganese formations have 3%. When moving from bottom to top along the section, carbonate and metamorphic rocks are replaced by igneous ones, the content of terrigenous rocks is quite stable what implies an increase in Eurasian material input and a decrease in Canadian one since MIS 3. The thin "dark gray-brown" layer in the middle of the core, distinguished by both the largest size of psephites and their highest content, reflects a period of active deposition of ice- and iceberg-rafted material. On the eastern slope and top of the ridge, a consistently high IRD content is observed (15-45 psephites/m3), while on the western slope, the occurrence does not

exceed 3 psephites/m3 in the box core, which is explained by a higher sedimentation rate on the western slope after the deglaciation peak.

2.2/Abstract 26: Jan Rene Larsen[1]
[1]Arctic Monitoring and Assessment Program (AMAP)

Observing the Arctic: Empowering indigenous and local perspectives

In recent decades, sustained observations of Arctic environmental and socio-economic
systems have revealed a pace, magnitude, and extent of change that is unprecedented by
many measures.

The purpose of the Sustaining Arctic Observing Networks (SAON) Roadmap for Arctic Observing and Data Systems (ROADS) process is to stimulate multinational resource mobilization around specific plans for coordinated observation of the Arctic. The process has a clear value propositions, to serve as a tool for the joint utilization of Indigenous and local knowledges and science, to coordinate engagement and to ensure that maximal benefits are delivered.

The aim of SAON-ROADS is to align diverse, pan-Arctic partners engaged in observing high priority observing foci - called Shared Arctic Variables (SAVs). This session will provide an update on the SAON-ROADS advisory process and highlight progress being made on candidate SAVs under a series of pilot efforts.

2.3/Abstract 33: Amy Macfarlane[1]
[1]UiT – The Arctic University of Norway, Tromsø

Ocean-sourced snow: An unaccounted process on Arctic sea ice

The water isotope composition of the winter snow cover on Arctic sea ice is strongly enriched in heavy isotopes near the snow-sea ice interface, incompatible with typical enrichment values through snow metamorphism processes alone. Our stratigraphic investigations using computed tomography combined with isotopic analyses of snow show that a substantial amount of the snowpack is not of atmospheric origin but created from the frozen sea ice. Here, we show that sea ice sublimation under the high-temperature gradients during the Arctic winter significantly contributes to the total snow water equivalent on Arctic sea ice. This, until now, unaccounted oceanographic source of ”snow” has a different chemical composition than atmospheric snow and is more likely to contribute to sea salt aerosols and a snowpack molecular iodine to Arctic ozone depletion. With the predicted decrease in sea ice thickness, this production of ocean-sourced snow will become an essential factor contributing to our

understanding of the influence of snow on regional atmospheric and sea ice processes.

2.4/Abstract 35: Flore Wijnands[1], Peter Heintzman[1], Matthew O'Regan[1], Nalan Koc[2], Tom van der Valk[1,3], Helen Coxall[1]
[1]Stockholm university, Sweden, [2]Norwegian Polar Institute, [3]Swedish Museum of Natural History

The use of sedimentary ancient DNA to study biotic responses to abrupt climate warming in the Central Arctic Ocean.

Global warming is leading to environmental changes in the Arctic Ocean which will greatly impact marine arctic ecosystems and the communities dependent on them. Consequently, there is a strong need to understand and predict these changes. One way to understand the future is to study the past. The Arctic Ocean has experienced multiple episodes of rapid warming during the Middle and Late Pleistocene, which may act as an analogue to the present situation.

Sedimentary ancient DNA (sedaDNA) is a relatively new method developed to study paleo-ecosystems based on ancient DNA fragments preserved in layered sediments of, for instance, lakes and oceans. While other paleoenvironmental proxies, such as microfossils and biomarkers are restricted to certain groups of microbial organisms, sedaDNA can be used to reconstruct entire ecosystems. Especially in the Arctic, sedaDNA seems a promising new method due to the near absence of microfossils during glacial periods. Available sedaDNA research on marine sediments is however still very limited and no studies have been published yet on the Central Arctic Ocean.

This summer we collected (near) surface sediments in the Nansen Basin as part of the Arctic Ocean II Cruise 2023, organised by the Norwegian Polar Institute. We are analysing ancient DNA fragments in these sediments using shotgun metagenomics with the aim of reconstructing biotic responses to rapid climate change at the Pleistocene-Holocene boundary and to broaden our knowledge of marine Arctic paleo-ecosystems. In addition, this study allows us to improve our methods for sedaDNA studies in marine arctic environments.

2.5/Abstract 69: Malou Johansen[1]
[1]UiT – The Arctic University of Norway, Tromsø

Spatiotemporal change in fish communities in NE Greenland

The Arctic is warming three times faster than rest of the world, which influences all trophic levels in one way or another.

Northeast Greenland is influenced by cold water coming from the Arctic Ocean, hence the species living there are more Arctic oriented compared to e.g., Barents Sea – a more Atlantic species oriented due to species coming with the Atlantic current. Arctic fish species have a narrower temperature tolerance, grow slowly, and get older; these characteristics make them prone to rapid change, which is currently happening.

I will be investigating whether there is a spatiotemporal change in fish diversity in NE Greenland between 2002-2022 and investigate whether there are differences between fjords and coasts. There have not been any studies focusing on this area before. It is going to be interesting to see whether any changes occur with the increasing temperature and melting glaciers. It is likely that the study finds change in abundance over the timescale.

2.6/Abstract 72: Ilkka Matero[1], Jan Larsen[2], Heïdi Sevestre[2], Mikko Strahlendorff[3], Katriina Veijola[3], Michael Karcher[4], Heikki Lihavainen[1]
[1]Svalbard Integrated Arctic Earth Observing System (SIOS), [2]Arctic Monitoring and Assessment Programme (AMAP), [3]Finnish Meteorological Institute, [4]Alfred Wegener Institute of Polar and Ocean Research, Germany

Shared Arctic Variable definition on theme permafrost

The process of defining Shared Arctic Variables (SAV) aims to improve on the current limitations of Arctic observing systems by expanding monitoring capabilities through broad inclusion of Indigenous Knowledge and Local Knowledge, as well as coordinating and enhancing Earth Observation capacity and capability through refinements based on the needs of diverse user groups including local communities, academics, policymakers and industry. This work is being done in support and guided by the Roadmap for Arctic Observing and Data Systems process of the Sustaining Arctic Observing Networks (SAON). The Shared Arctic Variables will focus on observable processes and phenomena that the Arctic user and observing communities identify as important enough to warrant focused coordination for their acquisition.

Changes in the conditions and extent of permafrost are expected to have significant impacts on livelihoods and infrastructure of the people present in the Arctic. Consequently, permafrost is one of the first themes that has been chosen for piloting the SAV process in the Arctic PASSION project, which is a Horizon 2020 -funded project that aims to co-create a coherent, integrated pan-Arctic Observing System of Systems. Here we present the process and its current state, planned timeline and expected outcomes. We also discuss the feedback received from the experts involved and experiences so far.

2.16/Abstract 78: Máté Mile[1], Stephanie Guedj[1], Harald Schyberg[1]
[1]Norwegian Meteorological Institute

An Arctic Observing System Simulation Experiment for satellite observations: Uncertainty estimation of emissivity retrieval over sea-ice, ocean, and land

The relative importance of present observing system component contributions in this Arctic Numerical Weather Prediction model system is already well documented through data denial studies. For future enhancements in observations usage, Observing System Simulation Experiments (OSSEs) can assess the expected impact. In the frame of the Arctic-PASSION EU-funded project, we aim at configuring an Arctic OSSE to assess the capabilities of the current and future observing systems with special attention to microwave sounding instruments and the related surface emissivity retrieval approach in data assimilation. The goal is to demonstrate the impact of assuming a "perfect surface description" for the simulation and the assimilation of microwave low-peaking channels (for instance instruments onboard EUMETSAT Polar system and NOAA satellites). This will provide information on the value of the improvement of modeling the surface contribution to the observation. Technically, the Nature Run of the Arctic OSSE (provided by Météo-France) is used first, to simulate perfect observations, then 2) produce the perfect surface conditions with related perturbations. In this preliminary study, we will show how much uncertainty is associated with emissivity retrieval over mixed and complex surface scenes (sea-ice, ocean, and land) and quantify how much we can expect to gain in forecast quality by reducing this uncertainty.

2.7/Abstract 181: Katrina Lutz[1], Ilaria Tabone[1], Angelika Humbert[2], Matthias Braun[1]
[1]Friedrich-Alexander University, Germany, [2]Alfred Wegener Institute, Germany

Temporal and Spatial Characterization of Supraglacial Lake Rapid Drainage Events over Northeast Greenland using In Situ and Sentinel-2 Data

Supraglacial lakes play an important role in glacial surface mass balance calculations in the Arctic, as they collect meltwater and act as conduits for surface and subglacial runoff. The dynamic nature of these lakes is primarily influenced by rainfall, surface temperature and snowpack thickness, leading to strong interannual variations in the size and developmental rate of the lakes over the melt season. An important, yet understudied, aspect of supraglacial lake behavior is the occurrence of so-called rapid drainages. These are impactful events during which moulins suddenly open, draining the majority of a lake within hours or days. This drained water flows vertically through the moulin to the glacier bed and

eventually to the ocean, in the case of marine-terminating glaciers. Not only does this contribute to glacier mass loss and freshwater influx into the ocean, but can also cause temporary glacier speed-ups due to the reduction of friction on the glacier bed. Currently, the influencing factors involved in triggering these rapid drainages are minimally understood. Thus, this research focuses on evaluating the temporal and spatial variances in the rapid drainages of supraglacial lakes in Northeast Greenland, specifically over Zachariae Isstrom and Nioghalvfjerdsfjorden (79N Glacier).

In this study, a novel supraglacial lake depth estimation equation has been developed based on in situ sonar measurements taken from four lakes in Northeast Greenland. This equation has been applied to Sentinel-2 imagery over the 2016 to 2022 summer melt seasons to produce a supraglacial lake volume time series. Through this, insights into both large and small-scale trends can be observed. Here, individual lakes are tracked throughout the seven melt seasons, allowing for a detailed analysis of rapid drainage occurrences. Each lake has its own behavior, but general trends can indeed be seen. Firstly, even though the lakes have varying drainage frequencies, a correlation between the temporal occurrence of a drainage and its physical location is evident. Furthermore, the underlying mechanics causing the opening of moulins tend to affect a large spatial domain, often causing the simultaneous drainage of several adjacent lakes. Additionally, a rapid drainage occurrence seems to be uncorrelated to the current volume contained in the lake, implying a stronger influence from underlying glacier mechanics. Overall, through this study, further understanding of the behavioral patterns and influencing factors involved with the rapid drainages of supraglacial lakes has been gained.

2,8/Abstract 189: Matias Uusinoka[1], Arttu Polojärvi[1], Jari Haapala[2]
[1]Aalto University, [2]Finnish Meteorological Institute

At the limit of floe scale: A high-resolution study of sea-ice deformation through seasons and zones

Past analysis on sea-ice deformation has relied on satellite imagery resulting in low spatial and temporal resolutions. This coincides with the fact that the lower bound of scale invariance in ice deformation is analytically estimated at the scale of ice thickness. Analyzing scale invariance in turn from highly accurate buoy records has been observed problematic due to a lack of established data points. In response to the gap in high resolution empirical data, we use a new deep neural network-based motion estimate method with ice-radar imagery gathered during MOSAiC between October 2019 and September 2020 for statistical analysis of sea ice deformation. The novel approach enables analysis in length

scales down to 10 meters at a 10-minute temporal scale in a 10 km × 10 km domain. Overcoming the statistical issues of capturing the scale-invariant behavior in high-resolution ice deformation observations, we output ∼3 × 107 daily deformation estimates. The method allows quantification of deformation characteristics and analysis of established scaling laws at resolutions never analyzed before. Considering the changing ice conditions in the Arctic, we emphasize seasonal variability and separation between ice zones to highlight the transition from pack ice to the marginal ice zone. The aim of this work is then to analyze sea-ice deformation characteristics at a length scale close to ice thickness and highlight the transition between changing ice conditions.

2.9/Abstract 201: Linda Latuta[1,2], Lars Smedsrud[1,2]
[1]University of Bergen, Norway, [2]Bjerknes Centre for Climate Research, Norway

Hydrographic changes in Disko Bay over the last decade

Disko Bay is a highly productive marine ecosystem on the western coast of Greenland, characterized by a seasonal ice cover. Since the mid-1990s, there has been a significant warming of the water masses in the bay, along with a reduction in sea ice thickness and coverage. Observations to date show no monotonic warming, but large year-to-year variability is evident. Here, we investigate the cause of this variability and present updated hydrographic observations from 2018 to 2023. Given the extended spatial coverage of the data, we inspect the water mass structure across the bay, focusing on the warm inflow from the West and glacial modification on the East. We discuss the mechanism behind the water mass exchange, along with its potential influence on the sea ice cover and marine pelagic ecosystem of the bay.

2.10/Abstract 107: Guillaume Boutin[1], Jonathan Rheinlænder[1], Heather Regan[1]
[1]Nansen Environmental and Remote Sensing Centre (NERSC)

Beneath the Surface: Investigating the Effects of Sea Ice Breakup on the Arctic Ocean Mixed Layer

In recent decades, the Arctic sea ice has significantly reduced in extent and thickness. The shift to a younger, thinner ice cover renders it more susceptible to breakup during winter from strong winds or ocean currents. This has profound implications for air-sea interactions, sea ice formation, and overall Arctic Ocean properties. Despite their potential to impact Arctic climate, these breakup events are not captured by current climate models, thus representing a significant

knowledge gap in our assessment of future high-latitude climate.

In this study, we combine data from a coupled ocean-sea-ice model with satellite and in-situ observations to examine the impacts of winter sea-ice breakup in the Beaufort Sea over the period 2000-2018. From this data, we identify several large breakup events during winter, which have a significant impact on the local air-sea fluxes and upper ocean properties.

We find that enhanced lead formation during breakup promotes significant growth of new, thin sea ice. This causes local variations in simulated salinity and temperature associated with brine formation during sea ice formation and drives a deepening of the ocean mixed layer. The model also shows an increasing trend in lead formation (~4% pr. decade), which can be linked to decreasing ice thickness in the Beaufort region.

As Arctic sea ice continues to thin, our findings underscore the importance of sea-ice leads in shaping future winter sea-ice mass balance, with potential knock-on effects on the spatial and temporal variability of the Arctic mixed layer. Importantly, this emphasizes the need for improved representation of sea ice breakup processes in climate models to better understand and predict changes in the Arctic's ocean mixed layer and its broader implications for climate and ecosystem dynamics.

2.11/Abstract 220: Evgenii Salganik[1], Philipp Anhaus[2], Steven Fons[3], Mats Granskog[1], Knut Høyland[4], Christian Katlein[2], Benjamin Lange[1,5], Ruibo Lei[6]
[1]Norwegian Polar Institute, [2]Alfred Wegener Institute for Polar and Ocean Research, Germany, [3]University of Maryland, USA, [4]Norwegian University of Science and Technology, [5]Norwegian Geotechnical Institute, [6]Polar Research Institute of China

Effects of sea ice density evolution on sea-ice thickness retrieval from its freeboard during melt season in the Central Arctic

Here we investigate the temporal evolution of Arctic sea-ice density of different ice types, including first- and second-year level ice and first-year ice ridges, during the MOSAiC expedition. We show that sea-ice hydrostatic balance is affected by both short-term meltwater drainage events and a gradual decrease in the sea-ice density of first-year ice. We examine the potential errors in not considering the seasonal evolution of sea-ice density in ice thickness estimates from aerial and underwater retrievals. For our hydrostatic weighing measurements during the MOSAiC expedition in 2019–2020, the gas fraction of first-year ice was 4% during the autumn season, 2% during the winter season, and 3–6% during the melt season, while the gas fraction of second-year ice and ridges did not have a strong seasonal dependence. This gave a decrease in the

first-year ice draft-to-thickness ratio from 0.92 to 0.87, with a freeboard increase despite a 0.5 m ice thickness decrease during the melt season. During the first half of the advanced melt season, from 22 June to 29 July, we measured an increase in first-year ice freeboard by 0.02 m, which limits the estimate of sea ice melt from its freeboard or draft evolution without knowledge of sea-ice density seasonal evolution. Despite a potentially strong effect of sea-ice density evolution on sea-ice thickness retrieval during freeze-up and melt seasons, the processes and parametrizations of density seasonal evolution are poorly studied.

2.12/Abstract 222: Sebastian Gerland[1], Torbjørn Eltoft[2]
[1]Norwegian Polar Institute, [2]UiT – The Arctic University of Norway, Tromsø

Overview on, and first results from the CIRFA-2022 cruise, a ship-based Arctic research expedition with focus on satellite remote sensing of floating ice

In April/May 2022, Norway's first ship-based Arctic research expedition with a focus on satellite remote sensing of floating ice took place in the western Fram Strait in the Greenland Sea. The cruise, a main activity of the Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA), was conducted using Norway's ice class research vessel "Kronprins Haakon" as the platform. The expedition's main goal was to collect ground-truth data for validating remote sensing products for sea ice, icebergs and ocean. The science team consisted of 33 scientists and engineers from Norway and France. In addition to the observations and sampling in conjunction with satellite remote sensing, several other synergetic projects addressed changes in sea ice and ocean. Validation of sea ice remote sensing products tells us more about how accurate and reliable their information is. To retrieve ground-truth validation data at a multitude of spatial scales, especially for synthetic aperture radar (SAR) satellite imagery, the science team collected data and samples with surface information ranging in scale from micrometres, inferred from snow pits and sea ice coring sites, to kilometres, inferred from transects and drone data. In addition, autonomous sensors were deployed in sea ice and ocean to reveal sea ice and ocean changes and dynamics. Relevant validation parameters such as surface roughness, temperature, density, salinity and internal microscopic structure of snow and sea ice were measured in situ. Ice and snow thickness was measured with transects walking along lines on the ice. A laser roughness profiler was used to reveal surface topography characteristics, and analysis of snow pit measurements and ice cores revealed the texture and physical properties of snow and sea ice. Validation of satellite remote sensing requires that the ground-based measurements are geographically co-located with satellite acquisitions and coincide in time. During the expedition, this was regularly achieved. A whole suite of satellite images was acquired, including scenes from the European Space Agency's Sentinel-1 and the Canadian

RADARSAT-2 satellites. The results from combined ground truth and satellite measurements will help in future studies to address important research questions in Arctic remote sensing and development of new technologies. Here, we will give an overview on the expedition and show some first results from the data and sample analyses.

Additional authors include the CIRFA-2022 cruise shipboard scientific team.

2.13/Abstract 230: Melissa Chierici[1], Agneta Fransson[2], Elizabeth Jones[1], Helene Hodal Lødemel[1]
[1]Institute of Marine Research, Norway, [2]Norwegian Polar Institute

Ocean Acidification and effects in a changing Barents Sea

The Barents Sea is one of the inflow shelves to the Arctic Ocean with large contrasts due to the seasonal sea ice cover in the north and the warm Atlantic water inflow in the south. Recently, the northern Barents Sea and adjacent Nansen basin has displayed large changes caused by climate change such as seasonal sea ice loss and warming and expansion of the warm Atlantic regime. Additionally, ocean acidification (OA) occurs at fast pace in the northern Barents Sea and rates up to more than three times the expected due to atmospheric CO2 increase and the global mean pH decrease rates. We also know that the Arctic water in the north has naturally lower pH and higher dissolution potential for calcium carbonate (Ω) than the Atlantic water in the south and that further depressions of pH and Ω are unfavorable for in particular calcifying organisms, but also detrimental for non-calcifying organisms. Here we use a combination of water column chemistry data (carbonate chemistry and nutrients) from NANSEN LEGACY sections, bottom water data from the IMR Ecosystem survey for spatial contrasts in bottom environment and biological information on species distribution of benthic calcifiers in the Barents Sea. A combination of multi-disciplinary data will be used to understand more on potential marine ecosystem effects and possibly reveal adaptive capacity for changes caused by OA and climate change.

3.1/Abstract 29: Abbie Tingstad[1]
[1]Center for Arctic Study and Policy, U.S. Coast Guard Academy

Could Serious Games Provide an Avenue for Facilitating Community-Based Decisionmaking in the Context of Arctic Climate Change and Development?

Accessing physical and social science information related to the changing climate and connecting it with the lived experiences of communities can be vital for successfully integrating local perspectives into decisionmaking about long-term plans related to adaptation and mitigation. Insights from local observers

can scope data collection, analysis, and interpretation; resulting scientific work can in turn empower local communities to consider problems and solutions from multiple angles and to communicate their concerns and ideas. Yet setting up such two-way communication in order to facilitate information exchange in a way that creates beneficial feedback loops is not routine and there are few widely discussed models for doing so. This presentation will consider the use for serious games as a mechanism for facilitating such two-way discussions, and in particular the potential for helping overcome Arctic-specific issues such as sparse population, long distances, and the tendency for decisions impacting the region to be made from lower latitudes. It will focus on a structure for incorporating data about Arctic climate change into different potential aspects of games, including status quo benchmarking, starting future assumptions, narrative scenarios, player turns, outcome adjudication, and after play reflection. It will weigh the pros and cons of using this style of facilitated discussion for both gathering local community insights to shape climate change research as well as providing local communities with information that can empower their ability to participate in decisionmaking.

3.2/Abstract 43: Marja Helena Sivonen[1], Paula Kivimaa[1]
[1]Finnish Environment Institute

Energy Transitions and Arctic Security: A Comprehensive Analysis of Finnish and Norwegian Arctic policy

The Arctic region confronts a paradox that is of global significance: while fossil fuel production and consumption contribute to massive-scale environmental and climate degradation, there is an urgent imperative to protect the Arctic's fragile ecosystems while ensuring its habitability. This paper embarks on an in-depth exploration of zero-carbon energy transition processes in the Arctic and seeks to unravel the underlying factors that support incumbent energy regimes and hinders the development of sustainable energy technologies and consumptions practices. Our central hypothesis posits that the concept of security serves as an essential in explaining the dynamics of energy transitions in this unique context.

We systematically analysed all Arctic strategies put forth by Finland and Norway from 2006 to today. In tandem, we conducted 27 expert interviews with Arctic stakeholders during the period of 2022-2023. Employing a robust discourse analysis framework, we scrutinised the narratives surrounding energy transitions within the overarching framework of Arctic security. Our analytical approach consisted of two primary steps: firstly, we identified and employed macro processes developed within the sustainability transitions literature to trace the evolution of these transitions. Secondly, we critically connected these processes to the dual conceptualisation of security, encompassing both positive

and negative security paradigms. This methodological approach enabled us to go beyond traditional state-centric security frameworks and broaden the perspectives to encompass the nuanced challenges intrinsic to policymaking and the multifaceted issues confronting the Arctic region.

Our findings indicate that the Arctic strategies of Finland and Norway emphasise the fortification of existing energy regimes, which is intricately linked to negative security considerations. Furthermore, our analysis has unveiled instances of positive security discourses intertwined with both niche development and regime support, with a notable emphasis on the Norwegian documents that highlight the development of niches within the context of the oil and gas industry. This has both positive and negative implications, as while the production is ongoing it also brings societal well-being in the North. Although energy niches are supported in principle, it happens with strict limitations and in the rules of the regime, harsh conditions, and sparsely populated areas with scarce economic resources.

In addition to the document analysis, our interviews with Arctic experts have contributed a crucial regional perspective to the intersection of energy and security. Our analysis indicates that after the Russian war in Ukraine the Arctic stakeholders have had to reconsider and emphasise their roles not only in mitigating the adverse impacts of climate change but also as focal points of global geopolitical attention. The region's distinct viewpoint on how the Arctic should be developed and for whose benefit while pursuing sustainability adds a layer of complexity to this multifaceted challenge.

In summary, our research aims to shed light on the intricate interplay between energy transitions and security concerns in the Arctic. By analysing the Finnish and Norwegian policymaking and opening the security dimensions within, we aspire to advance the scholarly discourse while providing valuable insights to policymakers tasked with harmonising environmental sustainability with the security and well-being of the Arctic region.

3.3/Abstract 56: Delphin Ruché[1]
[1]Wild Lab Projects, Norway

Restoring Nature, Trust and Hope: Wild Lab Projects' Commitment to Citizen Science in Northern Norway.

Wild Lab Projects (WLP), a non-profit organization active around Tromsø & Senja, Norway, is dedicated to the principles of nature conservation, citizen science, and regenerative tourism. This initiative emerged from a fundamental aspiration to offer inclusive opportunities for both local residents and travelers to actively engage in endeavors aimed at regenerating our natural environment. The term

"regenerating" in this context signifies the tangible and quantifiable positive impacts that participants have on nature and the local community. WLP utilizes citizen science as a tool to empower people through various research and nature conservation projects. WLP also aims to mend the dwindling trust in science by connecting scientists with the wider community.

WLP collaborates with several research partners and has collaboratively designed eight distinct citizen science projects, fostering mutually advantageous relationships between scientists, participants, and the natural environment. However, while encouraging scientists to actively involve citizens in research activities, significant hurdles obstruct the realization of citizen science as a reliable tool for informed decision-making.

This presentation centers on the challenges encountered in the pursuit of dependable citizen science, the innovative methodologies developed in collaboration with our research partners, and preliminary findings gathered after a year of welcoming, training, and assisting participants in the field.

3.4/Abstract 75: Hajime Kimura[1], Tetsuo Sueyoshi[1]
[1]Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

Gaming for the Arctic: Education tools to know and learn about the Arctic

As a part of the "Arctic Challenge for Sustainability project (ArCS)" funded by the Ministry of Education, Culture, Sports, Science and Technology, Japan, we developed “The Arctic”: a board game that incorporates the complex elements of environmental changes, politics, and economics in the region. We intend for the game to be used as a learning tool, for example in school classrooms, where students can learn introductory information about the changes in the Arctic and their impact on northern society. It is useful for learning about and discussing the complex and interrelated elements of environmental change, politics, and economics in the Arctic. Players sit themselves at the negotiation table as scientists, business people, diplomats or indigenous people, and make decisions to cope with the changing Arctic. They must balance the demand for economic development with the need for environmental protection.

In our presentation, we will introduce the design and structure of the game, and then the potential and practice of this type of tool for education and capacity building on Arctic issues. While the development of the game required close collaboration between natural scientists and social scientists, together with professional game designers, the game itself proved to be a tool to stimulate interdisciplinary discussions among researchers.

The game is a powerful tool for integrating research findings into education and

capacity building in an entertaining way. Through experiencing the roles in the game, players are encouraged to engage challenges in the Arctic. Our case studies of using this game in education and outreach show that this new initiative engages the players on a complex and essential issue and highlights the need for scientific and Indigenous/local knowledge in policy and decision-making.

3,5/Abstract 98: Felicia Söderqvist[1]
[1]Luleå University of Technology, Sweden

Stories of Hydropower in the Swedish Arctic and Swedish South – cross-regional perspectives

In Sweden today, hydropower is a primary provider of electricity. What started as small providers of power for local businesses at the end of the 19th century grew larger and became widespread - integrating larger facilities, entire rivers, and industries. Less than a handful of rivers have avoided being harnessed for hydropower production purposes. In the beginning, Arctic Sweden had posed more of a challenge for hydropower developers. The distance to the major energy consumers and, by today's standards, poor transmission systems turned power transference into a hurdle. Most large-scale hydropower facilities in Arctic Sweden were products of the industrialization and rebuilding economies in the wake of WWII.

These largely State hydropower projects in Arctic Sweden became major sources of employment, but also landscape alterations. I investigate the long-term consequences of hydropower through a comparative case study analysis. This ongoing Ph.D. project has focused on the different actors, geographical changes, and narratives dealing with such changes. As hydropower is viewed as a major building block to power a green transition, the long-term consequences of hydropower are important to comprehend. Regional differences included, why a southern and an arctic case of hydropower are being compared.

Locally, hydropower has meant major changes in the conditions for how it is possible to make a living. Through this presentation, I will explain how hydropower has become part of what conditions daily life and livelihoods, but also how they might become part of the local industrial history featuring various degrees of acceptance and integration. Climate change and the green transition are cornerstones in corporate narratives of hydropower. The national and international agendas for a climate-neutral tomorrow put pressure on the continuation and effectiveness of hydropower facilities built in the 20th century. In my cases, such narratives have become part of the local narratives about why hydropower is needed, facing off against stories of what once was and actors arguing for biodiversity. In this crackpot, the road to sustainability and the fight

against human-induced climate change becomes multifaceted and turned into a crossroad of pathways.

Northern Sweden has a history of being framed as an area rich in resources. Together with other extractive industries, among them mining and forestry, hydropower has become a commonplace feature in the Swedish Arctic. Minerals, power, and timber became the foundation of Sweden's industrial and economic growth. Today, Arctic Sweden has become a scene for large investments into 'sustainable' industrial activities that will (supposedly) light the way for a green transition. Hydropower and wind power here play the part of providers of fossil-free power.

3.6/Abstract 103: Mehmet Erk[1], Jerbelle Elomina[2], Niklas Jonsson[3], Jonathan Karkut[4], Julie Scott[4], Stefania Cardinale[4], Tetsuo Sueyoshi[5], Hajime Kimura[5]
[1]Canterbury Christ Church University, [2]University of Natural Resources and Life Sciences, Vienna, [3]Gran sameby, Sweden, [4]Touch TD, UK, [5]Japan Agency for Marine-Earth Science and Techology (JAMSTEC)

Bridging Worlds: Transforming Arctic Research into an Immersive Game Experience

In an initiative that combines scientific research with gaming technology, this project presents a novel platform for conveying detailed research findings about the Arctic region, fostering a deeper understanding of the region's rich cultural heritage. Through interdisciplinary collaboration, the project serves as an educational tool, engaging users in an immersive gaming experience and innovating the traditional methods of research dissemination, thereby bridging the gap between science and the broader public.

Collaborative efforts are fundamental to this project, with a peer review board of scientific experts and cultural representatives overseeing the accurate and sensitive portrayal of the Sami people's heritage and lifestyle. The game functions as a significant tool for disseminating current research findings, enhancing understanding and appreciation of the Arctic region's complex dynamics, and adhering to international ethical standards that emphasize cultural sensitivity and accuracy.

Central to this project is the refined adaptation of the Boids model, initially developed by Craig Reynolds in 1987 to simulate flocking behavior (Reynolds, 1987). This model has been substantially developed to incorporate new behavior models based on a series of research findings, including insights from studies by Baskin (2003), Hansen et al. (2022), Kolpaschikov et al. (2015), and Kumar et al. (2018), coupled with real-life reindeer footage provided by Arctic Hubs

researcher, Niklas Jonsson. This integration provides a visual insight into the nuances of reindeer movements, enhancing the game's depth and educational value.

Furthermore, the game introduces diverse Non-Player Characters (NPCs), representing various stakeholders in the Arctic region, including Arctic researchers, Sami reindeer herders, industry representatives, and tourists. These NPCs enable players to delve into the complex socio-economic and environmental dynamics of the Arctic, fostering a deeper understanding of the multifaceted challenges and opportunities present in the region.

The ArcticHubs project aims to develop innovative tools and methods that promote solutions to the problems of resource conflicts in an industrialized Arctic. By focusing on the complexities of reindeer herding, the project seeks to provide players with tools to creatively explore new methods for navigating the intricate socio-economic and environmental dynamics prevalent in the area, thereby offering an authentic insight into the Arctic's socio-cultural dynamics and environmental nuances.

3,7/Abstract 104: Katrin Losleben[1], Elizabeth Barron[2], Angus Carlyle[3], Paula Mikalsen[1], Britta Sweers[4]
[1]UiT - The Arctic University of Norway, [2]Norwegian University of Science and Technology, [3]University of the Arts London, [4]University of Bern, Switzerland

Citizen listening: empowering democratic engagement through sound in an interdisciplinary project based in Tromsø/Romssa

Arctic Auditories – Hydrospheres in the High North focuses on water environments in Tromsø and its surroundings in the North of Norway. This interdisciplinary project engages scholarship and methods from geography, applied ethnomusicology, and feminist studies and sound arts and literature to develop strategies for understanding environmental change through sound. Thus the project tackles a significant environmental challenge using the social sciences, humanities and arts as the entry point, providing a unique perspective on how to activate citizen engagement in decision-making.

We present the innovative mixed methods that make legible new forms of environmental engagements such as the auditory and experiential. One such method is soundwalking, as initiated by Hildegard Westerkamp, and further developed in Arctic Auditories through input from our respective fields. The adapted soundwalks enable local project participants to guide public groups through aquatic sites while drawing attention to sounds which are meaningful for them. Solicited journaling, audio recordings, focus group discussions,

photographs, and short videos also all provide material for qualitative analysis.

Our mixed methods approach reframes listening as a form of civic engagement. Spatially representing sound as a marker of environmental change allows it to be correlated with climatic data, environmental data, soundsheds, viewsheds, and profiles of developed areas. This novel methodology and the empirical findings derived from it will create mechanisms through which citizens can engage in democratic knowledge production for science and policy, and shows how methods from the humanities and social sciences can produce novel representations for use by the public and decision-makers.

3,8/Abstract 156: Karen Barton[1]
[1]University of Northern Colorado, USA

Empowering Local Stakeholders through Citizen Climate Conversations and Story Maps

This research explores the paradox of oil and gas extraction alongside progressive climate policies in Colorado, USA through the lens of Julian Agyeman's "just" sustainability and considers the ways in which our community-engaged research applies to the Arctic context. This U.S. State Department funded research initiative investigates the ways in which a series of "Colorado Community Climate Conservations" enables us to understand how bringing disparate stakeholders to the table can allow science communicators to amplify local concerns and to better understand climate anxiety and community resilience in the wake of global change. Landmark work by Julian Agyeman provides an excellent framework for understanding "just" sustainability, which claims that if we wish to understand sustainability our focus must be on both human quality and the natural environment. A truly sustainable approach is one in which wider questions of social needs, economic opportunities and gender disparities are integrated fully into solutions. By and large - a presupposition endures within some spaces - that is, that we are saving the world for everyone equally - a notion that absolves us from issues related to equity and justice. Our research highlights the ways in which equity-minded, face to face, community conversations related to climate change, particularly in rural regions, can allow disparate stakeholders to coalesce and co-design appropriate climate mitigation strategies while empowering disenfranchised groups in the process. We believe this work can be scalable for the Arctic environment and its local citizens, given the synergies between Colorado and Norway's energy economies and their similarly longstanding green identities. Our research involves story mapping deliverables based on the outcomes of a series of Colorado climate conservations, serving to amplify stakeholder voices and concerns.

3.9/Abstract 174: Zack Klockar[1]
[1]SINTEF, Norway

Identifying the Driving Factors of Community Social Acceptance for Green Technological Artefacts

The matter of social acceptance is a pre-requisite for social sustainability and of increasing importance to mining and renewable energy industry projects. If the social acceptance is low on a community level, it can result in local resistance to new green technological artefacts, in turn causing delays and disruption to the green transition. This challenge is further pronounced in the Arctic, where the modern economy is largely extractive and export based, whilst there is presence of indigenous people and unique cultural heritage.

This research applies a mixed method to two pilot demonstrators in the mining sector, of which one inside the arctic circle. The research aims to identify the most relevant stakeholder communities and model the driving factors that influence the acceptance of a technological artefact in a community, by using the industry's resources.

By combining an Actor-Network Theory framework with theories on social acceptance and NIMBY, including the scalar model of the Social License to Operate and the social gap, the method seeks to inductively identify the drivers of a community's social acceptance based on the community's perception of an artefact. The applied method is (to be) used on two Nordic demonstrator projects in the mining industry in different phases of operation, one arctic. The two demonstrators are mines looking to achieve sustainable practices contributing to the green transition and good community relations. The identification of driving factors is thought to inform better community engagement from industry. The demonstrators are planned to take place during fall 2023. Expected further research is on the relevance and adequacy of the model in different cultural contexts.

3.10/Abstract 183: Anna Soer[1]
[1]University of Ottawa, Canada

Social licensing and sovereignty: renewable energies as tools for autonomy in the North-East American Arctic

The Canadian Northeast – Nunavut and Nunavik – as well as Greenland are at the crux of two intersecting dynamics: Firstly, the two first territories are highly dependent on fossil fuels to subsist to their needs. Isolated settlements and communities in Greenland are off-grid and are similarly dependent not only on fossil fuels but also on shipping and delivery calendars of said-fuel. Secondly,

energy diversification is accompanied by geostrategic issues surrounding mining potential as well as hydroelectric and wind energy potentials. While Greenland's South enjoys hydroelectric production for part of their energy needs, Qaanaaq has seen small scale local initiatives to reduce its dependency on fossil fuels. The construction of windmills in Sanikiluaq (Nunavut) is emblematic of the territory's policy for greater shares of renewables on energy production and use, and "bringing home" control over energy production. While Nunavut as immense mining potential for minerals deemed critical for the energy transition and while the sector has experienced rapid expansion in the last 10 years to reach 40% of Nunavut's GDP, it remains controversial with sexual violence issues as well as environmental and ecological concerns for the local population. Nunavik, represented by the Makkivik Society, seeks to re-start negotiations with the Québec provincial government to establish an autonomous government – thereby seeing greater control over resource and energy (revenue) management. Nunavik is also pushing for greater hydroelectric development by establishing cooperation with HydroQuébec – the province electricity provider. The energy transition is thereby in between interests: on the one side independence or autonomy – in continuity of ongoing Inuit decolonial and devolution processes, as well as reduction of the nefarious health and environmental effects of fossil fuels; and on the other side rising global interests on resource extraction in the region, especially so in Greenland. The social licensing process, also as described by the Canadian government, to seek support for renewable energy development – from mining to energy infrastructures - is not only anchored on the populations's participation and democratic processes, but also on larger geopolitical dynamics cutting across national borders in between extractivist interests, and insertion into the global market seeking a fair share of the pie to support further autonomous development for the Inuit across the Northeast American Arctic. Social licensing thereby cuts across levels of analysis, from the hyper-local, to the regional, to the international sphere. This presentation and communication seeks to dive deeper into the sheer complexity of actor-network dynamics in the Northeast American Arctic within social licensing processes by using the three cases of Nunavut, Nunavik, and Greenland – geographically neighbors while all being entangled into specific devolution agreements, jurisdictions, colonial histories, and own socio-economic contexts as well as autonomy goals.

3.11/Abstract 190: Mikko von Bremen[1]
[1]Bielefeld University, Germany

The role of funding agencies in Arctic research and policy making

Arctic knowledge and the need for scientific research in and on the Arctic are considered the foundation for political decision-making. The debate on mitigation and adaptation of climate change, the participation of citizens,

decision-making processes and the science/politics relationship are complex. The motivation for the research project 'Worldviews of Ice' at Bielefeld University is to investigate how worldviews are still present in today's Arctic research and policy making. Based on theoretical concepts of Critical geopolitics and Science and Technology Studies (STS) we investigate how different and also competing worldviews of the Arctic influence research in and on the Arctic. With the examples of Canada, Norway and Germany we show in an idealized science-politics cycle how worldviews of the Arctic influence (1) research agendas and public funding, (2) the conduction of research and (3) the translation of science into policy making processes.

'Research agendas and public funding'
In this case study research funding agencies are considered to be in the centre of the science-politics interaction following different scientific, strategic and political purposes. While it is generally acknowledged that political decision making in Arctic policies should be evidence based. The question what research in and on the Arctic is 'relevant' for public funding is one of the contested boundaries among science and policy making.
Through bibliometric data and trend-analysis on publicly funded Arctic research publications and qualitative document analysis of research agenda and funding programmes the aim is to illustrate for Canada, Norway and Germany the development of research agendas and funding priorities in Arctic research in the time period of 1990 to 2020. Guiding research questions in the case study are:

- What are the main funding agencies in Arctic research and how are they structured?
- Who are the main actors involved in defining Arctic research objectives and funding programs and how did funding priorities in Arctic research developed since 1990?
- How are consultations between science and politics organized, and what are the main consultation mechanisms?

As preliminary results it is to give an overview of the main Arctic research funding agencies in Germany, Norway and Canada according to their institutional forms, operational control and research profiles. This idealized categorization in scientific, strategic and political funding agencies allows the further analysis and trans-country comparison. Also, first results will be presented from bibliometric trend analysis on the development and priority setting in funding mechanisms and research areas in Arctic research by individual funding agencies.

3.12/Abstract 242: Hanne Cecilie Geirbo[1]
[1]Oslo Metropolitan University, Norway

Computer game for citizen involvement in climate adaption

This paper will present preliminary results from a research project that is developing and testing a computer game that aims to inspire collective action for climate adaptation in neighborhoods. Data from particular neighborhoods is used to create a realistic game environment where citizens can learn about how climate change affects their neighborhood and try out different climate adaptation measures that is available to them. The game design draws on geographical information such as administrative borders, buildings and infrastructure, topography and vegetation, and combines this with environmental variables such as temperature, rain, and pollution to create a game environment where the players can expose themselves to future scenarios and explore different actions they can take to mitigate and adapt to climate change in their neighborhood. The project is also developing a gameplay method where neighborhood organizations are invited to gaming events where groups of citizens play the game together and participate in facilitated discussions about which actions they can take in their building or local environment.

The game is developed by Polish and Norwegian partners in the research project 'Communities for Climate Change Action' and is currently tested in Warsaw. Heavy rain, heat island effects and air pollution due to the use of coal for heating are challenges are relevant environmental challenges for Polish cities. Climate adaptation measures relevant to this environment can be establishing rain beds to reduce the effects of heavy rain, solar installations to reduce the use of fossil energy sources, and planting trees to reduce heat island effects. The paper will present the primary game design principles that are used in the development and discuss how these principles can guide the development of climate adaptation games that address the geographical, environmental, social and cultural characteristics of cities in the Arctic region.

3.13/Abstract 243: Clara Good[1]
[1]UiT – The Arctic University of Norway, Tromsø

Upgrading post-war buildings with solar energy – involving end-users in the energy transition

At the end of the Second World War, most of the houses in the northernmost parts of Norway were burnt to the ground. The main part of the existing building stock in Finnmark and Northern Troms dates from 1945 onward, and many were built in the so-called reconstruction style. The houses, called 'gjenreisningshus' in Norwegian, were built with limited resources and the materials that were

available at the time.

The energy performance of these buildings can be enhanced by utilizing new technologies. This includes improving their thermal properties, integrating energy generation, storage and control systems into the building, as well as empowering the inhabitants to take control over their energy usage.

The focus of the Northern Homes project is to investigate how reconstruction houses can be upgraded using solar energy integration, in a manner that respects the cultural heritage and architecture of the buildings, and at same time enables them to be a part in the transition to a more sustainable community.

In the project, we will work with a pilot building in a small community in Finnmark and study the process from idea to locally adapted solar installation. During this time, the project group will investigate how the inhabitants, both of the pilot building and the local community, view the reconstruction houses and the heritage they represent, what changes they are willing to make to them, and identify the barriers and drivers for energy refurbishment. In addition, the project group will investigate ways of involving both local businesses and community and work together to create solutions. The methods used include interviews, school visits, and open community meetings.

A pilot building was selected among several buildings, where the owners had volunteered to be part of the project after a public outreach campaign. The selection criteria included how representative the building was for the reconstruction period, location, favorable solar orientation, and several other factors. The first pilot building site visit and community meeting is in preparation at the time of writing this abstract and will take place in Havøysund in Finnmark during October 2023. We would like to present our findings, impressions, and lessons learned from this first community outreach campaign at Arctic Frontiers 2024, in order to discuss and it with the scientific community to get input on the way ahead for our project.

3.14/Abstract 360: Linda Y Brewer[1], Edith Vorderstrasse[2]
[1]T-3 Strategies LLC, USA, [2]Inuit Visions LLC, USA

Best Practices in Arctic Social Engagements

While many social studies have been deployed in Arctic environs over the past decades, even centuries, governmental requirements for “consultation” remain limited in time, quality of interaction, and in content. This article examines the emerging best practices in Arctic Social Engagements.

Due to multiple factors, including the isolation of the Arctic, the extremes of the environmental context, and the unique culture and community, we argue that the approach must be tailored, taking each of these conditions into consideration. While multiple approaches have been deployed, there are a limited few that standout as truly respectful and effective. Those include:

- Designing and building a long-term, multi-year relationship in advance of any local development agenda;
- Deploying an in-depth program of community listening studies;
- Ongoing and joint monitoring of potential impacts of development on both the environment and subsistence life-style;
- Leveraging traditional ecological knowledge (TEK) and applying it alongside western science;
- Building a program which includes a clear development legacy; and
- Cooperatively identifying opportunities for both the community and the development entity.

Having both grown up in Utqiaġvik, Alaska, and having worked delivering Arctic Social Engagements as professionals, we examine each of these standout approaches and the ways that they can positively support respectful co-development in the Arctic and with Arctic Communities.

4.1/Abstract 46: Tiziana Durazzano[1]
[1]UiT – The Arctic University of Norway, Tromsø

Exploring Seasonal Dynamics of Copepod Communities in the Arctic Marine Pelagic Ecosystem: Insights from Nansen Legacy Data

Copepods, vital components of the Arctic marine pelagic ecosystem, serve as the linchpin connecting microbial processes and higher-level consumers. They comprise approximately 70% of the total biomass of mesozooplankton in the pelagic realm and are particularly responsive to shifts in the water column. This makes them excellent indicators of environmental change. Nonetheless, our comprehension of the ecological function of copepods and their assemblages, especially in high-latitude regions, remains incomplete. To bridge this knowledge gap, the present study focuses on copepod community structures in different seasons. Data were gathered within the framework of the Nansen Legacy Project in the Barents Sea to cover the area east of Svalbard. Leveraging this valuable dataset enabled us to investigate copepod community assemblages from winter to summer.

To unravel the seasonal dynamics of copepod communities, a trait-based approach is used, and a trait table tailored for Arctic species is introduced. The

aim is to gain insights into the composition and functioning of the ecosystem based on the distribution of functional traits within the species pool. The functional traits encapsulate the individual's Darwinian fitness, reflecting their capacity for reproductive success. The consequences of individual performance and responses ripple through populations, communities, and ecosystems, ultimately shaping their ecological dynamics. The present work points to a functional understanding of how different seasons influence copepod community structures and their ecological contributions. To achieve this, we employ ordination methods, exploring environmental variability within the context of the Arctic's extreme seasonality. Furthermore, different functional diversity indices were investigated to capture the nuanced seasonal variation in copepod communities, elucidating how they adapt to and interact in the fluctuating Arctic environment.

In conclusion, by unravelling the intricate relationships between copepods, their functional traits, and the environment, we are seeking a deeper understanding of the vital role copepods play in the face of seasonal variability in the Arctic.

4.2/Abstract 66: Concepcion Melovidov[1], Leah Zacher[2], Andrew Seitz[1]
[1]University of Alaska Fairbanks, USA, [2]Alaska Fisheries Science Center, USA
Testing the Efficacy of Mark Report Satellite Tags (mrPAT) to Examine Movements of Large Male Snow Crab (Chionoecetes opilio) in the Eastern Bering Sea

Understanding movements of high-latitude marine species can help refine management strategies, especially in a changing climate. In 2021 and 2022, the National Marine Fisheries Service (NMFS) eastern Bering Sea (EBS) summer bottom trawl survey showed an alarming decline in the snow crab population, and researchers indicate it was likely a mass mortality event where immature snow crab failed to recruit to maturity. Further complicating matters, snow crab distributions have shifted northward in the EBS over the last several decades, and their movements may also be occurring in areas that are unsurveyed down the continental slope or out of the U.S. Exclusive Economic Zone. Currently, limited tagging research has been used to understand snow crab movements and distributions. This pilot study examines the efficacy of using mark report pop-up satellite tags for understanding the movements of mature male snow crab in the EBS. In 2022 we tagged 48 snow crab; 30 during the commercial fishery in April/May, and 18 during the NMFS survey in July. Of the 48 tags deployed, 37 tags (77%) popped up on or shortly after their scheduled pop-up date, and 40 tags (83%) provided location data. The 48 tags were at liberty for a minimum and maximum of 21 and 145 days, respectively. Tagged snow crab moved an average distance of 55.4 km (mean rate of 0.55 km/day) from their tag deployment location. These preliminary results indicate that these tags can be a promising method for examining movements of mature male snow crab,

especially to address transboundary management concerns. Further analyses of the tag data will help elucidate if crab sampled during the summer survey represent those in winter fisheries, if crab caught in the commercial harvest are represented in the summer survey, and if movement patterns are related to fluctuations in the Bering Sea thermal regime.

4.3/Abstract 76: Einar Jónsson[1,2], Tómas Árnason[1], Hrönn Egilsdóttir[1], Haseeb Randhawa[2], Sara Harðardóttir[1]
[1]Marine and Freshwater Research Institute, Iceland, [2]University of Iceland

Marine multiple stressor studies on Arctic species in Iceland.

Current and predicted anthropogenic changes in the marine ecosystems have sparked interest in exploring the ecological consequences of these changes. While traditional laboratory studies focus on examining the biological impact of one environmental driver at a time, it has been highlighted that there is a need to investigate the individual and interactive effects of multiple drivers to better understand the impact of anthropogenic changes in the ocean. The Marine and Freshwater Research Institute of Iceland has responded to this challenge by building a new state-of-the-art experimental laboratory designed specifically to investigate how different environmental drivers affect a variety of marine organisms. Current experiments focus on the world's first laboratory-reared capelin (Mallotus villosus) and a variety of phytoplankton species collected in the Nansen Basin during NPI's Polar Ocean II Research Cruise in 2023. The studies focus on the impact of pH and temperature on various endpoints, investigating parameters projected in near-future scenarios, using both a single and multiple stressor experimental strategy. The presentation will be centered on introducing the new multi-stressor facility at the MFRI, challenges of multiple stressor studies and first results of the project, such as the thermal perfomance curves of capelin.

4.4/Abstract 83: Haakon Hop[1], Vegard Stürzinger[1], Juni Bjørneset[1], Ole Arve Misund[1]
[1]Norwegian Polar Institute

Boreal fishes and jellies moving into the Central Arctic Ocean

The Central Arctic Ocean Large Marine Ecosystem (LME) is the largest Arctic LME with an area of 3.3 million km2. Logistically, this area has been difficult to access, but changes in sea-ice conditions and use of ice-going research vessels have made it more feasible in the recent decade. This has also introduced more pressures from human activities, such as noise and pollution from ship traffic. However, the largest changes affecting this LME are climate related with reductions in sea ice and intrusion of warm Atlantic water.

Boreal species of zooplankton and fish are expanding with Atlantic water into the Nansen Basin. However, the rate and extent of this expansion are unknown for areas off-shelf.

During a research cruise with RV Kronprins Haakon 11 – 29 August 2023, we investigated how far the distribution of boreal species had proceeded outside the continental slope north of Svalbard. Our sampling focussed on the mesopelagic layer, generally occurring at 300-500 m depth. Plankton nets and pelagic trawls were used to obtain samples along two transects, western (along E20-E22°) and eastern (along E29-31°).

Catches along the transects included capelin (Mallotus villosus), juveniles of redfish (Sebastes mentella) and Greenland halibut (Reinhardtius hippoglossoides), cod (Gadus morhua), pelagic amphipods and krill. In the ice-covered Arctic Ocean, only marginal catches of arrow worms, ctenophores, amphipods and krill were obtained. Additional trawl stations with a larger pelagic trawl at the slope of the continental shelf provided catches of juvenile Greenland halibut, cod, redfish, haddock (Melanogrammus aeglefinus), polar cod (Boreogadus saida) and capelin. The area where the mesopelagic layer interacts with the slope was sampled with bottom trawl. Most of the catch consisted of juvenile Greenland halibut (age-1 and older), cod, redfish, shrimp and sponges, as well as smaller benthic fish species. Medusas were present in most trawl hauls, including lion's mane jellyfish (Cyanea capillata) and the helmet jelly (Periphylla periphylla).

Acoustic surveying of fish and zooplankton was performed with Simrad EK80 echo sounder, with 38 kHz recording as the main hydroacoustic source. The recordings were post-processed with the Large Scale Surveying System (LSSS). Along the coast west and north of Svalbard, there were good recordings of capelin in a layer near surface and of demersal species like Atlantic cod in a layer from about 200 m depth to bottom. At the western transect, capelin was recorded north to about N81° 30' and at the eastern transect from N81° 45' and to the shelf.

Based on our survey, capelin seem to have expanded in the mesopelagic layer extending from the slope, and will likely be the first species to expand further into the Central Arctic Ocean. Jellyfishes are also more often recorded, and a northward expansion of P. periphylla is likely a result of climate warming. Boreal expansions are expected to result in structural changes in the marine food web with consequences for energy flow to upper trophic levels. Our knowledge will contribute to ongoing work by the ICES Working Group on Integrated Ecosystem Assessment for the Central Arctic Ocean.

4.5/Abstract 94: Jan Phillipp Geißel[1,2], Noé Espinosa-Novo[2], Luis Giménez[2,3], Steffen Harzsch[1], Gabriela Torres[2]
[1]University of Greifswald, Germany, [2]Alfred Wegener Institute for Polar and Ocean Research, [3]Bangor University, UK

Adapted to the cold? Larval thermal tolerance across the native range in the European shore crab Carcinus maenas and potential for range expansions into the Arctic

We studied the variation in larval thermal tolerance among five populations of the European shore crab Carcinus maenas spanning a 27° latitudinal gradient from Vigo (Northern Spain) to Tromsø (Northern Norway) including two Arctic populations from the northern edge of the distribution. In a laboratory common-garden setup, we exposed freshly hatched larvae obtained from two to six females per population, to eight temperatures (6 – 27 °C) to quantify survival and development to the zoea II. Experiments were carried out in natural seawater (32.5 PSU), and under ad libitum food conditions (freshly hatched Artemia nauplii). Larvae were reared in glasses (60 ml) in five replicate groups of ten individuals each; dead individuals were recorded and removed, and larvae were checked for moulting.
Our results show differences in larval performance among populations. At 6°C all larvae died, but larvae from Norwegian populations, especially from the North (Bodø and Tromsø) show longer LT50% than those in the south. The Norwegian populations (except the one from Tromsø) showed higher survival in 9° to zoea II than that from Spain. Generally, the population from the northern range limit (Tromsø) exhibited the lowest survival to zoea II. In addition, all populations showed very low survival at the maximum tested temperature (27 °C). We conclude that zoea I of Carcinus maenas are eurythermal (range 12 – 24 °C) along most of the distribution range. In addition, we found evidence for higher tolerance to and faster development in low temperatures in the Norwegian populations. Further we found an increase in dry mass of freshly hatched larvae with latitude across the native range. Based on this result, in a further study we want to use phenological modelling to further explore the species potential for poleward range expansions following the warming of the Barents Sea and the Atlantification of the Arctic.

Acknowledgement: this study was funded by DFG RTG 2010 “RESPONSE” and supported by the Helmholtz graduate school for polar and marine research POLMAR.

4.6/Abstract 120: Sonja Gindorf[1], Anna Madathil Suresh[1], Sofi Jonsson[1]
[1]Stockholm University, Sweden

Arctic Ecosystem Mercury Speciation and Distribution North of Svalbard during the NPI Arctic Ocean II Expedition

The heavy metal mercury (Hg) naturally occurs in all compartments of the environment in different forms. Despite its remote location, the Arctic Ocean is affected by anthropogenic Hg emissions (e.g. from fossil fuel burning) as Hg can be transported over long distances in the atmosphere. Moreover, climate change increases the direct release of Hg in the Arctic from natural sources, such as thawing permafrost and increased runoff from melting glaciers releasing previously sequestered Hg. In the marine environment, the organic form methylmercury (MeHg) can be formed through a microbial process called methylation. MeHg is of particular concern in marine ecosystems because it is a neurotoxin that effectively bioaccumulates and biomagnifies in the food web. As fish and marine mammals are key sources of nutrition for indigenous communities in the Arctic, we need to improve our understanding of MeHg concentration and biomagnification in Arctic species. This will help us to develop environmental management measures we can implement to limit the exposure of wildlife and people to this neurotoxin.

During the NPI Arctic Ocean II expedition in August 2023 onboard RV Kronprins Haakon, we collected mercury speciation samples from two transects along the slope north of Svalbard into the deep Nansen basin. Samples collected include the water column, surface sediment, biota of different trophic levels (primary producers, filter feeders, grazers, predators), and sea ice to better understand the complex interplay of these different parts of the biogeochemical cycle of Hg in the Arctic Ocean. This data will help us to improve our understanding of how mercury speciation and distribution changes across the shelf slope into the open ocean.

4.7/Abstract 130: Anita Parlow[1]
[1]Fulbright Association

Deep-seabed mining in the maritime Arctic: Emerging standards in domestic and international law

This presentation will consider the growing interest and development of deep-seabed mining of critical minerals in the Arctic with particular attention to the potential for coexistence of protected marine ecosystems and developers, as the world seeks to transition away from fossil fuels and, toward clean, renewable energy systems.

While scholarly journals such as Scientific American report that clean-energy technologies will require an enormous 500% increase in production of rare earth metals such as lithium, cobalt and manganese over the next several decades, the United Nations Environment Program - Financial-Initiaitve (UNEP-FI) cautions that years, if not decades, of research is needed to learn whether the anticipated environmental disturbances and potential risks of species' extinction can be mitigated. This presentation will reflect both on the growing support for investments in deep-sea mining and the pushback from scientists, NGOs worldwide, along with companies such as Google, Volkswagen and Triodos Bank, who have ruled themselves out of industrialization of the deep-seabed.

The UN agency cites a lack of scientific understanding of seabed disturbances, a growing awareness that a healthy sea is also vital to regulate the earth's surface temperature, and that with only a few exceptions, such as Norway, an international regulatory system, and enforcement capabilities, is incomplete. And, nearly impossible to enforce in the High Seas, beyond national jurisdiction.

This presentation would reflect upon Norway's regulatory approach, its gaps, and, more fully, the limitations of the International Seabed Authority (ISA) to develop a regulatory system regarding deep seabed mining of critical minerals, even as the UN agency has issued some 31 deep-sea exploration contracts to assess mineral deposits, with mining in international waters possible by 2026. The presentation would also reflect upon the growing international paradigm shift that asserts the "rights of nature," thus placing nature at the legal center of ecosystem protections from impacts of human activity. Within the context of co-existence between deep-sea mining and ecosystem protections, the most effective nature-based approaches will be discussed.

The significant increases in deep sea-bed mining is creating a sense of urgency in the need for management, policy and law that contains the ability to require the appropriate science. It will also address the ability to enforce clean and sustainable development both in international and state jurisdictional waters. This presentation would also address the growing support for the "rights of nature" doctrine where the ecosystem is legally entitled to personhood status, and thus the right to be free of injury without disruption by commercial or other interests.

This presentation addresses the view that deep sea-bed mining offers an opportunity to transition to green energy with a new resource source and new technologies. It also offers a critically significant opportunity to get it right at the front end of the mining process.

If anyone can do this – it is Norway.

4.8/Abstract 154: Johannes Röhrs[1], John Grue[2], Thea Ellevold[2], Ingrid Johnsen[3], Tina Kutti[3]
[1]Norwegian Meteorological Institute, [2]University of Oslo, Norway, [3]Institute of Marine Research, Norway

Shaping of hotspots for marine ecosystems by internal waves and circulation patterns on the Norwegian Continental Shelf

The Norwegian continental shelf is an area where warm and saline Atlantic water meets coastal water and flows over steep undulating bathymetry. A range of intermittent processes create unique conditions for marine life on the shelf. Tidally driven and wind-forced ocean currents flow over canyons and create strong internal waves at the interface between heavy deep water and lighter surface waters. In the Lofoten-Vesteralen area, internal waves with an amplitude up to 50 m at water depth of 100 m are observed from in-situ measurements and satellite imagery. The characteristics are further studied using numerical models to characterize and understand their implications on vertical mixing and its role in the marine ecosystem. Model simulations show how frequent conditions for such strong waves occur, how and where they are generated, and their effect on column-wide vertical mixing on the shelf. As a result, such locations appear to host an ecosystem with elevated productivity, as particle flux from the deep ocean to surface waters enhances primary production in summer time. Also areas with convergence of deep currents provide increased food supply to cold water coral reef communities. Understanding the conditions for these processes requires a synthesis of regional ocean modeling, idealized hydrodynamic models, remote sensing as well as conceptual and analytical theory to understand the pertinence of physical conditions that act on the continental shelf.

4.9/Abstract 215: Hanna Dinevik[1], Bodil Bluhm[1], Andreas Altenburger[1]
[1]UiT – The Arctic University of Norway, Tromsø

Ageing and growth of the Arctic brittle star Ophiopleura borealis (Echinodermata: Ophiuroidea) from the Barents Sea and East Greenland

Species inhabiting cold-water environments exhibit typically slower growth and a longer life span than warm-water species, implying a slowed ability to recover from natural and anthropogenic disturbances. Longevity estimates for species inhabiting the Arctic region are sparse, despite the ongoing changes and disturbances in the region. Brittle stars (Ophiuroidea) often dominate Arctic shelf epibenthic communities, impacting biogeochemical fluxes and sediment structure. Assessing their resilience to disturbances relies on estimates of their longevity. To date, a limited number of brittle star age estimates are available , including three on brittle stars from the Arctic. Maximum ages inferred for these exceeded all other maximum age estaimtes obtained for ophiuroid species at

lower latitudes, to the authors' knowledge. Ophiopleura borealis is a common brittle star species endemic to the Arctic and northeast Atlantic for which age estimates are lacking. For this study, the objective is to infer ages of O. borealis specimens from Greenland and the Barents Sea by counting annually formed bands found in the organisms' endoskeleton using scanning electron microscopy (SEM). A growth curve and growth rate will also be generated to test if indeed this Arctic brittle star grows slower and gets older than boreal species. Arm bones closest to the disc are isolated by dissecting the specimens and tissue removal by bleaching. Analyses of SEM photographs of arm bones show a presence of growth bands in form of shifting densities of the carbonate matrix constituting the bone. At least 13 bands were present in an adult O. borealis individual from the Barents Sea indicating a minimum age of up to 13 years in this species. Analysis of an appropriate sample size is ongoing. This study will yield the first age estimates for O. borealis and provide information on the longevity of an Arctic benthic invertebrate – which can be applied when estimating impacts of disturbances on the species and, consequently, the Arctic benthic ecosystem.

4.10/Abstract 224: Marta Lukasik[1], Lech Kotwicki[1], Sabine Cochrane[2]
[1]Institute of Oceanology, Polish Academy of Sciences, [2]Akvaplan-niva

Tidal flats as a vulnerable ecosystem in the context of climate change.

The Arctic region has been well recognized as a place where the impact of climate change is more extensive and visible than farther south. Ongoing melting ice cover and glaciers are changing the Arctic landscape. The impact of these changes is recognized in many habitats, as well as on tidal flats. Tidal flats comprise areas with muddy/sandy surfaces that are alternately submerged and exposed to the air by changing water levels. They are characterized by a relatively flat topography, such that the area of seabed exposed during low tide is often extensive.

Accurate characterisation of tidal flat habitats still requires further research, especially those above 60°N are under-studied. Three tidal flats around Svalbard and three in the Tromsø area are under observation to increase knowledge of this habitat type.

One of the main goals of this research is to study the inhabitants and the factors that impact tidal flats located in high latitudes. The synergy between seabed morphology and climatic influences strongly influences the living conditions. Water levels change, ice cover, temperature, and salinity change, such that water dynamics in the shoreline zones and proximity to the open sea and freshwater inflow are under observation. Samples are collected to conduct the following analyses: qualitative and quantitative macrofauna, meiofauna,

microfauna, E-DNA, sediment chemistry, sediment chlorophyll, and granulometry.

The study's first results indicate a high heterogeneity of the habitat and biological assemblages depending on the location. Moreover, it seems that the changes in the water level and length of ice coverage may have the most significant effects on tidal flats. Thus, the functioning of this valuable habitat in the Arctic under ongoing climatic changes is an important topic for research.

4.15/Abstract 235: Eun Jin Yang[1], Hyoung Chul Shin[1], Jihoon Jeong[1]
[1]Korea Polar Research Institute (KOPRI)

Korea-Arctic Ocean Warming & Response of Ecosystem (K-AWARE) Project and RV Araon-onboard collaboration in the Distributed Biological Observatory (DBO) framework

Over the past decade, the Korea Polar Research Institute (KOPRI) has actively engaged in research in the Pacific Arctic Ocean, with significant impetus from the Korea-Arctic Ocean Warming & Response of Ecosystem (K-AWARE) Project. In this presentation, we aim to provide an overview of the RV Araon-based project and its scientific collaboration within the Distributed Biological Observatory (DBO) framework.

The central question driving K-AWARE is how the Pacific Arctic region will be impacted by Arctic warming, including sea ice loss, increasing freshwater input, and rising sea temperatures. Our particular focus lies in the study of marine ecosystems and carbon systems, seeking to comprehend the repercussions of sea ice loss on Arctic Ocean system. Amidst the rapidly changing Arctic environment, our overarching objective is to better understand the evolving Arctic Ocean system over varying time scales, from seasons to decades. To support our field observations in the Bering Strait, Chukchi Sea, and East Siberian Sea, we rely on RV Araon, Korea's first icebreaking research vessel.

Research conducted within K-AWARE has contributed to broader efforts within the framework of the 'Distributed Biological Observatory (DBO)'. Since its implementation in 2010, the DBO has been instrumental in measuring biological responses to physical changes in the Pacific side of the Arctic Ocean. It has engaged in multidisciplinary and international efforts to better understand the physical, chemical, and biological processes of the Arctic Ocean system, to detect and assess environmental change in the Arctic Ocean. Updates and future work will also be presented, based on discussions from a workshop jointly funded by the NSF and KOPRI, which led to the proposal of a new Siberian DBO (S-DBO).

4.11/Abstract 245: Anita Holmgren[1], Fredrika Norrbin[1]
[1]UiT – The Arctic University of Norway, Tromsø

Zooplankton communities in Northeast Greenland fjords: Exploring differences and future threats to two fjords with different hydrography

The Northeast Greenland shelf receives the main outflow of cold, less saline Polar water from the oligotrophic Arctic Basin. Lately, a change in water masses has been observed, with increasing inflow of warm, saline Atlantic water. In Svalbard waters, the effects of Atlantification on the zooplankton community have been documented, most notably a shift from the Arctic Calanus glacialis andC. hyperboreus to the AtlanticC. finmarchicus.

During the TUNU-VIII expedition in August/September 2022, we investigated the zooplankton communities and environmental parameters in two fjords through WP-2 net sampling and in situ photography with a Video Plankton Recorder, as well as with CTD and water sampling. Taxa were classified morphologically, and C. finmarchicus and C. glacialis separated by DNA analysis.

This study explores differences in the zooplankton communities in two Northeast Greenland fjords, Besselfjord and Breddefjord, with contrasting hydrology and glacier conditions. Breddefjord had a marine-terminating glacier while Besselfjord was surrounded by land-terminating glaciers. Atlantic water was observed inside Breddefjord, while Besselfjord only contained Polar water, and differences were observed in the composition of the zooplankton communities. Hydrographical changes caused by melting of the Greenland ice-sheet and altered ocean circulation patterns may change the structure of these marine ecosystems in the future. The zooplankton community is an important trophic link in the Arctic pelagic ecosystem, and changes in size-distribution and taxa are expected to cause bottom-up effects altering trophic transfer.

4.12/Abstract 301: Alexis Bazinet[1], Steve Ferguson[2], Brent Young[2], William Koski[3], Ricky Kilabuk[4], Sarah Fortune[1]
[1]Dalhousie University, Canada, [2]Department of Fisheries and Oceans Canada, [3]LGL Limited, Canada, [4]Inuit Community Partner, Canada

Evaluating the nutritional impact of climate change for bowhead whales in the Eastern Canadian Arctic

Climate change is predicted to alter the biodiversity of the Arctic Ocean ecosystem. Shifts in oceanographic conditions such as decreased sea ice cover and increased sea-surface temperature are likely to impact primary and secondary production, which could have cascading effects for zooplanktivorous predators. A borealization, from a dominance of large-bodied, energy-rich Arctic

copepods (*Calanus hyperboreus* and *C. glacialis*) to poorer quality temperate species (*C. finmarchicus*) may have consequences for species feeding at lower trophic levels such as bowhead whales (*Balaena mysticetus*). Although a transition in zooplankton species composition has already been documented on bowhead whale foraging grounds (Disko Bay, Greenland) the energetic impacts of altered prey quality are currently unknown. An effective tool for evaluating nutritional conditions of live, free-swimming whales is through photogrammetric studies. Photogrammetric measurements of Eastern Canada-West Greenland (ECWG) bowhead whales were made using aerial drone data (2016-2023), collected in in Cumberland Sound (foraging ground) and Foxe Basin (calf rearing area) (Nunavut, Canada). Body measurements (e.g., total body length, % width increments along the body) were used to calculate a body area index (BAI) comparable across years, regions, and age-sex groups within the population. Combining molecular techniques to estimate age (epigenetic aging) and sex (genetics) of matched individuals (photo-identification) and inferences of age-class based on body lengths, demographics (age, sex, reproductive status) for a subsample of the population was ascertained. BAI was then compared across years for different age-sex groups.This research is beneficial for monitoring the long-term stability of the ECWG population with shifting prey resources to inform future ecosystem-based fisheries management strategies.

4.13/Abstract 315: Manon den Haan[1], Paolo Segre[2], Erik Kilubak[3], Mason Angnakak[3], Sarah Fortune[1]
[1]Dalhousie University, Canada, [2]University of Wisconsin, USA, [3]Kilabuk Services, Canada

Quantifying bowhead whale foraging behaviour by combining kinematics, video recordings and dive profiles

Bowhead whales (Balaena mysticus), a culturally important species to many indigenous communities and endemic to the Arctic, feed on zooplankton to meet their nutritional needs. Foraging dives are frequently inferred based on dive shape alone (e.g., square or U-shaped dives thought to reflect feeding while V-shaped dives indicate exploration or travel). We are determining the kinematic signatures of suspected foraging dives and using simultaneous underwater video recordings to validate behaviour. Incorporating the time-depth recorder data, we will test whether foraging dives can be reliably identified based on shape alone.

In August 2023, 17 bowhead whales were tagged with CATS (Customized Animal Tracking Solutions) and 8 individuals with LIMPET (Low Impact Minimally Percutaneous Transmitter, SPLASH-10, Wildlife Computers) in Cumberland Sound, Nunavut, Canada. Both bio-loggers are equipped with sensors that give horizontal (GPS) and vertical (time-depth profile)

movement of the whales. In addition, CATS tags have integrated high-resolution inertial sensors (3D accelerometer, magnetometer, and gyroscope), and a forward-facing pressure-rated camera. The animal-borne video footage confirms underwater feeding events, by the evidence of opening of the mouth. Using the confirmed feeding events, we extracted the combined kinematic signature (e.g., decreased speed) and dive profile and apply these on high-resolution biologging data and time-depth records without corresponding video recordings. The results of this study can be used to make an improved estimate of foraging efforts made by bowhead whales and provide the first quantitative measure of bowhead feeding with validation.

4.16/Abstract 109: Martta Viljanen[1,2], Malin Daase[3], Markus Majaneva[4], Kristian Donner[2], Magnus Lindström[2], Geir Johnsen[1], Sanna Majaneva[1,5]
[1]Norwegian University of Science and Technology, [2]University of Helsinki, Finland, [3]UiT – The Arctic University of Norway, Tromsø, [4]Norwegian Institute of Water Research, [5]Akvaplan-niva, Norway

Arctic zooplankton in changing marine lightscape

Arctic marine lightscape is on the change. As the Arctic has warmed, up to four times faster than the globe in average, the amount of sea ice has diminished and changes in the snow cover, melt ponds and river runoffs have been detected. With continued warming and reduction of sea ice, human presence in the region is likely to increase leading to more artificial light. All these factors bring unforeseen changes into marine light conditions. Light guided activities are central phenomena in marine ecosystem. Organisms have evolved under natural and predictable regimes of sun- and moonlight resulting in biological rhythms which are synchronized with cues of light and may be altered with the changing lightscape. The photobiology of Arctic species is still full of mysteries, but the latest technical developments give tools for opening some of the key questions. In LightLife project, we have applied a multi-tool approach to understand the impacts of the natural light regime (intensity, spectral composition and photoperiod) and changing light climate on Arctic zooplankton. By complementing traditional plankton net tows and acoustic data with environmental DNA metabarcoding we have achieved taxonomically more comprehensive picture of the effect of light on the spatial distribution of zooplankton. With behavioural experiments and studies on visual physiology by microspectrophotometry and electron microscopy we have revealed differences in visual functions at species and populations level. Our results indicate that Arctic zooplankton species have separate visual niches and thus changing light climate may affect them in different ways impacting the balance of the ecosystem. This indicates that the species-specific functional light regime of Arctic species and lightscapes should be taken into account when making

predictions of the effects of environmental changes on the Arctic zooplankton and marine Arctic ecosystem.

4.14/Abstract 246: Elizabeth Ellenwood[1]
[1]Fulbright Norway

Artistic Research on the Oslofjord

In 2021/2022 I lived and worked in Oslo while on a Fulbright Scholarship. My artistic research project focused on the pollution found in the Oslofjord. I collaborated with scientists at the Norwegian Geotechnical Institute and Fjord Clean Up, a volunteer run organization. At first glance, I thought the oslo fjord itself was healthy. The water system supports a vibrant working waterfront actively being used by its community and visitors. From ferries, to floating saunas, to common areas and parks, all enjoy the beauty and strength of the fjord. But diving under the surface, a struggling habitat was revealed to me. In the dead of winter I saw plastic fragments suspended in the water column. Very little sea life existed and sadly, when I did see fish they were creating homes in sunken beer cans. Each week I participated in the clean up group I became more intrigued with what we would find. Scooters, bikes, bottles, cellphones, tires, batteries, unrecognizable objects made from plastic, foam, metal. These pollution items and issues are not designated to just the Oslofjord, I find them in my hometown in the States as well. I create photographic imagery with these items in hopes to share and educate a greater population. For the Arctic Frontier's conference, I will share a selection of my photographs and video footage of pollution in the Oslofjord as well as speak to the methodology of using art and science together for greater communication. I believe in order to help the underwater ecosystems in the Arctic, and in all our waterways, we need to actively see what is happening under the surface. Looking and seeing are the core fundamentals of my photographic process and exploring my results with scientists allows for greater understanding and innovative ideas across our fields.

An example of an art and science collaboration is my Fulbright project, "The Interweaving of the Synthetic and the Natural World" . The self-published book examines plastics in the environment through a series of photographs and scientific writing by myself and scientists at the Norwegian Geotechnical Institute. My photographs are combined with thought-provoking text from Hans Peter Arp, an environmental chemist, to offer insight into pollution issues the natural world is facing. The photographs and writing act not only as evidence of the present time, but also challenge each reader to find their own personal connections to pollution and climate change. Not quite a scientific lab book, and not quite a fine art book, our collaboration lives in the very important in between zone. With scientific terms, and "I-Spy" inspired imagery, the interaction

opportunities in the book grow, unlocking opportunities to see and understand pollution in a new way. Ultimately, each reader is confronted with personal questions: How can I help? What is my role in creating a sustainable future? Where do we go from here?

To visit the online book: https://www.bonusprint.co.uk/view-online-photo-book?widgetId=7d0f4f6d-6140-40e1-8bb6-e5efc7e49cfe

5.1/Abstract 5: Juha Saunavaara[1]
[1]Hokkaido University Arctic Research Center, Japan

Smart energy solutions + cold climate + digital transformation = Arctic and northern data centers?

The earlier forecasts predicting that the data center industry would soon equal to 3-5% of the global electricity consumption failed to foresee the improvements in the energy effectiveness and concentration of computing power into larger units better suited to serve the needs of I(C)T equipment. However, the global data center electricity use is still huge (counted in hundreds of Terawatt hours per year even if crypto currency mining is not included) and the industry is growing fast. Besides striving for higher energy efficiency, the data center industry is searching for new ways to integrate itself with the electric grids that are increasingly dependent on renewable energy production. At the same time, the cold climate data centers have been forerunners in initiatives to re-use the "waste" heat produced within their facilities.

The immaterial Internet is a myth. The locational questions of the physical infrastructure supporting it are carefully considered and connected with numerous variables reflecting environmental (e.g. climate and natural hazard risk) and societal realities (e.g. human capital, infrastructure, laws, regulations, and policies) in a given spatial context. During the past decade, the data center industry has gradually moved toward the north and the Nordic countries, for example, have developed into a European data center industry hub. This has provided investments and employment opportunities in the northern and Arctic regions.

Besides the advantages related to the availability of cheap green energy and land, as well as the success in utilization of (hidden) assets such as cold climate and district heating networks, the Arctic and northern communities have also faced challenges when attempting to attract new data centers. Small population and distance to economic centers can, for example, lead to high network latency and recruitment problems. Yet, the planned trans-Arctic submarine cable projects, combined with national broadband projects in various countries, may radically change the connectivity situation in the Arctic. After providing a short

overview of the past developments and the current status of the Arctic and northern data center industry, this presentation analyzes the possible roles data centers can play in the smart Arctic and northern cities.

5.2/Abstract 7: Igor Ezau[1]
[1]UiT – The Arctic University of Norway, Tromsø

High-resolution urban meteorology data fusion and interpolation in applications to northern Europe cities

Stakeholders in European cities require diverse high-resolution societal, environmental, and climate information. Access to such urban climate information could be however limited as meteorological observational networks are sparce and often non-representative. Over recent years, however, we witness rapid development of non-conventional sources of meteorological observations. The list includes high-resolution satellite images, amateur-class citizen weather stations, and downscaling with integrated urban modeling systems. What is an optimal (in some sense) way to combine those data sources?

Our literature survey identified a set of geo-spatial interpolation methods based on kriging approaches as a promising methodology to combine space-born and ground-born observations with numerical simulation results. In this presentation, we report methodological aspects of such data combination, which we call following the terminology of remote sensing - data fusion. Data fusion in our study is approached through ordinary kriging with external drift and spatial interpolation. We tried also more sophisticated technologies such as universal kriging and simple Markov process co-kriging.

The proposed methodology of data fusion and interpolation is applied to a meteorological assessment in Bergen, Norway. Bergen is a mid-size northern European city embedded in geometrically and thermodynamically complex environment. A number of sea inlets (fjords), steep hills, and narrow valleys prevent free circulation of air in the city. Any ground-born observational station represents only a limited radius of its local environment. Model and satellite data are needed to recover urban meteorology at high spatial resolution across the whole city.

The data fusion and interpolation results for Bergen are presented as a set of high fidelity meteorological maps. The maps give higher weight to ground-born observations in close proximity of stations but refrain to satellite and model data in the areas poorly covered with observations. Additional information about data uncertainties is quantified and could be used by stakeholders.

The set of high resolution and high fidelity maps could be further used as input

for more advanced visualization tools, including augmented and virtual reality technologies. As model component is integrated in this data fusion methods, stakeholders can ask for visualization of effects of different policy scenarios, e.g., prospective urban development plans, on urban meteorology and more broadly on objective quality of the urban physical climate and environment.

5.3/Abstract 143: Sophie Roher[1]
[1]Well Living House, Canada

Nats'eji: Reimagining Indigenous wellness and healing at a hospital in Northwest Territories, Canada

Background: In the Northwest Territories (NT), Canada, where over 50% of the population is Indigenous, local Indigenous leaders and Elders have emphasized the need for better access to hospital-based Indigenous wellness and healing and for improved models for Indigenous and biomedical healthcare collaboration.

Objectives: In support of these calls, this presentation reports findings from a qualitative study which sought to: (1) examine how Indigenous patients and biomedical healthcare providers experience the Indigenous wellness services at a NT hospital, and (2) explore how patients and providers envision Indigenous healing successfully working with biomedical hospital care.

Methods: The study received research ethics approval from the University of Toronto. It was conducted from May 2018-June 2022 and was overseen by a regional Indigenous advisory committee. Guided by Two-Eyed Seeing and a narrative approach, the study involved 41 interviews with Indigenous Elders, patient advocates, healthcare providers, and policy makers, and iterative sharing circles with Indigenous Elders.

Findings: Elders and patient advocates emphasized that while the Indigenous wellness services at the hospital play a critical role connecting patients with cultural supports, the hospital was still not effectively bringing Indigenous healing into hospital care. Participants suggested that structural factors (i.e., policy and governance decisions) and deeply rooted forces (i.e., racism, colonialism, and biomedical dominance) underlie the delivery of care and inhibit the integration of Indigenous healing. Additionally, participants' responses revealed three models for how Indigenous healing could successfully work with biomedical hospital care in the future.

Conclusion: When examined altogether, the findings highlight that Indigenous peoples and communities need to be the ones to determine and define whether Indigenous wellness services are offered alongside hospital care and how those

services are provided. Indigenous governance and decision-making are critical to self-determination and to improving care for Indigenous peoples.

5.4/Abstract 182: Elizabeth Parry[1,2], Andrea Bersamin[1,3], Micah Hahn[4,5], Margaret Wills[6]
[1]University of Alaska Fairbanks, USA, [2]Ted Stevens Center for Arctic Security, USA, [3]Centre for Alaska Native Health Research, USA, [4]University of Alaska Anchorage, USA, [5]Institute for Circumpolar Health Studies, 6Maryland Department of Health, USA

The Measurement of Food Security amongst Indigenous Populations: A Scoping Review of the Literature

Indigenous populations throughout the world experience disproportionately high rates of food insecurity, with particularly high rates estimated in populations that maintain subsistence lifestyles. Conventional food security metrics are primarily economic focused, and use indicators such as poverty, unemployment, home ownership, and the average cost of food. This limits the utility of food security measurement tools among populations that maintain subsistence lifestyles, as they don't account for the multifaceted and interdisciplinary variables associated with subsistence lifestyles. A more holistic, mitigation-focused perspective is needed to address food insecurity amongst populations that maintain subsistence lifestyles. One Health offers an ideal perspective in which to address these issues, particularly amongst residents of the Arctic region, as it recognizes the inextricable link between the health of humans, animals, and their shared environment - a concept acutely relevant to subsistence lifestyles. In order to evaluate what is known about measuring food security amongst Indigenous populations, a comprehensive scoping review was conducted. The results of the review revealed that a growing body of academic literature is attempting to account for subsistence foods when measuring food security amongst Indigenous populations. However, a very limited number of studies have utilized holistic approaches, such as One Health, when measuring food security. The results of this scoping review will be used to develop a new tool in which to measure vulnerability to food insecurity amongst Alaska Native populations that maintain a subsistence way of life.

5.5/Abstract 203: Lihong Zhou[1], Eduard Khachatrian[1]
[1]UiT – The Arctic University of Norway, Tromsø

Will high-resolution satellite synthetic aperture radar (SAR) data make near-coast offshore wind energy more accessible in the North?

The European North is facing an increasing demand for energy to support sustainable growth of its towns and industries. As a result, offshore wind parks have emerged as an attractive energy source, leading to active promotion of wind park construction. Still, a significant challenge remains in identifying economically attractive locations for these offshore wind parks. This challenge primarily stems from the limited availability of high-resolution wind essential for evaluating wind conditions before selecting and constructing sites. To address this constraint, there is a need to explore offshore locations along the Norwegian coastline. Traditional sources of wind data, such as in-situ observations and reanalysis, fall short in meeting this requirement. In-situ data often suffer from discontinuity and limited spatial coverage, while reanalysis data struggle to accurately replicate observed wind speed trends. In this study, we have delved into the potential benefits of incorporating high-resolution Synthetic Aperture Radar (SAR) data into the renewable energy sector. SAR has emerged as a promising new source of offshore wind data, providing wind information with a spatial resolution of 1km near the coast since 2021. To assess the reliability of this SAR dataset, we conducted a comparative analysis with in-situ observations and ERA5 reanalysis products at the Goliat platform. Our research aims to uncover whether SAR data can enhance offshore wind energy exploration by offering more comprehensive wind information. Additionally, we seek to facilitate the integration of SAR data, reanalysis, and in-situ observations into wind data products. This study holds strategic significance for the continued offshore development in Norway, paving the way for informed decision-making in selecting optimal offshore wind park locations.

6.1/Abstract 16: Laura Rasmussen[1], Bo Markussen[1], Susanne Ditlevsen[1]
[1]University of Copenhagen, Denmark

When winter is weird: Quantifying the change in winters across the Arctic

Arctic winter climate is rapidly changing, with more variable snow depths, spring snowmelt timing, and more frequent midwinter thaw events. Less predictable conditions disrupt ecosystem balances and development in Arctic communities, and understanding winter variability across the Arctic and its influence on climate the whole year is needed to mitigate consequences of changing winters. However, access to in situ measured data has been limited and scattered in local databases. Hence, cross-Arctic winter studies are few and based on remotely sensed data with larger spatial and temporal coverage, but less local sensitivity, and the data-driven winter contribution to annual average temperature change has not been investigated across the Arctic.

In this project, we 1) obtain, clean and standardize in situ soil surface temperature, snow depth and soil moisture data from climate monitoring programs across the Arctic and create a database with cross-Arctic in situ

winter climate data from the last appr. 30 years. We use this dataset to 2a) estimate the accuracy of remotely sensed soil surface temperature, snow depth and soil moisture data using the regression model with the best fit, and quantify the bias, for each major Arctic region. We further 2b) construct an open access Winter Variability Index (WVI) for each major Arctic region based on the winter phenomena (average snow depth, snowmelt date, frequency of winter thaw events) that are most important drivers of a clustering analysis such as PCA, hierarchical clustering or autoencoders. Finally, we 3) use the change in WVI and in annual mean temperatures for each decade in a function-on-function regression analysis, which will quantify the contribution of winter variability change to annual average temperature changes in each Arctic region.

The project will produce a comprehensive dataset with potential for further research and will improve our region-specific understanding of remotely sensed data accuracy, which is key for confidence in climate system modelling. The WVI allows scientists or local communities to classify Arctic winter data within a quantitative framework of pan-Arctic winter variability also in the future, and to understand how important changes in winter variability is for Arctic climate changes the whole year.

6.2/Abstract 188: Mateusz Matuszak[1], Edel Rikardsen[1], Johannes Röhrs[1], Martina Idžanović[1], Kai Christensen[1]
[1]Norwegian Meteorological Institute

Monitoring of oceanic flow and particle transport using a combination of high-frequency radar observations and advanced diagnostic algorithms for sea surface currents.

Understanding dynamical processes governing fluid transport is important for both process studies and day-to-day forecasting. High-frequency (HF) radars provide ocean surface current observations at a high spatiotemporal resolution. MET Norway currently operates five HF radars along the Norwegian coast, with more to come. HF radars measure one directional component of the flow field, thus additional methods are required for constructing complete current velocities. Our study attempts to estimate current velocities based on radial measurements from single radar stations using two distinct methods: 1) a geometrical algorithm and 2) a neural network approach. Together with dynamical ocean modeling, these algorithms provide nowcasts of ocean surface current fields for the Norwegian Shelf Sea that can be used for environmental monitoring and decision making. The product may be used to compute particle trajectories, using a framework (OpenDrift) that time-integrates ocean current fields from either observations or models. Furthermore, we deploy a Lagrangian Coherent Structure analysis based on HF-radar derived current fields. The method provides effective nowcasts of particle accumulation areas without

further knowledge of particle origin and can describe the organization of particle patterns in chaotic flow systems.

7.1/Abstract 30: Mark Hermanson[1], Elisabeth Isaksson[2], Geir Gabrielsen[2]
[1]Hermanson & Associates, LLC, Netherlands, [2]Norwegian Polar Institute

Frozen pollutants

Svalbard glaciers and ice sheets are well-known archives of past climate and environmental conditions. Over the last two decades, ice cores have been retrieved from three major glacier-ice caps in Svalbard; Lomonosovfonna, Austfonna and Holtedahlfonna. The reconstructed winter surface air temperatures show that the 1800s was the coldest century in Svalbard going back 1200 years, and that there has been recent warming. The ice cores have also provided information of a range of pollutants; including black carbon (BC), polychlorinated biphenyls (PCB, 209 compounds), halobenzenes (HB, 16), brominated flame retardants (BFRs, 15), legacy and current use pesticides (LPs & CUPs, 64), poly and perfluoroalkyl substances (PFAS, 40) and most recently organophosphate esters, many of them used as flame retardants or plasticizers (OPEs, 13). The different geographical positions and characteristics of the coring locations also provide information on both spatial variability and the temporal record. We have also gained new knowledge about the transport of pollutants, and processes during and after deposition on the glaciers. Some of the pollutants show a clear east-west zonal gradient across the archipelago suggesting a different origin for air masses arriving in different sectors of Svalbard. There is also an indication that some of these sites have been affected by local sources of industrial contaminants (PCBs). These glaciers are going through rapid changes with increasing temperatures; the contaminants stored during many decades will eventually be released by melting and affect downstream ecosystems. The concentrations and effects of this still need to be investigated. In addition to the scientific importance, the results will contribute to filling important knowledge gaps highly relevant for the management of Svalbard. The results of this research will enable policy makers to determine what chemical manufacturing processes and resulting compounds need regulation to protect the Svalbard environment from the effects of widespread distribution of contaminants.

Among the contaminants that we have investigated in Svalbard snow and ice, the most concentrated with known or suspected toxicity are CUP chlorpyrifos, and the OPEs tris-2-chloroisopropyl phosphate (TCIPP), tris (2-chloroethyl) phosphate (TCEP), and tri-n-butyl phosphate (TNBP). While chlorpyrifos is a broad-spectrum insecticide, it is also identified more generally as a biocide because of its toxicity to non-target organisms. For example, chlorpyrifos has been found to be extremely toxic to marine unicellular algae Skeletonema

costatum, an organism found on Svalbard, by killing 100% of exposed individuals or having negative reproductive effects with lower exposure. Chlorpyrifos has been found to have a number of other toxic effects, including to microalgae, amphipods, rotifers, mussels, fish, and specifically damage to the digestive gland in molluscs. TCIPP and TCEP have been shown to have neurotoxic effects on zebrafish embryos, similar to an effect of chlorpyrifos. TCEP has been shown to have reproductive toxicity to Daphnia magna. These results show known or potential toxic effects to marine and other organisms by major toxic contaminants in Svalbard glaciers which may be released as a result of warming of the Arctic atmosphere.

7.2/Abstract 125: Marlena Szeligowska[1]
[1]Institute of Oceanology of the Polish Academy of Sciences

Emerging carbon sinks after the retreat of Arctic glaciers as a nature-based solution

The Arctic experiences fast warming resulting in marine-terminating glaciers retreating onto land. Emerging newly ice-free areas can immediately be claimed by pelagic and benthic organisms and act as efficient carbon sinks. However, there are numerous counteracting mechanisms that can simultaneously increase and decrease the capacity of carbon sequestration in these coastal waters. Thus, this study aimed to verify if ecosystem remodeling due to glacial recession has a net positive or negative effect on marine biological production and carbon burial. West Spitsbergen fjords (Svalbard archipelago), which are among the most studied in the Arctic, were investigated here as they represent areas of rapid regional warming with many ice-filled bays progressively expanding due to the retreat of marine-terminating glaciers. Long-term trends (1976-2022) in the West Spitsbergen fjords area and sea ice duration were analyzed based on Landsat images and satellite data products along with the drivers of ice loss, i.e. atmospheric and oceanic temperatures. Furthermore, existing regional data on pelagic primary production, zoobenthic production, and organic carbon burial were used to estimate potential net changes due to the retreat of marine-terminating glaciers considering the influence of sea ice cover and sediment discharge.

In West Spitsbergen, glacial retreat released around 200 km2 of marine habitat in the last 46 years (a 4.2% increase in the total area), which was comparable with other glaciated fjords in the Arctic (59 – 121 km2, 1.9 – 9.2% increase in the total area), and there is still a potential of more than 200 km2 of newly ice-free areas being formed. Even though sea ice duration decreased significantly (on average 32-34 days per decade), there was a net increase in sea ice cover area by around 100 km2 due to glacial retreat. Also, despite the negative consequences of meltwater discharge, i.e. increases in suspended sediment delivery and turbid

plume extent, glacial retreat is suggested here to have a net positive contribution to pelagic primary production, zoobenthic production, and organic carbon burial (estimated as 7.7, 1.6, and 2.0 GgC annually, respectively).

The observed large variability in particular fjords' capacity of expansion, productivity, and carbon burial implies that the future scenarios may largely differ among the studied locations. Thus, the need for a nuanced understanding of the complexity of the polar coastal waters is necessary for incorporating newly ice-free areas in global carbon burial estimates. Considering the scale of ice loss globally and the high efficiency of carbon sequestration in the glaciated fjords, the loss of marine ice could be considered a nature-based solution to increasing atmospheric carbon.

7.9/Abstract 196: Lisa Matthes[1], Elizabeth Kitching[1], Joannie Charette[1], Megan Lee[1], Guillaume Barut[2], Guislain Bécu[2], Monika Pucko[1], Mathieu Ardyna[2], Jean-Éric Tremblay[2], Christine Michel[1]
[1]Fisheries and Oceans Canada, [2]Takuvik International Research Laboratory, Université Laval, Canada

Photophysiology of Arctic phytoplankton communities in glacial influenced coastal waters during the sea ice freeze-up

Delivery of meltwater and material from glaciers to Arctic fjords and coastal areas during the melt season can affect the physical environment, light regime, and nutrient supply of the marine ecosystem with subsequent consequences for Arctic primary producers. Elevated nutrient concentrations in the subsurface waters of tidewater glacial fjords have been shown to increase primary production in summer, whereas high turbidity associated with sediment discharge near tidewater glaciers and decreasing light availability at the end of summer have a negative impact on phytoplankton communities. To better understand photoacclimation strategies and productivity of phytoplankton in this highly variable coastal environment at the end of the Arctic growth season, physical and biogeochemical parameters were collected in Nares Strait, Northern Baffin Bay and adjacent glacial fjords of Ellesmere Island as part of the ArcticCORE (Conservation, Observation, Research and Engagement) program onboard the CCGS Amundsen in September 2023. Here we present data on nutrient and light availability, photosynthetic pigments, and photosynthetic parameters of carbon assimilation of different phytoplankton communities during the freeze-up period. Results show higher phytoplankton biomass with chlorophyll a concentrations >2 mg m-3 in the surface water of Nares Strait despite a heavy ice cover consisting of multiyear ice floes and newly forming sea ice. In contrast, in partially ice-covered adjacent fjords and the open water of Northern Baffin Bay, we observed low phytoplankton biomass with chlorophyll a concentrations <1 mg m-3 in the surface and shallow subsurface chlorophyll

maxima with concentrations >3 mg m-3 between 15 – 20 m, which was above the 1% euphotic depth. Phytoplankton cells were well acclimated to the decreasing light levels at higher latitudes and lower depths, consistently showing highest photosynthetic rates at the depth of the chlorophyll a maximum. Overall, these results provide new information on the impact of changing environmental conditions during the summer-fall transition on photosynthetic performance and productivity of natural phytoplankton communities.

7.3/Abstract 206: Abhay Prakash[1,2], Qin Zhou[3], Tore Hattermann[4,5], Nina Kirchner[1,2]
[1]Stockholm University, Sweden, [2]Bolin Centre for Climate Research, Sweden, [3]Akvaplan-niva, Norway, [4]Norwegian Polar Institute, [5]UiT – The Arctic University of Norway, Tromsø

Uncovering how a warmer atmosphere will control the basal melting of Petermann Glacier Ice Shelf

Long-term stability of the Petermann Glacier Ice Shelf (PGIS), which buttresses 4% of the total Greenland Ice Sheet (GrIS) discharge, will significantly impact GrIS's contribution to future sea level rise. Basal melting of PGIS has been widely attributed to increased ocean warming, however, the role of a warmer atmosphere and the mechanisms that will dictate the basal melt have not been properly quantified. Here, we use a state-of-the-art 3-D numerical regional model setup centered at the Petermann Fjord to investigate how a warmer atmosphere, via enhanced subglacial discharge (Qsg), will control PGIS basal melt. Our results show that area averaged summer mean PGIS basal melt increases by threefold under a future warmer atmosphere as compared to winter (no Qsg), and is sensitive to how Qsg is routed across the grounding line. We show that if Qsg increases beyond 100% of present summer mean estimates, PGIS cavity enters a shear-controlled regime. Here, enhanced vertical shear of the Qsg intensified current is sufficient to drive substantial increase in melt, even if there is no further increase in ocean heat forcing. Given the recent estimates of Qsg and its expected future increase, we posit that a large part of the contemporary summer melt is being driven by this regime; and which will likely control the entirety of future summer melt.

7.4/Abstract 207: Keeya Beausoleil[1], Bruce Sutherland[1]
[1]University of Alberta, Canada

Modeling Effects of Ice Face Melt in Plume Mechanics of Greenlandic Fjords

The dynamics of tidewater glacial fjords play a pivotal role in understanding oceanic exchange at the ice face and the broader stability of the Greenland ice

sheet. Previous studies have examined turbulent plumes ascending against the vertical face, with the plume source arising from runoff emanating at the base of the glacial wall. Building upon recent work, we are using numerical simulations to investigate the mechanics of buoyant plumes rising along the wall due to the ice face itself melting. Simulations were performed using the Python-based code, Dedalus, a flexible and accessible framework based on Fourier series and Chebyshev polynomials to identify complex fluid relationships. The key objectives of this project aim to investigate the effects of viscosity and buoyancy flux on critical elements such as rise velocity, buoyancy transport, and potential onset of turbulence. Linear stratification will be applied to seawater density for a more accurate representation of natural conditions. Our work aims to provide valuable insights into the contributions of ice face melt in the processes governing buoyant plumes at the ice-ocean interfaces of marine-terminating glaciers.

7.5/Abstract 212: Eva Lopes[1,2], Miguel Semedo[2], Allison Bailey[3], Philipp Assmy[3], Catarina Magalhães[1,2]
[1]University of Porto, Portugal, [2]Interdisciplinary Centre of Marine and Environmental Research, Portugal, [3]Norwegian Polar Institute

The big small changes in a glaciated fjord

Exceptional warming at 5-7 times the global average as well as increased advection of warm Atlantic water masses, termed Atlantification, make the arctic archipelago of Svalbard an epicenter of climate change. As a result, sea ice and many glaciers in Svalbard have been retreating and thinning since the beginning of the 20th century with subsequent consequences for the marine ecosystem. While the environmental changes are relatively well studied, their impact on microbial communities inhabiting Svalbard waters and the marine environment near tidewater glaciers is poorly known. Microbes play key roles as the basis of the marine food web and in the cycling of organic matter and it is, therefore, essential to understand how climate change is affecting prokaryotic (bacteria and archaea) and protists members of the microbial communities with regard to their diversity, distribution, as well as their interactions. In this study, we focus on Kongsfjorden, a fjord on the west coast of Svalbard, which integrates inputs from Atlantic and Arctic water masses and glacier run-off and hence lends itself to studying climate change impacts on marine microbial dynamics.

As part of the Kongsfjorden seasonal pelagic monitoring program, we observed differences in these microbial communities between 2019 and 2020, characterized by contrasting environmental conditions. In 2019, there was a warm spring with little sea ice, while in 2020, the spring was cold with more extensive sea ice cover. In this study, we employed a 16S and 18S rRNA gene

sequencing approach to identify and characterize microbial communities at 15 m depth and 10 m above the bottom (300 m) and to observe how they changed over the course of spring and summer. Results showed that the structure of the communities of both years were significantly influenced by the same parameters: temperature, nutrients, chlorophyll, and phaeopigments. Interestingly, the communities were distributed, in a hierarchical cluster analysis, by years and not by depth. Regarding alpha diversity, the warm year 2019 presented higher diversity than the cold year 2020. The strong environmental changes in the Arctic and its water masses can result in the redistribution of microbial communities and it is therefore important to analyze how temporal trends will affect the microplankton biome at multi-diversity and functionality levels with potential cascading effects along the marine food web.

7.6/Abstract 219: Muhammad Shafeeque[1], Ben Marzeion[1], Jan-Hendrik Malles[1], Anouk Vlug[1]
[1]University of Bremen, Germany

Temporal Dynamics of Freshwater Runoff from Greenland's Peripheral Glaciers: Implications for Arctic Fjords and Coastal Areas

Greenland's Peripheral Glaciers, not dynamically linked to the ice sheet, constitute a small fraction of Greenland's ice in terms of area (~5%) and volume (~0.5%). However, they play a disproportionately significant role in the overall mass change of Greenland, contributing to approximately 20% of the total. Remarkably, they are experiencing loss rates 2.5 times higher than the main ice sheet and are particularly vulnerable to both atmospheric and oceanic climate variability. As integral contributors to global sea level rise, these glaciers also modulate freshwater inputs to Arctic fjords and coastal zones. Understanding their future dynamic responses to climate change is imperative for predicting sea level variations, freshwater fluxes, and biogeochemical impacts on Arctic fjords and coastal zones.

This study utilized the Open Global Glacier Model (OGGM), calibrated glacier-by-glacier using geodetic mass balance and frontal ablation data, to project the future evolution of these glaciers and delineate their influence on freshwater runoff composition and peak water timing under diverse emissions scenarios (CMIP6: SSP126, SSP245, SSP370, and SSP585) until 2100.

Our projections revealed staggering area and mass losses, translating to a potential sea level rise of 19±5 mm by 2100. OGGM projected significant shifts in freshwater runoff composition. By the end of the century, under high-emission scenarios, the proportion of runoff sourced from glacier meltwater is projected to decline from 91% to 73%. Rain and off-glacier snowmelt contributions are expected to rise, signaling a transition to a more precipitation-dominated

hydrological regime. The peak water year, indicative of the maximum meltwater release, varies significantly between emissions scenarios. This timing divergence between low (2050±21) and high (2082±9) emissions scenarios underscores the potential of glaciers to regain equilibrium, postponing climate change impacts.

The projected changes have profound implications for Arctic fjords and coastal areas. Altered meltwater contributions will influence fjord circulation, salinity gradients, nutrient dynamics, and ecosystem structures. The variable timing and composition of peak water inputs could critically affect biogeochemical cycles and associated ecosystem services, including fisheries, indigenous livelihoods, and carbon sequestration potentials. This study's findings spotlight the nuanced vulnerabilities and responses of Greenland's peripheral glaciers to future climate change. The insights generated underline the necessity for tailored management strategies that address the multifaceted impacts on Arctic fjord systems, emphasizing the urgency of mitigation efforts to prolong and preserve these crucial water buffers.

7.7/Abstract 361: Mateusz Moskalik[1]
[1]Institute of Geophysics, Polish Academy of Sciences

RAW – Retreat and Wither – Differences in the influence of tidewater and land-based glaciers on the fjord water.

The productivity of marine ecosystems is an important factor in conditioning elements and organic matter cycling on Earth. The world’s oceans are a great source of O2 and sink for atmospheric CO2. The Arctic Ocean is responsible for as much as 5-14% of the global CO2 uptake by marine regions. Recent findings show that Arctic fjords are especially effective in absorbing atmospheric CO2. The biogeochemistry of the fjord systems is, however, very complex and not yet fully understood. The great unknowns that remain include the effect of glacial retreat on the CO2 budget of coastal waters. Climate change is disproportionately strong in the Arctic. One of the observable consequences of the transformation of the Arctic environment is the rapidly receding glaciers. They are recognized as the main source of freshwater, minerals, organic matter, and nutrient supply into the fjord. However, deep water upwelling at the terminus of tidewater glaciers is usually rich in nutrients, including nitrogen. All nutrients affect marine primary productivity in the areas where there are tidewater glaciers. The opposite situation is near the land-based glacier inputs, where low nitrogen availability in meltwater limits productivity. Furthermore, sustained glacier recession will change the glacial regime from predominate tidewater to land-based. Therefore, it remains uncertain how the marine ecosystem productivity will respond to future changes in the Arctic. There are hypotheses, that the warming-driven glacier

recession causes a reduction in marine biological production in polar coastal regions and seas due to:

- unfavorable nutrient balance caused by a reduction in nutrient-rich deep water upwelling from buoyant meltwaters plumes;
- shallowing the euphotic zone caused by increased surface suspended sediment concentration;
- reduction of water mass exchanges and sediment-bound nutrients transfer between the fjord/open sea and newly formed bay due to hydrography and formation of natural sediment traps.

We present results of measurements of physical and sedimentological parameters of fiords water obtained during spring and summer field campings in 2023. Measurements were realized in two bays in Hornsund fiord (Hansbukta with tidewater glacier and Gashamna with land-based glacier) and two bays in the north part of Isfjorden (Ymerbukta with tidewater glacier and Trygghamna with land-based glacier) and include temperature, salinity, water turbidity, sediment concentration and sedimentation, chl-a, pH, dissolved O2 and CO2.

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Working group: Dagmara BOŻEK (1), Jerzy GIŻEJEWSKI (1), Oskar GŁOWACKI (1), Meri KORHONEN (1), Vineet JAIN (1), Lavkush Kumar PATEL (1), Ekaterina RETS (1), Jacob C. YDE (3), Siri ENGEN (3), Marthe GJERDE (3), Andrew HODSON (3), Karol KULIŃSKI (2), Anna DĄBROWSKA (2), Katarzyna DRAGAŃSKA-DEJA (2), Małgorzata KITOWSKA (2), Katarzyna KOZIOROWSKA-MAKUCH (2), Marlena SZELIGOWSKA (2), Beata SZYMCZYCHA (2), Emilia TRUDNOWSKA (2), Natalia GACKOWSKA (2), Łukasz STACHNIK (4) ((1) Institute of Geophysics Polish Academy of Sciences, Poland (2) Institute of Oceanology Polish Academy of Sciences, Poland (3) Western Norway University of Applied Sciences, Norway (4) University of Wrocław, Poland)

7.8/Abstract 362: Lukasz Stachnik[1,2], Jon Hawkings[3], Andrea Spolaor[4], Katarzyna Stachniak[5], Dariusz Ignatiuk[5], Slawomir Sitek[5], Krzysztof Janik[5], Elzbieta Lepkowska[5], Francois Burgay[6], Marcin Syczewski[2]
[1]University of Wroclaw, Poland, [2]German Research Centre for Geosciences, [3]University of Pennsylvania, USA, [4]Institute of Polar Sciences, Italy, [5]University of Silesia in Katowice, Poland, [6]Paul Scherrer Institute, Switzerland

Controls of sediment-bound and dissolved nutrient transport from a glaciated metasedimentary catchment in the high Arctic

Rapid warming in polar and alpine regions is causing significant glacier mass loss, resulting in increasing quantities of freshwater discharge from glaciers to the oceans. Recent research indicates that higher meltwater water runoff is likely to increase transport of solute and sediments, including nutrients, to downstream ecosystems. This enhanced delivery may drive a negative feedback effect on atmospheric CO_2 concentrations by fuelling primary production in fjords and near-coastal regions. Labile sediment-bound fractions constitute a high proportion of the total nutrient yield from glacierised basins but data are sparse and the impact of these particulate nutrients is debated. Here we determine sediment-bound and dissolved lithogenic nutrient (Si, Fe, P) delivery from a polythermal glacier in SW Spitsbergen (Svalbard). Suspended sediment and filtered water samples were collected from subglacial outflows and a downstream site for lab analysis. Our research shows that there is significant spatial variation in chemical weathering processes, resulting in heterogeneous sediment-bound nutrient concentrations. There are variations in the relative degree of sulphide oxidation and carbonation dissolution in channelized systems, while silicate weathering is a minor contributor of solute in subglacial outflows with short residence time. Channelized systems have sediment-bound iron content of two times higher compared to short residence time subglacial minor outflows. In contrast, sediment-bound amorphous silica is higher for the minor outflows. The yield of sediment-bound Fe and Si (2.3 and 1.3 Mg km^{-2} yr^{-1}, respectively) was several times higher than the dissolved flux of these elements. Sediment-bound Fe yields were within the range of values noted for the Greenland Ice Sheet. Our data shows the critical role of sediment-bound nutrients on nutrient budget and cycling in glacierised basins of the high Arctic.

Session 1: Navigating a Changing Arctic: Innovations for Sustainable Maritime Development. Part 1: Maritime Challenges and Data Needs

Tuesday 30th January, 15:45 – 17:15

Abstract 32: Malte Müller[1], Maaike Knol-Kauffman[2], Jelmer Jeuring[1], Cyril Palerme[1]
[1]Norwegian Meteorological Institute, [2]University of Tromsø

Arctic shipping trends during hazardous weather and sea-ice conditions

The Arctic's extreme environmental conditions and remoteness make it a complex and dynamic environment for maritime operators. In order to better understand the trends of Arctic shipping over the past ten years, and the exposure of ships to hazardous environmental conditions we analyzed the data of the Automated Identification System in combination with atmospheric reanalysis and sea-ice satellite data. On a pan-Arctic scale from 2013 to 2022, shipping activities have increased by 7% and the exposure to potentially hazardous conditions of ships has roughly tripled. Thus, an increasing number of ship operators need to take sea-ice and weather conditions into account, e.g. in their risk assessments and voyage planning to follow the Polar Code regulations. The suggested procedures in the Polar Code are, however, mostly connected to climatological approaches, rather than using existing operational weather and sea-ice forecasting infrastructure. We highlight the benefits of using sea-ice and weather forecasts through an analysis of a recent incident in the Northern Sea Route where several ships got stuck in the East Siberian Sea, as well as a sea-spray-icing-induced incident in the Barents Sea. Generally, we conclude that provider-user interfaces for weather and sea-ice forecasting need refinement and that the Polar Code could benefit from a more detailed integration of maritime warning systems and a broader description of hazardous conditions.

Abstract 47: Hjalti Hreinsson[1], Jon Arve Royset[2]
[1]PAME (Protection of the Arctic Marine Environment, Working Group of the Arctic Council), [2]Norwegian Coastal Administration

Arctic Ship Traffic Data: Collecting and Providing data on Arctic Shipping activities

PAME (Protection of the Arctic Marine Environment, a Working Group of the Arctic Council) operates a detailed database of Arctic shipping activities, Arctic

Ship Traffic Data (ASTD). Led by Norway and USA, satellites in polar orbit collect the data which is then distributed via ASTD. This database collects a wide range of information on shipping activities and has put PAME and the Arctic Council at the forefront of conducting analysis of shipping activities in the Arctic.

ASTD collects data for the whole Arctic, and includes ship tracks by ship type, calculated fuel consumption and emissions from ships, and details in individual ships. It also allows for downloads of data for detailed analysis on specific topics. A recently added feature will show data of ships entering over 400 ports in the Arctic, and will include information on each port.

The data is shared by PAME and benefits all Arctic States, the Arctic Council, research organizations, universities and others with an interest in Arctic shipping.

This project is a significant step by PAME to reduce the knowledge gap of circumpolar ship traffic in the Arctic. With changes in the Arctic sea ice extent and projected changes and increase in shipping in the Arctic, the ASTD System will allow the Arctic Council to be at the forefront of monitoring trends and assessing any changes for use in its studies, assessments, analyses, and the development of recommendations that enhance Arctic marine safety and support protection of Arctic people and the environment. This presentation will show how the database works, highlight how to get access and demonstrate how the data it is currently being used.

Abstract 74: Bernhard Schmitz[1,2], Christine Eis[1], H. Jakob Bünger[2], Christof Büskens[1]
[1]University of Bremen, [2]Drift+Noise Polar Services

How much travel time could we save using a navigation assistance system in ice?

For providing navigational assistance in polar regions, we develop a system offering on-demand route suggestions. The suggestions are based on near real-time earth observation data, bathymetry and drift / weather models. Within the FAST-CAST2 project, the ice classifications derived from earth observation data are interpolated in time to gain high-resolution knowledge about the changing ice conditions. By providing route suggestions that consider that many sources of information, it should be possible to not only reduce travel costs (time and fuel) but also allow safer travels.

Within the current work, we want to evaluate the performance with respect of travel time provided by such an automatic routing system. Therefore, travel times of generated routes are compared with simulated ship tracks.

For now, detailed knowledge of ship characteristics is lacking and therefore a ship travelling between a given origin and target without extra ice information available is simulated. That means that the ship doesn't have access to high resolution and near real-time satellite images, ice charts or helicopter support. It's assumed that the ship is aware of the ice conditions within the visual range of the ship's position.

The ship track is generated by an A* algorithm, which iteratively calculates a route from the origin to the target. The algorithm considers only the ice information that is known to the ship. Once a route was found, re-calculation is triggered. This time, the origin is set to the first waypoint of the previous calculated route. This is done until the target is reached. For analysis, this experiment had been carried out multiple times for visual ranges between 1 km and 20 km.

The generated tracks were compared to route suggestions which were derived by the same A* algorithm when considering ice information for the full area of interest. In all cases, the route taking all information into account performed best. For instance, a visual range of 6 km leads to travel times which are about 15% to 40% higher than we can achieve taking all information into account. A clear negative correlation between visual range and estimated travel time was found. However, a smaller visual range indeed did not increase the travel times necessarily. The analysis of different scenarios shows that the results strongly depends on the specific ice situation, e.g. on the occurrence of leads and the homogeneity of the ice.

Abstract 213: Tiantian Zhu[1], Masoud Naseri[1], Sushmit Dhar[1]
[1]UiT – The Arctic University of Norway, Tromsø

Multi-stage multi-criteria route planning and optimization for fishing vessels in the Barents Sea

Fishing is one of the primary economic activities in the Barents Sea. Optimizing fishing vessel voyage planning is a feasible avenue for enhancing efficiency, profitability, and sustainability while mitigating accidental risks posed by adverse weather conditions and reducing environmental impact through decreased fuel consumption. Currently, fishing voyage planning and route optimization rely heavily on the accumulated experience of skippers, thus it is a challenging task for inexperienced skippers. This presentation introduces a comprehensive multi-stage, multi-criteria route planning and optimization framework tailored for pelagic fishing in the Arctic. Developing such algorithms will allow the use of available data in decision-making, facilitating more efficient fishing practices. Simultaneously, these algorithms serve as a means of transmitting the empirical

knowledge of seasoned skippers to the next generation. The proposed model for fishing route planning and optimization prioritizes three key objectives: maintaining catch, maximizing safety, and minimizing operational costs. The relation between those objectives and visiting a fishing ground or passing a passage will be modeled. Graph theory and Pareto-optimality will be used in the algorithms to find a collection of optimal routes that contain a set of sequential fishing grounds to visit and a fishing factory to deliver the catch. Skippers can utilize the proposed approach as a decision support tool for their fishing trip planning and route optimization. At the same time, the algorithms can be tuned and improved through daily application and feedback to form a valuable body of knowledge for future generations.

Abstract 77: Andrew Fleming[1], Keld Quistgaard[2]
[1]British Antarctic Survey, [2]Danish Meteorological Institute

H2020 ArcticPassion Pilot Service for POLARIS Risk Management in Polar Seas

It is apparent that the POLARIS sea ice risk assessment system is not yet widely adopted by the maritime community for voyage planning or tactical navigation decisions. The International Ice Charting Working Group (IICWG) task team on POLARIS and the EU H2020 Arctic Passion project are investigating the role of POLARIS, current limitations and approaches to improving its usefulness.

We will present a summary of the current findings of these activities addressing the following points.

* The availability of POLARIS Products for support of shipping in Polar Waters, including plans for publication by the national ice services.
* How current POLARIS use and best practices are used in large scale voyage planning and vessel design.
* Initial findings of a historical analysis of Arctic ship traffic in relation to sea ice conditions, to understand patterns of historic ship risk in ice and how it relates to the POLARIS assessments. This aspect aims to provide insight into changes in maritime activity over time and how it relates to the changing Arctic sea ice.
* Gaps and limitations of the current approach to deriving POLARIS risk scores, comparing onboard calculations with wider area assessments from sea ice charts. This will inform requirements for new satellite observations and information products to support delivery of improved POLARIS assessments at the required temporal and spatial scales.
* Mariner training in use of POLARIS and how it is displayed onboard ships.
* New research activity to deliver short and medium term POLARIS forecasts to further improve its usefulness to the maritime industry.

We will also present a number from case studies of ship voyages into sea ice,

comparing various ice chart information with direct ice observations and discuss the relevance and use of POLARIS for onboard decision support. In addition we will present findings from the first onboard use of POLARIS forecasts and plans for future demonstrations in spring 2024.

Abstract 28: Abbie Tingstad[1], [1]Center for Arctic Study and Policy, US Coast Guard Academy

Potential Priorities for Data Needs to Support the Future Arctic Blue Economy

The Arctic Blue Economy holds much promise for the future, but there is much work ahead if fishing, shipping, mining, energy, tourism, and other activities are to be managed in ways that can also enable subsistence activities as well as promote safety, law enforcement, and environmental integrity. Central to this will be the continued evolution of data collection, processing, analysis, communication, and interpretation systems and practices. In particular, the ability to anticipate emerging risks and mitigation options will become increasingly important if the Arctic Blue Economy grows. Ideal information for decisionmaking about sustainable maritime development rarely – if ever – exists. What might a good enough or even ideal data and information architecture look like? What are tradeoffs between anticipatory, less perfect information and nearer-in or real-time data that affords less time for proactive decisionmaking? What geographical, technical, and geopolitical challenges must be overcome to support data and information for a sustainable Blue Economy in the Arctic? This presentation lays out a subset of these issues and suggests priorities for international cooperation in order to address them.

Session 1: Navigating a Changing Arctic: Innovations for Sustainable Maritime Development. Part 2: Sea Ice and Iceberg Monitoring and Forecasting

Wednesday 31st January, 11:30- 13:00

Abstract 80: Ed Blockley[1], Helge Goessling[2], Valentin Ludwig[2]
[1]Met Office UK, [2]Alfred Wegener Institute

Forecasts of sea ice drift and deformation from the international Sea Ice Drift Forecast Experiment (SIDFEx)

The Sea Ice Drift Forecast Experiment (SIDFEx) is an international community initiative, developed in 2017 under the auspices of the WMO's Year of Polar Prediction (YOPP), to solicit, collect, and analyse forecasts of sea ice drift. SIDFEx forecasts are generated by 13 research groups using 23 distinct forecasting systems of varying degrees of complexity, ranging from free-drift forecasts to forecasts derived from fully coupled dynamical general circulation models. More than 5 years on, the SIDFEx database contains over 200,000 forecasts trajectories for the drift of certain assets (mostly buoys) located in the Arctic and Antarctic sea ice, at lead times from daily to seasonal scale and mostly daily resolution.

Following two successful years simulating the drift trajectories of International Arctic Buoy Program buoys as a test of skill, SIDFEx near-real-time 'consensus' forecasts were developed for use in support of polar operations in both hemispheres. Consensus forecasts are constructed by merging sea ice drift forecasts from several international forecast and research centres, with lead-times ranging from days to several months, into a seamless drift forecast with explicit uncertainties. SIDFEx consensus forecasts of Arctic sea ice drift were provided for the RV Polarstern, and surrounding distributed networks, in support of the international, year-long, MOSAiC expedition. During MOSAiC, the SIDFEx forecasts were used for ordering high-resolution TerraSAR-X images in advance, with a hit rate of 80%. In the Antarctic, SIDFEx forecasts were used during the Endurance22 expedition to support the onboard team, who successfully located Shackleton's lost ship in March 2022. Several other campaigns have benefitted from SIDFEx support, including three Arctic icebreaker missions in the first half of 2023.

Currently, we evaluate drift forecasts in more detail. Having previously found

skill in predicting the location of single buoys, we extend this to studying the deformation of the polygon spanned by the buoys of the MOSAiC Distributed Network (DN). Deformation is derived from the spatial velocity derivatives of the buoy array. In this talk we will provide an overview of the SIDFEx project and the SIDFEx sea ice drift forecast database along with an analysis of drift and deformation using the MOSAiC DN.

Abstract 84: Rafael Grote[1], Malte Müller[1], Yurii Batrak[1], Frode Dinessen[1], Keguang Wang[1], Thomas Lavergne[1]
[1]Norwegian Meteorological Institute

Sensitivity of a kilometer-scale weather forecasting system to uncertainties in sea-ice concentration.

Arctic communities and arctic industries such as shipping, tourism, transportation and fishing are dependent on accurate short-range forecasts for a safe conduct of their activities. However, numerical weather prediction (NWP) models for high latitudes generally show lower forecast capability compared to other regions (Jung et al., 2016). The challenges are many. One particular problem is the representation of the sea ice, which is crucial for a realistic simulation of atmosphere/ice/ocean fluxes on a wide range of spatiotemporal scales.

We present an assessment of sensitivity experiments performed with different sea-ice concentration products in AROME-Arctic, a convective-scale weather forecasting system for the European Arctic; and first results of experiments with the ensemble version of AROME-Arctic where sea ice concentration is perturbed.

The sensitivity experiments were carried out using three different sea ice concentration fields: that from the global NWP system operated by ECMWF, a multisensor product from the Copernicus Marine Service (CMEMS) combining passive microwave (PMW) and synthetic aperture radar (SAR) data assimilated through a coupled sea ice-ocean forecasting system, and the product run at the University of Bremen based on passive microwave observations from the AMSR2 instrument.

The ensemble experiments use sea ice concentration fields and their uncertainty estimates from a new product based on AMSR2, which was developed at MET Norway during the NFR SIRANO project.

All three products used in the sensitivity experiments show significant differences on scales of 100 km in the northern Barents Sea, along the Marginal Ice Zone north of the Svalbard archipelago and towards the Fram Strait. These differences have a direct impact on the modelled surface temperature over the

ocean and sea ice, the turbulent heat flux and 2m air temperature. The results showed differences in the surface turbulent heat flux of up to 400 W/m2, which in turn results in 2m air temperature variations of up to 5°C. Over a 2-day forecast this can lead to uncertainties in weather forecasts of about 1°C even hundreds of kilometres away from the sea ice.

In the ensemble experiments, sea ice concentration perturbations are created based on pink noise fields and scaled such as to target areas of high uncertainty. First results show increasing spread of forecasted temperature and wind over the forecast time of 2 days, which suggests that perturbing sea ice concentration adds value to the EPS by capturing uncertainty in the initial sea ice state.

Abstract 85: Daniel Befort[1], Steffen Tietsche[1], Frédéric Vitart[1]
[1]ECMWF – European Centre for Medium-Range Weather Forecasts

ICECAP - A tool to support decision making processes by using sea ice forecasts from days to seasons

Improving the quality of Arctic sea ice forecasts as well as fostering user uptake of available sea ice information are one of the main objectives of the ACCIBERG project. One of the project's efforts is the development of a software tool (ICECAP) to support end-users to make informed decisions.

Here we present the currently implemented capacities of ICECAP, which include targeted user-related products based on sea ice forecasts. Examples for such products are: i) the temporal evolution of the ice edge distance for a stationary open-water location, ii) forecast freeze-up dates over the Arctic and iii) information on the length of the ice-free season. These products are accompanied by information on skill and reliability of the underlying sea ice forecasts with a special focus on forecast uncertainty quantification.

ICECAP aims to provide users with seamless sea ice forecast information by drawing on a series of forecasts from days to seasons and from different forecasting centres. This is achieved by providing easy access to sea ice forecasts across different Copernicus services through one single-entry point.

Abstract 110: Abigail Dalton[1,2], Luke Copland[2], Wesley Van Wychen[3], Alison Cook[2], Jackie Dawson[2], Adam Garbo[4], Derek Mueller[4], Adrienne Tivy[5]
[1]Natural Resources Canada, [2]University of Ottawa, [3]University of Waterloo, [4]Carleton University, [5]Environment and Climate Change Canada

Coexistence of icebergs and ships in the eastern Canadian Arctic: 2012-2019

Icebergs present a known hazard to ships operating in ice infested waters. Despite this knowledge, and the occurrence of many iceberg-ship collisions in Canadian waters since 1800, few recommendations exist for ships operating in the eastern Canadian Arctic (ECA). We use ship tracks derived from AIS (automatic identification system) data, in combination with iceberg drift locations derived from in-situ satellite trackers and the Canadian Ice Island Drift, Deterioration, and Detection Database (CI2D3), to identify the coexistence of icebergs and ships throughout the ECA from 2012-2019. Results show that icebergs were consistently present throughout the ECA, including Nares Strait, eastern Lancaster Sound, and along the east coast of Baffin Island. Between the periods 2012-2015 and 2016-2019, the total number of unique vessels operating in this region more than doubled from 134 to 271, while the number of trips taken increased from 6570 to 10966. The regions that saw the largest increases in iceberg-ship coexistence were along the east coast of Baffin Island and east of Bylot Island for dry bulk vessels, and northward into Smith Sound for passenger vessels.

These results highlight how iceberg-ship coexistence is increasing in the ECA due to the increased presence of ships there over the past decade and the continuing presence of icebergs in the same region. Recent reductions in the mean ice strengthening of ships operating in the ECA also means that the seriousness of any potential collision is likely increasing towards the present day, particularly for vessels that have minimal or no ice strengthening such as pleasure craft and passenger vessels. This motivates the need for increased monitoring of iceberg presence throughout the ECA for vessel navigation and offshore industry.

Abstract 42: Laurent Bertino[1], Steffen Tietsche[2], Thomas Lavergne[3], Catherine Downy[1]
[1]NERSC – Nansen Environmental Remote Sensing Centre, [2]ECMWF - European Centre for Medium-Range Weather Forecasts, [3]Norwegian Meteorological Institute

Improved monitoring and forecasting of Arctic sea ice and icebergs with the ACCIBERG project

Sea ice and icebergs are a major security risk for navigation and fisheries in Arctic waters. Both will remain a significant threat even in a warmer Arctic, where traffic is expected to increase. Sea Ice Services are needed more and more to support less experienced captains with automated high quality forecasts and new information about icebergs that are not available today.

To monitor and forecast sea ice types and icebergs ahead of time, adequate forecasts of sea ice, ocean, wind, and wave conditions for the whole Arctic are

crucial. The Copernicus Marine and Climate Change Services provide such information products. However their uncertainties are not provided in a consistent and user-friendly manner. Reliable uncertainty estimates can however be based on forecast ensembles across the two Copernicus Services.

ACCIBERG will improve the quality of sea ice, and ocean products and their uncertainty estimates in both Copernicus Services. It will also extend the spatial coverage of the satellite detection of icebergs and develop a completely new iceberg forecast service. ACCIBERG will build upon state of the art sea ice and ocean models, remote sensing algorithms, data assimilation and cloud computing to offer probabilistic sea ice and iceberg forecasts based on Copernicus data consistently. National or commercial sea ice services are limited to smaller regions and will benefit from the increased accuracy and consistency across the Copernicus products.

The new forecasts will be demonstrated in ACCIBERG by European Ice Services and ships of opportunity. The new iceberg forecasts will be automated and validated, and benefit a wide range of user groups navigating in the Arctic, from fisheries to cruise tourism, including Marine Surveillance under the Copernicus Security Service. We will provide prototype products ready to be implemented in the Copernicus services and accessible from a single entry point: its inherent cloud computing solution.

Abstract 111: Wieslaw Maslowski[1], Anthony Craig[2], Younjoo Lee[1], Mark Seefeldt[3], Darin Comeau[4], Robert Osinski[5], Milena Veneziani[4]
[1]Naval Postgraduate School, USA, [2]Private Contractor, [3]University of Colorado, [4]Los Alamos National Laboratory, USA, [5]Institute of Oceanology Polish Academy of Sciences

Advancements in Sub-Seasonal to Decadal Arctic Climate Modeling and Prediction Using the Regional Arctic System Model

The Regional Arctic System Model (RASM) has been developed and used for improved understanding and prediction of the process-level operation of the Arctic System at time scales from hours to decades. It is a fully coupled limited-domain climate system. Its regional domain covers the pan-Arctic region extending south to ~30oN in the North Pacific and to ~40oN in the North Atlantic Ocean. RASM default atmosphere and land components are configured on a 50-km grid and the ocean and sea ice components at 1/12o (~9.3km) in the horizontal space and with 45 vertical ocean layers. High-resolution model configurations include the atmosphere/land at 25-km and ice-ocean at 1/48o (~2.4-km) grids. Its boundary conditions along the lateral boundaries and in the upper atmosphere are derived either from global atmospheric reanalyzes or from Earth System Model (ESM) simulations. In the case of hindcast simulations, this

requirement allows comparisons of RASM results with observations in place and time, which is a unique capability not available in global ESMs, enabling diagnosis and potential reduction of biases. Combined with high spatial and temporal resolution, this approach allows improvements in representation of critical processes, coupling, and optimization of the scale-aware parameter space.

Within this framework, RASM has been also used to downscale output from global models, specifically from the National Center for Environmental Predictions Coupled Forecast System version 2 (CFSv2), the National Center for Atmospheric Research (NCAR) Community Earth System Model initialized Decadal Predictability Large Ensemble (CESM-DPLE), and the Department of Energy (DOE) Energy Exascale Earth System Model (E3SM). Forced with CFSv2, RASM has produced probabilistic intra-annual forecasts each month for the past 4+ years. The CESM-DPLE and E3SM output was used for downscaling multi decadal simulations. Here, we present a review of some of these results, including evaluation of RASM sea ice predictive skill in comparison with observations and relative to the original global output using the common metrics to quantify model skill. Finally, we preview some promising examples of RASM possible improvements and extensions of probabilistic prediction to Arctic marine ecosystems.

Session 1: Navigating a Changing Arctic: Innovations for Sustainable Maritime Development. Part 3: Maritime Operations and Safety

Wednesday 31st January, 16:00 – 17:30

Abstract 90: Lucy Vlietstra[1], Kayla Hinrichs[2]
[1]U.S. Coast Guard Academy, [2]Independent Researcher, USA

Proximity of Commercial Maritime Traffic to the Arctic Marginal Ice Zone, 2012 to 2023

The Arctic Marginal Ice Zone (MIZ) is a transitional region of the Arctic Ocean separating continuous or near-continuous ice coverage to the north from open water to the south. Sea ice formation within the MIZ is highly variable over space and time, with up to 80% of the water's surface covered in ice floes or fragments, making it a serious navigational hazard for most commercial vessels. Concern over mariner safety has grown in recent years as the volume of vessel traffic in the region has notably increased. To help emergency managers prepare for and respond to ships becoming hindered, entrapped, or damaged by sea ice, we characterize spatiotemporal patterns in the proximity of vessel traffic to the Arctic MIZ. Specifically, we use publicly available information on vessel density (monthly hours/km2) from the Global Maritime Traffic Density Service (globalmaritimetraffic.org) and daily sea ice chart products from the U.S. National Ice Center (usicecenter.gov) to characterize the geography of commercial ship exposure to the MIZ during select months from 2012 to 2023. Results include an analysis of ship proximity to the MIZ over time, across the Arctic Ocean, and by ship type (e.g., fishing vessels, passenger vessels). Overall, our goal was to identify locations where commercial ships, most of which are not ice strengthened, were most likely to encounter sea ice while underway above the Arctic Circle. The implications of sea ice hazard exposure are discussed in terms of the basic risk equation: Risk = Likelihood x Consequence.

Abstract 176: Dylan Jones[1], Ashraf Labib[1], Asrul Ismail[1], Zahirul Robin[1], Mikel Dominguez[2]
[1]University of Portsmouth, [2]JRCC – The Joint Rescue Coordination Centre

Progressing Arctic Maritime Search and Rescue Innovation Priorities: An Overview of the ARCSAR Project Stakeholder Workshops

This seminar presents an analysis of current and emerging Arctic and North Atlantic (ANA) search and rescue capability gaps and needs for innovation. The prime data source is a set of three stakeholder workshops organised as part of the EU Horizon 2020 funded ARCSAR (www.arcsar.eu) project. These took place in (i) Portsmouth, UK (ii) Svalbard, Norway and (iii) Cork, Ireland in the period May 2022 until February 2023. However, they are underpinned by a list of ANA priority innovation needs developed earlier in the ARCSAR project and findings from other Physical (LivEX) and Table Top (TTX) simulation exercises and events, as well as the broader literature and other projects in the ANA region.

An overview of each of the three stakeholder workshops will be given, including the range of participants involved and rationale behind the choice of keynote speakers. A mapping between the developed list of priority innovation needs and the topics considered at the workshops as a whole will be presented. The inclusion of emerging needs, such as the usage of drones and artificial intelligence-based applications, will be justified. The results of a set of SWOT analyses for each of the considered ANA priority needs will be discussed, including how the conclusions inform future ANA SAR research and innovation policy and consequent practice. An overall foresight analysis for each of the themed stakeholder events will then be presented. This analysis will include insights into:

1. The usage of emerging technologies such as drones and AI in ANA SAR
2. The production and timely usage of satellite data in SAR
3. The preparation and readiness of remote communities for response to potential future large-scale SAR incidents
4. The need for further, larger-scale LivEX and TTX type simulation exercises
5. The need for, and required level of, standardisation across ANA SAR

Finally, a summary will be given of the impact of the stakeholder workshops on policy makers and practitioners in the ANA SAR field and conclusions drawn.

Abstract 171: Claire Bernard-Grand'Maison[1], Sigurd Teigen[1], Kenneth Eik[1], Richard Hall[1]
[1]Equinor ASA

Ice Risk Management at Johan Castberg, Southern Barents Sea

Johan Castberg will be the northernmost producing oil field in the Barents Sea and on the Norwegian Continental Shelf. Production from a turret-moored Floating Production Storage and Offloading (FPSO) unit is planned to start in the fourth quarter of 2024 and will last for 30 years.

Even though the probability of sea ice or glacial ice intrusions at the Johan Castberg field is low (< 1% chance of ice intrusion during the production lifetime), the risk is non-negligible and needs to be managed to ensure safe operations. As part of its license to operate, Equinor has committed in the Plan for Development and Operations to implement an Ice Risk Management System (IRMS) and to continuously monitor ice conditions in the vicinity of the installation. The objective of the IRMS is to ensure that the risk of adverse consequences of sea ice and iceberg encounters is as low as reasonably practicable (ALARP).

Multiple surveillance technologies will be integrated to minimize the probability of ice drifting towards the installation without being detected and enable a timely production stop if ice comes close to the installation. As part of this development, Equinor is collaborating with the Ice Services and the Ocean and Ice Research Department Division from the Norwegian Meteorological Institute to improve the monitoring and reporting of ice intrusions in the Southern Barents Sea for the benefit of all maritime users. Implementation of results from the CIRFA Centre for Research-based Innovation hosted by the University in Tromsø is a key component in this effort.

The IRMS design is based on previous experiences of ice risk management for drilling operations in the Barents Sea with the additional aspect of supporting a permanent operation, where the probability of ice observations will be low on a year-to-year basis. In this long-term perspective, a higher degree of automation in integrating surveillance data is required to efficiently provide a clear risk picture to decision-makers.

This presentation will give an overview of the essential IRMS components for Johan Castberg: (1) detection, tracking and forecasting of ice intrusions; (2) threat assessment and alerting; (3) procedures and organizational set-up for responding to threatening ice; and (4) onshore and offshore personnel training. Proposals for improvements as new cost-effective surveillance technologies become available will also be touched upon.

Abstract 133: Kelsey Frazier[1], Matthew Richards[2], Randy Kee[3]
[1]University of Alaska Fairbanks, [2]United States Coast Guard, [3]Ted Stevens Center for Arctic Security Studies

Innovations in modeling future Arctic oil spills

Investment in Arctic resource extraction and transportation has forced regional and international entities to grapple with the looming threat of an oil spill in the Arctic Ocean. The consequence of an Arctic maritime oil spill is heightened by the dearth of information on oil slick motion beneath sea ice. This study employed satellite and remote sensor data from the Beaufort and Chukchi Seas to simulate under-ice morphology, which provided the necessary boundary conditions to run realistic gravity-driven flow models. Results produced volumes ranging from 30,000 – 1 million cubic meters of oil sequestration per square kilometer, depending on ice stage conditions. Further, models indicate under ice morphology herds the slick such that only 20-40% of the ice encounters oil. Implications of these estimates are that an Arctic spill cleanup could be far more challenging than previously imagined, and if encapsulated, sea ice could transport significant volumes of oil, from a spill location in one country's territorial waters, across international boundaries.

Abstract 280: Anna Karlsdottir[1]
[1]University of Iceland

Cruise Ships in the Arctic – Development 2003-2023
With the exception of the pandemic period, the arrival of cruise ships to Iceland and the nearby Arctic has been constantly growth since the turn of the millennium. This type of seaborn tourism generates income in many localities that would otherwise have little benefit from tourism, but in other areas the growth of tourists from ships has had a crowding out effect on other sometimes more profitable sectors of tourism. In the last twenty years, different studies on the arrival of cruise ships and their effects have been carried out regarding sustainable development of tourism, the experience of cruise ship passengers at the arrival points, etc. Here it will be based on five studies on cruise ship tourism in the circumpolar Arctic but particularly in Iceland and Greenland and span the period 2003-2023.
What has changed in cruise ship arrivals in 20 years? How have ideas about the impact of this type of tourism in the communities of calls in Iceland and Greenland changed and what are the most urgent questions regarding sustainable cruise ship tourism in the Arctic?
In many ports and coastal communities, tolerance limits have been reached in terms of the maximum number of tourists that the locals can adequately accommodate, but the season of cruise arrivals is getting longer. In most cases, port managers focus on spreading the load and applying certain criteria to determine what works and what doesn't, but more direct and indirect stakeholders need to be brought to the table to determine where the limits of tolerance lie. Information on cruise ships, administration and management is handled differently in Iceland and Greenland, and regardless of where the income flows - the question is what can be learned from the comparison between these different neighbouring countries, and which pathways are

feasible to ensure sustainability and satisfaction of as many different parties as possible.

Session 2: Observing Arctic Ice-Ocean-Atmosphere Interactions: Changes and Effects on Interannual to Centennial Timescales. Part 1: Sea Ice Observations

Monday 29th January, 13:30-15:00

Abstract 221: Hiroshi Sumata[1], Laura de Steur[1], Dmitry Divine[1], Mats Granskog[1], Sebastian Gerland[1]
[1]Norwegian Polar Institute

Long-term monitoring by the Fram Strait Arctic Outflow Observatory reveals regime shift in Arctic Ocean sea ice thickness

Arctic Ocean, characterized by its perennial sea ice cover, has experienced drastic changes in the last decades. Reduction of sea ice modified heat and momentum transfer between the atmosphere and underlying ocean, and concurrent changes occurring in the ocean supposedly play a key role in regulating polar climate in future. Changes in Arctic sea ice have been featured as a gradual reduction of summer sea ice extent in recent decades. We found, however, that the sea ice thickness in the Arctic Ocean experienced a stepwise, distinct shift from one regime to another. The Fram Strait Arctic Outflow Observatory, maintained by the Norwegian Polar Institute, captured the shift in Arctic sea ice thickness that occurred in 2007. The shift was from thicker and deformed to thinner and more uniform ice cover. After the shift, the modal thickness reduced by approximately 1 m (2.7 m to 1.7 m), and the fraction of thick and deformed ice dropped by half and has not recovered to date. Our analysis shows that the timing of the shift was preceded by a two-step reduction in mean residence time of sea ice in the Arctic Basin, initiated first in 2005 and followed by 2007 (approximately 1.6 years reduction, from 4.3 years to 2.7 years). The reduction of the residence time of the sea ice is correlated with summer sea ice extent in areas of sea ice formation (Alaskan sector: r = 0.65, Siberian sector: r = 0.73), indicating that the drop of September sea ice concentration in these areas triggered the drop of the residence time. The reduction of thicker and deformed ice after the regime shift made sea ice more mobile and sensitive to wind forcing. The transpolar drift stream, which carries sea ice from the central Arctic to the Atlantic sector of the Arctic, accelerated by 37% (from 2 km/day to 2.7 km/day on average) after the shift. The thinner and more mobile sea ice is seemingly more vulnerable to atmospheric extreme events. We show an example of such an extreme event, a strong dipole anomaly of sea level pressure observed in the Atlantic sector of the Arctic in 2018. This atmospheric event

caused the record minimum of sea ice export from the Arctic Ocean to the northern North Atlantic Ocean in 2018 (less than 40% relative to the mean between 2000 and 2017).

Abstract 6: Edmond Hansen[1], Kenneth Eik[2], Sigurd Teigen[2]
[1]NORCE, [2]Equinor

Coupled sea ice thickness and ocean heat variability in the Barents Sea observed by long-term (2014-2020) observations

The Barents Sea is a region of pronounced air-sea ice-ocean interactions. Owing to decreasing sea ice extent, Svalbard air temperatures are drastically increasing. The sea ice extent is controlled by oceanic heat from inflowing Atlantic water, and by inflow of thick ice from the Arctic Ocean which upon its melt strengthens the local stratification, thereby reducing the efficiency of the mixing processes in exposing the remaining sea ice to ocean heat. This inflow of thicker ice is again controlled by atmospheric circulation patterns. In this air-sea ice-ocean interaction loop, where most relevant air and ocean parameters as well as sea ice extent are observed and relatively well described, little is known about the sea ice thickness. Here we demonstrate and quantify how the thickness of sea ice in the Barents Sea responds to the interaction with the ocean, and how the thickness co-varies with the extent. The findings are derived from consistent long-term observations of sea ice draft by upward looking sonars at five sites on Spitsbergenbanken and Storbanken in the Barents Sea during the period 2014-2020. The average draft of locally grown level ice at the end of winter is approximately 0.6 m. Reflecting decreasing ocean temperatures at the observation sites, the draft of locally grown level ice exhibits an increasing trend of approximately 5 cm (corresponding to approximately 8% of the average level ice draft) per year during the observation period. This short-term increase in thickness is accompanied by a short-term increase in extent over the same period, superimposed on the long-term trend of decreasing sea ice extent. The sea ice draft observations show that sea ice exported from the Arctic Ocean reached the observation site during late winter of 2020, with level ice drafts of nearly 2 m. This is a year where anomalously high inflow of sea ice into the Barents Sea from the Arctic Ocean occurred. It is likely that this inflow contributed to the large draft of the locally grown sea ice and the extent of the Barents Sea ice cover.

Abstract 194: Robert Ricker[1], Thomas Lavergne[2], Emily Down[2], Mari Anne Killie[2], Stefan Hendricks[3], Stephan Paul[3]
[1]NORCE,[2]Norwegian Meteorological Institute, [3]Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung

Unlocking Arctic sea ice dynamics: daily drift-aware satellite-derived sea ice thickness maps

The polar regions are a hot spot of climate change, and large-scale satellite observations to monitor sea ice decline are important. One of the essential climate variables (ECVs) is sea ice thickness, controlling the heat exchange between ocean and atmosphere.Within the European Space Agency (ESA) Climate Change Initiative (CCI) project, consistent sea ice thickness time series across different satellite altimetry missions (ERS, Envisat, CryoSat-2, Sentinel-3) are generated to observe long-term trends. To provide monthly maps of ice freeboard and thickness, daily trajectories are averaged on a 25 km grid, while each trajectory only represents the ice thickness in the moment of the satellite overflight. However, sea ice can drift significantly within one month, especially in areas with typically high drift rates, like in the Beaufort Gyre or in the Fram Strait. Moreover, in the context of climate change, studies suggest that sea ice will become more mobile in the future. Neglecting sea ice drift when generating monthly sea ice thickness maps from satellite altimetry will cause blurring of the spatial distribution of ice thickness. We therefore suggest synergizing sea ice freeboard and thickness information from satellite altimetry with sea ice drift estimates from passive microwave satellite sensors. With our approach, we successively advect individual parcels of satellite altimeter measurements daily over a time span of one month to obtain drift-aware sea ice freeboard and thickness maps. Because of the drift correction, we can also determine sea ice that was overflown by the satellite multiple times. This allows to estimate growth rates and changes in the sea ice thickness distribution due to deformation and thermodynamic ice growth between satellite overflights. With the estimation of sea ice growth, measurements can be corrected for the time offset between the acquisition day and the target day, the day to which all measurements within a month are projected. Here we present daily drift-aware sea ice freeboard and thickness maps, using CryoSat-2 and ICEsat-2 data, covering the entire Arctic sea ice domain. These data will be especially useful to study sea ice dynamics as a result of ice-ocean-atmosphere interactions. We will show how this product can inform about the dynamic nature of sea ice and will present first comparisons with year-long sea ice thickness observations and growth estimates from the Multidisciplinary drifting Observatory for the Study of Arctic Climate expedition (MOSAiC).

Abstract 41: Weixin Zhu[1], Siqi Liu[1], Shiming Xu[1], Lu Zhou[2], Yong Luo[1], Jianbin Huang[1]
[1]Tsinghua University, [2]University of Gothenburg

Satellite Remote Sensing of Marginal Ice Zone in the Atlantic Arctic by Delay-Doppler Radar Altimetry of CryoSat-2

The marginal ice zone (MIZ) is the region of an ice cover which is affected by the open ocean. Wave-affected MIZs are dominated by waves and swells and their propagation in the sea ice cover, which involves close coupling between sea ice, the ocean and the atmosphere. In situ campaigns provide us with direct observation of these processes in the MIZ. However, their spatial and temporal coverage of the MIZs is limited, and there still exist great challenges for large-scale and long-term monitoring of the MIZs in the polar oceans.

In this study, we explore the capability of the CryoSat-2 delayed Doppler radar altimeter to retrieve wave-affected MIZs. We developed a retrieval algorithm to determine the locations of the MIZs based on waveform and waveform stack parameters. Subsequently, we compare the retrieval results among CS2, ICESat-2 and Sentinel-1, showing a significant degree of agreement and the effectiveness of the retrieval algorithm. Meanwhile, utilizing CS2 data since 2010, we generate a record of the wave-affected MIZs in the Atlantic Arctic region, spanning 12 winters between 2010 and 2022. The results indicate that, although significant spatial and temporal variability is present, there exist no significant changes in the mean and the extreme widths of the MIZs during the study period. Notably, extensive MIZs exceeding 300 km were observed in the Barents Sea, which is significantly wider than in other regions of the Atlantic Arctic. We also compare our results with the traditional definition of MIZ based on sea ice concentration. Remarkably, the CS2-based MIZs are systematically wider than those based on SIC, and very weak correlation is observed between the two. It is worth emphasizing that the proposed MIZ retrieval algorithm can also be applied to various historical and future radar altimeters. Therefore, there is great potential in combining multiple radar altimeters for complementary observations and the construction of the long-term climate record for MIZs.

Abstract 129: Andreas Preußer[1], Thomas Krumpen[1], Marcel Nicolaus[1]
[1]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research

Interannual variability of snow and ice thickness across the Transpolar Drift as derived from drifting sea ice mass balance buoys

The presence of sea ice on polar oceans is both controlling and, at the same time, getting influenced by the transfer of energy, moisture and momentum between the oceanic and atmospheric boundary layers. The seasonal evolution of the ice and snow thickness is critical for modulating these interactions, among other physical properties that evolve in concert under temporally and spatially variable growth and decay processes. As a backbone for a regular monitoring of sea ice characteristics, autonomous drifting buoys have been deployed in both Arctic and Antarctic seas for more than a decade. The use of sea ice mass balance buoys (SIMBA type) relies on characteristic thermal properties of air, snow, ice and sea water to delineate sea ice interfaces based on

profile measurements of ambient and heating temperatures. In some cases, they can further reveal snow and/or ice metamorphism such as flooding.

In our study, we aggregate and utilize data from about 70 SIMBA buoys to investigate the long-term variability of ice and snow thickness along the Transpolar Drift System between 2012 and 2023. We apply an augmented uniform processing scheme to all buoys, which is newly developed to reduce prior methodological ambiguities in the derivation of snow-ice-ocean interfaces. This consistent data set improves the comparability of different buoys in terms of derived snow and ice thicknesses and respective growth and melt rates. Based on an analysis of the retrieved sea ice properties, we assess how the observed interannual variability of the sea ice mass balance relates to some of the large-scale changes in the Arctic. We find that our results are in line with other (satellite-based) observations of a thinner and more seasonal ice cover with increased drift speeds in recent years. Interestingly, buoy deployments in the marginal ice zone of Fram Strait (summer 2022) feature a high proportion of surface melt and only little melt at the ice bottom, despite the proximity to warmer Atlantic waters. Through comparisons with auxiliary parameters derived from satellite data (altimeters, passive microwave and optical/thermal infrared systems) and atmospheric reanalysis, we aim to gain further insight into the local sea ice mass balance along the drift of each buoy, taking into account both thermodynamic and dynamical influences. An initial comparison with AWI's satellite-based CS2SMOS ice thickness product indicates a rather good representativeness of the derived buoy ice thicknesses for a larger (~ 25 x 25 km²) surrounding area.

Abstract 18: Lu Zhou[1], Shiming Xu[2]
[1]Gothenburg University, [2]Tsinghua University

Deciphering Arctic Atlantification: A Detailed Analysis of Sea Ice and Snow Mass Balance Over Recent Decades

Arctic Atlantification, characterized by the warming and thickening of the Arctic Ocean's Atlantic layer, has been extensively studied in a hotspot region spanning the Eurasian Basin to the Fram Strait, and directly responsible for reducing sea ice predictability, changing Arctic ecosystem dynamics and increased coupling of climate variabilities between mid-latitudes and the Arctic. Building on established research, we developed and utilized a proprietary retrieval algorithm to gain detailed insights into the intricate ocean-ice-atmosphere system. This algorithm leverages data sourced from CryoSat-2/ICESat-2 and SMOS, facilitating a nuanced analysis of bi-weekly changes in Arctic sea ice thickness and snow depth over the past 12 years. To coordinate the Atlantification features in different regions, we focused on two marginal ice zones, Fram Strait and the north of the Barents Sea. In the Fram Strait, we identified the differences in the

deep and upper ocean's impact on the ice and snow mass changes between the 1990s and 2010s. Moving our lens to the north of the Barents Sea, we outlined the dynamical and thermodynamical roles in the ice mass budget, attributed the thermodynamic flux in sea ice mass changes from ocean and atmosphere during the 2000s and 2010s, and assessed their discrepancies under the context of recent seasonal and thin sea ice conditions. Ultimately, we aim to provide a bottom-up understanding of the factors driving the observed changes in sea ice and snow mass balance, and how they relate to Arctic Atlantification.

Abstract 218: Evgenii Salganik[1], Mats Granskog[1], Mario Hoppmann[2], Polona Itkin[3], Ruibo Lei[4], Marcel Nicolaus[2], Ian Raphael[5], Daniel Scholz[2]
[1]Norwegian Polar Institute, [2]Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, [3]UiT – The Arctic University of Norway, Tromsø, [4]Polar Research Institute of China, [5]Dartmouth College, USA

Representativeness of ice mass balance buoy measurements during the MOSAiC expedition

Investigations of snow and sea ice mass balance incorporate a few methods, including measuring ice draft from underwater sonars, snow, and ice freeboard using laser and radar satellite and airborne altimetry, total ice thickness using electromagnetic sounding, and ice drilling. Meanwhile, only a few methods allow us to distinguish between sea ice surface and bottom growth or melt, with ice mass balance buoys, ablation stakes, and hot-wire gauges. Distinguishing surface and bottom melt allows for the study of the thermodynamic coupling of sea ice, ocean, and atmosphere. Meanwhile, single-point measurements of ice mass balance may be affected by the high spatial variability, including snow depth, surface, and bottom melt rates, as well as by the representativeness of various ice types, including leads, ridges, and ponded sea ice.

In this study, we use data from buoys deployed during the MOSAiC expedition in 2019–2020. We mainly focus on temperature buoys, including Digital Thermistor Strings (DTCs), Ice Mass Balance buoys (IMBs), and Snow and Ice Mass Balance Arrays (SIMBAs). We compare the key parameters governing ice mass balance, including ocean heat fluxes, snow depth and thermal conductivity, ice thickness distribution, and surface and under-ice melt pond fractions, with broader measurements available for the MOSAiC floe and its surroundings. We attempt to identify the main errors and biases in the estimates from ice mass balance buoys, which can help to improve the interpretation of buoy data in cases where other high-resolution measurements are not available.

Session 2: Observing Arctic Ice-Ocean-Atmosphere Interactions: Changes and Effects on Interannual to Centennial Timescales. Part 2: Interactions

Tuesday 30th January, 09:00-10:30

Abstract 210: Guillaume Boutin[1], Christopher Horvat[2,3], Timothy Williams[1], Jonathan Rheinlænder[1], Einar Olason[1], Laurent Brodeau[4], Pierre Rampal[5]
[1]Nansen Centre for Environmental Remote Sensing (NERSC), Norway, [2]University of Auckland, New Zealand, [3]Brown University, USA, [4]DATLAS, France, [5]French National Centre for Scientific Research (CNRS)

Modelling the wave impact on sea ice dynamics in the Arctic

As sea ice extent decreases in the Arctic, surface ocean waves have more time and space to develop and grow, exposing the Marginal Ice Zone (MIZ) to more frequent and energetic wave events. Waves can fragment the ice cover over tens of kilometres, with the potential to strongly affect sea ice dynamics in the MIZ. To assess this impact, which remains largely unknown, we have developed a new coupled framework, combining the spectral wave model WAVEWATCH III with the sea ice model neXtSIM. This model allows us to represent the effects of wave-induced fragmentation on sea ice mobility. This effect is significant when waves propagate far enough to break thick and compact ice, which occurs regularly in the Barents and Greenland seas. We conclude that wave impact on sea ice primarily depends on the distance over which the wave can break the sea ice, i.e., the Marginal Ice Zone extent, which remains poorly constrained due to a lack of observations. However, the ICESat-2 altimeter has recently been shown to be able to detect ice-covered areas affected by waves. We develop a new method to use these first estimates as a proxy of the wave-affected MIZ extent, allowing us to evaluate our model results over the whole Arctic for the period December 2018--May 2020. The modelled MIZ extent is consistent with ICESat-2 observations, allowing us to use our model to investigate the evolution of the Arctic MIZ extent over the last three decades.

Abstract 162: Manuel Bensi[1], Leonardo Langone[2,3], Vedrana Kovacevic[1], Patrizia Giordano[2], Aniello Russo[4]
[1]OGS - National Institute of Oceanography and Applied Geophysics Italy, [2]CNR – National Research Council of Italy, [3]ISP - Institute of Polar Sciences, [4]Centre for Maritime Research and Experimentation, Italy

Weak signs of dense water cascading from the Storfjorden in 2020 in a long and persisting phase of Arctic Atlantification

The only way to observe climate change is to record sufficiently long time series of data. Here, we present more than one hundred months (from June 2014 to June 2023) of oceanographic mooring data collected at Site S1 (76°N, 14°E), anchored along the 1000 m isobath above the continental slope on the southwestern margin of Svalbard Archipelago (Fram Strait). There, the main branch of the West Spitsbergen Current transports Atlantic Water (in the upper layer) and Norwegian Sea Deep Water (below 900 m depth) poleward into the Arctic Ocean. Site S1 is strategically located at a point where water of Atlantic origin, the heat source for the Arctic Ocean, meets waters from the Storfjorden (Spitsbergen's largest fjord) and shelf waters flowing off the West Spitsbergen continental shelf. The S1 oceanographic mooring, part of the SIOS (Svalbard Integrated Arctic Earth Observing System, https://sios-svalbard.org/) marine infrastructure network, has been progressively improved over the years as it has been expanded to include data in the intermediate layer starting in the summer of 2022.

We focus on thermohaline properties, ocean currents, and particulate fluxes data recorded in the deep layer to examine short-term and seasonal variability over the past 9 years also in relationship with meteorological conditions and sea ice concentration trends. Our data, obtained from the oceanographic mooring and including repeated Conductivity-Temperature-Depth (CTD) casts during summer surveys, show that the 2014-2021 period was characterized by limited potential production of dense water in the fjords, while the wind-induced vertical mixing and the resulting internal oscillations were probably favored. During this period, a gradual decline in sea ice cover in winter is observed in the S1 area and adjacent fjords. The only exception is the winter of 2020, when the sea ice extent returned apparently to pre-2013 levels, and at 1000m depth there were weak signs of cascading of dense shelf water, probably originating in the Storfjorden polynya.

In the investigated period, temperature and salinity data measured at 1000 m depth showed no, or very little, positive trends, while they are clearly evident in the literature for Atlantic waters. However, periodic intrusions of relatively warm and saline water into the deep layer were also observed. They occur most frequently during winter periods and are associated with the passage of internal waves that promote the turbulent mixing of the intermediate Atlantic waters with the deep water, and the heat spreading also toward the deep ocean.

Abstract 232: Laura de Steur[1], Theodoris Karpouzoglou[1], Hiroshi Sumata[1], Mats Granskog[1], Dmitry Divine[1], Michael Karcher[2,3], Frank Kauker[2,3], Paul Dodd[1], Agneta Fransson[1], Melissa Chierici[4]

[1]Norwegian Polar Institute, [2]Alfred Wegener Institute, Germany, [3]OASys, [4]Institute for Marine Research, Norway

The Arctic Outflow in Fram Strait: observed changes and drivers from a long-term observing system.

The Fram Strait is the widest and deepest gateway to the Arctic Ocean where large exchange of heat and freshwater occurs with the Nordic Seas. The Fram Strait Arctic Outflow Observatory has been measuring ocean freshwater transport and sea ice volume export with the East Greenland Current (EGC) since 1997 and 1990 respectively. Quantifying changes in freshwater and sea ice from the Arctic are essential to monitor and to identify how Arctic climate change can impact the stratification and large-scale overturning circulation further south. Besides a permanently installed array of ocean moorings measuring ocean physics and sea ice parameters continuously, an annual cruise complements the measurements with sea water chemistry.

In this presentation we summarise key findings from this observing system from the last 15 to 30 years identifying significant changes and drivers. The sea ice thickness in the EGC has declined significantly and in particular since 2007. While the Polar Water in the EGC has been warming in recent years related with a reduction in sea ice cover in summer, the Atlantic Water presence has been increasing between 2015-2019 in winter. Both processes have had a significant impact on the sea ice cover east of Greenland further south. In addition to these observed changes, ocean acidification has clearly progressed in the Arctic outflow waters during the last decade.

While the year-round freshwater transport through the strait has not shown a clear trend in the last decades, it is highly variable in time, with periods of weaker and stronger export. The main drivers of these variations are found to be local wind forcing over the strait, and upstream processes identified as Beaufort Gyre weakening and North Pole convergence, both happening at several months up to two years prior to increased export with the EGC. We identified even longer timescales of up to ~10 years being at play for determining the abundance of Pacific Water in Fram Strait since the 1980s. Changes in the SLP patterns from the north Pacific to the central Arctic drive a slow restructuring of the large scale hydrography and circulation which impacts how much Pacific Water the Transpolar Drift is able to carry towards Fram Strait.

Abstract 247: Zoe Koenig[1], Karley Campbell[1], Brent Else[2], Morven Muilwijk[3]
[1]UiT – The Arctic University of Norway, Tromsø, [2]University of Calgary, [3]Norwegian Polar Institute

Turbulent fluxes at the ice-ocean interface in the Arctic Ocean

Sea ice algae are at the base of the food web in the Arctic. With ongoing climate change and a shrinking sea ice cover, their habitat is compromised, and the sea ice algae communities are changing. With a more mobile ice pack, the physics at the sea ice – ocean interface is modified, influencing the turbulence in the ice-ocean boundary layer, the supply of oxygen and nitrate to the sea ice algae and fluxes of gases at the ice interface. Under-ice turbulence appears to be a key factor in controlling ice algal growth and should be parameterized in models to better represent the sea ice algae biogeochemistry. The under-ice turbulence was documented in 2022 in the Canadian Archipelago (Cambridge Bay in spring) and in the deep Arctic (Nansen and Amundsen Basin in summer). We used an eddy covariance system associated with fast Dissolved Oxygen (DO) sensors and nitrate sensors. We found that turbulent heat fluxes at the ice-ocean interface are about -2 W/m2, and DO fluxes vary from 0 to 150 mmol m-2 d-1. To reach the variations in DO fluxes caused by the sea ice algae, the influence of sea ice melt should be removed, and this signal can in some circumstance dominate. Once removed, variations in DO fluxes are correlated with the tidal signal with a lag of one hour. Nutrient fluxes in the water column in the Arctic Ocean are very low, less than 0.02 μmol m2 s-2. We will also compare the fluxes obtained with the primary production that was also monitored at each site.

Abstract 175: Ramiro Saurral[1], Francisco Doblas-Reyes[1,2]
[1]Barcelona Supercomputing Center, [2]Catalan Institution for Research and Advanced Studies

Sea ice depletion in the Arctic effects storminess variability in the Mediterranean region

The ongoing reduction in the amount, thickness and areal extent of sea ice in the Arctic region is known to play a significant role in the atmospheric dynamics of the Northern Hemisphere. In this study, we look at differences in storminess (i.e. frequency of cut-off lows genesis) over the Mediterranean region in Polar Amplification Model Intercomparison Project (PAMIP) experiments with and without Arctic sea ice melt.

We find that the meridional migration of the upper-level jet arising from Arctic Amplification leads to significant variations in the frequency of storms affecting the Mediterranean region, and that these changes are more prominent over two hotspots: one covering the Iberian Peninsula and a second one over the eastern Mediterranean (Greece and Turkey). We also analyze the associated changes in extreme precipitation over both regions and highlight how these can be, at least partially, associated with the observed alterations to Arctic sea ice. These results can be of particular interest for water management over southern Europe, in particular under the severe drought conditions that have been plaguing Portugal

and Spain and the increased frequency of damaging storms affecting Greece that have been observed in recent years. As a final message, our results are also expected to increase concern about the urgent need to stop the human alterations to the Arctic ecosystem.

Abstract 49: Huidi Yang[1], Jianbin Huang[2], Yong Luo[1], Shiming Xu[1], Xiangdong Zhang[3]
[1]Tsinghua University, [2]College of Resources and Environment, University of Chinese Academy of Sciences, [3]North Carolina State University

Winter Barents-Kara Sea Ice and Its Impact on June Precipitation in China: Exploring Pathways

This study delves into the potential ramifications of winter ice conditions in the Barents-Kara Sea on June precipitation patterns across China, shedding light on the underlying mechanisms. Utilizing correlation analysis, our research reveals a notable association between increased Barents-Kara Sea ice extent and distinct rainfall patterns in China. Specifically, increased Barents-Kara Sea ice levels correspond to increased rainfall in the Yangtze-Huai Rivers Valley and reduced precipitation in South China. Further investigation reveals the pivotal role of abnormal spring snowfall in bridging the gap between winter Arctic sea ice conditions and subsequent summer rainfall patterns in China. These relationships are found to be closely tied to the Arctic Oscillation (AO), wherein positive anomalies in Barents-Kara Sea ice during winter coincide with a positive AO phase. This anomalous atmospheric circulation triggers localized hydrothermal alterations, subsequently impacting snow depth across North Eurasia and summer precipitation in China.

Abstract 10: Simon Woods[1], Andrea Ceccolini[1], Cian Sherwin[1]
[1]Real Ice UK

Real Ice - Preserving & Restoring Arctic sea ice

First proposed by Flannery et al in 1971, researchers such as Professor Steven Desch, proposed ‘Arctic Ice Management’ as a method of Solar Radiation Management (SLR) in 2016. Zampieri 2019 and Pauling/Bitz 2021 further investigated and built upon the original research suggesting this specific ice thickening method.
The purpose of Real Ice is to demonstrate this practical approach to Arctic sea ice thickening to preserve and restore Arctic sea ice, and directly contribute to global warming mitigation by virtue of our methods and publicise the results.

Real Ice has named the process ‘Aquafreezing’ - with our approach (informed by Pauling/Bitz). We are proposing to flood the snow layer with seawater pumped

from under the sea ice at the beginning of winter, to increase heat conductivity from the cold air to the bottom of the ice layer, thereby increasing the rate of natural accretion below the sea ice. During this period, we expect the sea ice to grow thicker than control areas where no intervention has taken place. Additionally, at the end of the winter, we are investigating an approach to add to the snow layer, to insulate the underlying sea ice from the warmer weather, and to increase the albedo, resulting in increased reflection of solar radiations. The investigation will be conducted using zero emission water pumping devices and a distributed system to scale to large areas. This scheme maximises the impact of the ice thickening efforts for minimal renewable energy input.

We have laid out a 4-year roadmap of research which will include the design and delivery of a hydrogen fueled, automated underwater vehicle prototype which carries a seawater pump and can independently contribute to the ice thickening of large areas of the Arctic.

Step 1 in the roadmap saw the completion of the design, prototyping and field testing with a battery operated electric pump, tested in Nome, Alaska, in February 2023.
Step 2 introduces hydrogen and a fuel cell to drive an electric seawater pump. This will be tested in Arctic conditions in Cambridge Bay (Nunavut/Canada) during November 2023.

From 2024, we intend to introduce underwater vehicles, with increasing levels of automation, to scale to large areas of the Arctic, far from shore, and using adaptive and flexible planning, to respond to variable sea ice, snow and weather conditions.

Additional research into our approach will include modelling an incremental deployment plan for our engineering, finding the optimal seasonal and multi-year strategy, and modelling the impact of ice thickening on the Arctic sea ice and on global climate.

Session 2: Observing Arctic Ice-Ocean-Atmosphere Interactions: Changes and Effects on Interannual to Centennial Timescales. Part 3: Biogeochemical Cycling and Paleoclimatology

Tuesday 30th January, 11:00-12:30

Abstract 226: Melissa Chierici[1], Agneta Fransson[2], Laura de Steur[2], Mats Granskog[2], Colin Stedmon[3], Paul Dodd[2], Svein Kristiansen[4]
[1]Institute of Marine Research, [2]Norwegian Polar Institute, [3]Technical University of Denmark, [4]UiT – The Arctic University of Norway, Tromsø

The chemistry in the Arctic outflow waters is changing

The Fram Strait is the main gateway and exit for Arctic waters in the western part to capture the surface and cold and fresh outflow waters from the Arctic Ocean. In this study, we explore the chemical change in the dissolved inorganic components of nutrients and inorganic carbon system including ocean acidification between 2011 and 2019 in the top 400 m at 79°N in the East Greenland Current (EGC, 6°W-3°W), and on the NE Greenland shelf (NEGS) between 11°-7°W. The EGC is the main outflow for waters originating in the Arctic Ocean and the Eurasian Arctic and the NEGS is more influenced by local processes, and potentially the effect of glacial meltwater. Trends were estimated based on linear regression on annual mean values of pH, total alkalinity, and aragonite saturation (ΩAr), in the polar mixed layer (<30m), the Arctic halocline (>40-150 m), and the >150-400m originating from the Atlantic water (AL). ΩAr and pH decreased in all depth layers and areas. Fastest change of -0.0077 yr-1 was observed in the PML in the EGC, which was nearly four times faster than the global ocean mean surface pH decrease. This was attributed to changes in the seasonal sea ice cover and meltwater. Potential effects of the observed changing chemistry on biological processes (primary production), and continued CO2 uptake and carbon pump will be discussed.

Abstract 136: Lucie Goraguer[1,2], Philipp Assmy[2], Doreen Kohlbach[2], Bente Edvardsen[3], Melissa Chierici[4], Anna Maria Dąbrowska[5], Rolf Gradinger[1], Elizabeth Jones[4], Miriam Marquardt[1], Agnieszk Tatarek[5]
[1]UiT - The Arctic University of Norway, Tromsø, [2]Norwegian Polar Institute, [3]University of Oslo, [4]Institute of Marine Research, [5]Insitute of Oceanology of Polish Academy of Sciences

Unravelling phytoplankton seasonality in the northern Barents Sea

The productive Barents Sea is a highly dynamic system of strong seasonal variability. The observed increase of warm Atlantic water inflow causing reduction in sea ice cover, impacts the timing, duration, magnitude, and composition of phytoplankton blooms with potential cascading effects on dependent marine food webs. However, we lack a good understanding of phytoplankton seasonality in ice-covered waters of the Barents Sea, especially for the winter and early spring periods. This knowledge gap limits our predictive capability to assess longer term trends, especially as remote sensing of ocean color is very poor for high latitude systems. In this study, we have compiled in situ phytoplankton data from six Nansen Legacy cruises in 2018, 2019 and 2021 along a latitudinal transect from the southern ice-free Barents Sea across the shelf into the deep Nansen Basin north of Svalbard along a seasonal gradient covering the months of March, May, July, August and December. This space-for-time approach allowed us to the spatial and seasonal variability in phytoplankton biomass and taxonomic composition and how it relates to changes in environmental factors such as sea-ice extent, water mass properties and biochemistry with inorganic nutrients.

Extensive areas of the northern Barents Sea were ice-covered during observations with the least sea ice cover in August 2018. The southern Barents shelf station and northern shelf slope stations were characterized by Atlantic-influenced water masses, while the interior Barents shelf stations had cooler and fresher Arctic water masses. Nutrients were depleted in surface waters by late summer as a result of uptake by the phytoplankton spring bloom, and successively replenished over the winter. Surface nutrient inventories at the end of winter (March) differed between Atlantic and Arctic water influenced stations, suggesting differences in carrying capacity.

The spring bloom, recorded between May and July depending on ice conditions, started earlier in Atlantic-influenced waters and was dominated by diatoms, while mixotrophic flagellates, dinoflagellates and ciliates contributed significantly to phytoplankton biomass in August. Interannual differences in late summer phytoplankton composition and biomass between August 2018 and 2019 were attributed to the earlier and more extensive sea ice retreat in 2018. In winter (December and March), extensive sea-ice cover aligned with low Chl a concentrations and dinoflagellates dominated the phytoplankton community indicative of a generally more heterotrophic system during the dark winter months, especially in December with higher ciliates biomass.

Our observations highlight the impact of water mass characteristics and sea ice cover duration for phytoplankton seasonality in the northern Barents Sea and

emphasize the need for seasonal monitoring of Arctic marine ecosystems against the backdrop of climate change.

Abstract 241: Rosalie McKay[1], Janina Osanen[2], Christine Michel[3], Brent Else[4], Karley Campbell[1]
[1]UiT – The Arctic University of Norway, Tromsø, [2]NTNU- Norwegian University of Science and Technology, [3]Fisheries and Oceans Canada, [4]University of Calgary

Influence of contrasting turbulence regimes on sea ice microbial communities

The Dease Strait region of the Canadian Arctic Archipelago is overwhelmingly characterized by nitrogen deplete conditions and limited sea ice primary production. Previous studies have demonstrated localized enhanced bottom ice algal growth within nitrogen deplete water masses, hypothesized as an effect of greater nutrient supply by strong sub-ice currents as water is constricted through a shoaled tidal strait. In this study, two locations of land-fast first-year sea ice in the Dease Strait region were routinely sampled 27 April to 4 June, 2022, over a spring bloom period. Sample sites were selected due to their contrasting sub-ice turbulence regimes that are thought to promote differences in nutrient availability, one site was protected from the tidal strait by an embayment while the second site featured dynamic water bodies flowing between the Finlayson Islands. Overall, we documented low water column nutrient concentrations, net community production (NCP) and chlorophyll a values compared to previous measurements in the region. Patterns within this inter-site comparison emerge as measurements of NCP, flow cytometry, DOC, POC and chlorophyll a are explored relative to turbulence driven nutrient availability of the bottom ice. Building upon the horizontal NCP heterogeneity observed with contrasting sub-ice turbulence, vertical profiles of the NCP of middle and upper sections within the ice column were also compared. The study is a component of the BREATHE (Bottom-sea ice Respiration and nutrient Exchanges Assessed for THE Arctic) research project funded by the Norwegian Research Council.

Abstract 73: Emily Stidham[1], Russell Hopcroft[1]
[1]University of Alaska Fairbanks

Two-decades of observations on pelagic tunicates and pelagic snails in the Northern Gulf of Alaska (NGA).

Mucus-net feeders are under-appreciated in the literature with limited information regarding their abundance and biomass, including their response to warming ocean temperatures and marine heatwaves. In the Northern Gulf of Alaska (NGA) and Prince William Sound (PWS) this group is represented primarily

by pelagic tunicates (larvaceans, doliolids, salps) and pelagic snails (pteropods). These organisms are important prey for many seabirds and fishes. Their presence can also have a large impact on how organic matter moves through food webs and sinks in the water column. Analysis of the populations of these mucus-net feeders in the NGA and PWS from 2012-2021 is combined with data from preceding years to create a 20-year time-series. There is strong seasonal clustering of larvacean abundance and species composition with higher diversity observed during autumn, due to the periodic presence of warm-water species. Preliminary summer sampling has begun to show another distinct grouping with overlapping similarity to autumn. There is also a distinct cross-shelf gradient with Oikopleura dioica, in particular, pushing out with the lower salinity Alaska coastal current during the autumn. We are also observing shifts in mucus-net feeder species composition and abundance during marine heatwaves. Our long-term species-level records of mucus-net feeders in the NGA and PWS provide a better understanding of how the zooplankton community may continue to shift in the face of a changing ocean climate.

Abstract 52: Bethan Langley[1], Nick Kamenos[2], Heidi Burdett[2], Karen Cameron[1]
[1]University of Glasgow, [2]Umeå Marine Sciences Centre (UMF)

Arctic and sub-Arctic marine carbon storage; a meta-analysis

Marine sediments constitute an expansive sink of organic carbon and can store carbon for millions of years if undisturbed. The burial of organic carbon in marine sediments plays an important role in the global carbon cycle and in regulating atmospheric carbon dioxide over Earth's history. Sediment cores offer an archive of carbon burial over varying timescales and provide insight into historic variations in rates of carbon storage. Marine sediment carbon stocks are sensitive to climate change and anthropogenic activities, and with the Arctic warming 4 times faster than global averages, it is vital to gain a more comprehensive understanding of current and historic carbon storage to begin to formulate predictions on carbon burial in marine sediments in the future.

Here, we synthesise existing data on organic carbon concentrations from 625 marine sediment cores across the Arctic and sub-Arctic. We spatially predict carbon stocks spanning latitudes from 50 to 90° N and identify high concentrations of organic carbon in coastal areas and hotspots in regions including the Barents Sea, Baltic, and East Siberian Sea. By quantifying carbon stocks in the top 1m of sediment, we show that Arctic and sub-Arctic marine sediments are a globally important sink of organic carbon contributing a large proportion to global carbon stock estimates. Constructing age-depth models for sediment cores, we delve into the temporal dynamics of carbon burial and compare these findings between geographic regions and geomorphic units.

This study demonstrates the importance of protecting marine sedimentary carbon stocks in the Arctic and sub-Arctic and highlights regions where management and conservation efforts are imperative to ensure marine sediments remain undisturbed and continue acting as nature-based solutions to mitigating climate change. By examining historic carbon burial, this study begins to explore the future of carbon storage in Arctic and sub-Arctic marine sediments amid a changing climate.

Abstract 91: Jan Sverre Laberg[1], Kevin Zoller[1], Ingrid Olsen[2], Tom Arne Rydningen[1], Matthias Forwick[1], Katrine Husum[3]
[1]UiT – The Arctic University of Norway, Tromsø, Geological Survey of Norway (NGU), [3]Norwegian Polar Institute

The response of the NE sector of the Greenland Ice Sheet (~73 – 77N) to past climate warming

The Greenland Ice Sheet (GIS) is a contributor to global sea-level rise, and especially the marine-based part of the ice sheet is vulnerable. To learn more about the potential future response of the GIS outlet glaciers in regard to the present global warming, as well as to provide empirical data for numerical ice sheet modelling, we have reconstructed the dynamics of outlet glaciers during the last deglaciation and the present (Holocene) interglacial. For this study, we have focused and investigated specific fjord and shelf areas in NE Greenland shelf (~73 – 77oN), including the Kejser Franz Josef Fjord system, the Young Sound – Tyrolerfjord, and the Bessel fjord – Dove Bugt - Store Koldewey Trough, a previously poorly researched area. From the presence of landforms (morainal ridges, mega-scale glacial lineations), dated marine sediment core samples*, and onshore dates from other work, it is inferred that the ice front receded from the continental shelf to reach the coastline during the Younger Dryas period. For all fjord systems, transverse ridges have been identified, implying temporal halts and/or readvances during their deglaciation, likely during one of the cold events identified in the Greenland Summit temperature records. The oldest dates from the inner part of the fjords are 8.75 and 7.8 ka cal BP (Kejser Franz Josef Fjord system), 7.8 ka cal BP (Tyrolerfjord), and 7.2 ka cal BP (Besselfjord), respectively, representing a minimum age for the deglaciation of the fjords as none of the dated cores penetrated to the base of the deglacial deposits. The studied fjords in NE Greenland are, thus, interpreted to have been deglaciated in early Holocene, around the onset of the Holocene Thermal Maximum (HTM), a period when the mean July temperature was 2–3 C higher than at present. The mean ice recession rates for the deglaciation of the studied shelf – fjords are ~29 – 34 m/yr, which is in conformity with results from fjord - shelf systems further north in Greenland. During the cooling phase that followed the HTM, ice caps in Bessel Fjord may have fluctuated with greater sensitivity to climatic conditions than the NE sector of the GrIS.

* Multibeam swath bathymetry data, sediment core and high-resolution seismic profiles have been acquired in the period 2013 – 2022 as part of the TUNU-program at UiT the Arctic University of Norway.

Session 3: Empowering Arctic Citizens for Involvement in Decision-Making. Part 1: Governance, Justice and Decision-Making

Tuesday 30th January, 09:00-10:30

Abstract 67: Sigrid Engen[1], Else Grete Broderstad[2], Jannike Falk-Andersson[3], Per Fauchald[1], Georgina Gurney[4], Vera Helene Hausner2, Rose Keller[1], Fransisco Javier Ancin Murguzur[2], Christopher Raymond[5], Emma Salminen[2]
[1]Norwegian Institute for Nature Research, [2]UIT-Arctic University of Norway, [3]Norwegian Institute for Water Research, [4]James Cook University, Australia, [5]University of Helsinki, Finland

Blue justice: eliciting perceptions of environmental justice related to planning and use of coastal areas in Northern-Norway

Ocean-based economic development arising from an increasing interest in the 'blue economy' is placing people and nature under pressure. The dominant policy response for dealing with multiple uses is the allocation of coastal space through coastal zone planning. Studies have shown that the rush to develop the blue economy and regulate coastal activity can result in social injustices and the exclusion of less powerful and unrecognized groups (e.g., small-scale fishers, women, Indigenous peoples and youth).To achieve a primary goal of the 2030 sustainable development agenda to "leave no one behind", it is important to understand the implications of coastal planning and development for different groups and industries. We adopt a social survey approach for examining perceptions of justice and challenges related to planning and development of coastal areas. We will present preliminary results from surveying commercial fishers in Northern-Norway (N: 3878, 22% response rate) and coastal planners in (N: 139, 30% response rate) in 2021 and plans to expand the work to include aquaculture and tourism industry as a part of the CoastShift project (2022-2026) funded by the Fram Centre.

Abstract 53: Jerbelle Elomina[1,2], Ivana Zivojinovic[1,2], Karen Candace Calanasan[1], Isidora Dabic[1,2], Per Sandström[3], Stefan Sandström[3], Seija Tuulentie[4], Ragnheidur Bogadóttir[5], Kristine Lynge-Pedersen[6], Anna Guðrún Edvardsdóttir[7]
[1]University of Natural Resources and Life Sciences, Austria, [2]European Forest Institute, Austria, [3]Swedish University of Agricultural Sciences, [4]Natural Resources Institute Finland, [5]University of the Faroe Islands,

[6]Greenland Institute of Natural Resources, [7]Hólar University College, Iceland

Exploring local people's perspective on Arctic development using Q-method

The race for Arctic resources can bring vast economic opportunities but in many cases at the expense of environmental and socio-cultural degradation. Arctic nations have developed policies to avoid these negative impacts, however current research still found that present policies and activities are not successful in responding to the needs of the local people. Successful policies are however dependent on clear understanding of local people's perspectives, and so delineating areas of agreement and conflict is crucial. Therefore, this paper aims to explore how local people and stakeholders perceive the current state of development of economic activities in the European Arctic? This empirical study, based on 15 selected municipalities in Faroe Islands, Finland, Greenland, Iceland, Norway and Sweden, examines emergent perspectives on the development of economic activities, such as fish farming, forestry, mining, tourism and indigenous people's activities including reindeer husbandry and fishing. By conducting expert interviews and Q-methodology at two levels, we would be able to compare the general and the specific perspectives of the local people in the Arctic. The two-level Q-methodology included studies at (1) the Arctic region context; and (2) local level context in 6 selected localities: Egersund, Gällivare, Kittilä, Nuuk, Sudoroy and Westfjords.

The analysis will reveal shared perspectives among multi-stakeholder groups such as experts of the economic activities, indigenous people, city council, NGOs, media, researchers and citizens. Given that our study stretches across six different Arctic countries, we do not necessarily expect that our respondent perceptions are purely guided by their national identities or cultures. On the other hand, we hypothesize that respondents will be clustered along similar issues across different countries. We expect different opinion types to appear, around pro-development: where advocates believe that industries and local communities develop in tandem; anti-development: advocates are anti industry expansion and operations and believe in strict nature protection; but also some that are more Neutral to development: advocates support industry operations as long as the benefits trickle down to the members of the local community and the revenues are not just sent to the 'South'. The implications of these competing perspectives will also be discussed in light of the green transition used to justify industry expansion at the detriment of indigenous people's land and culture. This study will contribute to the scant literature of humanities study in the Arctic and to provide input to decision making and in revising guidelines and policies relevant to the economic activities under study.

Abstract 128: Anita Parlow[1]
[1]Fulbright Association

Empowerment, Democracy and Indigenous Sovereignty in the Arctic

The renewed and vibrant debates centering around broadening and deepening participation to produce more effective initiatives, thereby, strengthening democratic processes and citizen-participation in the Arctic, is producing effective strategies to enhance democracy. As citizens of the Arctic empower their communities for meaningful engagement in decision-making, democratic process is reaching new levels in law, policy and the priorities of science. Given the urgency of the need for environmentally sustainable initiatives in the context of climate change and the increases in commerce to a more accessible Arctic region, democratization, informed by equity and the urgency of the challenges regarding climate, commerce and geopolitics, contains the capacity to heighten democratic process in the region as it faces a growing global interest in Arctic resources and shipping routes.

As many policy decisions regarding the Arctic are made in capital cities distant from their High North regions, issues such as transitions to green energy, policies that regulate commerce and protections to marine ecosystems, can serve interests other than those more widely supported by their Arctic citizenry.

Tools such as 'social license to operate,' or NGOs and other organizations that would appear to support and protect democratic processes, often, unwittingly, impede the interests of peoples, some long marginalized, rather than elevating their priorities.

This proposed presentation is designed to reflect upon successful strategies in the Arctic, where both Indigenous and, non-indigenous peoples have been actively developing approaches to empower their communities. The advances in democratic process is evidenced by greater participation in regional decision-making processes, particularly regarding climate and biodiversity. The challenges are complex, as for example, reindeer herders and loggers who seek the same terrain. Or, Svalbard's Continental Shelf and its implications for crabbers or Norwegian commercial fishers. This presentation would address the interlinked issues of nature-centered ecosystems policies with examples of successful initiatives to advance effective, specific, and region-wide sustainability practices.

This presentation will also discuss the evolving legal jurisprudence and legal pluralisms as are or can be applied to Arctic issues, thus supporting sustainability strategies that reflect the inseparable and interconnected political realities of Arctic conditions and priorities. The emerging law, in part, is inspired

by major indigenous rights organizations such as the International Indian Treaty Council, the Inuit Circumpolar Conference and others seeking to reclaim sovereignty in both law and practice, underscores the need for a constantly-evolving democratic processes. With respect to Svalbard, the sovereignty of a nation is maintained by the Norwegian government and commercial interests that continue to exercise their rights.

The presentation would reflect upon the relatively new law and policy regarding legal recognition of the rights-of-nature, the concept of ecocide as a crime, and nature-based approaches in science, law and policy that is arising in the discourse of democratic inclusion at the region's decision-making tables.

Abstract 121: Helge Flick[1], Jukka Teräs[1], Marco Giardino[2], Riccardo Beltramo[2], Harald Vacik[3], Teresa Aschenbrenner[4], Jerbelle Elomina[3], Ivana Zivojinovic[3]
[1]NORCE Norway, [2]University of Turin, Italy, [3]University of Natural Resources and Life Sciences, Austria, [4]Swedish University of Agricultural Sciences

Experiences from applying the DPSIR framework to 18 locations in the Nordic Arctic: The ArcticHubs DPSIR framework

While the Nordic Arctic shares and connects an identity of environmental beauty and cultural uniqueness, it is also characterised by industries that continuously compete for an array of natural resources. The opening up of new economic sectors, including mining and tourism, alongside the industrialization of many traditional livelihoods, such as fishing and forestry, is driving land-use conflicts between several competing sectors. This produces profound transformations on Arctic nature, lives, and communities at economic, environmental, socio-cultural, and political levels.

The EU Horizon ArcticHubs project explores the above-mentioned dynamics with the goal to develop sustainable, solution-oriented tools for reconciling competing livelihoods and land-use modes whilst respecting the needs and cultures of local populations. Here, the ArcticHubs project focuses on 18 Arctic “hubs” classified as geographic nodes that host either a combination of economic activities, or one main industry or means of livelihood, where challenges and impacts facing the Arctic region are tangible and acute. Here, alpine learning cases were included for comparison.

To meet a need for a framework that maps economic activities from several sectors, assesses resulting changes in the Arctic environment and ecosystem services, and drafts responding political and managerial reactions, the ArcticHubs project has applied the Driver–Pressure–State–Impact-Response (DPSIR) model, putting it for the first time into a holistic Nordic Arctic

perspective. Developed in the 1990s as an environmental reporting tool by the European Environment agency, the DPSIR model describes a causal framework with cause-and-effect relationships between five categories representing impacts of specified anthropogenic activities on ecosystems as well as social systems. The model organizes analysis results with a holistic system perspective that links and facilitates communication between science, experts, policymakers, and the public.

Over the last years, the DPSIR framework has been revised, modified, and integrated in a variety of ways to explore its analytical and conceptual limits. Our work has extended these limits to a new dimension by applying the model to 18 case hubs with an Arctic context. Here, an industrial focal point was on the environmental and social impacts of forestry, aquaculture, mining, tourism, and indigenous activities. The DPSIR model has also become a helpful communication and participation tool within the project that links stakeholder insights from all Arctic locations to draw conclusions and implications for future co-management of land-use systems in the Nordic Arctic.

In our paper, we want to share our experiences of applying the DPSIR framework to an Arctic context including its potential for integrative industrial impact-analysis and its function as a platform for communication and participation among stakeholders. Here, we guide through 3 research questions:

R1: How can the DPSIR framework be used to map industrial activities and assess environmental and social impacts within an Arctic context?

R2: How can the framework be used as a communication and participation platform to draw conclusions about environmental problems exerted by Arctic industries from various perspectives?

R3: What are the advantages and limitations of applying the DPSIR model in an Arctic context?

Session 3: Empowering Arctic Citizens for Involvement in Decision-Making. Part 2: Public Participation and Citizen Science

Tuesday 30th January, 15:45-17:15

Abstract 11: Mia Bennett[1]
[1]University of Washington

Inverted Worlds: Remote Sensing and the Reordering of Arctic Lands and Imaginaries

Remote sensing is defined as the art, science, and technique of gathering information about an object without making physical contact with it. Despite the distance it extends between the observer and observed, the touch-free practice still impacts the planet. While remote sensing platforms such as satellites monitor Earth from space, their operations affect people and places on the ground. Many of the affected communities and locations are in the Arctic, which offers access to polar orbits from which satellites can collect planetary-wide data. Remote sensing places demands on lands, especially northern ones, by driving their transformation into ground stations and launch facilities. The practice also shifts cultures of envisioning the Earth, privileging top-down perspectives that classify land according to electromagnetic spectra over bottom-up, locally grounded scales. Yet spaceborne Earth observation is not the only form of remote sensing. The practice of the Inuit, an Arctic Indigenous People, of listening through a wooden oar placed into the ocean for whalesong forms a type of remote sensing, too. By combining fieldwork and discursive and visual analysis and framed within the emerging subfield of critical remote sensing, this talk seeks to identify spaceborne remote sensing's environmental and cultural impacts and reimagine the technology along more expansive lines in and from the places affected by its development, including the Arctic.

Abstract 22: Seija Tuulentie[1], Esa Inkilä[1], Taru Rikkonen[1], Rannveig Ólafsdóttir[2], Kristine Lynge-Pedersen[3], Ari Nikula[1], Roy Robertsen[4], Audun Iversen[4], Sten Siikavuopio[4]
[1]Natural Resources Institute Finland, [2]University of Iceland, [3]Greenland Institute for Natural Resources, [4]NOFIMA

Involving local communities in tourism planning – public participation GIS (PPGIS) as a tool for the tourist resorts in the Arctic

Tourism industry is expanding in global scale including many parts of the Arctic. However, tourism industry often operates in its own bubble without contacts to or cooperation with local communities. These bubbles can be completely detached from everyday life, such as cruise ships, but they can also be part of local communities, such as tourist resorts and activities, and the locals still have no chance to influence them. Justification of growing tourism in remote regions continues to be rooted in the economic advantages it offers. However, as tourism continues to thrive, the drawbacks for the locals are becoming increasingly evident.

To locate problematic areas, to empower the local communities, and to enhance dialogue between different positions in local communities, we have implemented online Public Participation Geographic Information Systems (PPGIS) in various tourist destinations in the Arctic with emphasis on land use issues. Inari in Finnish Lapland, Westfjords in Iceland, Varanger in Norway and Nuuk in Greenland. Situations in tourism differ in these areas: Tourism in Finnish Lapland has grown drastically during last 20 years and in our case study area of Inari the tourism-related land use issues and behavioural patterns have led to substantial criticism. In Iceland, tourism has grown faster than in Finland, and prior to the onset of COVID-19, overtourism was a prominent research concern. However, in this research our interest is in the area of Westfjords where tourism growth is less intense than in the southern parts of the country. Varanger in Norway attracts especially seawater fishing tourism, but also land-based tourism throughout the year. Nuuk in Greenland represents tourism market that has only recently started to attract international visitors. However, already there have been warnings about potential severe negative consequences if Iceland's approach to tourism development is followed.

The results of the PPGIS surveys show that it works in identifying the areas with a risk of conflict. It is also obvious that selected case study areas share certain common concerns, but they also exhibited region-specific issues and concerns related to growing tourism. Some aspects, like the effects of industry on local economy and job markets were quite commonly seen as positive for locals, whereas views of the effects on local culture and livelihoods were more diverse. A central issue prevalent across all these three locations was that the development of tourism in their areas should involve active collaboration with local communities.

Abstract 81: Nathalie Labonnote[1], Berit Time[1]
[1]SINTEF AS

Empowering (Arctic) Citizens for Holistic Climate Adaptation: A Multi-Scale, Multi-Dimensional Approach in Norway

Building on the successes of Klima 2050, a Centre for Research-based Innovation (SFI) funded by the Research Council of Norway and consortium partners from 2015 to 2023, a new project initiative seeks to expand the scope and deepen the impact of climate adaptation efforts in Norway. Klima 2050 focused on reducing societal risks related to climate changes, specifically concerning enhanced precipitation and floodwater exposure in built environments. Its SFI status allowed for long-term research conducted in close collaboration with industry stakeholders, thereby fortifying Norway's capabilities and competitiveness in the area of climate adaptation. The present project initiative leverages the valuable insights and methodologies developed under Klima 2050, extending them to include not only the built environment but also natural ecosystems and smaller communities across Norway's diverse landscape. In contrast to Klima 2050's infrastructure-centric approach, the current project initiative places a greater focus on the human dimension, aiming to empower citizens to actively participate in climate-related decision-making processes.

Addressing the growing societal risks associated with climate change necessitates a nuanced and holistic perspective. A gap exists between scientific knowledge and the active involvement of citizens in the formulation and execution of risk-mitigation strategies. This project initiative aims to fill that gap by adopting a multi-dimensional, multi-scale approach to generate a comprehensive strategy for climate adaptation and risk mitigation. Key elements include:

* Various pilot studies strategically located to represent Norway's diverse geographic, societal, and ecological landscape, from urban centres to remote communities.
* A systematically evaluation of different categories of mitigation strategies—prevention, maintenance, and repair—to understand their long-term efficacy and sustainability.
* The establishment of common data structures and the definition of Key Performance Indicators (KPIs) to enable consistent and comparable assessments across pilots.
* The deployment of advanced machine learning algorithms to leverage large amounts of structured data and to comprehensively analyse the long-term impacts on human populations, built environments, and biodiversity.
* The testing of partnerships with the banking sector to explore the potential of financial measures, such as preferential loans or tax benefits, to encourage private- and community adoption of risk-mitigation strategies.
* The investigation of behavioural and social incentives to enhance citizen engagement in both adopting and maintaining climate-adaptation practices.
* The development of special knowledge-transfer and replication mechanisms to ensure that the findings and best practices from the pilot studies are

seamlessly disseminated and scaled-up for nationwide implementation.

The project initiative is presently in development and intends to address the Artic context, recognizing its unique challenges such as significant climate change impact, vast geographical distances, low population density, and externally-driven decision-making. Stakeholders, researchers, and community members, particularly from the Artic regions, with an interest in climate adaptation and participatory decision-making are cordially invited to establish contact.

Abstract 187: Elina Hutton[1,2], Tomas Brage[1]
[1]SALT Lofoten, [2]University of Lapland, Finland

Exploring experience-extending technologies to trigger radical innovations for nature-based solutions in Arctic cities. A thought experiment.

The emergence of what may be called experience-extending technologies for public participation in urban planning processes – Virtual, Augmented and Extended Realities, among others – open unprecedented possibilities for direct and widespread local democracy. However, after more than a decade in development and with encouraging results in pilot projects, public or private institutions have not adopted these tools in public participatory projects.

Based on exploratory literature and project review, we claim that financial and technical constraints aside, this same public affordance represents a potential disruption of established professional practices and decision-making mechanisms. One of the foreseeable consequences of this revolution in participatory urban planning would be to compel urban planners, landscape architects, urban ecologists, and engineers to find radically novel nature-based solutions to satisfy public needs and preferences.

This work presents a thought experiment in which the generative power of a cocktail of these emergent technologies is explored to discuss extreme fictional scenarios that we call “nature-based chimaeras”. The chimaeras are thus not shaped as nature-based solutions but rather stories that may act as triggers for radical urban innovation. The aim is to inspire urban planning professionals and the public to confront the potential impact of experience-enhancing technologies for supporting resilient and sustainable arctic communities.

Abstract 82: Rannveig Ólafsdóttir[1], Jonathan Karkut[2], Ragnheiður Bogadóttir[3], Anna Edvardsdóttir[4]
[1]University of Iceland, [2]Touch - TD, Tourism, Culture & Heritage Specialists, [3]University of the Faroe Islands, [4]Holar University, Iceland

Arctic cruise tourism and Social License to Operate

There is an expanding debate about the impacts that the rapidly increasing volume of cruise ships to the Arctic region are having on the destinations visited by those ships. This has manifested around the numbers of visitors that arrive and concentrate around often remote and sparsely populated communities. Concerns are arising too over the behaviour and interactions of cruise tourists when they observe unfamiliar local practices (such as traditional hunting or culling of animals) or overwhelm local residents through curious observations of their everyday lives.

Social acceptance by residents is therefore important to build trust between those local communities and visiting cruise ships. Social license to operate (SLO) is a tool that has gained traction among mining and forestry companies to reduce conflicts between different stakeholders and promote trust among the local residents. SLO is not an administrative license granted by the authorities, or a strategy devised solely by corporate interests. Rather it is an interactive process to create and maintain the consent and trust of the residents with the interested parties in local governance and industry businesses involved in the cruise tourism sector. The license is based on the concepts of sustainable development on the one hand, and corporate social responsibility on the other hand. Significantly it places an emphasis on understanding the overall picture and forging a consensus across all stakeholder groups.

In this paper, the focus is on cruise ships and SLO, and how or if it is possible to use SLO in the management of cruise ship visitation to Arctic ports and destinations. Case studies are taken from Suðuroy in the Faroe Islands and Ísafjörður in the Westfjords, where the various interactions that take place between the destination and cruise ships have been examined. The experiences of the regions' different stakeholders on tourism are investigated, as well as the knowledge, perceptions and experiences of passengers, crew and local authorities at the destination. Those perspectives are then drawn together to respond to the applied research questions: i) what might it take to devise an SLO for cruise tourism in Arctic destinations? Ii) what it might take to generate ‘buy in’ or a form of social contract around this cruise tourism-destination interaction? And consequently, iii) how may SLO be fed in to local or regional policy around cruise tourism to improve its social sustainability in the Arctic?

A mixed method quantitative and qualitative approach is used, combining

questionnaires among passengers, and interviews with regional stakeholders, as well as cruise ship crews and managers. The first results will be presented at the Arctic Frontiers conference.

Session 3: Empowering Arctic Citizens for Involvement in Decision-Making.
Part 3: Green Transition and Social License to Operate

Wednesday 31st January, 11:30-13:00

Abstract 24: Vigdis Nygaard[1], Katrine Eriksen[2], Roy Robertsen[2], Seija Tuulentie[3], Gun Lindestav[4], Riccardo Bertramo[5], Leena Suopajärvi[6], Juulia Tikkanen[6]
[1]NORCE, [2]NOFIMA, [3]LUKE, [4]SLU, [5]UNITO, [6]University of Lapland, Finland

SLO, a relevant concept for cross-industry research?

Developing economic activities can crucially depend on good relationships with the local communities where the activities will take place and having their trust and acceptance. Examples are extractive industries, large-scale manufactures and other production that occupy large areas, convert land- and seascapes and have significant environmental and social effects locally. At the same time, such industries typically generate large benefits far beyond the local communities. This geographical imbalance of risks, costs and benefits can be a source of controversies for the local communities. As local communities' expectations and requirements to companies are rising, failing to gain social acceptance can result in substantial costs for the industries due to interruptions (Moffat et al. 2016, Owen, 2016)

The concept of social licence to operate – SLO – was introduced by the Global mining initiative in 1998 as a response to the bad reputation of the mining industry and the increased social risks (Thomson Boutilier, 2011) associated with affected communities' perception of acceptance of the industry. Not gaining a SLO can in some cases terminate a planned project (Jijelava & Vanclay, 2018). The concept developed in the research literature, providing the mining industry with tools to measure the level and work with acceptance in local communities. The SLO concept gradually expanded from a company-community relationship to a broader society relationship (Zhang, 2015) that also exceeded the original notion of scale. Earlier focus on local communities is no longer geographically constrained as the national level, through laws and policies, brings in governance issues of fairness in distribution of wealth and loss.

This paper draws on studies of five nature-based industries (forestry, mining, tourism aquaculture and indigenous culture) in the European part of the Arctic.

We have studied how these industries affects selected local communities (Arctic Hubs) and how local people can be involved in decision-making promoting og restraining industry development. One of the objectives in the ArcticHubs project is to adapt the SLO concept developed for mining to other industries and businesses in the Arctic. We ask how the SLO-concept can be understood in different nature-based industrial settings, and what we can learn from SLO experiences in one industry to another.

The globalisation and rush for extraction of valuable natural resource puts extra strains on European Arctic communities. Industrial ownership is often located outside the region, challenging industry-community relationship. Increased focus on indigenous rights to culture, traditional industries and self-determination brings an important dimension to the SLO concept and dialogue as a tool for sustaining local communities. Previous methods often fell short. There is a need for more cross-industrial knowledge and tools on how affected communities and peoples can be involved.

Abstract 27: Ria-Maria Adams[1,2]
[1]University of Vienna, Austria, [2]University of Lapland, Finland

Young, Rural Stayers in Finnish Lapland: Decision-Making, Infrastructures & Wellbeing

Rural young people in Finland commonly leave the community where they were born. Far from being a solely Finnish phenomenon, the outmigration of rural youth is a global trend that affects the whole Arctic area. While some dream of urban surroundings – cities in more southern parts of the country – others imagine travelling the world beyond the borders of their homeland. Still others have arrived from distant, faraway countries, while some see their future in their rural hometowns, places they never aspired to leave. As diverse as young people's dreams and aspirations of a “good life” may be, equally varied are their perceptions of what determines their wellbeing and how they are involved in important decision-making processes.
The Arctic region is often described as suffering terms of decay or loss, and as lacking infrastructure, educational possibilities and employment opportunities – factors cited when the subject is young people leaving their rural hometowns. At the same time, extractive industries and the shift to "green energy" are rapidly changing the places where young people live, study and work, with young voices often absent from decision-making processes affecting their future.
This presentation, based on an ethnographic long-term study, brings together different views of young people in northern Finland and investigates what wellbeing means from their own perspectives. In an era of climate change mitigation and "green transition," the decision of young people to stay or leave is becoming an essential question for the viability and liveability of Arctic towns.

Abstract 59: Karin Buhmann[1], Mark Stoddart[2], Paul Bowles[3]
[1]Copenhagen Business School, [2]Memorial University, Canada, [3]University of Northern British Columbia

What constitutes 'Meaningful engagement' in green energy contexts? Experiences and views of Indigenous and settler communities in Atlantic and Pacific Sub-Arctic Canada

Climate change and its impacts demand urgent, deep and rapid responses to decarbonize societies. This requires a scaling up of renewable energy systems and other 'green' technologies. However, these transitions can have unintended negative social impacts for Indigenous and other local communities. Across the Nordic and North-American Arctic, countries enjoy the rule of law, stable institutions, high legal requirements for citizen involvement in impact assessments, and authorities intent on observing those rules. Yet, reports show that Indigenous and other local communities may feel run over by priorities given to the technical and economic aspects of the transition. For example, Indigenous Sami are experiencing pressures on their traditional reindeer herding due to the siting of wind-farms; and in Canada, First Nations have objected to large-scale hydro-power projects.

This suggests that existing engagement requirements and practices are too often inadequate for addressing community concerns in a manner that is meaningful to the affected community, and thereby ensuring the social acceptability of green transitions. Meaningful engagement of affected people and communities is a key element in risk-based due diligence, originally conceived as a management approach for companies to identify and manage their harmful impacts on society, based in soft law but increasingly set out in hard law. So far, many studies on engagement with rights-holders and other affected groups related to Arctic 'green' energy or transition-related mining focus on inadequate practices. Accordingly, there is a knowledge gap in regard to practices that work well, in particular 'best practice', 'good practice' and operational implications and skills. Based on a larger research project funded by the Nordic Council of Ministers' Arctic Cooperation Programme, this presentation addresses that knowledge gap by sharing findings from fieldwork on experiences and views of Indigenous and settler communities in Atlantic and Pacific Sub-Arctic Canada.

The overall project highlights the role of affected people in informing and influencing decisions, thereby contributing to improved engagement in sustainability transitions. Methodologically, to help bring out points on 'best practices' and 'good practices' during field work, we adapt a dual approach. We analyze cases that involve more invasive renewable/green energy and transition

minerals mining. We also draw on projects which aim to preserve environment and culture, through UNESCO World Heritage Sites, as projects for supporting alternative development pathways. In the Arctic and sub-Arctic, several UNESCO World Heritage sites are in close proximity to energy or mining sites. Offering parallel green economy options based on nature conservation and/or tourism, the planning of such sites is subject to UNESCO requirements on community engagement and the generation of local support.

The presentation shares comparative insights in regard to hydro-energy and UNESCO projects in the Atlantic and Pacific regions of sub-Arctic Canada for advancing meaningful engagement of affected Indigenous and non-Indigenous communities. We set the findings into the larger research context of our project, including field work research in Iceland and Greenland, and propose preliminary outcomes.

Abstract 79: Maaike Knol-Kauffman[1], Kåre Nolde Nielsen[1], Nina Kivijervi Jonassen[2], Claire Crowley[1]
[1]UiT The Arctic University of Norway, [2]Arctic Energy Partners

Institutional barriers to offshore renewable energy development: Exploring sustainable pathways between top-down government and bottom-up mobilization

In the Arctic, there is a large potential to speed up sustainability transitions through offshore renewable energy production. The Norwegian government has adopted the goal to reduce CO2 emissions by at least 55% by 2030, and Norway is now investing heavily in an internationally competitive offshore wind energy sector. Aiming for 30 GW by 2040, the sector is expected to play a large role in the green transition.

The international and national visions and strategies around offshore renewable energy development go hand in hand with local and regional mobilizations of businesses and other actors interested to play a part in the green transition. These processes, however, are not necessarily congruent. Building on a typology of institutional barriers, the objective of this paper is to analyze the performance of top-down renewable energy governance in connection to bottom-up regional initiatives. Empirically, the focus is on a case study of a planned innovative ocean multi-use concept off the coast of Helgeland in northern Norway, which is proposed to combine offshore wind energy development with other functions. Through this case study, we explore issues such as actor eligibility and participation, responsibility, adaptiveness, and accountability in offshore renewable energy governance.

Through a lens of co-production, we analyze pathways to sustainability

transitions and explore how we, together with stakeholders and end-users, can contribute to enhance the performance of multi-level governance. While this case is part of the PERMAGOV project focusing on the implementation of the European Green Deal in marine contexts, this work will draw relevant lessons for sustainability research in wider Arctic contexts.

Abstract 260: Hans Kristian Hernes[1], Niek Mouter[2], Ragnhild Batseba Ødegaard Skaugen[1], Toril Ringholm[1], Toyah Rodhouse[2]
[1]UiT – The Arctic University of Norway, Tromsø, [2]Technical University of Delft, Netherlands,

Digital participation for climate change transition and the embedding in municipal planning

The urgency of transition in the light of climate changes is among other challenges also a challenge to democracy. The conflicts are becoming both harder and more significant, and questions are raised about whether democratic institutions have the capacity to integrate conflicting questions and answers into current input, throughput, and output arrangements. Eco-authoritarianism is pointed to as one possible threat to the widely accepted standards of democracy (Fischer 2017). At the local level, in Norway as in several other countries, the planning system is expected to combine the handling of spatial and societal conflict and democratic participation from various groups of citizens. This is possibly the reason why several developments and innovations in participation take place in connection with planning processes. However, a recurring challenge in this connection is the question of how to engage the young people (Selboe & Sæther 2018; David & Buchanan 2019). This becomes even more urgent in parallel with the growing urgency of the climate change.

Our paper is based on experiences from an innovation project on participation in climate-, environment- and energy planning (CEE-planning) in rural coastal municipalities in Norway, in particular addressing young people, along with business leaders and politicians. In this project, three various forms of participation is being tested. One of them is digital – the Participatory Value Evaluation (PVE). In the PVE, the participants are put in the decision makers place and asked to make choices based on resource limitation. The first round of PVE will be carried out in the municipalities in spring 2023. PVE as a tool has been carried out in other contexts previously, but this is the first time in a Norwegian municipality, and the choices are designed on the bases of the local context.

The paper will address the question of whose viewpoints that are most pronounced in the plan documents. By comparing the results from the PVE

and the plan documents we will be able to detect to what degree the viewpoints of the three groups of participants diverge or match each other and the prioritisation that emerge from the plan documents: Whose values are embedded in the plan? As the municipalities that take part in the PVE are in different stages of the planning process, we have data ranging from both a plan that is decided and plans in the making. The paper is thus based on both data from the PVE, document analysis and interviews.

Session 4: Healthy Marine Arctic Ecosystems: Coexistence and Adaptive Management. Part 1: Multiple Pressures, Risk and Impact

Tuesday 30th January, 11:00-12:30

Abstract 65: Griffin Hill[1], Amy Mackintosh[1], Jorge Assis[1,2], Mark Costello[1]
[1]Nord University, Norway, [2]University of Algarve, Portugal

Climate analogs and Arctic aquaculture: vulnerability even under a best case emissions scenario

Marine aquaculture is the fastest growing food production industry, but remains exposed to climate change. Despite rapid advances, marine aquaculture remains largely reliant on ambient environmental conditions and is not nearly as capable of relocation as wild populations, especially across geopolitical boundaries. Anthropogenic climate change is driving, and will continue to drive, changes in the marine environment, including the global redistribution of marine populations as they attempt to track their ideal conditions. Climate analogs, matching climates at a different location in time or space, aid in identifying areas of the world most and least likely to be exposed to extreme climate dissimilarity in the future. Shifts in economically relevant wild populations could result in short-term gains in some fisheries, but with roughly 89% of global capture fisheries fully exploited, over exploited, or collapsed, aquaculture is increasingly emphasized as the marine food source of the future. Climate analogs have long been used in the terrestrial realm as a means to communicate the distribution and severity of climate displacement effects, providing a highly relatable metric for scientists and policymakers alike. We provide the first global accounting of aquaculture exposure to regional climate change, expressed as climate dissimilarity, across multiple climate scenarios affecting over 300 cultured species. Here, we present the distribution of such impacts on aquaculture in the marine environment, providing quantitative rankings of exposure at the Exclusive Economic Zone level. Under moderate to extreme climate change the worst effects are concentrated in equatorial regions and enclosed seas of Europe and Asia. The well-documented increased rate of change in the Arctic is revealed in an increased proportion of exposed species under lower emissions scenarios. Even if the ambitiously conservative emissions goals of the Paris Agreement are adhered to, the Arctic will face pockets of extreme climate dissimilarity affecting the majority of the aquaculture species currently present there.

Abstract 57: Annika Heimrich[1], William Halliday[1,2], Francis Juanes[1]
[1]University of Victoria, Canada, [2]Wildlife Conservation Society Canada

The Arctic marine soundscape near Cambridge Bay, Nunavut - key destination for ship traffic passing through the Northwest Passage

The Arctic Ocean is an important ecosystem, providing either temporary or long-term habitat for numerous migrating and resident marine species. Compared to other marine areas, the Arctic Ocean has had historically less noise disturbance from anthropogenic activities as sea ice provides both a dampening effect and a physical barrier to ship traffic. However, longer ice-free periods during summer caused by climate change are leading to elevated underwater noise levels as anthropogenic activities such as shipping increase. Consequently, resident marine mammals and fish, many of which are important subsistence species for Inuit, are exposed to rapidly changing habitat conditions. Since the underwater soundscape is a crucial habitat feature for marine organisms, it is important to monitor, understand and mitigate the effects shipping can have on the Arctic's marine species.

This study will present collaborative efforts between the Ekaluktutiak Hunters and Trapper Organization (EHTO) of Cambridge Bay, the Wildlife Conservation Society (WCS) Canada and Transport Canada resulting in the first long-term soundscape analysis of passive acoustic data collected in the Kitikmeot Region of Nunavut, Canada between 2017 and 2021. Acoustic data were analysed for marine mammal and fish vocal presence, with a strong focus on a temporal overlap between marine animals and ships during the shipping season (August-October).

Ringed seal (Pusa hispida) and fish vocalizations were present consistently throughout the year, whereas bearded seal (Erignathus barbatus) vocalizations were present between October and August with a peak during the species breeding season between April and June. Beluga (Delphinapterus leucas) vocalizations were detected on a single day in October 2017. Underwater sound levels were strongly driven by natural sound sources such as wind speed and sea ice concentration, as well as ship noise, with ship noise only occurring during the shipping season. Our findings suggest that ringed seals in particular are exposed to high levels of ship noise, raising concern as the species is listed as of Special Concern in Canada (COSEWIC 2019).

This study presents the first long-term passive acoustic measurements in the Kitikmeot Region and provides important baseline measurements for future studies on underwater noise within this region.

Abstract 158: Deborah Sharpe[1,2], William Halliday[1,2], David Yurkowski[3], Steven Ferguson[3], Francis Juanes[1], Stephen Insley[1,2]
[1]University of Victoria, Canada, [2]Wildlife Conservation Society, Canada, [3]Fisheries and Oceans Canada

Ringed seal (Pusa hispida) exposure to underwater shipping noise in the eastern Canadian Arctic

Climate change is driving unprecedented changes in sea ice coverage throughout the Arctic, and as the duration and extent of ice-free periods has increased, so has vessel traffic and underwater vessel noise. Marine mammals, who use sound for foraging, communication, and navigation, are among the species most impacted by vessel noise - which can mask and diminish the effective range of their acoustic signals, cause behavioral disturbance, and even contribute to hearing damage. Ringed seals (Pusa hispida) are an ice-obligate species well-adapted to quiet underwater soundscapes, and are integral to both Arctic ecosystems and Indigenous communities. They are designated as a COSEWIC species of special concern, but little is known regarding the extent to which ringed seal behavior and movement patterns are influenced by increases in Arctic shipping activity. A critical first step to answering this question is to determine how often ringed seals are exposed to shipping vessel noise. Using data from 12 ringed seals equipped with satellite tags in the eastern Canadian Arctic in 2012, 2013, 2017 and 2018, we implemented a continuous-time movement model to improve location estimates derived from error-prone Argos data. Fitted seal relocations were then compared with the interpolated tracks of large commercial vessels obtained from satellite Automated Identifier System (AIS) data. Our results are the first to illustrate the extent to which ringed seals and commercial vessels overlap in the Canadian Arctic. In addition, we demonstrate the potential of leveraging archived Argos data to fill in our understanding of when and where marine mammals are encountering vessel noise. Future applications of our methods to other species and regions will provide needed insight for developing informed vessel management plans as the Arctic continues to rapidly change.

Abstract 239: Hallvard Strøm[1], Vegard Bråthen[2], Sebastien Descamps[1], Morten Ekker[3], Børge Moe[2], Arnaud Tarroux[2]
[1]Norwegian Polar Institute, [2]Norwegian Institute for Nature Research, [3]Norwegian Environmental Agency

Large-scale tracking of seabirds in the North Atlantic – SEATRACK

Many seabird species undergo extensive seasonal migrations, often across large marine ecosystems or between marine areas under different national jurisdictions. Through the advances of electronic tracking and especially the

application of Global Location Sensors (GLS or geolocators), it is now possible to study the seasonal movements of seabirds and link breeding populations to non-breeding habitats. To take full advantage of this development for better management and conservation, and to broaden the scope of scientific questions that can be assessed, there is a need for large-scale and multi-species programmes. The SEATRACK project with partners from 15 countries aims to identify the year-round distribution and movements of seabirds breeding in colonies across the northern part of the North Atlantic. By 2023, more than 23000 loggers were deployed on 15 species in 83 colonies, and data from 12 000 retrieved loggers have been analyzed and compiled. The project models and maps important marine habitats for the different populations, studies the potential overlap with offshore human activities and documents how changes in environmental conditions in non-breeding areas affect demography and population trends. We will present the design of this successful international collaboration network, the power of standardization, the main data products and examples of the strength of this international effort in answering overarching questions in modern marine research.

Abstract 62: Monica Moritsch[1], Mattias Cape, Jamie Collins[1]
[1]Environmental Defense Fund, USA

Release of sediment carbon from bottom trawling in areas of ice retreat

As global oceans warm and Arctic ice melts, fish stocks are shifting. Many species in the northern hemisphere are moving poleward. Currently, bottom trawling in the Arctic is minimal due to ice cover. Ice retreat will open new areas for fish populations and for fishing fleets to access them. Bottom trawling activities penetrate the seabed and can liberate carbon stored in seabed sediments, potentially creating positive feedback between ice melt and further release of carbon dioxide into the atmosphere. We estimated where and how much carbon could be released to the atmosphere if new bottom trawling occurred in areas of future ice melt on a decadal time scale. Using two climate scenarios (SSP 2-4.5 and SSP 5-8.5), we combined projections of summer sea ice retreat and trawling probability with a model of arctic sediment carbon (C) stock using ArcMap 10.8. We estimated the amount of C disturbed based on literature estimates of common trawling gear dimensions and historical data on hours trawled per square kilometer. Disturbed C that is converted to carbon dioxide can remain dissolved at sufficient pressures from water depth. We applied a depth-dependent remineralization relationship to the disturbed C to calculate the total C remineralized over 100 years for a given pixel. We estimated that in the next century, summer ice retreat in water of trawlable depths (≤ 2,000 m) would open 1.9 to 3.4 million km2 to fishing fleet access. The areas of ice retreat overlay between 820 and 28,000 metric tons C km-2. Within ice retreat areas, 0.29 to 0.95 Gt C could be remineralized upon disturbance.

However, the total amount remineralized depended heavily on future trawling probability. This probability was higher at lower latitudes, particularly near continental shelves, where C stocks were also generally higher, indicating a higher degree of potential carbon release from new bottom trawling in these locations. We suggest that carbon remineralization and the subsequent feedbacks on climate are critical considerations for climate-smart fisheries management and global climate mitigation strategies.

Abstract 36: Geir Skeie[1], Håvard Gulbrandsen Frøysa[2], Frode Vikebø[2], Raymond Nepstad[3], Ole Broch[3], Daniel Howell[2], Achim Randelhoff[1], Gro Harlaug Refseth[1], Jolynn Carroll[4]
[1]Akvaplan-niva, [2]Institute of Marine Research, [3]SINTEF Ocean, [4]Independent Researcher

Advanced Simulations of Impacts from Large Oil Spills on Six Commercially Important Fish Stocks in the North Atlantic

The SYMBIOSES project has run in three phases over a period of > 10 years, financed by the Norwegian Research Council and a number of operators on the Norwegian Continental Shelf. In this third phase of the project we apply a high resolution 3-D coupled biological-physical model that includes a toxic effects module to simulate impacts of large oil spills on the recruitment and subsequent changes in the Spawning Stock Biomass (SSB) of six commercially important fish stocks in the North Sea, Norwegian Sea, and the southern Barents Sea. The SYMBIOSES model (j.marpolbul.2022.114207) includes species characteristics and annual variations in recruitment and is used to simulate a range of years and spill locations, as well as a range of sensitivity to oil toxicity.

Two sets of simulations were run for all fish species and a range of years. Simulation set 1 was run for a number of producing fields and exploration wells, with site specific oil types and discharge characteristics as used in authority permits. Simulation set 2 was run for locations near significant spawning areas in the Norwegian and Barents Sea.

Simulation set 1, which included activities from the North, Norwegian and Barents Seas, gave up to 14 % Early Life Stage (ELS) mortality across all species when applying the strictest of four parameter sets for toxicity, resulting in a maximum reduction of SSB by 2 %. For the three northernmost fields in the Barents Sea, ELS mortality was up to 9 %, and the maximum SSB reduction in a year of 2 %.

Simulation set 2 gave up to 56 % Early Life Stage (ELS) mortality across all species and years when applying the strictest of four parameter sets for toxicity, and a maximum reduction of SSB in a year by 18 %.

The SYMBIOSES modeling tool extrapolates impacts on individual fish to the entire population, delivering comparative information for diverse fish species in the North Atlantic. These simulation results provide valuable information for the Management Plan, and results can be applied for environmental risk assessment. They allow managers to identify and compare options for reducing the environmental footprint and impact of activities on the marine ecosystem.

Abstract 285: Katrin Vorkamp[1], Kaj M Hansen[1], Jesper H Christensen[1], Patrik Fauser[1]
[1]Aarhus University, Denmark

Chemicals of emerging Arctic Concern: Understanding impacts from local sources and long-range transport for chemicals management.

The presence of harmful chemicals in the marine environment of the Arctic has been recognized as a potential threat to Arctic ecosystems and human health for several decades. Main concerns have been related to the long-range transport of persistent organic pollutants (POPs) and heavy metals such as mercury, now regulated under the Stockholm Convention on POPs and the Minamata Convention on mercury, respectively. Since the early 1990s, Arctic data have been collected systematically under the Arctic Monitoring and Assessment Programme (AMAP). This evidence of long-range transport (and often, bioaccumulation) has been instrumental for risk assessments under the Stockholm Convention and effectiveness evaluations via temporal trend monitoring.

A recent AMAP assessment documented that climate change challenged the direct link between primary emissions of chemicals and environmental levels in the Arctic, as secondary sources gain importance in a warming Arctic. In addition, indications of local sources in the Arctic have been reported increasingly, in particular for unregulated chemicals, i.e. chemicals of emerging Arctic concern (CEACs). Their local emissions might increase with increasing marine activity in a warming climate, e.g. from shipping, tourism, fishing, oil and gas exploration etc., raising questions about the unambiguity of Arctic monitoring data to document long-range transport. In this project, we have studied the relative importance of local sources and long-range transport for seven current-use flame retardants (FRs) at Nuuk, Greenland, including brominated and phosphorous FRs as well as dechlorane plus, recently recommended for listing under the Stockholm Convention.

In a first step, we established global emission inventories for these FRs. Using the Danish Eulerian Hemispheric Model (DEHM), we calculated the long-range transport to Nuuk, with resulting concentrations in the Arctic environment and

characterisation of global main source regions. Regarding the local scale, we estimated local emissions to air, water and soil at Nuuk and predicted environmental concentrations, including the uptake and accumulation in a fish-seal food chain. Finally, we added a human risk screening based on the exposure to these FRs in air and marine food (fish, seals).

The modelling results indicated a significant contribution from local sources to the FR levels in the environment of Nuuk. While few towns of this size exist in the Arctic and AMAP monitoring sites are placed in remote areas, easier access to the Arctic may increase local impacts in the future, from a variety of activities and uses. This happens in addition to the ongoing long-range transport of POPs and CEACs, their increasing release from secondary sources and complex pressures from climate change and emerging threats, such as plastics and zoonotic diseases. Our study contributes to a better understanding of sources of Arctic pollution, for a careful planning of monitoring activities and considerations of multiple input pathways of contaminants to the Arctic in an efficient and comprehensive management of chemicals.

Abstract 223: Ina Helene Ahlquist[1], Emily Cowan[1], Rachel Tiller[1]
[1]SINTEF Ocean

Adaptive ecosystem management in the Arctic: seriously plastic pollution is not a game but, in this study, we play as if it were

The Arctic is vulnerable and subject to anthropogenic stressors. Among them is the ever-increasing crisis of plastic pollution that threatens not only humans and wildlife in the Arctic - but our planet as a whole. With the ongoing UN negotiations on a treaty to end plastic pollution, countries will after its adoption and signature, hopefully by the end of 2024, need to ratify the treaty at the national level. We therefore need innovative solutions for the Arctic that can facilitate the actions needed to tackle plastic pollution that are relevant and proactive in terms of protecting ecosystems and human wellbeing sustainably. We argue that necessary steps towards facilitating such actions include knowledge sharing and increased awareness. In this study, we present results from a Serious Game methodology to elicit knowledge about plastic pollution issues in the Arctic while gathering citizen perceptions relating to Arctic governance thereof. Serious Games can be used for learning and developing perceptions around a specific problem while non-intrusively collecting data. The game was played during the 2023 Arctic Circle Assembly in Iceland where a diverse group of policy makers, scientists, business representatives and other stakeholders took part as players. During the Serious Game, the players took on the role as policy makers in the Arctic with opportunity and power to implement effective governance strategies on plastics in the Arctic. The participants were exposed to events concerning plastic pollution and had to choose mitigation

efforts while evaluating sustainability outcomes of all events and countermeasures and discussing in light of the United Nations Sustainable Development Goals. Furthermore, the game had a special emphasis on ensuring provision of a clear distribution of regulatory responsibility from state to region to industry. The game presents storylines to stimulate reflection and ensuring that the players were faced with complex topics turned comprehensible while facilitating strategic reflections on actions that needed to be taken. The game story in question captured how changes can occur fast in the Arctic and have ripple effects over time in turn affecting future generations. We investigate how serious games can be used as a tool to share knowledge of important issues while providing an alternative way to collect data on people's perceptions on sustainability, sustainable development, plastic pollution in the Arctic and different management alternatives that prioritizes certain environmental, economic, and social aspects. We present the game and the story step by step, and the results from the workshop.

Session 4: Healthy Marine Arctic Ecosystems: Coexistence and Adaptive Management. Part 2: Integrated Monitoring, Risk Assessment, and Adaptive Management

Tuesday 30th January, 15:45-17:15

Abstract 68: Cathrine Stephansen[1], Eva Leu[1], Tonje Rogstad[2], Jørgen Skancke[3], Christophe Bernard[4], Anders Bjørgesæter[4]
[1]Akvaplan-niva, [2]Equinor, [3]SINTEF Ocean, [4]IKM Acona

ERA Acute for the Marginal Ice Zone – a simplified ecosystem-based approach using dynamic ice data

ERA Acute, the current method for assessing environmental risks of oil spills in Norway has recently been expanded to include the Marginal Ice Zone (MIZ) as a valuable and sensitive ecosystem. With increasing activity and traffic in Arctic areas, the risk of oil spills needs to be assessed for this ecologically important habitat, while considering that the MIZ's extent is highly dynamic, of seasonally varying importance to inhabiting species, vulnerable and threatened by climate change.

The MIZ is included as a Valuable Ecosystem Component (VEC) habitat into ERA Acute as a separate methodology which captures the daily dynamics of both the ice extent and spreading of oil. The vulnerability scoring, Bloom Intensity Factors (BIF) is a simplified approach to weighting the ecological importance and value of MIZ for all trophic levels and for steering how the sensitivity and vulnerability of the MIZ changes through the seasons. The potential environmental damage to the MIZ from the daily oil coverage is calculated and geolocated based on the percentage of the area that is covered by ice, using daily ice concentrations from historic data. The damage is weighed by the ice density interval's seasonally varying ecological importance, using four key ecological groups of the MIZ' biological productivity tied to the ice extent, as indicators of the MIZ' ecological significance. Thus, BIF integrates the primary and secondary producers to the higher trophic level consumers attracted to the MIZ in the spring and summer algal blooms.

BIF varies each month with the ice concentration interval's importance for each of key primary producer groups; ice algae and pelagic phytoplankton, and for secondary producers in the water column and under ice. The sensitivity of the MIZ to the environmental stressor will thereby move north in the melting season

and reflect the dynamic nature of the MIZ, thus allowing for greater detail for environmental management. A base weight value is given to the Polar Night and "non-bloom" months and the factor increases with the significance of the damage at the height of the key organism group's importance for the ecosystem. Values are set based on scientific judgement of the intensity of the planktonic bloom, ecological significance and ecosystem vulnerability for each group in the ice concentration and relevant month. The ice concentration interval and the months represent environmental factors based on scientific experience. Additional weight has been assigned to high concentrations of ice, which represents a higher probability of multi-year ice, an especially important habitat for ice-obligate species which is threatened by climate change, .

The BIF weighting system reflects the daily dynamics of the MIZ, whilst aiming to be a robust simplification of the intricate ecosystem mechanisms involved. As a simplified approach, it represents a way forward for assessing the potential effects oil spills or other environmental stressors on an ecosystem, which can be refined as knowledge gaps are filled. The BIF weighting system for the seasonally varying importance of different parts of the MIZ' could be expanded to other areas of environmental management.

Abstract 140: Arnaud Tarroux[1], Per Fauchald[1], Marie-Anne Blanchet[2], Jens Boldingh Debernard[3], Vegard Bråthen[1], Sébastien Descamps[2], Morten Ekker[4], Børge Moe[1], Hallvard Strøm[2]
[1]Norwegian Institute for Nature Research (NINA), [2]Norwegian Polar Institute, [3]Norwegian Meteorological Institute, [4]Norwegian Directorate for Nature Management

Spatiotemporal variation in exposure of Arctic-breeding seabirds to fisheries and ship traffic in the North-East Atlantic
Human activities are adequately identified, so that effective resource-management policies can be developed. With the retreating sea ice in the Arctic, human activities will expand northward, concurrently to many marine species, including seabirds. Marine Spatial Planning and Ecosystem-Based Management are often proposed as tools that can help achieve sustainable use of marine resources. However, these tools require adequate scientific data about the distribution of both marine species and human stressors, at spatiotemporal scales matching the high environmental variability inherent in northern marine ecosystems. Within these ecosystems, seabirds play key ecological roles, integrating ecological information across trophic levels and food webs at large spatiotemporal scales. For this reason, seabirds often used as indicators of the state of marine ecosystems. While more research is now focusing on the effects of anthropogenic activities on marine ecosystems in general, and seabirds in particular, there is still need for data regarding where and when anthropogenic activities can affect seabirds. The need is particularly acute in areas that are less

accessible, typically offshore areas in international waters, and during periods where biological surveys are generally more difficult and thus less frequent (e.g. wintering season for seabirds). Here, we provide a first large-scale assessment of the spatiotemporal overlap between seabirds and two major anthropogenic stressors: industrial fishing and maritime traffic. Our assessment covers the North-Atlantic Ocean and Barents Sea throughout the annual life cycle of six pelagic seabird species nesting in the Arctic: northern Fulmar (Fulmarus glacialis), Black-legged Kittiwake (Rissa tridactyla), Common Murre (Uria aalge), Thick-billed Murre (Uria lomvia), Little Auk (Alle alle) and Atlantic Puffin (Fratercula arctica). Our assessment is based on three large-scale datasets: SEATRACK (monthly seabird distribution), Global Fishing Watch (fishing effort), and AIS (Automatic Identification System, informing us on the intensity of maritime traffic). Combining these datasets allows us to map and investigate the spatiotemporal dynamics in overlap between pelagic seabirds and these anthropogenic stressors. This constitutes a critical first step towards identifying areas and periods of higher vulnerability.

Abstract 228: Sabine Cochrane[1], Herman Hummel[2], Jan Węsławski[3], Julie Bremner[4], Tasman Crowe[5], Mike Elliott[6], Christos Arvanitides[7], Charlotte Weber[1], Britt Thijssen[2], Ingvild Utengen[1]
[1]Akvaplan-niva, [2]Hummel Foundation for Sustainable Solutions (HUFOSS), The Netherlands, [3]Institute of Oceanology Polish Academy of Sciences, [4]Centre for Environment, Fisheries and Science (CEFAS), UK, [5]University College Dublin, Ireland, [6]International Estuarine and Coastal Specialists Ltd, UK, [7]LifeWatch ERIC, Spain

Linking marine biodiversity, changes in ecosystem functioning and services with societal goods and benefits (the MARBEFES project).

European Member States (MSs), as with countries worldwide, have a fundamental need to understand how biodiversity and ecosystem functioning must be maintained to ensure that they deliver ecosystem services and societal goods and benefits, which must in turn be sustainably utilised by humankind to support a lasting “Blue Economy”. Norway and other Arctic nations have a particular responsibility for understanding ongoing climate-driven ecosystem changes in high latitudes, where the impacts of change are highly visible. Svalbard, in particular, is a valuable study area as not only is the climate changing, but human use of the marine environment is increasing and much of the economy now stems from destination tourism, targeting marine wildlife and nature.

There therefore is an international need to value coastal and marine biodiversity and their ecosystem services and societal goods and benefits, as a basis for cost-effective environmental management. Above all, this requires ecological

and monetary and non-monetary valuation. The MARBEFES project ensures an increase in understanding biodiversity and the delivery of improved methods for ecological and socio-economic valuation.

We use a suite of 12 study locations within the four main overarching European marine regions, covering the breadth of European marine biodiversity, from the Arctic to semi-tropical areas, across dominant habitats and iconic species, and from shallow to deep areas. Some of the key assessments made are ecological, social and financial evaluations of the study areas, and how these may be applicable to the relevant practitioners and managers.

The project runs from 2022 to 2026 and comprises 23 international partners. We have so far conducted over 250 stakeholder surveys and interviews across Europe. Some interesting trends have arisen, when comparing the attitudes and challenges facing Arctic practitioners and societies relative to those elsewhere in Scandinavia, UK and Ireland as well as central and southern Europe. In general, the people, businesses and industries of the northern locations had a markedly higher connectedness to the societal benefits of the marine environment. Issues related to nature conservation and sustainability were perceived in the northern areas as less important than in southern European areas. Because climate change, and resulting changes in ecosystem structure and functioning, are so apparent in the Arctic, these issues came more to foreground in the Arctic. Therefore, a sound understanding of the links between society, livelihoods and nature is crucial in order to understand arising risks and how to manage human uses of the marine environment.

The project advances methodologies for both financial and non-financial valuation of marine resources and culminates in a toolbox that will assist practitioners in both asking the appropriate questions – and selecting the appropriate methodology for the specific areas in question. One of the final major outcomes will be a mechanism for upscaling from local-scale issues to broader applications on a pan-European and wider international scale.

Abstract 354: Igor Eulaers[1], Kari Ellingsen[2], Raul Primicerio[3], Audun Stien[3], Nigel Yoccoz[3], Evert Mul[2]
[1]Norwegian Polar Institute, [2]Norwegian Institute for Nature Research, [3]UIT – The Arctic University of Norway, Tromsø

Towards an actionable inter-disciplinary framework for adaptive ecosystem-based management of multiple pressures

The transparency and actionability of ecosystem-based management of multiple pressures is at present hampered by variable terminology, definitions, and values

of human-environment interactions. While the Drivers-Pressures-State change-Impact-Response (DPSIR) framework has been widely adopted, the increasing intensity and complexity of human-environment interactions beg for improved operability of this inter-disciplinary framework through an actionable and transparent vocabulary across natural scientific disciplines, realms and pressures.

We will present the DPSIR framework and how it is used, including inherent definitions, in various realms, ranging from terrestrial over coastal to marine ecosystems. Moreover, we will assess its position in relation with two recently proposed alternative conceptual frameworks, i.e. the DAPSI(W)R(M) (including human Welfare and Measures) and $DPSCR_4$ frameworks (Drivers-Pressures-Stressors-Condition-Responses). Our focus will be on the frameworks suitability for assessing and managing multiple pressures, e.g. accommodating regional versus global pressures, interactions among pressures, and their potential for actionability. Finally, we will present a workflow for the assessment of Ecosystem Health and Condition using the different frameworks, and evaluate how they can support Adaptive Management, Sustainable Development and Wellbeing.

Abstract 208: Katherine Dunlop[1], Johanna Myrseth Aarflot[1], Anna Siwertsson[2], Mette Skern-Mauritzen[1], Cornelya Klutsch[3], Gabriela Wagner[3], Hallvard Jensen[3], Tor-Arne Bjørn[3]
[1]Institute of Marine Research, [2]Akvaplan-niva, [3]Norwegian Institute of Bioeconomy Research

CoastShift: Assessing ecological risk from current and future food systems in coastal northern Norway

Arctic coastal regions are experiencing an increasing demand on resources and space under blue growth strategies which promote economic development in marine food and energy production, while aiming to protect the environment and ensuring social sustainability. The future of Arctic marine ecosystems is also being planned around green shift policies to achieve net-zero Co2 emissions. The CoastShift Fram program is addressing what the likely future green-shift and blue growth scenarios will mean for future food systems in Northern coastal Norway, a major marine and growing terrestrial food producing region. The project is also assessing the cumulative risk of negative effect from current and future food systems on coastal Arctic ecosystems and the services they provide. Integrated ecosystem-based assessment and management approaches aim to consider multiple pressures and impacts on several ecosystem components simultaneously. Such risk assessments aim to achieve a more holistic ecosystem-based management currently in demand by environmental managers. The proposed presentation will present an overview of the CoastShift

program and its relevance to the management of anthropogenic impacts on natural resources in Arctic coastal Norway. Focus will be given to new approaches in the project to integrated ecosystem-based risk assessments frameworks for both marine and terrestrial ecosystems and ecosystem services by adapting the ODEMM (Options for Delivering Ecosystem-Based Marine Management) methodology.

Abstract 60: Tamer Abu-Alam[1], Lena Schøning[1], Vera Helene Hausner[1], Cristina-Maria Iordan[2], Sigrid Engen[3], Sarah Schmidt[2], Elisabeth Fugger[2], Charlotte Teresa Weber[4], Per Fauchald[3], Eirik Mikkelsen[5]
[1]UiT– The Arctic University of Norway, Tromsø, [2]SINTEF, Norway, [3]Norwegian Institute for Nature Research, [4]Akvaplan-niva, Norway, [5]NOFIMA, Norway

Charting Northern Norway's Blue Food Systems: Scenarios for Sustainable Growth and Environmental Stewardship by 2040

Blue food systems hold the potential to address a multitude of economic, social, and environmental challenges on a global scale. However, their development also poses threats to regions reliant on traditional blue food production. The CoastShift project, funded by the Fram Centre, is dedicated to envisioning various scenarios for Northern Norway region that navigate the path to 2040 with a focus on environmental sustainability, inspired by the EU Taxonomy Regulation, and driven by active governance and regulatory frameworks. Collaboratively constructed with diverse stakeholders, we present four compelling scenarios for consideration. In the 'Re-generative Scenario,' Northern Norway undergoes a remarkable transformation, embracing sustainable local food production and circular economies. Rooted in environmental values and active governance, this scenario leads to thriving communities and international recognition. In the 'Centralized, High-Tech, Industrial Food Production Scenario', biotechnology fuels global food trade and centralized operations, ushering in efficiency while raising questions about local identity and environmental impact. The 'Strong Economic Growth with No Transition Scenario' prioritizes economic expansion, at the expense of environmental concerns, as Northern Norway pursues petroleum, marine minerals, and high salmon production, facing scrutiny from environmental advocates. Finally, the 'Conservation Scenario' champions stringent environmental regulations, resulting in protected areas and biodiversity preservation. The aquaculture sector contends with restrictions, while nature-based tourism flourishes. This research offers profound insights into the intricate interplay between economic growth, environmental stewardship, and community well-being within Northern Norway's dynamic blue food systems.

Abstract 100: Raul Primicerio[1]
[1]UiT – The Arctic University of Norway, Tromsø

Challenges and options for the integrated management of Arctic ecosystems under climate change

The integrated management of cumulative risk in marine ecosystems requires knowledge of relevant impact pathways and of their connection to management options. In Arctic marine ecosystems, rapid climate change modifies the cumulative risk due to direct impact pathways by affecting the intensity and distribution of human activities and associated hazards, the distribution and exposure of species, and their sensitivity to multiple hazards. Further, by reorganizing food-webs, climate change alters indirect impact pathways and affects systemic risk. The challenges to adaptive, integrated management emerging from climate-driven change in ecosystem state and cumulative risk will be discussed illustrating with data and models from Arctic marine and coastal ecosystems. Adaptive management approaches and measures that can help mitigate cumulative risk to biodiversity and ecosystem services under climate change will be critically evaluated.

Abstract 105: Malgorzata Smieszek-Rice[1], Frode Vikebø[2], Raymond Nepstad[3], Tor Nordam[3], Emma Litzler[3], Kai Håkon Christensen[4]
[1]UiT – The Arctic University of Norway, Tromsø, [2]Institute for Marine Research, [3]SINTEF, [4]Norwegian Meteorological Institute

Assessing cumulative impacts of climate change and potential oil spills in the Arctic

The Arctic seas and their natural resources are facing cumulative pressures from climate change and multiple human activities. The primary example is the Barents Sea that is expected to become the first summer ice-free Arctic region by around 2050, if not sooner, and where the rapidly receding sea ice opens new areas farther north for economic activities such as oil and gas exploration and shipping. Extracting and transporting oil come with the risk of accidental oil spills, including in the areas near ice – the marginal ice zone and ice edge - that are critical to spawning and recruitment of the cornerstone of the Arctic food chain – polar cod. While the negative effects of declining winter sea ice cover on polar cod are partly established, the ACTION project ("Arctic ecosystem impact assessment of oil in ice under climate change") examines now the cumulative impacts of climate change and oil pollution on that key species in the Barents Sea ecosystem.

The main objective of ACTION is to develop and demonstrate an approach to risk assessment of those cumulative impacts and through that inform relevant

policy-making processes. It is done through the development, advancement, and coupling of data-driven mechanistic models, including high-resolution coupled ice-ocean models, new models for early life stages of key Arctic fish species, and the improved model of oil behavior in the marginal ice zone and ice edge that better reflects oil-ice interactions and accounts for oil transport in ice-covered waters. Taken together, these models will lead to more accurate and realistic understanding of the potential impact of oil spills in the Arctic.

While results of the project will fill important knowledge gaps in our understanding of mechanisms by which pollutants and climate change interact to affect key Arctic species, there are inherent limitations in the studies of this kind. Among others, they relate to complexity of investigated processes, nature of obstacles that prevent the filling of knowledge gaps, climate change timescales under examination, and tipping points that – if crossed – might render today ś risk assessments inadequate.

In that context, understanding of risk and related uncertainties becomes of paramount importance, especially among stakeholders with potentially different value perceptions. To address that issue, ACTION examines conceptions of risk among decision-makers and stakeholders in offshore petroleum industry and it seeks ways to improve treatment and communication of related uncertainties. It also considers the implications of those for decision-making processes.

By addressing all the above, ACTION represents development toward assessing cumulative impacts on ecosystems rather than singular pressures on individual ecosystem components. It also contributes to knowledge- and system-based decision making and to sustainable development of Arctic marine ecosystems. Finally, it provides relevant input to discussions about the health of Arctic marine ecosystems and related management advice.

Session 4: Healthy Marine Arctic Ecosystems: Coexistence and Adaptive Management. Part 3: Frameworks for Bridging Science and Policy

Wednesday 31st January, 11:30-13:00

Abstract 234: Hyoung Chul Shin[1], Eun Jin Yang[1], Jihoon Jeong[1]
[1]Korea Polar Research Institute (KOPRI)

An unlikely success in conserving Arctic marine ecosystem?: the development of the Central Arctic Ocean Fisheries Agreement (CAOFA)

Unprecedented high paced climate changes have led to a new Arctic and opened a new horizon of governance. A remarkable achievement in this evolving Arctic landscape is the successful launch of the Central Arctic Ocean Fisheries Agreement (CAOFA). CAOFA represents a unique historic milestone in terms of both the management of marine living resources in remote international waters and intergovernmental cooperation in the Arctic. As the first embodiment of a precautionary and ecosystem-based approach preceding the commencement of any fishing activities, the agreement has created a new form of Arctic governance supported by both Arctic coastal states and non-Arctic governments, on an equal footing. The inclusion of time-honored Arctic Indigenous knowledge in the management as stipulated in the Agreement calls for collaboration to harmoniously integrate different knowledge systems, offering insights and a foundation for future efforts in the Arctic and elsewhere.

Despite significant geopolitical concerns and a host of other challenges, CAOFA serves as a testament to the power of cooperation to uphold flexible yet robust Arctic governance. Understanding the factors contributing to this success and exploring potential future scenarios is crucial, as they provide valuable insights to lay down the path for the new Arctic. In this presentation, we aim to delve into a historical account of how the Agreement came into existence, its significance, the nature of success in its implementation by the Parties so far, and the future challenges that lie ahead. This perspective is offered by the Republic of Korea, which turned out to be a significant contributor in the timely implementation of CAOFA by hosting the first and second Conference of the Parties meetings.

Abstract 71: Agneta Fransson[1], Bodil Bluhm[2], Doreen Kohlbach[2], Nansen Legacy JC2-2 Team
[1]Norwegian Polar Institute, [2]UiT – The Arctic University of Norway, Tromsø

Central Arctic Ocean Basin ecosystem properties with implications for future resource management

The Eurasian Basin of the central Arctic Ocean (CAO) consists of two deep basins separated by the Gakkel Ridge: the Nansen Basin and the Amundsen Basin. The increased inflow of warm Atlantic water masses into the Nansen Basin causes rising water temperatures with changes in stratification and ocean chemistry as well as a significant reduction in sea-ice cover ('Atlantification'), while environmental conditions in the Amundsen Basin are markedly influenced by the Transpolar Drift and Siberian river inflow. Based on these contrasts in environmental settings, it is reasonable to expect that ongoing climate change might impact the two basins differently. Comparative investigations of ecosystem properties of the basins are therefore crucial. Our study provides an inventory of the current state of the two basins, investigating chemical, physical, and biological components of sympagic, pelagic and benthic habitats sampled during the Nansen Legacy Joint Cruise JC2-2 in late summer 2021. Specifically, we contrast i) sea-ice conditions, ii) biogeochemical properties of the sea ice and seawater iii) composition of ice-associated and pelagic protist communities, as well as iv) faunal communities inhabiting sea ice, water column and benthic sediments under current environmental conditions to serve as a baseline for anticipation of future change in these ecosystems.

The possible end of the 'Agreement to Prevent Unregulated Fishing in the High Seas of the Central Arctic Ocean' in 2037 and the expansion of open water areas may introduce new opportunities (as well as management needs) for commercial fishing activities, increase the Arctic states' interests in extracting mineral resources from the seafloor and have initiated debates about a seasonal trans-polar shipping route. These issues warrant a thorough assessment of biotic (including harvestable) and abiotic resources in this region as well as of the potential consequences of human activities in the CAO to ensure retaining an intact and functioning ecosystem. Resource managers are urged to adjust strategies to account for significantly lower primary production and biotic densities and different species, including taxa with slow growth, high longevity, and unknown resilience to change, than observed on the adjacent shelf. Thus, our study provides needed knowledge regarding the state of the CAO ecosystem and will inform future sustainability guidelines, environmental management and conservation policies.

Abstract 114: Connor Rettinger[1], Jackie Dawson[1], Kirstin Holsman[2], Sierra Beacher[1], Selina Baffour-Asare[1], Lyra Evans[1]
[1]University of Ottawa, Canada, [2]NOAA Alaska Fisheries Science Center

Framework for Quantifying Risk, Residual Risk, and Adaptation (RRAD) within Polar Environments

Climate change has significantly altered environmental processes through sea ice melt, changes in animal migration patterns and species ranges, and air temperatures, with cascading implications for northern communities' economic, political, socio-cultural, and environmental systems. Climate change has allowed new opportunities for humans to intervene and capitalize on regional development, such as resource extraction, tourism, and shipping opportunities. With these emerging opportunities and risks, it is more pertinent than ever to effectively assess and adapt to ongoing change. Understanding the risks of climate change to different ecological and social sectors is also one of the most important tasks of the IPCC Assessment reports and one of the most critical evaluations for use among national and international decision-makers and government agencies. The presentation reports on innovative developments made during the recent AR6 Assessment cycle by IPCC WGII to establish a risk assessment approach incorporating key variables in climate risk, such as residual risk, adaptation limits, effectiveness, and feasibility. This research aims to bridge the current knowledge gap through the development of the Residual Risk and Adaptation Database (RRAD), to comprehensively examine the relative risks of critical ecological and societal sectors (i.e., food and fiber, economic areas, ocean, terrestrial, health, tourism, cities and settlements, others) across polar regions. RRAD is a tool that will be used to assess researchers' publications and reports in determining the risk level for hazards and the effectiveness of climate adaptation measures. It also enables additional analysis of sub-regions, including the Pan-Arctic and Inuit Nunangat. The RRAD tool is designed for open-source sharing by using Shiny, R, and github, so that others can use and modify the approach in the future to meet the needs of climate scientists, industry experts, researchers, policy, and decision-makers.

Abstract 102: Bodil Bluhm[1], Eva Ramirez-Llodra[2], Saskia Brix[3], Heidi Meyer[4], Hanieh Saeedi[3]
[1]UiT – The Arctic University of Norway, Tromsø, [2]Rev Ocean, Norway, [3]Senckenberg am Meer, German Center for Marine Biodiversity Research, [4]Institute for Marine Research, Norway

Seafloor habitats and benthic biodiversity in the deep Arctic Ocean

The deep seafloor occupies the largest ocean area globally. These areas today receive increasing attention due to their role in sequestering carbon, housing

minerals, and - highly underexplored – unique biodiversity. In the Arctic, sea ice cover declines and access to the previously permanently ice-covered Central Arctic Ocean opens, making an update on underappreciated habitats and taxonomic diversity urgent in this area before the human footprint increases further. Under the framework of the Challenger 150 initiative and other efforts, current knowledge on benthic habitat and taxonomic diversity of eurkaryotes was summarized for the deep Greenland-Norwegian and Iceland Seas and Central Arctic Ocean. The taxon inventory of metazoan fauna in these areas, based on >170,000 compiled taxon occurrence records from GBIF and additional research efforts, yielded >1800 morphologically identified species for which >500 have COI barcodes available (though very few from the Central Arctic Ocean). As in most oceans, arthropods, annelids and mollusks were the phyla with most documented taxa and most occurrence records. The number of occurrence records and taxon richness were highest in the upper 1500 m. For habitat diversity, substantial advances have been achieved in biodiversity knowledge of previously neglected habitats, including hot vents (which lack the large fauna typical of vents further south), seamounts (with, e.g., dense sponge occurrence even far north), oceanic ridges and continental slopes. Remaining knowledge gaps in species, habitat, and functional diversity and resilience of these systems at the deep Arctic seafloor should be filled to be able to inform management decisions in the best possible way.

co-authors from Challenger 150 working group in addition to those listed: Alexey Golikov, Ana Hilario, Angelika Brandt, Anne Helene S. Tandberg, Arunima Sen, Christiane Hasemann, Dieter Piepenburg, Henk-Jan Hoving, Hrönn Egilsdóttir, Severin Korfhage, Jennifer Dannheim, Joana R Xavier, Jörundur Svavarsson, Mari Heggernes Eilertsen, Pedro A. Ribeiro, Pål Buhl-Mortensen, Rachel Downey, Stefanie Kaiser, Steinunn Hilma Olafsdóttir, Sylvie M Gaudron, Tanja Stratmann, Karlotta Kürzel, James Taylor, Thomas Soltwedel, Autun Purser, Carolin Uhlir, Anne-Nina Lörz, Irina Zhulay, Lis Lindal Jørgensen, Rhian Waller, Jan Steger, Anna Gebruk, Franziska I. Theising

Session 5: Smart Arctic Cities: Health, Wellbeing, Air Quality and Energy Needs. Part 1: Data, Digitalization and Decision-Making

Monday 29th January, 09:00-10:30

Abstract 19: Johannes Brozovsky[1], Simone Conta[1], Stian Stavland[1]
[1]SINTEF

Urban Environment Lab – Cutting-edge sensor network for research on liveable and healthy cities

Densification is one of the prioritized strategies in Norway and internationally to make cities more sustainable. However, with more than 82 % of Norwegians already living in urban communities and ongoing urbanization, densification implies hard conflicts that need detailed knowledge to find effective solutions.

City centres should be attractive areas of residence for families and all population groups. However, previous research shows a strong correlation between dense urban spaces and high levels of noise and air pollution and overheating during summerly heatwaves. All three are known to be greatly harmful to the health of city dwellers, cause thousands of premature deaths and cost society billions of NOK every year in Norway alone.

Detailed monitoring of environmental factors and understanding their relation to land use, urban morphology, mobility, etc. are key to create liveable, healthy, and safe cities for urban dwellers and particularly vulnerable population groups. While in the past, some attempts have been made to monitor different health-related environment factors like noise, air quality, air temperature and local wind conditions, available measurement data are of very low spatial and/or temporal resolution, limiting the possible research on these topics.

SINTEF recently proposed the concept of Urban Environment Lab and is leading a consortium which aims to build the infrastructure. Urban Environment Lab is a dense and area-covering sensor network that captures all health-related environmental factors. The aim is to provide a cutting-edge research infrastructure and excellent data basis for researching the urban environment at international top level. The sensor network shall measure, e.g., sound levels, microclimatic parameters, air quality and link data from other data sources and networks. Thus, Urban Environment Lab builds on and extends existing e-infrastructures for data storage, analysis, visualisation, retrieval and shall link the data to geographical information systems (GIS). This provides a basis for

mapping and analysis that is commonly used in science and in the industry. Thus, researchers and engineers across numerous fields are addressed, e.g., building and infrastructure engineering, city planning, health and medicine, social sciences, biology, climatology and many more. Research building upon the Urban Environment Lab is expected to deliver invaluable knowledge for authorities and the government to ensure the transformation to a sustainable, intergenerationally just, resilient, and smart city of the future that ensures a high quality of life for its inhabitants.

Abstract 192: Andrew Pulsipher[1], Michail Giannakos[1]
[1]Norwegian University of Science and Technology

Circular Research for Smart-Environments: Applying Principles of Circular Economy for More Sustainable Research

In recent years, we have seen tremendous progress toward the computer science research vision of creating built environments (BE) saturated with sensing, computing, and wireless communication that gracefully support the needs of individuals and society. There is a strong and growing body of literature that addresses the user's sustainability within these smart BE. However, less attention has been given to the researcher's sustainability in designing these systems. Infusing BE with computers impacts the natural environment through the extraction of resources to power, develop, and install devices. Thus, researchers must strive for environmental sustainability, both in the systems we design and in the very way we conduct our research. Despite smart-environment research's heavy reliance on physical resources, there is so far no examination of the sustainability of the research practices within the smart-environment community. Without careful and creative approaches to managing resources, our consumption of materials will remain unsustainable. Correcting this is essential if we hope for our smart environment solutions to be adopted by society and scale up to their potential.

This paper provides a critical reflection on research activities in smart-environments with a focus on research prototype design, development, and deployment. First, we discuss relevant literature on sustainability and explain the concept of Circular Economy (CE), emphasizing the differences between slowing and closing resource loops. We then examine strategies for slowing resource loops in the context of smart-environment research, applying them to prototype design and project management. These strategies include designing products for long-life and life-extension, sharing products between researchers, reducing purchases of new devices, and recycling unneeded products and materials. We relate these strategies to current smart-environment research activities and propose ways to adapt the strategies for use by the research community. The aim of this paper is to bring awareness to the need for the adoption of more

sustainable practices in smart-environments, and to present and discuss effective strategies for making smart-environment research more sustainable by adopting circular processes.

While this paper is targeted toward the smart-environment community, the principles of CE are highly relevant to any researcher working with computing technology, especially as it relates to BE. We want to create technologies that improve the sustainability of our BE, such as our cities, but we must also consider how our own research practices are impacting the natural environment. By adopting CE principles to engage in circular research, we ensure that our work minimizes its footprint on the world's sustainability problems while leveraging smart-environments' potential for our society.

Abstract 195: Jacob Tafrate[1], Zoe Garbis[1]
[1]George Washington University

Data and Decision-Making for Sustainable Arctic Cities

In order to determine which factors of sustainability drive urban transformations forward, we collected and analyzed data across the last 20 years for three northern cities, Fairbanks (US), Yellowknife (Canada), and Luleå (Sweden). In this project, work centers around an iterative process of study site visits involving all three mayors where meetings take place with multiple stakeholders related to sustainability in the city. We ask how standardized sustainability indicators in combination with local mayoral knowledge can be used to better understand the role of Arctic cities in promoting a sustainable Arctic future. We are interested in the question of how we can represent an Arctic city through data–what do the residents prioritize vs. what do politicians and bureaucrats want the city to achieve? Additionally, we ask what factors are most relevant to decision making in Arctic cities through understanding the relationship between data points, civic engagement, and municipal resources. Initial findings suggest that while standardized indicators prove valuable in comparing trends between cities, they fall short in representing the diverse range of visions for urban sustainability harbored by stakeholders. Through collaboration with the three mayors, this project explores a new framework for circumpolar knowledge-sharing among cities across international borders to facilitate sustainable urban transformations in the Arctic.

Abstract 225: Evgenii Aleksandrov[1], Elena Dybtsyna[1]
[1]Nord University, Norway

Smart Cities for Sustainable Arctic?: opening up critical discussion from governance and management perspective

The so-called 'smart city' idea has received growing attention as a concept that can play an essential role in the sustainability of the Arctic. Nowadays, the idea is associated with the use of ICT and technology development for improving the quality of life, more efficient and effective use of cities' infrastructures and resources, and fostering social inclusion and mitigation of environmental harm in urban areas. Yet, the relationship between smart cities and Arctic sustainability is still unclear, especially from a position of governance and management perspective instead of technology-centric optimism in the Arctic. Thus, this paper aims to provoke more critical discussion on the value of smart city concept for the Arctic cities. To do so, we reflect on how the sustainability of Arctic cities can be challenged by urban dynamics in metrics for smart city development (1), politics and the bureaucratization of smart city initiatives (2), and the citizens role (3). The paper has several implications for academia, practitioners and policymakers. For academia, it opens up a critical governance and management perspective to illustrate and further examine the complex relations between smart city development and Arctic sustainability. For practitioners and policymakers, the paper opens up the problematic but often hidden side of smart city development in the Arctic, stressing the need to carefully translate the concept and its promises into a unique Arctic context.

Abstract 44: Victoria Miles[1,2], Lasse Pettersson[1,2]
[1]Nansen Environmental and Remote Sensing Center (NERSC), [2]Bjerknes Centre for Climate Research

Measuring the resilience of Arctic cities: an eye-level, top-down view

In the Arctic, urban vegetation is crucial for preserving biodiversity, enhancing prosperity, and maintaining ecological balance amid warming, urban growth, and densification. It serves as a refuge for wildlife, improves air quality, mitigates climate change effects, and boosts psychological well-being in pursuing sustainable and inviting Arctic cities. Additionally, as the Arctic experiences more frequent and intense heat waves due to warming, urban vegetation becomes increasingly vital in providing natural cooling and alleviating heat stress, addressing pressing climate challenges.
To ensure the effectiveness of urban vegetation in this emerging Arctic urban landscape, we are implementing a multifaceted approach. This approach integrates citizen observations and advanced remote sensing techniques to create a monitoring tool that assesses the environmental value of urban green spaces (UGS). This dynamic method actively involves residents in monitoring and preserving the local environment, offering invaluable insights into the health and vitality of UGS.
We utilize remote sensing to produce maps of urban microclimates and assess urban vegetation productivity. By combining these top-down views with eye-level citizen observations, we seamlessly incorporate these insights into

Geographic Information Systems (GIS) like ArcGIS, creating a comprehensive data analysis and visualization platform. The approach assessing green space quality, encompassing various quality components, and introducing a multi-criteria framework to evaluate green space quality. Additionally, This GIS-based framework incorporates the perception of green space quality, resulting in indicator maps that provide a comprehensive view of green space quality in the urban environment.
Furthermore, ArcGIS Dashboards furnishes a user-friendly interface for real-time monitoring of dynamic aspects of urban vegetation. This integration of technologies contributes to the development of data-driven strategies for managing urban green spaces and promoting sustainable urban development.

Session 5: Smart Arctic Cities: Health, Wellbeing, Air Quality and Energy Needs. Part 2: Climate, Energy and Wellbeing

Monday 29th January, 11:00-12:30

Abstract 209: Sobah Petersen[1]
[1]Norwegian University of Science and Technology

Digital Technologies at the Energy, Health and Well-being Nexus

The energy, environmental quality, and the people's wellbeing nexus is an essential part of meeting the United Nation's Sustainable Development Goals (SDG). This is the focus of many stakeholders including researchers, urban developers and decision makers. The dependencies among energy and the people's wellbeing are well documented and energy security has been identified as a key variable in the relationship between energy and people's well-being (Mayer & Smith, 2019). Energy security has been described in terms of three dimensions; economic, which is about a household's ability to pay for their energy; physical, which is about the quality of the built environment in terms of energy efficiency and thermal comfort, and behavioural, which is about the behaviour of a household with respect to their energy needs. Focus on the physical dimension by improving the energy efficiency of the built environment and transitioning to environment friendly renewable energy sources has provided households new opportunities to improve their energy sources, e.g., to solar energy. However, these often come with many challenges such as the cost of the transition and regulatory restrictions to change the facade or interior of the building. More importantly, the lack of knowledge about these new opportunities causes stress to many people. We have developed some concepts as mobile applications, where we look at the nexus of many SDGs, e.g., energy, mobility and health (Petersen et al., 2020), or energy, built environment and economy, to raise the awareness and understanding among people, that could help them make sustainable transitions.

Abstract 199: Johannes Hoejm[1]
[1]UiT – The Arctic University of Norway, Tromsø

How can two arctic fishing communities teach us how to handle the energy challenges of the future? A presentation of the preliminary results of the Smart Senja project.

The Smart Senja project aims at solving the energy challenges of the two fishing communities of Husøy and Senjahopen, located at the island of Senja in Northern-Norway. And at the same time develop solutions that in the future can be implemented other places in the Norwegian electrical grid to mitigate the challenges that is caused by increased peak demand from activities like charging of electric vessels and vehicles.

The communities of Husøy and Senjahopen are to day experiencing a weak and unstable connection to the main electricity grid. This causes a lot of challenges in the day to day operation of the fish processing industry. The restrained gird is limiting economic development as well as the switch from fossil fuel to clean energy.

The project is a cooperation between the local grid operator, university, tech companies, fishing industry and the local community. We are now 3 years in to the 5 year project period. Smart load management have been implemented in households and industry and two large grid integrated batteries have been installed. This have so far reduced the number of grid disturbances and also allows for more output of power in the communities so use of fossil fuel in back up generators and for heating can be avoided.

More information at www.smartsenja.no

Abstract 51: Elena Adasheva[1], Róisín Kennelly[2], Kaylia Little[3]
[1]Yale University, USA, [2]University of Oxford, UK, [3]University of Waterloo, Canada

Connecting Energy Transitions Across the Arctic

Many Arctic communities still rely on diesel for their energy needs which demonstrates a timely demand for transition to renewable energy sources. While great developments have been made in transitional technologies, current energy solutions often do not take into account local infrastructural and sociocultural concerns that may impede their successful adoption. This is especially true in the Arctic where factors such as disconnect from the grid, remoteness, community participation and a wide range of technological development and governance approaches among Arctic nation-states complicate the transition to renewable energy.

This research brings together three Arctic communities - Iqaluit (Canada), Tiksi (Russia), and the Faroe Islands - to discuss both distinctive and shared experiences of transition in remote energy systems. This project is based on fieldwork by early career researchers in three Arctic regions, providing fertile ground for analytical comparisons and collaborative thinking. Combining

anthropological and energy studies approaches, researchers utilized a combination of qualitative and ethnographic methodologies. By looking at these three Arctic localities through an energy lens, similarities such as the conventional reliance on diesel and other fossil fuels, potential wealth of renewable resources, and absence of reliant and relevant infrastructures were revealed. Researchers noted significant differences and barriers in replicability across regions due to factors such as levels of international investment, community inclusion, and access to resources.

This research highlights that it is not enough to create solutions which rely upon technologies that can be 'dropped in' to regions across the Arctic and expected to thrive. Research into these energy transitions can foster collaborative approaches across the Arctic. By uncovering the complexities and commonalities of energy transitions in the Arctic, a foundation can be built for shaping realistic policies and workable solutions for remote energy projects in the North.

Abstract 177: Elham Andalib[1], Alenka Temeljotov-Salaj[1]
[1]Norwegian University of Science and Technology

Built environmental factors impact on health gap and inequalities

Background: Cities are facing development projects and changes with the aim of being healthy and sustainable. As a part of these future developments, it is highly impactful to consider the combination of SDG3 "ensure healthy lives and promote well-being for all at all ages" in the development of the cities to have a strong overlap with SDG 11 "make cities and human settlements inclusive, safe, resilient and sustainable".

Based on the rapid review of inequalities in health and well-being in Norway, Norway is facing a health gap in life expectancy difference for women and men when compared to the international level. As a part of increasing the level of public health, one of the factors affecting health equity is living conditions that could help increase life expectancy and reduce the health gap.

Objective: This research aims to identify the built environmental factors that are beneficial for reducing the health gap and increasing life expectancy for future city planning.

Method: A scoping literature review was conducted in 4 databases PubMed, Scopus, Web of Science, and ScienceDirect to answer the question of what built environmental factors increase the level of health in urban citizens.

Result: A variety of environmental factors such as access to amenities, facilities,

social integration and inclusivity, access to greenery, social public spaces, physical activity, and a safe environment are considered critical dimensions of environmental factors that affect life expectancy, and mental and physical health. These findings identify the critical built environmental factors affecting the health gap and outcome of the society.

Conclusion: Through a comprehensive study this literature review gives an overview of what environmental factors affect the health of citizens. This review contributes to a better understanding of the key aspects of the built environment addressing health inequalities to have a better perspective of built environmental factors that need to be considered in urban development. The finding emphasizes factors that need to be considered in strategies for cities' sustainable development for fostering health issues related to urban development.

Implications: The scoping review indicate significant implication of factors that need to be considered in sustainable and healthy urban development. Identification and categorization of factors affecting health inequalities and overall community well-being lead to shaping guidance for urban planners and government to improve the health status of citizens and reduce health inequalities. Shaping the foundational resources for urban development strategies based on aspects that could serve to increase health and equity will help in decision-making that prioritizes health and sustainability in urban planning.

Abstract 17: Regina Pshenko[1], Tatiana Zhigaltsova[1]
[1]Northern (Arctic) Federal University named after M.V. Lomonosov, Russian Federation

Emotional well-being of elderly residents as a prerequisite for sustainable development of Arctic settlements

The report will highlight the results of the study conducted in 2023 in three small Arctic settlements situated on the islands of the Solovetsky Archipelago and the White Sea coast (Russia) and undergoing global processes of population ageing and departure of younger residents to larger cities. This brings forward a crucial question of psychological and emotional well-being of the elderly residents who stay to live in the area. Therefore, the aims of the study included evaluation and search for tools and practices facilitating sustainable development of small historical settlements (villages) such as Solovetsky, Tamitsa and Kyanda in view of the consequences not only of transformation of their architectural and ethnographic environments, but also emotional landscapes beginning from 1950s and up to present. During the study, we conducted surveys among 17 elderly residents of Solovetsky, and collected 18 in-depth interviews from 18

elderly residents of Tamitsa and Kyanda. In addition, archival work was carried out in local museums. Based on the findings of the study, a series of interactive maps of emotional memory and present-day emotion maps (http://emogeography.com/mainrnf.html), featuring the respondents' sayings and photographs of places of their emotional attachment and rejection were developed. The report will discuss recommendations on creating favorable sustainable and resilient environments for the elderly residents required to maintain their emotional health in the long-term perspective.

Abstract 58: Maria Justo Alonso[1], Peng Liu[1], Hans Mathisen[2]
[1]SINTEF, Norway, [2]Norwegian University of Science and Technology

Enhancing Energy Efficiency and Indoor Air Quality in Arctic Smart Cities: A Novel Approach to Demand-Controlled Ventilation

The Arctic region faces unique challenges related to climate change, which necessitate innovative solutions that prioritize Sustainable Development Goals (SDGs) such as health, energy efficiency, and environmental quality. A critical issue in Arctic smart cities is maintaining indoor air quality while conserving energy.

As a result of supplying standardized airflow rates, conventional mechanical ventilation systems can lead to low relative humidity (RH) indoors during winter in cold climates. Additionally, another challenge during periods with low outdoor air temperatures and the use of 100 % outdoor air, is that the air has high particulate matter (PM) concentrations due to for example, increased wood burning for heating and inefficient combustion processes in low temperatures. A share of these PM fractions may get to the indoor air due to cracks in the building envelope or faulty filters. These two challenges may impact occupant comfort and health.

Understanding the impact of climate change on outdoor air quality in the Arctic is crucial, given factors like increased desertification further south in the globe, and thus larger amounts of sands that may fly to the North as the Sahara dust storms, more forest fires, and altered PM deposition patterns due to changes in outdoor air RH, temperature, and winds. These changes can significantly affect individuals with asthma and allergies. The approach of this work targets to adapt ventilation strategies to changing outdoor conditions, safeguarding indoor air quality and occupant health while maintaining the energy consumption levels low.

This research proposes a novel solution for demand-controlled ventilation of the supply and recirculation of the extract air. A controlled recirculation of extract air enables two possibilities: to boost winter RH levels without additional humidifiers

and to protect the users of the building from temporary peaks of pollutants in the outdoor air. Therefore, in this work it is proposed to focus on achieving precise monitoring and control of indoor, recirculated, and outdoor air quality. For that, low-cost sensors (LCS) are used to measure RH, PM2.5 and formaldehyde in addition to the typical control parameters namely, CO2 and temperature. This allows to use the concentrations of pollutants and their differences between indoor and outdoor to control the ventilation with respect to the supply and the recirculated air. With this, the low RH during winters can be addressed and high outdoor air pollution events can be recognized and introduced in the control of recirculation of extract air.

A co-simulation model in Energy Plus and CONTAM, validated using the data collected with LCS in an existing office environment, allows to study the effects of different control strategies in energy use and the IAQ. Additionally, by using different outdoor air quality scenarios, the effect of climate change can be simulated and adaptations of the control in several climate change scenarios can be provided.

Session 6: Innovative Data Solutions: Applications of a Digital Twin and AI in the Arctic. Part 1: Innovative Data Solutions

Wednesday 31st January, 16:00-17:30

Abstract 21: Ilaria Crotti[1], Alice Cuzzucoli[2], Paolo Fazzini, Marco Montuori[2,3], Antonello Pasini[3], Srdjan Dobricic[1]
[1]European Commission, Joint Research Centre, Italy, [2]Institute of Atmospheric Pollution Research, National Research Council, Italy, [3]Institute for Complex Systems, National Research Council, Italy,

Improving air quality forecast in the Arctic with machine learning

Air pollution in the Arctic mainly derives from northward transport of air masses from mid-latitudes (Law & Stohl, 2007). However, local sources such as shipping, extraction activities, and metal smelting are known to contribute to the level of pollution in Arctic villages and cities, especially during winter (Schmale et al., 2018). Global warming is affecting northern latitudes at a faster rate in comparison with other areas of the Earth, increasing the risk of wildfires, boosting anthropogenic activities, and increasing population exposure to air pollutants (AMAP, 2021). In this context, relying on accurate short-term forecasts of particulate matter (PM10) concentrations becomes decisive for local populations in order to implement adaptation measures in case of intense pollution events.

The analysis and forecast of atmospheric pollution for the European Arctic is provided by the Copernicus Atmospheric Monitoring Service (CAMS) (https://atmosphere.copernicus.eu), based on an ensemble of deterministic numerical models. Nonetheless, PM10 concentrations forecasted by CAMS in the European Arctic appear to less accurately fit monitoring station observations compared to the rest of Europe (Schulz et al., 2020). Here we present a novel PM10 forecasting approach tailored for the Arctic and based on established machine learning algorithms (Fazzini et al., 2023). Our approach consists of combining PM10 historical time series (January 2020–December 2022) registered by eight Arctic air pollution monitoring stations with 24-hour predictions from the Copernicus Atmosphere Monitoring Service (CAMS) as inputs for different types of Artificial Neural Networks (NN). We compare the 24h forecast obtained from recurrent neural networks (RNNs), gated recurrent unit networks (GRUs), long short-term memory networks (LSTMs), echo state networks (ESNs), and windowed multilayer perceptrons (MLPs), each together

with CAMS forecasts. Our results show that all of the NNs outperform the CAMS models, with an average improvement of the forecast Mean Square Error (MSE) ranging from 25% to 40%.

Considering the enhancement in PM10 forecast quality, we are extending this data-driven approach to 100 air quality monitoring stations in Northern European countries (Finland, Norway, Sweden, and Iceland) and we further aim at refining the NN forecast model by including meteorological variables (temperature, wind speed, planetary boundary layer height) as input parameters. Our PM10 forecasts will be released on a daily basis on a web platform developed within the Horizon 2020 Arctic PASSION project. Local communities, policymakers, and citizens will be able to access this website and take efficient adaptation measures in case of forecasted high PM10 concentrations in their areas.

Abstract 23: Are Frode Kvanum[1,2], Cyril Palerme[1], Malte Müller[1,2], Jean Rabault[1], Nick Hughes[1]
[1]Norwegian Meteorological Institute, [2]University of Oslo

Developing a deep learning forecasting system for short-term and high-resolution prediction of sea ice concentration

The continuous thinning and retreat of Arctic sea-ice due to climate change has caused a steady increase in marine activity throughout the Arctic Ocean during the last decades, and maritime end users are requesting skillful high-resolution sea-ice forecasts to ensure their operational safety. Sea-ice concentration forecasting systems based on supervised deep learning have shown promising results, but only a few systems operate on high, less than 10 km, -scale resolutions. We present the development of an image-to-image convolutional deep learning forecasting system based on the U-Net architecture that can predict sea-ice concentration on a 1 km grid for short lead times (1 to 3 days). This system has been trained using gridded sea-ice charts from the Norwegian Ice Service as both predictor and target. In addition, predictors are used from the Arctic regional numerical weather prediction system developed by MET Norway and a linear sea-ice concentration trend computed over previous days derived from OSI SAF passive microwave observations. The deep learning forecasting system is compared against two baseline forecasts as well as two state-of-the-art dynamical sea-ice forecasting systems (neXtSIM and Barents-2.5) and validated against the ice charts. From this verification, we can conclude that the deep learning sea-ice forecasting system achieves a higher level of skill in predicting the position of the sea-ice edge for multiple WMO sea-ice concentration categories (very open drift ice, open drift ice, close drift ice, and very close drift ice). In order to understand the contribution of each predictor, we have investigated how the deep learning forecasting system utilizes each

predictor. The predictor importance analysis suggests that including forecasted atmospheric predictors increases the performance of the deep learning forecasting system beyond persistence-forecasting, motivating the future inclusion of additional forecasting systems as predictors, such as ice-ocean interactions. However, the analysis also suggests that the deep learning system does not utilize the past trend. Our promising results suggest that computationally cheap data-driven forecasts based on deep learning can be used in a production environment, providing a high-quality sea-ice forecast to end-users.

Abstract 255: Elisabeth Ytteborg, Chris Noble[1], Lynne Falconer[2]
[1]Nofima, Norway, [2]University of Stirling, UK

How marine aquaculture sites can provide data for climate change assessments

Long-term datasets of in-situ observations are essential for monitoring changes in the marine environment. There are monitoring programs and observation stations all over the world, but the ocean is huge and coastlines are long and complex, and observations are still lacking. Hence, there is a need for more data to better understand actual conditions, especially in the Arctic, where changes are faster than in other areas of the world.

Most aquaculture species are kept in fixed production systems unable to move beyond the farm boundaries. Small changes in environmental parameters, such as temperature or salinity or combinations of these, may have huge impact on the health and welfare of the animal. If the farming environment changes to unfavorable conditions, the animals must be able to tolerate and adapt to the stress, unless production procedures are changed. Thus farmers must monitor their sites frequently as part of their operational procedures, in order to be able to respond to the farmed animal's needs.

Since aquaculture sites are found in many coastal areas throughout the world, the potential role of aquaculture as a data provider for observing coastal changes and climate change assessment should be considered. The number of active farms varies slightly each year, but the average number of sites in seawater in Norway is around 1000, located along most of the coastline. It is a regulatory requirement that these sites submit a weekly report to the Norwegian Food Safety Authority, including temperatures at 3m depth. Data is kept as open access data on Barentswatch.no, thus providing a national-scale overview of the seawater temperatures in Norway.

The BarentsWatch platform has been operating for over 10 years. Consequently, it is a good case study to explore the prospects and challenges in repurposing aquaculture data for other users and uses, such as climate change. Focusing on

sea temperature, the aim of our study was to consider if, and how, the temperature data in BarentsWatch could be used as observations of coastal change and potential use in climate change assessments. The first step involved examining the quantity of available data and assessing data quality. The next step involved screening the data to identify and clean any suspected errors. Finally, the cleaned dataset was analysed to characterize the reported sea temperatures.

Our study has shown that aquaculture has the potential to deliver long-term datasets that are urgently required to understand and analyse changing conditions across coastlines. The positioning of fish farms offers an exceptional opportunity to gain detailed information on the rate, magnitude, and variability of climate change in coastal areas. However, improvements are needed to unlock the full potential of the aquaculture data and their use for understanding changes in coastal conditions. Such improvements must be prioritised as this will increase usability and generate important knowledge not only for the aquaculture sector, but with the potential for a much broader use. Delays in realising the value of this potential data source are lost opportunities to gain important information.

Abstract 61: Sara Aparício[1,2]
[1]NOVA School of Science and Technology, Portugal, [2]Solenix for the European Space Agency, Italy

A Multisensory SAR-based approach for melt ponds retrievals

Melt ponds form in sea ice during summer and spring as a consequence of melting ice. Their darker color drastically reduces the ice albedo, increasing the flux of absorbed solar radiation playing a pivotal role in the Artic energy budget. Despite their relevance in the climate context, the current scarce information on melt ponds is pointed as a source of uncertainty for the underestimations of sea ice extent extension in climate models projections. Furthermore,current melt pond products are based in optical data (and thus impacted by cloud coverage) and have a coarse resolution.

The objectives of this study were to enhance temporal and spatial accuracy of detection and characterization of melt pond by retrieving daily melt pond fractions (MPF) with the following characteristics:

• higher resolution than existing products (which have 500m resolution)

• using radar-based sensors which are not impacted by presence of clouds

• generated through an autonomous approach, using Artificial Intelligence (AI)

algorithms

The workflow had two main steps. The first consisted in the generation of an optical-based MPF. This dataset was generated after selecting Sentinel-2 (S2), an optical satellite, cloud-free areas. The data was processed by removing land pixels and atmospheric corrected and new bands/indexes were generated with some of its 13 spectral bands. A Random Forest (of 15 trees) was trained to predicts pixels the S2 bands/indexes as belonging to classes ice or melt pond (which were priorly humanly extracted). The resulting predicted binary maps, were then converted into a MPF by estimating percentage (%) of melt pond pixel per total pixel area, resulting in a dataset of melt pond fractions - MPF. On the second step, Sentinel-1 (S1) Synthetic Aperture Radar (SAR) bands were used as input/predictor and MPF maps as target/output to teach a deep learning algorithm. The Convolutional Neural Network (CNN) created has three convolutional layers using ReLu activation followed by two MaxPooling layers, a Flatten layer and two Dense layers (i.e., fully connected layers) with ReLU and linear activations. A CNN was chosen, as it does not require manual feature extraction and in addition it can learn from the pixel's geospatial correlation. First step generated a dataset of 64x64 pixel classified images with a size of 30k samples, with an overall accuracy of 0.87 , which were then converted to MPF. The second step generated a dataset of MPF with a Mean Absolute Error (MAE) of 0.0721. In order to enhance the results from the second step, i.e., to generate MPF based on radar images, aiming at achieving a lower MSA value as possible, the training dataset size (generated from step 1 of methodology) needs to be increased and the deep learning model could be subject to improvements. As such the next steps are:

• Increase significantly the training dataset generated on step 1

• Fine-tune hyperparameters of the deep learning model (CNN) on step 2

• Include wind and temperature daily datasets as part of training data on step 2

• Explore Generative Adversarial Networks (GANs) for the generation of synthetic MPF from Sentinel-1

Abstract 87: Jakob Grahn[1], Eirik Malnes[1], Filippo Bianchi[1,2], Hannah Vickers[1], Markus Eckerstorfer[3], Karsten Müller[3], Stian Normann Anfinsen[2]
[1]NORCE, Norway, [2]UiT – The Arctic University of Norway, Tromsø, [3]Norwegian Water Resources and Energy Directorate

Remote Sensing for Avalanche Prediction: Towards a Digital Twin of the Snowpack?

Avalanches pose significant risks to lives and infrastructure in Norway, necessitating effective monitoring and forecasting. In this work, we are going to present results obtained in collaboration with the European Space Agency (ESA) and the Norwegian Water Resources and Energy Directorate (NVE). Our research focuses on integrating physical models and artificial intelligence (AI) with remote sensing data to advance avalanche monitoring on a large scale. Specifically, our research employs Sentinel-1 Synthetic Aperture Radar (SAR) data to automatically detect and monitor avalanche debris across Norway. For this purpose, we generated a dataset of unprecedented size containing manually annotated debris in SAR images since 2014. The new dataset makes it possible to use advanced statistical techniques to discover complex relations between meteorology and avalanche activity. Specifically, modern deep learning models are adopted for predicting avalanche activity given certain meteorological and snowpack conditions. This enables short-term avalanche activity prediction and offers insights into avalanche hazards in a changing climate. Our work can be regarded as a stepping stone for a "Digital Twin of the Snowpack". We invite discussion on the integration of remote sensing, digital twins, and avalanche research, emphasizing actionable insights from our extensive dataset to improve avalanche risk management and understanding.

Abstract 184: Margareta Johansson[1], Carl Sundström[2], Maria Erman[2], Tomas Gustafsson[2],
[1]Lund University, Sweden, [2]AFRY, Sweden, Lund University, Sweden

Improving access to environmental data in the Arctic with the help of AI

INTERACT is a network of 74 terrestrial research stations in the Arctic and adjacent boreal and high Alpine areas. Some of the stations have been running for more than a Century and the amount of data gathered over time is huge. After an inventory, it was obvious that many of the stations had research data lying in drawers waiting to be analysed but as this is a time consuming and daunting task, personnell resources to do the work were often lacking. Under the lead of AFRY, INTERACT has explored ways how artificial intelligence and machine learning can be used to make more existing environmental data from the Arctic available. Examples include automatic analyses of photos to identify wildlife and to digitize fieldwork diaries. The conclusion from the last three years' work is that there is a large potential to improve the use of AI at the INTERACT research stations that would improve access to important environmental data.

Abstract 231: Georg Gartner[1]
[1]Technical University of Vienna, Austria

What we see and what we don't see – The relevance of Maps in a sensitive region

The demand for joint efforts of various stakeholders in the Arctic on working collaboratively in the region requires the integration of scientific, local and indigenous knowledge into decision-making processes. To support this the collection and combination of various types of knowledge data, spaces and collaboration across different thematic domains gains importance in all kinds of levels, the global, regional, national and local ones. For a large extent, a geospatial reference and structure is a key element on building such knowledge infrastructures.

A spatial knowledge infrastructure envisages a cooperative/collaborative information landscape with enabled trust, mutual understanding, comprehensive knowledge, informed decisions, full automation of spatial data integration and adaptive analytics for knowledge expansion.

However, in this contribution it is argued, that without maps we stay "spatially blind", although various sources of spatial data might be available. It is only through cartographic visualization that the narratives, the stories, the relations, the context, the overview to name a few of the functions maps fulfill, become available to human awareness, understanding and reasoning. Contemporary concepts of service-oriented mapping, location-based services and spatial knowledge networks are available technological fundaments. Modern cartographic visualization techniques establish an integrative part between spatial knowledge extraction, spatial knowledge production, spatial knowledge transmission and spatial knowledge storage and function as a 'central organizational device for networked communications', an adaptive interface through which users can access, alter and deploy an expansive database of information.

By highlighting current aspects and development the potential and applicability of contemporary cartography as means to underpin cooperation in the Arctic is discussed and examples presented.

Session 6: Innovative Data Solutions: Applications of a Digital Twin and AI in the Arctic. Part 2: Applications of a Digital Twin and AI

Wednesday 31st January, 18:00-19:30

Abstract 25: Laurent Bertino[1], Julien Brajard[1], Sébastien Barthélémy[2], Antoine Bernigaud[1], Léo Edel[1]
[1]Nansen Environmental Remote Sensing Centre, Norway, [2]University of Bergen, Norway

Synergies between data assimilation and machine learning for faster and more accurate sea ice data assimilation.

The ocean and sea ice forecasts are relying heavily on numerical models and data assimilation techniques to honour satellite and in situ measurements. One method with good statistical properties is the Ensemble Kalman Filter, but requires an expensive ensemble of tens to a hundred numerical model simulations. Since supercomputing capacities are limited, the computing time of the ensemble simulations limits the resolution of the forecast models. On the other end, several new remote sensing and robotic observations offer increasingly high resolution data to be assimilated.

Machine learning techniques thankfully offer complementing properties to data assimilation techniques. Data assimilation handles optimally the irregular and imprecise observations, while machine learning can recognize systematic errors caused by low-resolution numerical models: biases, and slow-moving ocean eddies for example. NERSC has thus introduced new hybrid methods taking synergies between machine learning and data assimilation, either to anticipate the forecast biases or to better assimilate high-resolution data, the latter method being called "Super Resolution Data Assimilation (SRDA)".

We will present the implementation of real-world applications of the SRDA approach to Arctic ocean currents, marine biogeochemistry and sea ice models.

Abstract 99: Sara Aparício[1,2], Shridhar Jawak[3,4], William Harcourt[5], Ekaterina Kim[6], Jie Zhang[7]
[1]NOVA School of Science and Technology, Portugal, [2]Solenix for European Space Agency, Italy, [3]The Climate and Environmental Research Institute NILU, Norway, [4]Svalbard Integrated Observing System (SIOS), [5]University of Aberdeen, UK, [6]Norwegian University of Science and Technology, [7]Uppsala University, Sweden

Artificial Intelligence in Svalbard (AI4Svalbard)-The outcomes of a training course in Svalbard

Last autumn, the Svalbard Integrated Arctic Earth Observing System (SIOS), offered an training course on how to effectively utilize Artificial Intelligence methods in Arctic Earth observation, in a unique setting at UNIS, Svalbard. The course, “Artificial Intelligence in Svalbard (AI4Svalbard)” had student-active learning activities with a focus on problem-based learning as well as guided collaborative coding, with real life data on the location where it takes place, offering a unique immersion and enriching the concepts from real-life to theory.

Digitalization of Arctic societies is rapidly growing and aspects of practical AI use for Svalbard-relevant applications was an important part of the curriculum. The applicability of the approach was demonstrated during a one-week course program for a group a students with diverse backgrounds. This talk will focus on the impacts that the immersion and experience of the environment in which AI tools are applied, and how it allowed for understanding existing Arctic challenges, while providing beginners with the know-how to develop a short project the following month. The main outcomes will be addressed.

The AI4Svalbard training course had a special focus on research in Svalbard and was designed for early careers researchers with little to no prior experience with AI, aiming to teach participants the fundamental skills required to employ AI techniques with Arctic Earth observation datasets, while some of the data was also collected in-situ. The training was delivered by remote sensing experts from SIOS member institutions, alongside international researchers and encompassed a range of activities, including theoretical lecture series, hands-on demonstrations and practice sessions, field excursions, social events, and mini-projects. By the conclusion of the educational activities in September 2022 and the subsequent mini-projects, participants acquired a comprehensive understanding of spatial and temporal data analysis with AI techniques, focusing on SIOS data and Earth observation data. Additionally, participants had gained proficiency in processing, visualizing, and manipulating specific data through computer programs, applying and interpreting machine learning algorithms like clustering and decision trees, and utilizing deep learning techniques on selected datasets. The course had enabled participants to obtain a beginner's understanding of AI in the Arctic, grasp AI applications in Earth observation, employ basic AI methods in their research, and formulate mini-scale projects using their own data or SIOS data.

The results from the mini projects will be presented, showcasing the knowledge, tools and AI approaches that were acquired during the training course. Among those projects were classification problems using machine learning for land

cover change detection in Svalbard, also deep learning using R-CNN for glacier calving front detection and SAR-based mapping in Svalbard using UNETs; as well as regression problems such as estimation of variability of average wind speed using Gradient Boosting. The choice of unsupervised and supervised approaches by participants also showed a good understanding of the best approaches to AI-based problem solving, revealing a successful harness of concepts and methodologies by participants and the usefulness of fostering the knowledge of AI within the Arctic/Svalbard community.

Abstract 193: Robert Ricker[1], Eirik Malnes[1], Hannah Vickers[1], Jakob Grahn[1]
[1]NORCE, Norway

Advancing Snow Science in Svalbard: A Journey towards a Digital Twin

During the last few decades, satellite remote sensing has been developed as a significant tool for long-term monitoring of snow cover, avalanche activity and snowmelt, as well as for time series on snow depth and snow water equivalent. Together with occasional in-situ measurements, airborne campaigns, and meteorological and hydrological modelling (past, present, and future) there is a potential to assimilate observations and models in a digital twin framework to fill data gaps, thus assisting to improve the temporal and spatial accuracy of both realms. We will discuss and exemplify a variety of future developments within this field. Within the Svalbard Integrated Arctic Earth Observing System (SIOS) framework, we produced snow cover fraction as an essential climate parameter for a substantial period using satellite spectroradiometer measurements. Within SIOS we have also studied how snow cover observations from remote sensing correlates with models for the snow cover. Our main conclusion is that models and observations correlate well, but that a better assimilation of earth observations in models could even improve the results. We think a digital twin framework for the assimilation of EO data in models and feedback to EO algorithms could improve snow parameter retrieval significantly. One could for example envision that historical snow data can be used to improve the spatial resolution of climate forecasts of snow, but also, to predict other snow parameters such as snow depth and snow water equivalent in historical datasets where we do not have appropriate sensors. We will show examples where we predict snow cover and snow depth at high resolution (~10 m) in Adventdalen (Svalbard) for periods (before 2015) where only coarse resolution data remote sensing data were available (500-1000m). We also explore satellite laser altimetry (ICESat-2) to estimate todays snow depth along the satellite ground tracks over Svalbard, complementing existing time series of in-situ snow depth and potentially to be used for data assimilation in models.

Abstract 118: Johannes Röhrs[1], Lars-Anders Breivik[1], Ann Kristin Sperrevik[1], Øystein Godøy[1]
[1]Norwegian Meteorological Institute

Digital twin components for Arctic Ocean

We will present regional modeling and analysis tools at MET Norway that can be used as building blocks in an Arctic Digital Twin (DT) system focusing on applications related to climate, weather and ocean. We focus on ocean model systems and related infrastructure and how this can be integrated as components in a DT system for Arctic applications. The goal is to contribute to DT system development as part of European initiatives and to cover national needs.

Barents-2.5 is a coupled ocean and sea ice ensemble prediction system for the European Arctic with 2.5 km resolution constrained by data assimilation. Operationally the ocean and sea ice is forced by atmospheric fields from the regional AROME-Arctic weather prediction model. The use of state-of-the-art assimilation methods to include observations helps to constrain the numerical model predictions. Applications of the Barents-2.5 model are forecasts of ocean state parameters, which can be used in oceanic drift applications, and downstream machine learning (ML) approaches. For drift applications the open source framework OpenDrift provides means to project movement of objects and substances in the ocean, e.g. for search-and-rescue missions, marine pollution and ice bergs. All of these applications need ocean current information and its uncertainty from the hydrodynamic component.

ML-approaches for ocean now- and forecasting require training data that describe the ocean state and its history with a high level of detail, including aspects that are not well observed, e.g. ocean temperature and salinity at depth, currents, ice thickness, and atmospheric conditions at high altitude. Reanalyses and re-forecasts from the Barents-2.5 and AROME-Arctic provide a source of information to inform ML algorithms, which eventually mimic the intrinsic physics of the dynamical models with benefits in efficiency and versatility.

An important aspect of Digital Twins is the framework that links the digital representation of a physical object or process (e.g. numerical model) with representations of the object (e.g. geoscientific data). These parts are coupled through a communication framework and done through integration of data (input/output). MET Norway infrastructure is already linked with European infrastructure through the European Weather Cloud (EWC) at the hardware level and complements the integration of FAIR compliant data and services. EWC is based on the same approach as the European Destination Earth program. FAIR compliant data and services is together with infrastructure integration key to

position existing and new components (both models and observational data) in the emerging DT ecosystem. MET is an active actor in facilitation of Arctic data exchange and FAIR data management. Some examples include the National ground segment for satellite data which coordinates and facilitates use of Copernicus Sentinel data for Norwegian area of interest (including Arctic) and the data management of SIOS (Svalbard Integrated Arctic Earth Observing System). Integration of Arctic data can be done through integration of data and services adhering to the FAIR guiding principles (Wilkinson et al, 2016). Details of how this can be done is still discussed.

Keynote: Arnt-Børre Salberg[1]
[1]Norwegian Computing Centre

Foundation models for Arctic Earth Observation

Session 7: Polar Fjords and Coasts: Interactions with Glaciers Part 1: Biological Interactions

Monday 29th January, 09:00-10:30

Abstract 363: Fiamma Straneo[1]
[1]Scripps Institution of Oceanography, University of California, San Diego

Meltwater, icebergs, nutrients, ecosystems and communities: A holistic view of a Greenland glacial fjord

Kalaallit Nunaat's (Greenland's) glacial fjords are characterized by the convergence of Atlantic and Arctic waters, glaciers, icebergs, sea-ice and intense, synoptic wind-events. The interaction of these components gives rise to rich and biodiverse marine ecosystems which, in turn, support communities living and fishing in the vicinity of the glacial fjords. Here, I describe pan-Greenland physical, biological, and social settings and show how they are shaped by the interaction of the ocean, the atmosphere, and the ice sheet. Next, I focus on Sermilik Fjord, one major glacial fjord in southeast Greenland, and its tributary fjords, where Helheim Glacier and several smaller glaciers discharge. Using a combination of physical, chemical and biological data collected from the fjord and shelf over more than a decade, I show how the fjord is characterized by a heterogenous distribution of nutrients and species reflecting the microclimates created by the interaction of water masses, glaciers and the exchange with the continental shelf.

Abstract 14: Agnes Weiner[1,2], Magdalena Łącka[3], Margit Simon[1,2], Tristan Cordier[1,2], Joanna Pawlowska[3], Dhanushka Devendra[3], Marek Zajączkowski[3], Jan Pawlowski[3], Stijn De Schepper[1,2]
[1]NORCE, Norway, [2]Bjerknes Centre for Climate Research, Norway, [3]Institute of Oceanology of Polish Academy of Sciences

Tracing changes in past biodiversity in the Arctic using ancient DNA

Coastal areas and fjords in the Arctic are highly sensitive to climate change and are currently being altered by increasing water temperatures, changes in sea ice conditions, melting glaciers and direct anthropogenic stressors. These rapid changes will inevitably have profound effects on marine biodiversity and productivity. However, so far, our knowledge on the cumulative impact of these changes on benthic and planktic communities remains limited, despite their important roles in food webs and nutrient cycling. In order to understand

ongoing and future changes in Arctic ecosystems and the resilience of marine communities, it is essential to assess their response to past changes in environmental conditions. To date, such studies are limited to lineages with a fossil record, leaving an incomplete picture of the remaining diversity.

To address this issue, we are now applying sedimentary ancient DNA (sedaDNA) sequencing as a new tool for reconstructing past changes in entire marine communities in relation with past environmental changes. Nucleic acids can be preserved in sediment for long periods of time, and they hold the key towards a better understanding of how biodiversity changed over time. We are focusing on marine sediment cores from Arctic coastal zones and fjords and assess environmental and biodiversity changes over hundreds to thousands of years in the past. Here, we will present results from a sediment record from a coastal area of northern Svalbard (Hinlopen Strait) that covers the Holocene. We successfully extracted ancient DNA and traced a wide range of eukaryotic taxa through time. These paleogenomic data were then compared to reconstructions of past environmental conditions, such as changes in sea ice cover and water temperature, to identify drivers of biodiversity change.

This work is supported by the Norwegian Financial Mechanism for 2014-2021, project no 2019/34/H/ST10/00682.

Abstract 89: Sünnje Basedow[1], Janne Søreide[2], Malin Daase[1], Michael Lemke[2], Katarzyna Dmoch[3]
[1]UiT – The Arctic University of Norway, Tromsø, [2]University Centre in Svalbard (UNIS), [3]Institute of Oceanology, Polish Academy of Sciences

Fjord type characterizes zooplankton productivity and carbon sequestration

Arctic fjords face changes to ecosystem structure and productivity through local respones to climate warming as well as through increased advection of sub-Arctic and Atlantic watermasses and communities. Here, we sampled plankton communites in 8 Svalbard fjords (Isfjorden, Billefjorden, Kongsfjorden, Wijdefjorden, Rijpfjorden, Wahlenbergfjorden, Storfjorden and Van Mayen fjorden) by plankton net tows and laser optical plankton counter during a 10-day cruise September 2022. Size spectra analyses of the plankton communities revealed significant deviances from a linear decrease with size in the size range of major herbivore copepods, especially pronounced in Rijpfjorden, Billefjorden and Wijdefjorden. These pronounced deviances can indicate lipid accumulation in the copepods. In combination with migration to overwintering depth of large numbers of copepods, lipid storage and metabolism is a major pathway of carbon sequestration in high-latitude marine ecosystems. We estimated carbon sequestration based on total lipid content in the copepods, analysed by image analyss of net-sampled copepods, and test for differences between fjords

(Arctic vs Atlantic-type water mass, sill-no sill, strongly glacier-influenced vs not). Our study also provides a baseline study for how to efficiently access zooplankton productivity in Arctic fjords.

Abstract 8: Lorenz Meire[1]
[1]Greenland Institute of Natural Resources

The impact of melting glaciers on coastal productivity

The Greenland Ice Sheet is melting at an unprecedented rate, and as a result, fjords and continental shelves around Greenland are exposed to an increasing freshwater runoff. To resolve the effect on Greenland's fjord, sampling was conducted in several fjords impacted by melting glaciers in Greenland and physical, chemical and biological gradients were studied from close to the glaciers towards the open sea. Hydrographic and biogeochemical data from several fjord systems adjacent to the Greenland ice sheet, suggest that ecosystem functioning largely depends on whether the fjords are impacted by land-terminating or marine-terminating glaciers. Rising meltwater plumes originating from marine-terminating glaciers provide a renewed nutrient supply sustaining high phytoplankton productivity dominated by diatoms and larger mesozooplankton throughout summer. In contrast, fjords with land-terminating glaciers are characterized by pronounced surface warming and high turbidity during summer. This strengthens stratification, which reduces annual productivity by two thirds and halves the CO2 uptake compared to a fjord impacted by marine-terminating glaciers. Fjord with land-terminating glaciers are characterized by dominance of picophytoplankton and bacteria, grazed by heterotrophic nanoflagellates and smaller mesozooplankton. The rapid retreat of Greenland's marine-terminating glaciers can be expected to profoundly reduce productivity and cause a regime shift in food web dynamics with cascading impacts on the regional ecosystem.

Abstract 48: Olof Bengtsson[1], Christian Lydersen[1], Guttorm Christensen[2], Jan Marcin Węsławski[3], Kit Kovacs[1]
[1]Norwegian Polar Institute, [2]Akvaplan-niva, Norway, [3]Institute of Oceanology, Polish Academy of Sciences

Marine diets of anadromous Arctic char (Salvelinus alpinus) and pink salmon (Oncorhynchus gorbuscha) in glacial fjords and open coastlines in Svalbard, Norway

Marine ecosystems in the Arctic are undergoing drastic climate-induced changes. The physical environment is changing with increased air and ocean temperatures and new species are shifting their distributions northward. One such species is the pink salmon (Oncorhynchus gorbuscha), which is

increasingly present in Svalbard's marine environment, raising important questions about dietary competition and ecological interactions with the native anadromous Arctic char (Salvelinus alpinus). To explore potential dietary competition between these salmonids in Svalbard, this study investigates the stomach contents of Arctic char (n = 301) and pink salmon (n = 28) from both glacial fjords and open coastlines with high levels of influence of Atlantic Water.

Both Arctic char and pink salmon exhibit strong affinities for amphipods, with the pelagic Themisto libellula (B = 26.0%) being especially important for Arctic char and the intertidal Onisimus litoralis (B = 35.0%) being especially important for pink salmon. Pianka's niche overlap analysis reveals a moderate dietary overlap (Oobs = 0.59) - particularly pronounced for intertidal invertebrates - between the two species in Kongsfjorden/Krossfjorden, where a direct comparison was possible in our study. Arctic char demonstrated a broader diet overall and engaged more in offshore pelagic feeding, which included consumption of pelagic fish. Conversely, pink salmon exhibited dietary specialization, which was particularly focused on intertidal invertebrates. Furthermore, a high proportion of pink salmon with empty stomachs indicates that they were likely preparing for up-river migrations to spawn.

The diet of Arctic char differed between areas, with intertidal invertebrates making up a large proportion of the diet in glacial fjords, while fish and pelagic invertebrates were dominant prey in more open areas. Surprisingly, the diet of pink salmon in Svalbard is predominantly comprised of Arctic species associated with soft bottom tidal flats, reflecting its tightly coastal feeding behavior. In contrast, native pink salmon populations in the North Pacific and the introduced population in the Norwegian Sea are known to have a varied, predominantly pelagic diet, comprised of amphipods, euphausiids, small fish, copepods, pteropods and squid.

This study reveals that Arctic char and pink salmon share important prey species in Svalbard and that pink salmon are likely attempting to spawn in Svalbard rivers. The overlap in diet between the two salmonids creates the potential for competition between the species, which is likely to increase with continued warming of the Arctic. Moreover, the prospect of pink salmon successfully spawning in Svalbard is a further cause for concern with respect to the status of the native population of anadromous Arctic char.

Abstract 123: Kirstin Meyer-Kaiser[1], Kharis Schrage[1]
[1]Woods Hole Oceanographic Institution, USA

Impacts of glacial retreat on coastal seafloor communities in Kongsfjorden, Svalbard

As glaciers across the Arctic experience accelerated melting, icebergs become more likely to disturb the seafloor. Simultaneously, declines in sea ice reduce ice scour impacts in shallow areas. Disentangling the complex impacts of a changing ice regime on seafloor communities requires targeted research. Specifically, we aim to understand how environmental factors drive gradients in seafloor invertebrate communities in the model system of Kongsfjorden, Svalbard. Sediment samples collected in January 2020 showed impacts of sea ice scour on diversity across a bathymetric gradient, and comparisons of our data to previous research showed temporal patterns driven by changing ice conditions. In addition, we collected meroplanktonic larvae during the polar night in 2020 and 2023 to show which species undergo development during the winter months. Larvae and juveniles are more sensitive to environmental conditions than adults, so understanding the impacts of changing ice conditions requires a full life-cycle perspective. A seafloor camera system, CATAIN, enabled the first study on settlement dynamics for Arctic seafloor species. Together, our data provide insights for understanding community structure patterns in a changing Arctic and show surprising biodiversity in Kongsfjorden during the polar night.

Abstract 108: Luisa Düsedau[1,2], Florian Weinberger[3], Inka Bartsch[1], Stein Fredriksen[4], Amanda Savoie[5]
[1]Alfred Wegener Institute of Polar and Ocean Research, [2]University of Bremen, Germany, [3]GEOMAR Helmholtz Centre for Ocean Research, Germany, [4]University of Oslo, Norway, [5]Canadian Museum of Nature

Novel molecular assessment of marine macroalgae from two Arctic fjords reveals a high proportion of cryptic biodiversity

Traditionally biodiversity studies are based on morpho-anatomical identification tools and misidentifications are common. This results in an underestimation of biodiversity and incomplete information about species distributions. New molecular techniques provide scientists with powerful methods to reveal hidden species and overlooked biodiversity. However, modern studies like the metabarcoding of environmental DNA (e.g. water or sediment) samples always rely on valuable baseline knowledge provided by basic DNA fingerprinting (barcoding). In this context, Arctic macroalgae are one of the many examples of genetically highly understudied groups. As major primary producers and ecosystem engineers they play a fundamental role along the rocky shores of the Arctic and worldwide. However, molecular work on macroalgae is difficult as each lineage (red, green, and brown) requires a specific technique for DNA barcoding while the resolution achieved with universal metabarcoding methods is often not sufficient. To better document expected biodiversity changes in habitats, especially those subjected to severe ongoing climate change, it is therefore essential to genetically verify morpho-anatomical species and

document inherent cryptic diversity. We investigated macroalgal biodiversity in two Arctic fjord systems at different stages of cryosphere loss, namely Kongsfjorden on Svalbard which is surrounded by glaciers, while Porsangerfjorden in Northern Norway is ice-free and characterized by a sub-Arctic to cold-temperate climate. In two expeditions (2021 & 2022) we sampled 61 macroalgal species from Kongsfjorden and 92 species from Porsangerfjorden in subtidal kelp forests as well as intertidal zones. Through DNA barcoding we created a novel macroalgal sequence database from these European Arctic locations to facilitate the identification of Arctic macroalgae in the future. In this molecular biodiversity investigation, we were able to precisely identify the collected macroalgae and reveal numerous cryptic species of red, green, and brown algae which were so far overlooked in classical assessments. Additionally, we successfully detected green algae species in coastal water samples collected along both fjord axes using a newly developed metabarcoding method for isolated field locations. Our findings suggest that especially rapidly changing Arctic fjords influenced by glacial melt host high amounts of hidden macroalgal biodiversity that wait to be taxonomically described. Furthermore, we propose that only a combination of DNA barcoding ground-truthing together with metabarcoding environmental samples can reliably estimate species biodiversity and range shifts in molecular monitoring initiatives as long as barcode reference libraries remain incomplete.

Session 7: Polar Fjords and Coasts: Interactions with Glaciers Part 2: Biogeochemical and Physical Interactions

Monday 29th January, 11:00-12:30

Abstract 3: Christoph Schneider[1], Anselm Arndt[1], Shin Sugiyama[2], Lukas Langhamer[1], Franziska Temme[3], Tobias Sauter[1]
[1]Humboldt-Universität zu Berlin, Germany, [2]Hokkaido University, Japan, [3]Friedrich-Alexander University Erlangen-Nuremberg, Germany

On the impact of calving on the temperature sensitivity of glaciers: insights from a bi-polar perspective on Patagonia and Svalbard.

On-going climate warming in the Arctic impacts terrestrial ice in many ways. The surface mass-balance of glaciers directly responds to atmospheric variability following well-known principles of accumulation and ablation processes. However, the response of glacier volume is not necessarily linearly related to surface energy and mass balance. Ice-dynamics play a crucial role for all land-based glaciers. Glaciers with calving fronts at their terminus show even more complicated patterns.

As in other regions worldwide, many glaciers in the Arctic terminate into proglacial lakes or fjords. Two main mechanisms of glaciers with calving fronts determine whether glacier response to atmospheric variability may temporally be de-coupled on multi-annual to decadal time scales: Firstly, the thermo-dynamic interaction at calving fronts impacts frontal ablation and calving activity, while secondly geometric changes due to spatial variation of the calving front and overall bedrock topography influence calving flux and stability at the glacier front. Such processes interact with varying amounts of englacial and subglacial meltwater and discharge efficiency shaping variations of glacier velocity.

In this presentation, we exemplify how different geometric settings determine the impact of the proglacial waters on the climate sensitivity of the glacier mass-balance at Glaciers Grey and Schiaparelli in Patagonia. We use these two examples from outside the Arctic and from the Southern Hemisphere since we can combine high-resolution multi-annual observations of glacier velocity and calving activity, both from terrestrial time-lapse photography and remote sensing, with geodetic mass-balance, and with modelled climatic surface mass-balance using a physically consistent glacier energy and mass balance model based on previous work for these locations. In both cases, specific data from the

proglacial lakes allow for discussing the thermo-dynamic and geometrically induced interactions at the calving front. This discussion partially draws on published material.

In many parts of the Arctic and similar to Patagonia glacier response to climate warming is largely impacted by the ice-flow velocity and their associated calving flux the relation of calving front length to glacier area, and the bedrock geometry along calving fronts, and possibly modulated by whether the glacier ends into tidewater or freshwater. We hypothesize that the larger the ratio between calving and surface mass balance, the smaller is the first-order relative temperature sensitivity of the overall mass balance to atmospheric forcing. To test whether our findings from Patagonia and subsequent hypotheses are transferable to the Arctic, we use results from climatic surface-mass balance modelling with the same modelling approach as for glaciers in Patagonia for neighbouring glaciers in the Southeast of Spitzbergen (Svalbard) with no, moderate and large calving fronts. Relating to a recently published modelling scheme extensively tested for glaciers in High Mountain Asia, we will determine how the climate sensitivity of glaciers on the southeast coast of Spitzbergen depends on the extent of calving fronts and possibly glacier velocity. We speculate that an overall assessment of calving front geometries from worldwide glacier inventories would provide hints on the climate sensitivity of glaciers in the Arctic to climate change.

Abstract 240: Geir Moholdt[1], Josephine Maton[1], Jack Kohler[1], Øyvind Lundesgaard[1]
[1]Norwegian Polar Institute

Rapid response of Svalbard glaciers to ocean warming

About one third of the glacier area of the Arctic drains towards ocean-terminating fronts that ablate by calving and melting above and below the waterline. This frontal ablation is a significant but poorly quantified part of the overall mass budget of Arctic glaciers, as well as an important source of freshwater and calved ice for marine ecosystems. We present a detailed analysis of frontal ablation for all Svalbard's ~200 tidewater glaciers for 2013-2023, a period with abundant availability of satellite imagery. We account for changes in frontal position, surface velocity and ice thickness at time scales from monthly to yearly, and we separate the results into components of glacier retreat and ice discharge. Although the ice discharge can be high year-round, especially for surging glaciers, we find that almost all frontal ablation occurs from late summer to autumn when the ocean is warmer. This represents a delayed freshwater flux to the fjords and open ocean compared to surface meltwater runoff which is more confined to the peak of the atmospheric summer season. Annual frontal ablation was exceptionally high during 2016-2018 and in 2022, which coincides

with periods of high inflow of Atlantic water and warmer temperatures in the upper ocean. Links with air temperature and meltwater runoff are less clear. The observed variability in frontal ablation demonstrates how reactive these glaciers are to ocean warming, and this feedback mechanism need to be considered in studies of polar marine environments and future glacier retreat.

Abstract 15: Pedro Duarte[1], Philipp Assmy[1], Haakon Hop[1], Sebastien Moreau[1]
[1]Norwegian Polar Institute

The impacts of tidewater glacier retreat on functioning of Arctic fjords: observations and modeling

The main goals of this study are to discuss the effects of tidewater glacier retreat on fjord biogeochemistry based on observational and modeling evidence collected in Kongsfjorden, Svalbard, and on published studies. We here present a fjord conceptual model, including a benthic compartment, to visualize the biogeochemical fluxes between the sediments and the water column.

The effects of tidewater glaciers on fjords are conveyed through: (i) the heat exchanges between the glacier fronts and the calving icebergs, on one hand, and the water column with advection of Atlantic water on the other hand, and (ii) the physical and biogeochemical interactions between the glacier melt water and the sea water, strongly dependent on flow type - surface or subglacial. The effects of subglacial discharges have been discussed in the literature, with emphasis on local upwelling caused by the rising meltwater plumes, entraining deep, nutrient-rich, sea water to the surface.

Our observational evidence suggests that subglacial water has higher ammonia concentrations, when glaciers are moving over an “old” seabed with high loads of organic matter available for bacterial degradation. This provides a glimpse into the expected changes resulting from the retreat of tidewater glaciers and the newly exposed organic-rich sediments with mobilization of nutrients and organic matter to the water column. It also emphasizes the need for fjord biogeochemical models to include a benthic compartment to simulate sediment-water biogeochemical interactions. Such a model should include diffusion, adsorption-desorption, mineralization, nitrification, denitrification, and uptake and release fluxes by most relevant benthic organisms. Some of the mentioned fluxes depend on oxygen and temperature and may be represented without the explicit inclusion of bacteria for the sake of simplicity. Another argument for inclusion of a benthic compartment in such biogeochemical models is the increasing biomass of macroalgae and their spread to shallower waters in Arctic fjords. However, their relative importance on fjord primary production and nutrient sinking needs to be established. We argue that sediment-water interactions are key to properly quantifying the impact of ice sheet and glacier

retreat, in the Arctic and in Antarctica, on the global biogeochemical cycles of carbon and nitrogen within a framework of climate change. Thus, our conceptual model may serve as a "template" for application in larger scale models.

Abstract 9: Katharine Hendry[1], Bryan Spears[2], Amy Pickard[2], Alanna Grant[2], Nathan Callaghan[2], Michael Meredith[1], Geraint Tarling[1]
[1]British Antarctic Survey, [2]UK Centre for Ecology and Hydrology

Biogeochemical processes and nutrient cycling in changing polar fjord systems

The oceans play a vital role in absorbing atmospheric carbon dioxide, mitigating a significant proportion of anthropogenic emissions. The supply of nutrients from the polar regions drives a large part of this global carbon cycle component. However, these high-latitude regions are experiencing some of the most rapidly changing environmental conditions in the world, and the impact of these changes on nutrient fluxes from land – and their export to the land-ocean continuum – is poorly understood. The UK-based project BIOPOLE aims to improve ability to quantify this export and identify its sensitivity to climate change, together with international project partners. Here, we will summarise some of the initial results of our literature review and first field seasons in the Arctic, including case studies from fjords in Greenland, Iceland and Svalbard. We have combined physical and chemical tracers of meteoric waters, biogeochemical observations, and process-based experiments, to track and understand the major sources of nutrients in each case study. Our results highlight the complexity of biological and abiotic interactions across salinity gradients and in fjords and coastal regions for the supply of different limiting nutrients into the Arctic and North Atlantic Ocean.

Abstract 214: Agneta Fransson[1], Melissa Chierici[2], Mats Granskog[1], Paul Dodd[1], Colin Stedmon[3]
[1]Norwegian Polar Institute, [2]Institute of Marine Research, Norway, [3]Technical University of Denmark

Impacts of glacial and sea-ice meltwater and biological CO2 drawdown on ocean acidification state in northeast Greenland fjord and shelf

Arctic fjords are sensitive to impacts by climate change such as increased meltwater from glaciers, sea ice, and river runoff. Increased freshwater reduces the seawater alkalinity, carbonate ions and calcium carbonate saturation state resulting and decreased potential for calcium carbonate formation of shells by marine organisms. The north-east Greenland and waters adjacent to the Nioghalvfjerdsbræ (79 North Glacier, 79NG) are influenced by Greenland Ice Sheet (GrIS) melt, sea-ice meltwater and waters on the adjacent northeast Greenland shelf (NEGS). Therefore, we investigated Dijmphna Sound and the

impact of meltwater from 79NG and sea ice regarding ocean acidification (OA) variables and the role of freshening, primary production, and air-sea CO2exchange. Studies during two summers in 2012 and 2016 showed different physical and biogeochemical conditions in the 50m surface layer. Unusually large runoff reported from the Greenland Ice Sheet (GrIS) in 2012 suggested to be the main cause for the higher freshwater content and concurrent decreased aragonite saturation state (ΩAr) observed in the surface water of Dijmphna Sound in 2012 than in 2016. However, biological CO2 drawdown at primary production caused increased ΩAr in the surface, which compensated for most of the ΩAr decrease due to the freshwater dilution of carbonate ions reducing total alkalinity, hence preventing corrosive conditions. This was most pronounced near the 79NG front in 2012, where surface stratification was most pronounced coinciding with large glacial meltwater fractions.

We discuss future conditions where increased meltwater effects may overcome the alleviating effects of biological CO2 drawdown on OA with unfavorable conditions for calcifying organisms. However, our study also suggests that primary production may be stimulated by stratification from surface meltwater. On the other hand, Atlantification and sub-glacial discharge may result in upwelling of inorganic nutrients that could promote primary production. The results from this study will be compared with other Greenland fjords and Svalbard fjords.

Abstract 50: Andrew Hodson[1]
[1]University Centre In Svalbard

Nitrate delivery to Svalbard fjords by glacial runoff

Glacier ablation releases meltwater with the capacity to influence the magnitude of nutrient fluxes entering Svalbard's fjords. Fluxes typically increase with discharge, but they also become more dilute, which complicates the assessment of their fertilisation potential. This is further complicated by their mode of delivery, and great attention is currently being given to the differences between estuarine-style delivery versus sub-marine delivery as a buoyant, subglacial plume. To help understand this complexity, this talk explains its relevance to nitrate, a critical productivity-limiting nutrient in Svalbard's fjord ecosystems. Data from various glacier-fed rivers in Svalbard are used to demonstrate show how both atmospheric (snowpack) nitrate and microbial (nitrification) nitrate are sensitive to climate warming over seasonal and longer time scales. It is argued that nitrate subsidy of fjord ecosystems by atmospheric nitrate (i.e. snowmelt) is probably most important in early summer, when primary production remains high, yet the glacial drainage system remains poorly developed. It is also shown that microbial nitrate dominates from mid-summer onwards, when an increasingly efficient glacier drainage system produces very large yet dilute

fluxes whose utility in the fjord has been questioned. However, later on, very high concentrations evolve as runoff declines and the mixing ratio of water from shallow groundwater or subglacial flowpaths conducive to nitrification increases. Since primary production has declined markedly at this point, the fertilisation potential for late season nitrate is unclear and requires us to consider the over-winter fate of this nitrate-rich runoff. Finally, the source of the non-atmospheric nitrate will be discussed, and it will be shown that ammonium release from the shales in Central Spitsbergen is regionally significant, especially where shallow groundwaters in glacier forefields, moraines and beneath smaller glaciers are able to promote its nitrification. By contrast, longer residence time subglacial flowpaths beneath large tidewater glaciers are more likely to promote denitrification, and thus reduce the importance of this process. The nitrogen cycle is therefore highly sensitive to the impact of glacier retreat upon the loci of rock-water interaction and we really need to assess the importance of nutrient subsidy by geological nitrogen as we consider the impact of diminished nitrate supply by snowmelt.

Abstract 54: Sarah Tingey[1], Jemma Wadham[1,2], Jonathan Hawkings[1,3], Murat Ardelan[4], Stephen Kohler[4], Leo Magerl[1], Andrew Hodson[5], Fotis Sgouridis[2], Peter Wynn[6], Guillaume Lamarche-Gagnon[1]
[1]UiT The Arctic University of Norway, [2]University of Bristol, UK, [3]University of Pennsylvania, USA, [4]Norwegian University of Science and Technology (NTNU), [5]University Centre in Svalbard (UNIS), [6]Lancaster University, UK

The METALLICA project: Hg mobilisation from Arctic glaciers

The Arctic is at the forefront of climate change, undergoing amplified warming nearly four times the global average. This is driving the retreat of marine terminating glaciers, expansion of glacier forefields and shifts in freshwater and sediment discharge, with important implications for downstream fjords and their ecosystems. Past research has shown that glaciers and their forefields are hotspots for the cycling of trace metals, including potentially toxic species. Biogeochemical weathering can liberate mercury (Hg) from underlying bedrock and proglacial soils, which are exported into fjords. Hg transformation to methylmercury (MeHg), a bioaccumulative neurotoxin, has been shown to be elevated in some Arctic fjords, where it has the potential to impact food webs, fish stocks, seabirds and human health. However, Hg mobilisation from Arctic glaciers and its subsequent transformation to MeHg remains poorly understood. Here, we present the METALLICA project which aims to evaluate the lithological, biogeochemical, and glacial controls on Hg export to fjords via comprehensive hydro chemical sampling across multiple glacierised catchments in Norway and Svalbard glaciers over melt seasons in 2022 and 2023. We present preliminary data indicating the importance of glaciated catchments as a source of Hg to downstream rivers and fjords, including transformation of Hg to MeHg. Finally,

we evaluate the potential for shifts in Hg cycling in the Arctic due to changing glacial meltwater exports and glacier forefield expansion.

Session 8: Legacy of War

Monday 29th January, 15:30-17:00

Abstract 2: Stephen Wickler[1]
[1]UiT – The Arctic University of Norway, Tromsø

The Tirpitz wreck site from an archaeological perspective: trash or maritime heritage?

The role of Tirpitz has undergone a complex series of transformations running the gamut from feared warship to shipwreck to salvage debris from its construction in 1939 to sinking in 1942 and salvage operations from 1947 to 1958. Høvding Skipsopphoggeri (now Saga Shipping) was given ownership and exclusive rights by the Norwegian government to salvage some 400 German war wrecks, including Tirpitz. There were minimal demands for accountability with regard to procedural documentation, safety concerns and environmental impacts, resulting in a lasting legacy of problematic issues that remain unresolved. As a sunken ship from WWII, Tirpitz is a member of the largest category of submerged cultural heritage to be found in northern Norway. Since automatic protection under the Cultural Heritage Act is restricted to sunken vessels built more than 100 years ago, it is also a problematic category with limited legislative safeguards. The designation of Tirpitz for temporary protection in 2014 by the Directorate for Cultural Heritage as the first step in obtaining permanent protection was therefore noteworthy. Although the main argument for this action was a perceived threat from widespread looting of artefacts by recreational divers, there were undoubtedly political factors involved. The discovery that the wreck is presently owned by the Norwegian government rather than the salvage company was a significant factor. The diving ban associated with protected status was difficult to enforce and in 2016 the status of Tirpitz quietly reverted to unprotected. Vocal objections to protection of the wreck from the recreational diving community played an important role in the reversal and highlight the problematic status of shipwrecks salvaged by Høvding. Divers raised a valid point regarding the questionable value of discarded material dumped on the seabed during salvage as heritage. This also reflects a more widespread lack of appreciation for the cultural value of items from recent historic shipwrecks among divers. In this presentation, I take a closer look at the ambivalent status of Norwegian war wrecks and those that have undergone extensive salvage operations in particular. What factors need to be considered when assessing the value of such wrecks? What are the long-term consequences of wreck salvage sites with significant environmental impacts from pollutants such as heavy oil, toxic chemicals and PCB contamination? Who

is responsible for cleanup?

A second issue of a much different nature that applies to the Tirpitz project is the unique approach applied to documenting shallow water wreckage that has been extensively impacted by salvage operations. The utilization of cutting edge technological survey, monitoring and analytical tools in documenting the Tirpitz site is a groundbreaking aspect of the project. The integration of aerial and underwater drone technology in particular represents a significant advance in marine archaeological methods. The application of these techniques will be discussed in greater detail in the following presentations.

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Through-water photogrammetry in the Tirpitz Site Project

Through-water photogrammetry has been shown to be possible as a method of determining the three-dimensional structure of objects submerged in shallow water, though it has undergone limited investigation as a tool of marine archaeology. In this contribution, we describe the analysis of trispectral (RGB) and multispectral imagery collected from the Tirpitz Site Project (TSP) area using relatively inexpensive UAVs (uncrewed aerial autonomous vehicle, or 'drone'). Data had previously been processed using the Structure-from-Motion (SfM) approach to generate a three-dimensional trispectral point cloud. Here, we present a preliminary analysis of the point cloud to examine the utility of the data, to determine the geometry of the submerged wharf and the principal debris piles, and to perform a depth-corrected trispectral classification of the debris area.

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The Arctic Legacy of War Research Programme (Arctic LOW) and the Tirpitz Site Project (TSP)

War in the Arctic has left a legacy of destroyed ships, aircraft and abandoned ground warfare equipment, munitions and associated equipment dumps, and salvage sites. Research, including the recent North Sea Wrecks Project, has confirmed that these remains of war are not dormant or benign. As casings corrode, their explosive contents are released into the biosphere and enter human exposure vectors. Also, there are other pollutants, e.g. lead, asbestos, mercury, PCBs and fuel. In addition to direct impacts on human health, there is the potential for economic damage; how does the fishing industry respond when fish are found with cancers from exposure to military contaminants? The Arctic

Legacy of War Research Programme (Arctic LOW) has commenced examining these issues. Its fieldwork utilises, when possible, remote sensing and robotics to reduce its climate impact footprint while extending the range and depth of the areas being investigated.

Arctic LOW's first project is the German battleship Tirpitz salvage site. Tirpitz was deployed to Norway in WWII, posing a grave threat to the Allies' Arctic conveys supplying the USSR. After numerous attacks by the Royal Navy and Royal Air Force, the ship was sunk using Tallboy bombs on 12 November 1944. During the subsequent salvage, pollutants were released, and commercially worthless material was dumped on the seabed. Located near Tromsø, it is in the High North environment with comparatively rapid climate change. Based on historical research, and images from aerial and underwater drones, initial fieldwork has produced the first map of the core site with the salvage wharf and debris piles.

The primary objectives of the Tirpitz Site Project are to enhance our knowledge of the environmental and societal legacy of Arctic military ship operations and salvage sites, and inform ways of responding to contaminates. The secondary research objectives are to develop novel methods of assessing shallow marine arctic environments more generally. The Tirpitz Site Project will utilise the Tirpitz salvage area for archaeological, environmental, technological, humanities and social science data production and research. The research goals include:

• Producing an historical account of the Tirpitz in Tromsø: its deployment and destruction, salvage, previous research endeavours, and subsequent diving activity;

• Producing related historical, humanities and social science studies;

• Production of a map and archaeological survey of the site that can be enhanced by knowledge from the local diving community;

• Development and enhancement of related technologies, including remote sensing and in-situ sensors, for environmental monitoring;

• Quantifying the ongoing dynamics of the ecological impact of the remains of the Tirpitz;

• Developing site-based technologies to monitor anthropogenic activity;

• Monitoring climate change impacts on the remains of the Tirpitz;

• Developing and enhancing ROV (remotely operated vehicle) technologies for physical interventions, and dealing with contaminates;

• Enhancing integrated aerial and underwater remote sensing techniques for global application.

The Arctic Legacy of War Research Programme is an ongoing endeavour of UiT Norway's Arctic University that welcomes interest from other universities, institutes and industry.

Abstract 112: Markus Dreyer[1]
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Innovative Aerial Mapping and Photogrammetry of the Tirpitz Salvage Site

Over the last 8-10 years, airborne drones with cameras have become integrated into terrestrial surveying and mapping. The Tirpitz Site Project has utilised and enhanced drone technology and photogrammetry techniques from the terrestrial realm to map - through shallow waters - the seabed of the Tirpitz salvage site.

Planning for this proof-of-concept experiment considered and accounted for factors that could impact the quality of the data collection. External factors included available daylight, cloud conditions, wind, probability of waves, reflections from the sea surface, algae blooming, tidal conditions, and camera settings (exposure and shutter speed). A DJI Matrice 210 UAV, carrying a Zenmuse X4s sensor, was used for the primary data collection. The flights were carried out at ~ 25 metres above sea level, with parallel transects 5 metres apart, giving 80% overlap. The camera was angled orthogonal to the sea to reduce reflections. The resulting images were excellent, allowing the first site map of the Tirpitz salvage wharf, debris piles, and the former site of the ship´s centre section to be produced. In addition, analysis based on photogrammetry has resulted in the first 3-D images of the debris piles and allowed an initial assessment of their surface areas and volumes. In future, different flight patterns and camera angles are being considered to enhance the details and quality of the images for 3D models. However, this could result in more pronounced reflections at the surface and effects from the angle of refraction due to an increased camera angle degrading image quality. Further field trials will provide the data necessary to resolve these questions. Another expansion of the project is integrating data from surface and underwater drones, providing additional data to enhance the mapping and photogrammetry.

The first season on the Tirpitz site has demonstrated that, in the right conditions, an aerial drone platform can provide high-quality images for mapping and photogrammetry in shallow waters. This technique is both cost-effective and has a minimal environmental impact. In the coming seasons, there will be

further enhancements to this promising technique.
Abstract part of UiT Arctic Legacy of War, Tirpitz Site Project

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Monitoring Technologies

Numerous subsea locations possess significant historical and emotional significance, necessitating their preservation and protection. Particularly during the Second World War, a multitude of ships, aircraft, and other artifacts found their final resting place beneath the ocean's depths. Many of these sites are regarded as war cemeteries and thus demand the utmost respect. Given their wartime origins, these underwater sites often have unexploded ordnances (UXO), which, despite their age, remain dangerous and in many cases unstable and represents hazards to both security and the environment.

Unauthorized access to these historical subsea sites, exemplified by activities like scuba diving, can pose a threat against the historical value but also represent a grave desecration. Such scuba diving access typically occurs in shallow waters, like at the wreckage of the German battleship Tirpitz in Tromsø. Nevertheless, recent decades have witnessed advancements in subsea and diving technology, extending the reach of researchers and other stakeholders to deepwater historical sites. With the utilization of advanced diving technologies, including gas mixing, it has become feasible to explore deep-water relics like the Blucher, another Second World War battleship located near Oslo. Moreover, there have been instances of individuals accessing deep-water historical sites, such as the Titanic, using homemade submarines, even it ended disastrously in the final end. The decreasing cost of advanced subsea equipment has increased the access to such technology, even remotely operated vehicles (ROVs) with respectable depth ratings are now available at the private market.

To deter unauthorized activities at historical sites, the implementation of monitoring technology is imperative. The simplest approach is manual monitoring of the sea surface above these sites and often involves locals. An alternative method entails recording data from Automatic Identification System (AIS) transponders in the vicinity, although this method may not always guarantee reliability. Employing camera and radar technology for continuous site monitoring, especially in coastal areas, represents another option. A particularly effective alternative is passive acoustics, which employs hydrophones positioned either on or near the underwater artifact.

Depending on the configuration of the hydrophone, a trigger level can be set to activate an alarm when sound levels exceed predefined thresholds, detecting nearby vessels, ROVs or divers. Another configuration involves analyzing the frequency spectrum to distinguish between noises originating from ships, ROVs, divers, echosounders, and sonars. Most ships and even ROVs employ active acoustics, emitting signals within specific frequency ranges detectable by passive acoustics. However, the use of active acoustics can also serve as a means of detecting unauthorized activity at historical subsea sites. By utilizing bottom-mounted echosounders or sonars, it becomes feasible to scan the water column for signs of activity such as divers, ROVs, or even surface vessels. Similar bottom-mounted active acoustic technologies are extensively employed in both scientific research and the oil and gas industry. The most common arrangement for active acoustics for monitoring will be instrument platforms and the landers, in some cases also buoys.