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# Seismological monitoring in the Arctic: An introduction to INTAROS

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The Arctic is experiencing the rapid changes in the climate system. Accordingly, several natural disasters, e.g. landslides or earthquakes among others, are likely to increase together with the expected changes in the climatic conditions in the Arctic.
To study the temporal variations of the Arctic seismicity and assess the seismic hazard in the area, a unified earthquake catalogue is required. Many datasets are currently available through national and international monitoring networks, however there has been little effort to integrate these data and make it available to the scientific community. Eu-funded INTAROS project (Integrated Arctic Observation System) is expected to assess the strengths and weaknesses of the existing observing systems, and contribute with innovative solutions to fill some of the critical gaps in the in situ observing network. The seismological session of the INTAROS is focused on creating a baseline earthquake database, and in this regard a catalogue of seismological monitoring capabilities was developed for the Arctic region between 1960 – 2016, together with relocations and new focal mechanism calculations for larger events.
To improve the existing catalogue and fill part of the large observational gap in the offshore regions of the Arctic (mainly due to the harsh weather conditions), Ocean Bottom Seismometers (OBS) were deployed in the Fram Strait near the Northern Mid-Atlantic Ridge during summer 2018 and will sit on the sea floor for one year. The improvement of the monitoring coverage will provide a new dataset which will enable us to lower the earthquake detection threshold in the study area.

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# Beaufort Gyre Observing System (BGOS) in 2003-2018 from observations and model results

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Goals of the Forum for Artic Modeling and Observing Synthesis (FAMOS) project include improving Arctic regional ice-ocean models and advancing understanding of the physical processes regulating variability of Arctic environmental conditions through synthesis of observations and model results. The Beaufort Gyre centered in the Canada Basin of the Arctic Ocean constitutes a natural laboratory for application of FAMOS modeling capabilities to resolve numerous scientific questions related to the origin and variability of this climatological flywheel and freshwater reservoir of the Arctic Ocean. The unprecedented volume of data collected in this region facilitates documentation of the ocean state and changes in this environmental system at synoptic, seasonal and interannual time scales. The in situ and remote sensing data characterizing ocean hydrography and sea surface height, ice drift, concentration and thickness, ocean circulation, and biogeochemistry have been used for model calibration and validation, been assimilated for historic reconstructions, and taken as initial conditions for numerical predictions. This presentation describes time series of Beaufort Gyre data, summarizes new methodologies in observing, modeling and analysis, discusses ideas about the mechanisms regulating Beaufort Gyre dynamics and speculates on the transition to a new Beaufort Gyre state under different climate forcing.

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# A process-based climatological evaluation of AIRS tropospheric thermodynamics over the high-latitude Arctic

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Measurements from space borne sensors have a unique capacity to fill spatial and temporal gaps present from the ground-based atmospheric observing systems. This is especially true for profiling over the high latitude Arctic polar region, where observing stations are limited to the pan-Arctic landmasses and infrequent field campaigns. The hyperspectral infrared sounder instrument AIRS, on the Aqua satellite, polar-orbiting within the A-Train satellite constellation, has provided retrieved thermodynamic profiles from the global atmosphere twice daily since its launch in 2002. These measurements are critically important for weather prediction models where modern data assimilation techniques allows radiances rather than retrieved temperatures to be used for determination of model initial states. Similarly, retrievals of thermodynamics from AIRS over the Arctic have been used to quantify and improve the understanding of important processes and features of the sparsely observed Arctic atmosphere. A detailed investigation into the accuracy of AIRS thermodynamic profiles over the high-latitude Arctic has however been lacking.

In this study, we have compiled a wealth of radiosounding profiles from long-term Arctic land stations, also including soundings from several intensive icebreaker-based field campaigns in the central Arctic Ocean, and use these to evaluate daily mean thermodynamic profiles from the satellite sensor. The results indicate that while the mid- to upper-troposphere temperature and specific humidity are relatively well captured by the satellite, the lower troposphere is susceptible to specific seasonal, and even monthly, biases. These differences across the lowest atmospheric levels have a critical influence on the lower tropospheric stability structure. The relatively coarse vertical resolution of AIRS retrievals, together with infrared retrievals through persistent low Arctic cloud layers, lead to artificial thermodynamic structures that fail to accurately represent the lower Arctic atmosphere. These thermodynamic errors are likely to introduce artificial and erroneous structures in the boundary layer and may have led to misinterpretations of the associated physical processes.

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# Unusual tremors in Greenland

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Greenland is the origin of a wealth of seismic signals. Every year more than a thousand small to moderate magnitude earthquakes are located primarily along the coasts. Most known Greenlandic earthquakes range between ML 1.0 and ML 3.0, and it can be a challenge to locate them due to the large distances and sparse network. The data collected and distributed by the Greenland Ice Sheet Monitoring Network (GLISN) federation and its members is important for the successful identification and location of seismic events in Greenland. The data are routine processed for tectonic events on a daily basis at GEUS.
A class of emergent non-tectonic signals clearly stands out from the tectonic earthquakes. Many of the signals lack both clear P- and S-onsets, but are coherent over a smaller part of the network. In rare instances the signals are detected over all of Greenland. The S-energy dominates and the duration of the signals can be up to a few minutes. ML measured on the wave train, typically yield values ranging from 1.0 to 3.0, similar to the local tectonic events. For the larger tremors the frequencies peak in the 1-5 Hz range, the smaller tremors are more pronounced at slightly higher frequencies.
The GLISN seismographs are located several hundred kilometers apart and constitute a regional network. Fortunately, the geology and noise conditions in Greenland are very favorably for seismographs, allowing the signals from the slow tremors to be registered 5-600 km away. Lacking a dense seismograph network and clear onsets, the events are hard to locate precisely, but using the trained eye strategy it is possible to build consistent solutions. The origin of the events are in many cases close to major glaciers and ice streams, especially the Jakobshavn Isbrae in west Greenland. The tremors show similar characteristics as glacier-related earthquakes in other parts of the world. Some of the emergent events are located away from large glaciers and the cause is of now unknown. This presentation will give an overview of the current state of analysis of the non-tectonic tremors in Greenland.

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# A support to discovery of subglacial impact crater in northwest Greenland by gravity aspects from Earth gravity model EIGEN 6C4 and other data

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We support the very recent discovery of a large impact crater beneath Hiawatha Glacier in northwest Greenland (Kjaer et al 2018). We use a wholly independent way – mainly the gravity aspects (not only the traditional gravity anomalies, but also the second derivatives of the Marussi tensor, the gravity invariants and their specific ratio, known also as 2D indicator, the strike angles and the virtual deformations) which were derived from the recent global static Earth gravity field model EIGEN 6C4 and from the digital magnetic field database EMAG v.2 with the ground resolutions of around 10 and 5 km, respectively.

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# Programme for Monitoring of the Greenland Ice Sheet (PROMICE)

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Initiated in 2007, the Programme for Monitoring of the Greenland ice sheet (PROMICE) is an ongoing effort to monitor changes in the mass budget of the Greenland ice sheet. PROMICE is operated by the Geological Survey of Denmark and Greenland (GEUS) in collaboration with the National Space Institute (DTU Space) and the Greenland Survey (Asiaq). PROMICE focus on observing key variables for:
1) Determining the Greenland ice sheet surface mass balance. We make use of a network of 22 automatic weather stations observing meteorology and ablation/accumulation. PROMICE are supplementing regional climate modeling by providing daily albedo grids from MODIS. PROMICE also tests the performance of regional climate models by in-situ surface mass balance observations and ice-sheet meltwater discharge monitoring.
2) Determining the Greenland ice sheet dynamic mass loss. We calculate ice movement towards the oceans through fluxgates around the PROMICE perimeter. The introduction of data from Sentinel-1 for ice velocity, IceBridge BedMachine Greenland for bed topography, and the Greenland Ice sheet Mapping Project for digital elevation, we can now estimate iceberg flux at over 400 individual tidewater glaciers around the ice sheet.
3) Mapping Greenland ice area change. We rely on Landsat 8 and Sentinel-2 imagery to continue to track changes in the extent of the ice sheet and surrounding individual glaciers.
PROMICE remains committed to maintaining a well-documented database for storing and disseminating Greenland glaciological and meteorological data free of charge. See www.promice.dk for more information.

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# Arctic sea level study. Satellite and in-situ observations for more than 25 years

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Sea level information is an important Arctic Ocean parameter for an Arctic observing system. However the presence of seasonal or even permanent sea ice limits the way this parameter can be observed.
Tide gauges are available from more than 50 year but are frequently sheltered from the open ocean in rivers severely contaminating the “sea level” observations by river flow variations and ice.
Satellite altimetry is available for more than 25 years from conventional satellites like ERS-1/ERS-2/ENVISAT and SARAL. However, sea level from these satellites are contaminated with sea ice melange and water on sea ice and only monitoring up to 82N. Recently SAR altimeters like Cryosat-2 and Sentinel 3A and B has vastly improved our ability to monitor sea level up to 88N from satellite altimetry enabling altimeters to capture sea level in leads in the sea ice.

We present a new retracked DTU/TUM Sea level observation products for the Arctic Ocean covering the period from 1995-2017 from the ESA satellites ERS2, Envisat and CryoSat-2. A comparison with a former DTU reconstructed sea level dataset from 1950-2010 indicate that sea level in the Arctic Ocean has increased significantly from 2.1 mm (1950-2010) to close to 4 mm today (1995-2017). Both datasets exhibit significant higher trend in the Beaufort Gyre region.

The components of sea level change can be divided into a change of steric height and a change of mass. Where the mass change can be derived from measurements by the GRACE-satellites (06.2002 – 06.2017), the steric component can only be modelled or calculated using T/S-profiles from floats (e.g. ARGO). The DTU/TUM sea level product is compared to these studies and show good agreement.

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# Greenland GPS Network to monitor ice mass changes under the INTAROS project

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The Greenland GPS Network (GNET) uses the Global Positioning System (GPS) to measure the displacement of bedrock exposed near the margins of the Greenland ice sheet. We provide 3D displacement time series from GPS available at (https://catalog-intaros.nersc.no/dataset/ice-mass-change-of-the-greenland-ice-sheet) to study uplift in response to present-day changes in ice mass. We compare present-day 3D deformations with modeled results. To retrieve 3D elastic displacements from GPS time series, we correct our observations for glacial-isostatic adjustment and tectonic plate motion. To model 3D elastic displacements, we first estimate mass loss using 1995–2014 NASA's Airborne Topographic Mapper (ATM) flights derived altimetry, supplemented with laser altimetry observations from the Ice, Cloud, and Land Elevation Satellite (ICESat) during 2003–2009; the airborne Land, Vegetation, and Ice Sensor (LVIS) instrument during 2007–2013; radar altimetry from the CryoSat-2 satellite during 2010–2018; and European Remote-Sensing Satellite–1 (ERS-1) and ERS-2 data during 1995–2003. We convert the volume loss rate into a mass loss rate accounting for firncompaction. We predict the elastic displacements by convolving mass loss estimates with Green's functions for vertical and horizontal displacements.

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# Marine robotics for sampling air-sea-ice interface in the Arctic region

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Although chemical-physical characterization of air and water columns in the proximity of fronts/tongues of tide-water glaciers is fundamental for understanding dynamics of atmospheric and water masses, only a few data are available due to the dangerousness in the access to these areas.
In recent years, field experimental activity carried out by Italian CNR researchers in Arctic regions supported the evaluation and demonstration of capabilities and effectiveness of Unmanned Marine Vehicles, aerial, surface and underwater, in sampling air-sea-ice interface in these dangerous and inaccessible areas. In particular three campaigns were carried out in Ny-Ålesund, Svalbard Islands, in 2015, 2017 and 2018 respectively to demonstrate: i) the capability of an Unmanned Semi-Submersible Vehicle (USSV) to approach a glacier tongue collecting water samples just below it; ii) the capability of a USSV to work in cooperation with Unmanned Aerial Vehicles for sea surface and air column characterization in the proximity of glaciers' fronts; iii) the capability of a USSV, equipped with suitable tools and instruments, to perform repetitive sampling of water surface as well as studying water and air column's parameters close to glaciers tongues. During the 2018 campaign in the Svalbard Islands, there was also a field training period for researchers in the framework of the H2020 project "EXCELLABUST - Excelling LABUST in marine robotics" focused on technological and operational innovations specifically introduced for the development of the data acquisition.
This paper will discuss the field activity, logistically supported by the Dirigibile Italia station in Ny-Ålesund, carried out in the proximity of the Blomstrandbreen, Kronebreen, Kongsbreen and Conwaybreen glaciers, in the Kongsfjorden, using the prototype USSV Shark (2015) and the modular vehicle PROTEUS (2017, 2018) together with the OTTO Unmanned Aerial Vehicle (2017).
Particular attention is paid to technological innovations introduced during the 2018 Excellabust campaign where PROTEUS, a portable, modular and reconfigurable USSV (45 kg weight, 1.5 m long, 0.35 m wide and 0.35 m high) was equipped with a new Mini Automatic Water Sampler (MAWS) for the collection of multiple water samples at different distances from the glacier front. Moreover, for carrying out a complete characterisation of the underwater-surface-air vertical column, two release systems based on automatic winches were installed on PROTEUS. One winch was used for launching and recovering an aerostat filled with helium and carrying a system for air quality monitoring (humidity, temperature, CO, $CO_2$, $O_3$, $NO_2$). The other winch was used for releasing and recovering a set of instruments for the chemical-physical characterization of the water column: a CTD (conductivity, temperature, depth,pH, Eh, oxygen), a multi-probe sensor (depth, temperature, chlorophyll a1, chlorophyll a2), a fluorimeter and a turbidimeter.
The paper will also highlight the advantages and issues given by single and multiple vehicle operations (surface and aerial) as well as logistic and operational lessons learned in the three campaigns carried out.

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# Russian Arctic in the PEEX Observational System

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Pan-Eurasian EXperiment (PEEX; www.atm.helsinki.fi/peex) initiative is an international, multi-disciplinary, multi-scale programme focused on solving interlinked global challenges influencing societies in the regions of the Northern Eurasia and China. In particular, PEEX is aimed to establish an in-situ observation network covering environments from the Arctic coastal regions, tundra to boreal forests, from pristine to urban megacities. It is based on existing stations activities and establishing new stations. The first step taken towards a comprehensive observation network included an overview of measurement capacity of exiting stations.
Although more than 200 stations are presented in the PEEX regions of interest, but so far only about 60 Russian stations have metadata information available (peexdata.atm.helsinki.fi - under request). The station metadata enables to categorize stations in a systematic manner and to connect them to international observation networks, such as WMO-GAWP Program, China Ecosystem Network, and perform standardization of data formats. Moreover, PEEX published the stations catalogue introducing the measurements and contact information of the Russian stations - PEEX collaboration network (www.atm.helsinki.fi/peex/index.php/peex-russia-in-situ-stations-e-catalogue). The catalogue aim is to promote research collaboration and stations as partners of the collaboration network and to give wider visibility to the stations activities.
As INTAROS contribution, the updated metadata were obtained from 11 measurements stations located within the Russian Arctic territories. Metadata include basic information, physico-geographical and infrastructure description of the sites and details on atmosphere and ecosystem (soils–forest–lakes–urban–peatland–tundra) measurements. Measurements at these sites represent more local conditions of immediate surrounding environment and datasets are available under request. As a "show case" of the PEEX Observational System capabilities, the detailed analysis results for selected Russian station (Marre-Sale) is presented. These include inter-annual, month-to-month and diurnal cycle variabilities of meteorological and ecosystem parameters, which are underlying climatic and environmental changes observed in the Arctic regions of Russia.

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# Towards implementation of seabed seismological network in Laptev Sea and Mega seeps geo-structural study by 3D active nodal array.

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The current studies were conducted during the 73th scientific cruise to the Laptev Sea as part of the Russian Academy of Science Arctic Research Program onboard of R/V “Academic Mstislav Keldysh”. The network of broad band ocean bottom seismometers (BB OBS) with long term autonomy was installed in order to investigate the Laptev Sea seismic regime and its possible relation to the Laptev Sea shelf permafrost degradation; to detect and locate active tectonic faults and microplate boundaries within the investigation area and to perform deep sounding of the Laptev Sea earth crust by using tele-seismic events. The previous studies showed that the degradation of permafrost in the Russian Arctic seas represents one of the major fast-growing sources of methane emission at the Northern hemisphere. Such phenomenon dramatically affects the present-day climate change and global warming, especially in the Northern hemisphere. There are many observations in the Laptev Sea (mostly with multi-beam echo sounders) of so-called Mega Seeps, which are exhibited as methane gas chimney rising from the seafloor to the sea surface. Year to year observations in the Laptev Sea show a significant growth of the number of existing Mega seeps and their size. The imaging of the seafloor deep structure in the vicinity of the Mega seeps is an extremely important for understanding Mega Seep gas roots and genesis. The deployed array of 4C self-popup nodes and active seismic source was used to solve this problem. This was the first 3D/4C seabed seismic survey performed in the Russian sector of the Arctic.

The design of BB OBSs used for the current installation sustains more than one year of permanent recording and is based on previously developed self-popup OBS desiged by the Russian Company GNS (OBS GNS). BB OBS has molecular electronic broad band seismometer (100 sec – 50 Hz frequency range) while also preserves all new advanced features of GNS OBS. GNS OBS were employed for active seismic seabed study of mega seep structure.

The presentation outlines the description of seabed instruments, survey details and results obtained during the performed marine studies.

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# Enhancement of *in situ* observing systems in the Arctic under the H2020 INTAROS project

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The H2020 project Integrated Arctic Observation System (INTAROS) aspires to increase the temporal and geographic coverage of *in situ* observations and add new key geophysical and biogeochemical variables in selected regions of the Arctic. By using a combination of mature and new instruments and sensors in integration with existing observatories, INTAROS aims to fill selected gaps in the present-day system and build additional capacity of pan-Arctic monitoring networks.

Three reference sites have been selected as key locations for monitoring ongoing Arctic changes: Costal Greenland, paramount for freshwater output from the Greenland ice sheet; North of Svalbard (shelf to deep basin) - the hot-spot for ocean-air-sea ice interactions, and heat and biological energy input to the European Arctic; and Fram Strait - the critical gateway for exchanges between the Arctic and the World oceans. Two distributed observatories: for ocean and sea ice and for terrestrial and atmospheric measurements will be extended with multidisciplinary observations, still missing from the central Arctic and remote coastal areas. New sensors, integrated platforms and experimental set-ups will be implemented during a two-year long deployment phase (2018-20020) with an aim for sustained use in a future iAOS. New observations will be used for integration of new data products, demonstration studies and stakeholder consultations and contribute to ongoing and future long-term initiatives (e.g. OSPAR, SAON, YOPP).

Here we will address the technical development, integration and system design carried out for the selected reference sites and distributed observatories during the first phase of the project, and review new *in situ* observational efforts, implemented during the first INTAROS field season in 2018.

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# Exploring the Monitoring Capacity of a Cabled Coastal Observatory in the Arctic as a Proxy for Seasonal Phytoplankton Dynamics: A 6-year time-series in Cambridge Bay, Nunavut, Canada

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In an effort to broaden understanding of Arctic marine environments, Oceans Networks Canada (ONC) installed fixed-point cabled sub-tidal and shore-based observatories in the fall of 2012 in Cambridge Bay, Nunavut, in the Canadian Arctic Archipelago (CAA). The sub-tidal observatory was equipped with: CTD, acoustic sea-ice profiler, camera, hydrophone, acoustic Doppler current profiler, dissolved oxygen ($O_2$), chlorophyll fluorescence, turbidity, PAR, pH and $pCO_2$ sensors. The onshore meteorological station measures standard weather parameters, including air temperature, downward irradiance, humidity, and wind speed and direction. The shore station also has an AIS receiver. Data is being recorded at between 1 and 60 Hz resolution, on the sub-tidal and shore observatory systems, all of which is freely available for download at oceannetworks.ca. The motivation for the present study was to take advantage of the unique high-resolution time-series to identify the seasonal timings of abiotic and productivity-associated events and investigate regulation of inter-annual variability. Seasonal biotic events include a shift from net respiration to production (based on $O_2$ measurements) and changes in the production of phytoplankton biomass that are related to solar irradiance and ice thickness. In all years, prior to sea-ice melt (late March to April), a shift from net respiration ($O_2$ decrease and $pCO_2$ build-up) to net production ($O_2$ increase and $pCO_2$ drawdown) is observed. Net production is generally reached just prior to the sea-ice break up (early July) and its seasonal duration is positively correlated to the number of ice-free days annually. We also demonstrate a light-dependent relationship in fixed-point chlorophyll fluorescence measurements in sea-surface waters of Cambridge Bay, discuss necessary data corrections and consider future instrument options.

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# A first assessment of observational gaps in the Arctic

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Planning and prioritization of funding for observing systems requires identification of gaps in the current knowledge. Here we perform an assessment and gap analysis of present Arctic observing systems, using a web-based survey supported by model sensitivity studies. The survey represents a first collection of homogeneous and consistent information about in-situ and satellite observations across disciplines in the Arctic, and was carried out under the H2020-project “Integrated Arctic Observation System (INTAROS)”. Our synthesis highlights crucial gaps in the observing systems and related datasets, addressing spatial/temporal coverage, resolution, uncertainty, as well as sustainability and data management of the existing in situ observation networks.

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# An increasing role of Argo floats in Arctic oceanographic observations

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The Argo system has proved its utility in oceanographic observations by providing already more than 2 000 000 casts collected by profiling floats. The spatial coverage in the open ocean is satisfactory and the marginal seas, even so shallow as the Baltic Sea are slowly getting covered by the network of floats. The largest gaps in the Argo system are still found in the Arctic regions, where the network of floats is poorly developed. Scientific institutions are usually reluctant to deploy floats in the Arctic Ocean and even the Nordic Seas are weakly covered. This can be explained by the fact that the float life time in the midlatitudes can reach up to 4 years while in the northern regions event two years are considered as very optimistic estimate. For a standard Argo float, the close approach to the ice edge is usually mortal.

However even limited information from the Argo floats can provide extremely valuable contribution to the ocean observation system in the Arctic and sub-Arctic regions with capability to complement other observing methods and fill the gaps due to their limitation. The advantage of an Argo float is that it works year-round while the ship-borne measurements are performed usually during the spring to autumn season. The second important feature is that profiling Argo floats cover the whole water column from the surface down to 2000 m and deliver a continuous profile of measured variables. Mooring-based measurements provide discrete data and in the Arctic regions where the sea ice is a risk factor, the surface layer is usually not covered. Fast-paced development of the Argo float technology, including the implementation of new biogeochemical sensors and progressing efforts on ice-sensing and ice-avoidance methods, increases robustness of Argo floats in the harsh Arctic environment and make them a promising source of the most demanded biogeochemical and biological data. The closer collaboration between the Argo and Euro-Argo programs and other Arctic-oriented research and infrastructure projects is of a highest importance, particularly in the context of shrinking sea ice cover and growing areas of open water where Argo floats can be fully operational. The Argo network can soon become an important part of the integrated Arctic Observing System, complementing a well-proven, yet expensive and limited in coverage network of ice-tethered instruments.

Here we present new results from oceanographic observations obtained by Argo floats deployed by the Institute of Oceanology PAN in the eastern Nordic Seas. We compare Lagrangian measurements along the northward and westward float trajectories with Eulerian observations at the selected deep ocean moorings and quasi-synoptic ship-borne hydrographic surveys of key ocean variables in the entrance to the Arctic Ocean.

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# Exploitation of Sentinel satellite data to characterize Arctic river catchments

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Across broad spatial and temporal scales, riverine and coastal dissolved organic carbon (DOC) dynamics are linked to the characteristics of river catchments (e.g. its soils and sediments, topography, vegetation and permafrost). Datasets to support spatial analyses, to provide characteristics of river catchments across the Arctic are required.

C-band SAR has shown to be of value for identifying wetlands, shallow water bodies, soil organic carbon content in the upper meter, snow melt patterns and recently also vegetation height in tundra. With Sentinel-1 which consists of two twin satellites, it is possible to monitor Arctic river catchments and their properties with high temporal and spatial resolutions.

Several Arctic river catchments have been selected and compared, grouped by permafrost and landcover characteristics exploiting the ESA DUE GlobPermafrost Permafrost Information System (part of APGC - Arctic Permafrost Geospatial Data Centre hosted by the Alfred Wegener Institute for Polar Research) in a first step. In combination with in situ observation, algorithms for the extraction of spatio-temporal properties of Arctic river catchments were developed. This includes transfer of methods developed for the predecessor ENVISAT ASAR to Sentinel-1.

To facilitate cross-disciplinary analyses, the data will be eventually combined with GIS-data on human settlements and infrastructure within the HORIZON2020 project Nunataryuk (led by AWI).

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# Assessment and exploitation of pan-arctic hydrological observation systems and data for monitoring fresh-water flow to the Arctic Ocean and changes in arctic hydrological regimes

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The Arctic-HYCOS observing system provides daily and monthly gauged river discharge data from a selection of stations operated by the national hydrological services in the Arctic Council member states. The set of stations have been selected to provide a basis for monitoring fresh water flow to the Arctic Ocean and for monitoring changes in the hydrological regime. We have performed an assessment of the observation system with respect to these objectives, focusing on spatial and temporal coverage, as well as metadata and data management aspects. The current list includes 427 stations of which 72 are listed as flow-to-ocean stations, representing the most reliable downstream station in the river basins. The flow-to-ocean network represent about 60% of the drainage basin area of the Arctic Ocean and related northern seas (excluding Greenland) – and about the same fraction of the total flow-to-ocean estimated by the Arctic-HYPE hydrological model (http://hypeweb.smhi.se/). The largest gaps in spatial coverage was found in Greenland, Svalbard, and northern coastal areas of Eurasia and North America. Scandinavia was also rather poorly represented in the selected station network mainly due to a spatial limit of the basin area to be included. Metadata on station location were assessed and improved by cross-checking information from several databases and aligning stations to flow accumulation data from the GWD-LR database. A method was developed for estimating effective upstream area using high resolution elevation data and applied using the Arctic-DEM dataset. The impact of the improved hydrological data is assessed using the Arctic-HYPE model. This assessment was carried out under the H2020 project “Integrated Arctic Observation Systems (INTAROS)”.

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# Towards constraining the circumpolar nitrous oxide budget

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Arctic soils and sediments are well known for their huge carbon stocks and the significant positive feedback carbon dioxide ($CO_2$) and methane (CH4) emissions can have on climate change. However, the vast amounts of nitrogen (N) and possible emissions of the strong greenhouse gas nitrous oxide (N2O) from Arctic soils are much less considered in this context. Arctic soils have been neglected in global N2O accounting, since their N2O emissions were traditionally thought to be low due to the general N-limitation of biological processes. Recent results suggest, however, that this assumption is unwarranted and needs to be revised. Still, although we know about the risk for increasing N2O emissions from the Arctic with warming, data are available only from a handful of sites and we are lacking any estimate on the circumarctic N2O budget even under the present climate. This presentation will introduce our plan to produce the first circumarctic N2O budget, an important baseline scenario against which changes in circumarctic N2O emissions can be observed with ongoing warming and global change. In order to estimate the first circumarctic N2O budget, we synthesize existing data and organize large-scale surveys of N2O fluxes across the Circumarctic. In our synthesis effort, we collect published and unpublished data on N2O emissions and N2O soil gas concentrations and analyze the data for driving variables and mechanisms underlying the N2O fluxes from various sites with different soil and vegetation characteristics. In addition, we organize measurement campaigns (via the INTERACT remote access program) to quantify N2O fluxes across a wide variety of Arctic sites using a network of collaborator stations with simple, standardized methods, and combine this N2O screening with GIS approaches to scale up the N2O fluxes step-wise from plot to regional and circumarctic levels. Ultimately, these data will be combined with existing data-sets and archived in a database that will be made available for process modelers in order to develop and improve the performance N2O models for permafrost soils.
N2O flux data were published in 21 articles from 16 Arctic sites. In the frame of this project, N2O flux measurements were conducted in 2018 at 18 study sites located in Russia, Scandinavia, Svalbard, Canada and Alaska. First analyses show that N2O is released from a range of environmentally distinct sites and at variable magnitudes with soil N content, soil C/N ratios, vegetation cover, water availability, and nutrient content likely playing significant roles. Ultimately, this project will not only provide a valuable input towards the first estimate of the circumarctic N2O budget but also towards understanding the controls of Arctic N2O fluxes which is necessary for future projections. There is urgent need for collaboration among partners in this effort and we would thus like to invite interested researchers to contribute with further published or unpublished data on N2O fluxes/concentrations from Arctic sites to support our synthesis effort. Scientists are also highly requested to sample additional N2O data from "their" Arctic sites with the simple methods introduced here, in order to help us filling large data gaps.

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# Glacial drainges and trasfer of freshwater to the Artcic Ocean in Kongsfjorden (Svalbard)

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Most of the Svalbard fjords are affected by freshwater and sedimentation from glaciers and riverine inflow, as well as sea-ice dynamics from seasonal ice formation and melt (e.g., Svendsen et al., 2002). Moreover, many glaciers on Svalbard are retreating and have shown decreasing glacier volume (e.g., Kohler et al., 2007; Nuth et al., 2010; Moholdt et al., 2010). To study the transfers of fresh water, major ions and carbon towards the Arctic Ocean, we started an isotopic and physical-chemical monitoring of inland glacier drainages and ocean water into the Kongsfjorden, on the West-Spitsbergen shelf (Svalbard).
The inland field-work regards glacial streams that originate from different glaciers neighbouring the Kongsfjorden. Seawater sampling is performed in several points, moving from the Ny-Ålesund coast line towards the inner part of the fjord.
Here we discuss the interaction between freshwater coming from main glacier drainages and sea water at different depth and the seasonal and interannual variability of the Total Dissolved Inorganic Carbon (TDIC), partciculate matter, and freshwater fractions from 2015 to 2018 into the Kongsfjorden.
The results highligth the interaction between freshwater coming from main glacier drainages on the southern coastline of the fjord and sea water collected at different sites inside the fjord. The relation Depth-$\delta$18O (also $\delta$D) shows that upper layer water in Kongsfjorden is significantly affected by glacial melt. Indeed, the $\delta$18O and $\delta$D represent a suitable tracer to identify high-latitude freshwater sources and, more in general, to study the relationship between ocean water,meteoric water and glacier and sea-ice meltwater inside the fjord.

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# EMODnet Physics: a horizontal platform serving blue growth

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EMODnet - the European Marine Observation and Data network – is a long term marine data initiative from the European Commission Directorate-General for Maritime Affairs and Fisheries (DG MARE) involving and networking more than 150 organizations for assembling marine data, products, and metadata. The data infrastructure has been developed through a stepwise approach in 3 major phases by running 7 thematic portals, 6 regional check points and a Data Ingestion facility.
EMODnet Physics (www.emodnet-physics.eu) is a domain specific portal of portals aggregating data and metadata from several data sources. The concept of the portal is a federation, intended as 'alliance' (federation from latin foedus = alliance). This means that there is a mutual agreement between EMODnet Physics and the data providers, each contribution being visible in the portal. Interoperability is a key issue of the federated system: common vocabularies, compliance with ISO, OGC standards and adherence to INSPIRE Directive build coherent services for users, although individual components are technically different and managed by different organizations.
EMODnet Physics is developing a combined array of services and functionalities such as facility for viewing and downloading, dashboard reporting and machine-to-machine communication services, to obtain, free of charge data, meta-data and data products on the physical conditions of the ocean from many different distributed data sets (www.emodnet-physics.eu/map).
EMODnet Physics is providing Regional stakeholders and international networks with tools to serve their users and communities. As an example Physics is powering and hosting the South Ocean Observing System (SOOS) data portal (http://www.soos.aq/data/soosmap) and SOOS is helping Physics to unlock and make available more valuable data. By this a great data sharing momentum has started in the area with new datasets added on a regular basis.

EMODnet Physics has recently set up a similar portal (in pre-mode) for the Arctic region with the same goal as SOOSMap to enable additional data from the Arctic to be made available, visible and used by a wider community.

The acquisition of physical parameters is largely an automated process that allows the dissemination of near real time information. In particular EMODnet Physics is a stock-share portal strongly federated to the Copernicus Marine Environment Monitoring Service In Situ Thematic Assembly Center. Historical validated datasets are organized in collaboration with SeaDataNet and its network of National Oceanographic Data Centers. The EMODnet Physics portal is currently providing easy access to data and products of: wave height and period; temperature and salinity of the water column; wind speed and direction; horizontal velocity of the water column; light attenuation; sea ice coverage and sea level trends (relative and absolute).

EMODnet Physics is continuously increasing the number and type of platforms in the system by unlocking and providing high quality data from a growing network. Lately EMODnet Physics started working on river runoff data, total suspended matter and underwater noise (acoustic pollution).

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# Improving Arctic Observation Systems through coordination – examples from the first State of Environmental Science in Svalbard (SESS) report

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The Norwegian archipelago Svalbard in the European High Arctic is an attractive platform for research due to its location, accessibility and rich infrastructure. More than 10 nations have established world-class research infrastructure and conduct intensive research and monitoring programmes. Svalbard Integrated Arctic Earth Observing System (SIOS) is developing and maintaining a regional observational system in and around Svalbard. It addresses Earth System questions related to global change by bringing together existing and new research infrastructure owned by a large number of international research institutions, thereby attracting leading scientists in fields related to Earth System science.

The State of Environmental Science in Svalbard (SESS) report is the annual report produced by SIOS. It summarises the state of current knowledge of key Earth System Science parameters in the Svalbard region. The SESS report outlines the work that has been done in the previous years within the SIOS cooperation to optimise the observing system and recommends research priorities for the following year(s). It combines the long-term monitoring data that form the core of the observing system with new, innovative monitoring and research. In addition to evaluating the state of current knowledge, the SESS report highlights the questions that remain unanswered and recommends solutions.

The first SESS report, published 14 January 2019, takes us through all the spheres from the deep permafrost through the surface interfaces, into the ocean and into the upper atmosphere approaching space. It illustrates the breadth of Earth System Science questions as well as the breadth of Svalbard research. As the first report it provides a baseline for future reports that will provide comprehensive summaries of environmental developments. The current report focuses on knowledge gaps and recommendations on the future and is a strong contribution to the coordination efforts of SIOS. Many chapters gather for the first time researchers and data throughout entire Svalbard.

We will present the key findings from the first SESS report and discuss steps to further improve the Observing System for Earth System Science in Svalbard following the recommendations in the report.