INTAROS

OBSERVING THE ARCTIC

Technologies and methods demonstrated in the H2020 INTAROS project - Integrated Arctic Observation System

Stein Sandven and Ruth Higgins (Eds.)

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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"Collecting in situ data from a wide range of platforms and sensors is a fundamental part of an Arctic observing system. Development of the in situ observing systems requires a joint effort by many institutions working in the Arctic under challenging conditions"

- Stein Sandven, INTAROS Coordinator, Nansen Environmental and Remote Sensing Center, Norway.

Introduction

The main objective of INTAROS is to advance the development of an integrated Arctic Observation System covering ocean, atmosphere and terrestrial systems with the special focus on their in situ components. While polar orbiting satellites produce vast amounts of data from the Arctic every day, there is a large gap in the observing systems on the ground and in the ice-covered ocean. A major obstacle in developing the in situ systems is the implementation of robust platforms and sensors for use in the hostile Arctic environment.

The data from the observing systems represent the first step in the data value-chain from raw data to higher-level information products. The data is the basis for scientific analysis including modelling, development of remote sensing algorithms, and as validation data for models and satellite products. In addition to scientific observing systems, there are Community-Based Monitoring (CBM) systems where data are collected by local communities to support their requirements for information about climate change, natural resources, and other topics.

The INTAROS project has demonstrated how an integrated Arctic observation system is built on many observing sensors and platforms. For land-based observations, a number of in situ systems are operated from stations around the Arctic. For ocean-based observations, there is a significant difference between ice-free and ice-covered areas. In open ocean, ships, floats, moorings and various surface platforms are commonly used, but in the ice-covered areas it is required to use icebreakers which can deploy ice-based platforms and underwater moorings.

A major challenge in development of an integrated Arctic observing system is data management and data sharing within and between scientific disciplines. This is due to the heterogeneity and complexity of observational data collected in various scientific disciplines. With development of new instruments and platforms, the amount of environmental data collected is expected to increase year by year. Citizen science and CBM are also growing and will contribute to the observing systems. INTAROS has focuses on improving the data accessibility from a large number of distributed observing systems and to developing adequate data management systems.

In this document, we present a number of technologies and methods representing different components of an Arctic observing system, which will form the basis for further development of the system in the next decade.

Sections

1) Data Access

The data from the observing systems represent the first step in the data value-chain from raw data to higher-level data products. These products are used in scientific analysis, modelling and remote sensing algorithms. The observational data are collected in various scientific disciplines and stored in different data repositories that are organized on international, national or institutional level. The complexity of the data repositories is a challenge for data management and data sharing within and between the scientific disciplines. In this section examples of distributed data repositories are presented which are accessible via portals and catalogues. The INTAROS data catalogue is a single entry point to data produce or made available through the project.

2) Land-based Observations

The observing capacity of terrestrial observing stations has been strengthened in Greenland, Alaska, Canada, Northern Finland, and Siberia. The quality and number of observed parameters have increased and their data management (storage, access, interoperability) have improved. Novel technical solutions have been applied to increase the instrumental resilience to Arctic weather conditions and the automatization, thus enhancing temporal resolution and reducing the costs associated with human-operations. The developed instrumentation is operated from stations on the ground as well as from airborne platforms, enabling data collection on different spatial scales. These activities enable the creation of new products combining modelling, in situ and remote sensing observations, and increase the value of supersites, which are multidisciplinary stations belonging to multiple networks. Supersites provide long time series for climate monitoring and ground truth for validation/calibration of satellite-based data and model development. An example is the delivery of Merged Observatory Data Files (MODF) for the Year of Polar Prediction Supersite Model Intercomparison Project (YOPPSiteMIP).

3) Marine-based Observations

The observing systems for the ocean areas are based on field experiments with ships and icebreakers in the central Arctic Ocean, in the Svalbard area, the Fram Strait, Barents Sea, Baffin Bay and in the coastal waters of Greenland. Data are collected along the sailing routes from ships carrying atmospheric and oceanographic instruments, mainly during the summer when most of the ship cruises take place. Icebreakers are used to deploy and recover instruments in ice-covered areas, in particular drifting ice buoys (SIMBA and ITP buoys), oceanographic and acoustic moorings and seafloor observatories that operate continuously through the year. During ice stations in situ measurements of sea ice thickness and snow cover are obtained together with atmospheric and ocean observations. In the ice-free waters Argo floats and gliders are also used. In addition to physical oceanography, data collection includes biogeochemical variables (pCO2, pH), isotope analysis, optical measurements, and passive acoustics. A significant part of the work is devoted to testing the instruments and preparing for deployment and recovery during the field expeditions. Calibration, processing and analysis of the collected data is performed before uploading to various data repositories.

4) Satellite Observations

Polar orbiting satellites provide regular data coverage of all Arctic land and ocean areas. The data are important both for long-term climate observations and in daily, operational monitoring providing near real-time data for weather and ice forecasting. The data are used to retrieve a number of environmental variables, e.g. of sea ice, snow, glacier, hydrology, vegetation, permafrost, biodiversity and more. The Copernicus programme with the series of Sentinel satellites and other polar orbiting satellites represent the most extensive contribution to the Arctic observing systems. However, the satellite data require in situ data for algorithm development and validation of the data products.

5) Community-based Observations

In the Arctic, it is a priority of governments and Indigenous peoples' organizations to increase the spatial and temporal coverage of environmental observations. One solution is to enhance community-based monitoring and citizen science observations. By their nature, community-based and citizen science programs tend to focus on those issues of greatest concern to local stakeholders; thus, outcomes from such observing programs have considerable potential to influence on-the-ground decision making and natural resource management. Arctic community-based and citizen science programs are diverse, with many successful approaches. In this section examples of community-based systems are presented ranging from programs entirely undertaken by community members to programs led by scientists and where citizens are collecting the data.

6) Climate Modelling and Observations

Relevant observational data are needed to develop, evaluate and initialize various numerical models used in research and services. Modelling systems are invaluable tools to understand climate and environmental processes. The climate model systems are important for prediction of future climate under different mitigation scenarios and provide input to assessments of climate change, climate services and climate impact research. In this section examples are presented showing how some modelling systems use observational data.

Data Access

"INTAROS generates unique Arctic datasets from ocean, sea ice, land and atmosphere. Storing data in sustained open repositories using standard metadata and data formats ensures long-term availability for reuse by science, public and private sector, and accrediting data producers."

- Torill Hamre, Nansen Environmental and Remote Sensing Center, Norway.

Nansen Environmental and Remote Sensing Center

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Survey of Arctic in situ observing systems and data collections

Marine data in the Arctic – From mapping to knowledge. ARCMAP was a spinoff project from INTAROS with the objective to develop a web-based survey application for collection of updated information about Arctic in situ observing systems and their collected data.

The background for ARCMAP was a questionnaire used in INTAROS for surveying in situ observing systems in the Arctic (Fig. 1). The results of the survey are available in Ludvigsen et al. 2018).

ARCMAP
FROM MAPPING TO KNOWLEDGE

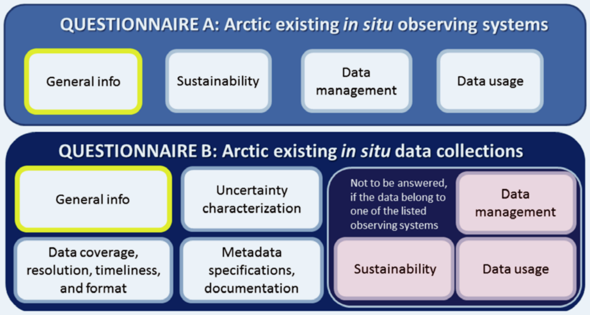

Fig. 1 Structure of the questions used in the INTSAROS survey.

In ARCMAP we

- Extend the questionnaires from INTAROS
- Develop a web-based survey application for easy registration and update of information
- Develop tools to analyze the collected information
- Conduct a survey among Norwegian institutions

ARCMAP survey application is developed in Python and JavaScript using open source frameworks Django and wq. The application can be run in a common web browser; no additional plugins are needed.
ARCMAP is accessed at
https://arcmap.nersc.no/#ac_3575/2/90.0/0.0

ARCMAP development has been supported by the Norwegian Ministry for Climate and Environment and the Nansen Environmental and Remote Sensing Center.

References:
Ludvigsen, C. A., Pirazzini, R., Sagen, H., Hamre, T., Sandven, S., Stette, M., et al. (2018). INTAROS Deliverable 2.1. Report on Present Observing Capacities and Gaps: Ocean and Sea Ice Observing System.

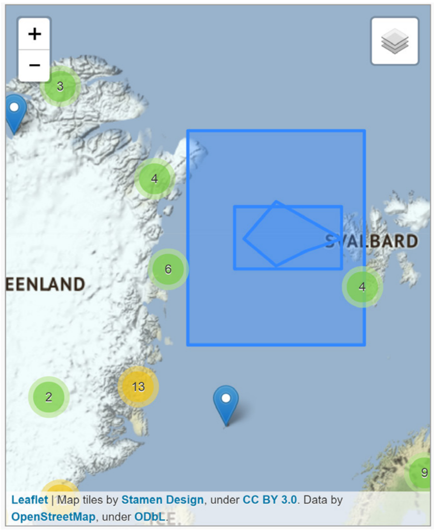

Fig. 2 Map of the areas surveyed by ARCMAP.

Contributors: Frode Monsen and Tor I. Olaussen (NERSC) and Roberta Prazzini (FMI).

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INTAROS Data Catalogue and iAOS Portal

The objective of the INTAROS Data Catalogue is to provide access to datasets collected or generated in the project. The iAOS Portal contains the INTAROS Data Catalogue and provides access to additional selected data from other sources and services developed within the project as well as in spin-off projects. Together the data catalogue and portal offer a joint access point to the data incorporated by the integrated Arctic Observation System (iAOS).

INTAROS collects data in different areas (Fig.1) and spheres, using scientific instruments and through community-based monitoring. These data as well as data from earlier projects documented and formatted by partners in the project are registered in the **INTAROS Data Catalogue**. The metadata for each dataset includes, among others, a list of parameters, keywords, data license, available formats, contact details and links for data access.

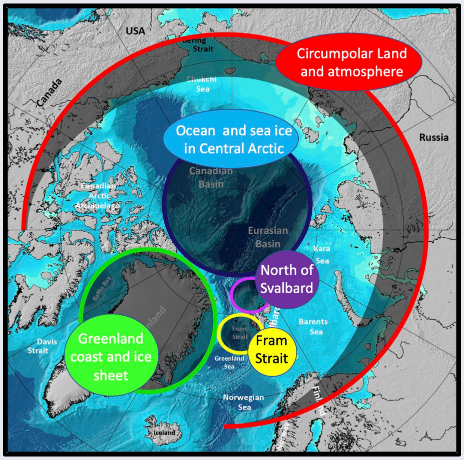

Fig. 1 Regions targeted in INTAROS.

The **iAOS Portal** provides access to selected data from other data repositories, chosen services developed in the project and descriptions of some of the observing systems feeding data into the iAOS (Fig.2).

Users can search the INTAROS Data Catalogue and the iAOS Portal by multiple facets:

- Title (free text)
- Keyword
- Data provider
- License
- Format

INTAROS Data Catalogue:
https://catalog-intaros.nersc.no

iAOS Portal:
https://portal-intaros.nersc.no

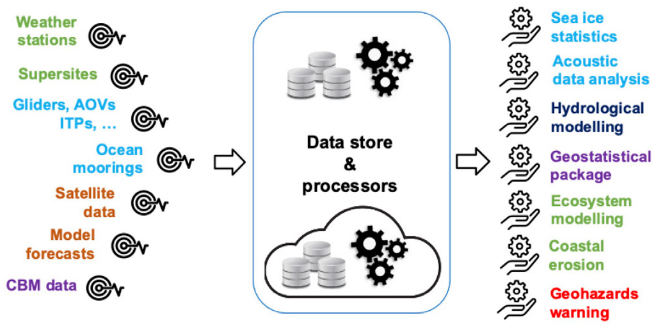

Fig. 2 Data value chain in iAOS.

Contributors: All partners collecting or generating data in the project are contributing to the INTAROS Data Catalogue.

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INTAROS Data Catalogue Example Dataset

INTAROS collects data in different areas and spheres, using scientific instruments and through community-based monitoring. In addition, partners work with satellite data and run numerical models to derive important environmental parameters.

Resulting data are registered in the INTAROS Data Catalogue with metadata providing contact details, data license, formats and links to where data are stored. The long term storage of data is ensured by existing Arctic data systems with secured funding.

In the project, GEUS has derived ice velocity maps of Greenland from Sentinel-1 imagery (Fig.1). These maps can be found through the INTAROS Data Catalogue, providing a description of the spatial and temporal resolution as well as a data access link (Fig.2).

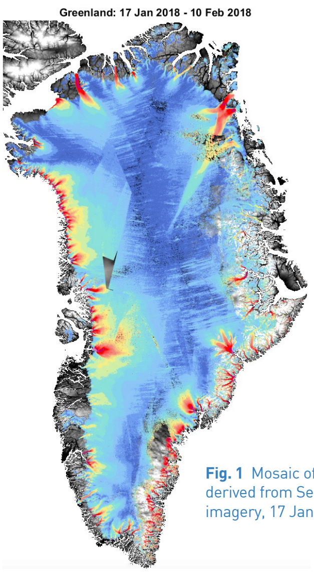

Fig. 1 Mosaic of ice velocity derived from Sentinel-1 imagery, 17 Jan – 10 Feb 2018.

Ice velocity maps of the Greenland ice sheet margin based on Sentinel-1 data

This dataset consists of Ice velocity maps with a high temporal resolution. The velocity maps are derived from Sentinel-1 A and B SAR data using offset-tracking. The maps cover the Greenland Ice Sheet margin (and the interior when data is available) with a grid resolution of 500 m. Each product is a mosaic produced of all 12-day image-pairs and a selection of 6 day image-pairs available within the timeperiod of two consecutive cycles –i.e. 24 days. A new product is produced every 12 days.

Data and Resources

IV_20180117_20180210.png
PROMICE ice velocity maps covering the Greenland ice sheet margin: an...

Explore

Greenland | Ice velocity | SAR | Sentinel-1

Additional Info

Field	Value
Source	https://dataverse01.geus.dk/dataverse/Ice_velocity
Principal Investigator	Robert S. Fausto
Data Curator	Anne Solgaard
Version	2.0
State	active
Last Updated	March 11, 2021, 2:53 PM (UTC+01:00)
Created	November 26, 2018, 2:59 PM (UTC+01:00)
Parameter name(s)	Ice surface velocity
Project/Program name(s)	PROMICE is supported by Danish Cooperation for Environment in the Arctic (DANCEA) under the Danish Energy Agency and the Geological Survey of Denmark and Greenland (GEUS)
Observing system name	PROMICE - Programme for Monitoring of the Greenland Ice Sheet

Fig. 2 Dataset page for the GEUS ice velocity map.

- INTAROS Data Catalogue: https://catalog-intaros.nersc.no
- Access to data: https://dataverse01.geus.dk/dataverse/Ice_velocity

NERSC GEUS

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YOPP Merged Observatory Data File for Sodankylä

The Merged Observatory Data Files (MODF) are produced for intercomparison between observations from several supersites and weather/climate models. The MODFs apply the same nomenclature and format (netCDF) as the model output files.

The YOPP Model Inter-comparison Project organizes process-based evaluation and verification of numerical weather prediction and climate models with observations from key locations in the Arctic, Antarctic and Third Pole.

Sodankylä observatory is located just north of the Arctic Circle, in Lapland, Finland.
The Sodankylä supersite is a cluster of stations due to the fact that in an area of few square kilometers, there are various measurement towers/sites serving different purposes and projects. Some of the sites are shown in Figure 1 and include the Micrometeorological and ICOS towers, the automatic sounding station, and the Petland site. Data from each station will be included in the Sodankylä MODFs.

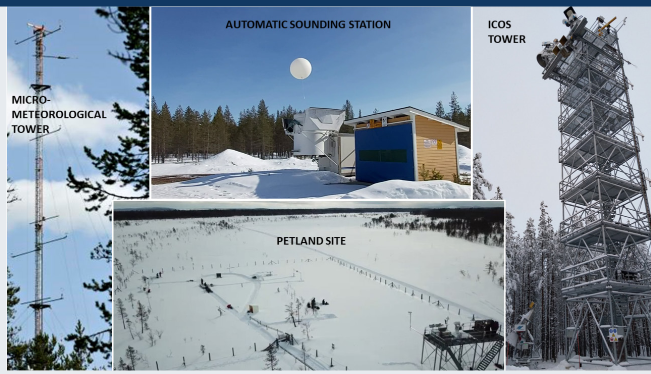

Fig. 1 Photos of selected station in the Sodankylä supers

FMI provides a separate MODF for each YOPP Special Observing Period (SOP) from 2018 to 2020. Each MODF will have a DOI and be openly accessible through the YOPP data portal (https://yopp.met.no).
The Sodankylä MODFs are initially used by the partners in YOPP and in the H2020 APPLICATE project. In particular, they will be applied to test and develop numerical weather prediction models to improve the forecasts in the Arctic. Also other scientists will use the Sodankylä dataset for model validation and process studies.

Reference:
Arduini, G et al. (2019). Journal of Advances in Modeling Earth Systems, https://doi.org/10.1029/)

Table 1 Extract from the content of the Sodankylä MODFs

Surface variables	Energy fluxes	Radiosonde measurements
Surface snow thickness	Upward surface shortwave radiation	Radiosonde latitude
Surface snow area fraction	Downward surface shortwave radiation	Radiosonde longitude
Snow water equivalent	Upward surface longwave radiation	Radiosonde altitude
Snow surface skin temperature	Downward surface longwave radiation	Radiosonde air pressure
Snow temperature	Surface turbulent latent heat flux (bulk method)	Radiosonde air temperature
Snow density	Surface turbulent latent heat flux (Eddy covariance method)	Radiosonde air humidity
Canopy area fraction	Surface turbulent sensible heat flux	Radiosonde wind speed
Surface ground skin temperature	Ground heat flux	Radiosonde wind direction
Soil temperature	Surface albedo	

Contributors: Anna Kontu, Rigel Kivi, Roberta Pirazzini, and Markku Kangas (FMI).

FMI YOPP YEAR OF POLAR PREDICTION

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PEEX Russia in situ observations metadata

The objective is to provide overview of the Russian Arctic-boreal in-situ station networks, and to facilitate further collaboration between stations and international community.

e-Catalog, coordinated in collaboration with Gepgraphical Faculty of the Moscow State University, provides for stations information on measurement capacities, facilities and instrumentation used, primary contacts and data requests.

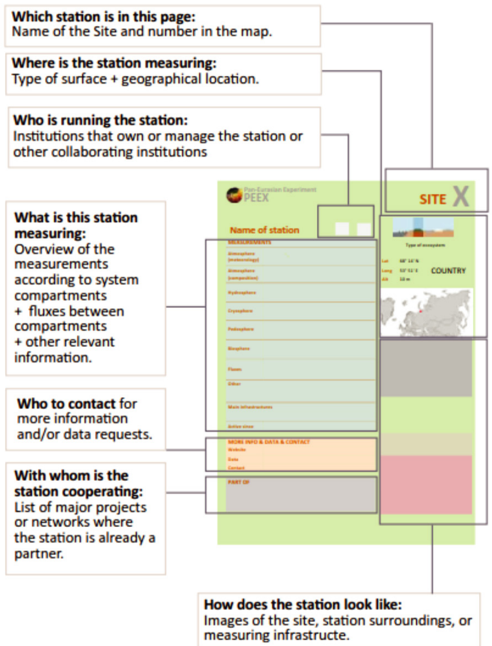
Users and stakeholders:

- Research communities inside and outside Russia.
- Policy & decision-makers: planning future Artic and high northern latitude observational systems.

Impact - datasets as products for:

- multi-scale modelling of atmosphere – ecosystem interactions and feedbacks
- assessment studies of environmental impact science education & training

e-Catalogue:
https://www.atm.helsinki.fi/peex/index.php/portfolio-items/in-situ-stations/?portfolioCats=38



Pan-Eurasian Experiment PEEX
INAR INSTITUTE FOR ATMOSPHERIC AND EARTH SYSTEM RESEARCH
ACCC ATMOSPHERE AND CLIMATE COMPETENCE CENTRE

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Land-based Observations

"The Arctic land surface is home to a wide range of interacting processes with multiple linkages and feedbacks. Only by an integrated approach to observing and modelling this complex system can we begin to understand how it functions now, how it will evolve, and its role as a driver and responder to climate change."

- Shaun Quegan, University of Sheffield, UK.

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SodSAR radar system

SodSAR is a ground-based imaging radar system aiming to provide quasi-continuous monitoring capability of soil, snow cover and vegetation at microwave frequencies.

SodSAR is a fully polarimetric tower-based wide frequency (1-10 GHz) range Synthetic Aperture Radar (SAR) installed in Sodankylä, Finland (Fig. 1). The system is based on a Vector Network Analyzer (VNA) operated scatterometer mounted on a rail allowing the formation of SAR images, including interferometric pairs separated by a temporal baseline. The radar was developed in collaboration with FMI and Harp Technologies Ltd. (Finland).

More information:
https://www.harptechnologies.com/references/

Fig. 1 SodSAR mounted on a 21 m tall tower.

SodSAR will be used to develop retrieval methods for satellite SAR systems (e.g. ALOS-2, Sentinel- 1, TerraSAR X) with focus on cryosphere applications. Commercial ground-based systems with equivalent capabilities are not widely available, and SodSAR has the potential to provide unique multi-frequency datasets for refining existing satellite products and enable the generation of new retrieval algorithms.

Reference:
Jorge Ruiz, J.; Vehmas, R.; Lemmetyinen, J.; Uusitalo, J.; Lahtinen, J.; Lehtinen, K.; Kontu, A.; Rautiainen, K.; Tarvainen, R.; Pulliainen, J.; Praks, J. SodSAR: A Tower-Based 1–10 GHz SAR System for Snow, Soil and Vegetation Studies. Sensors 2020, 20, 6702. https://doi.org/10.3390/s20226702

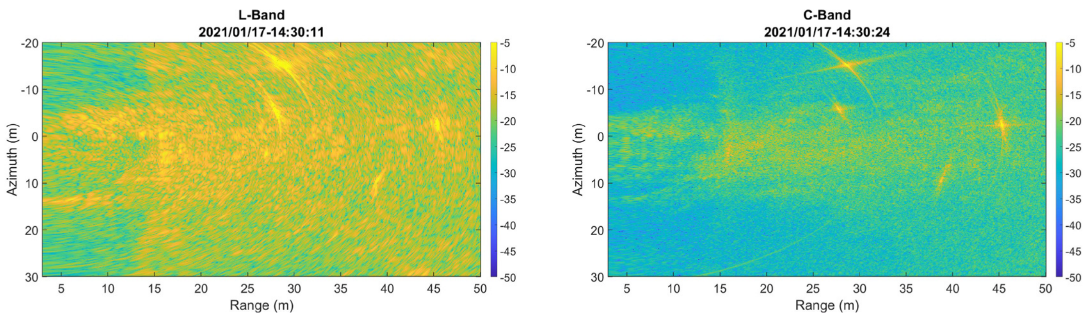

Fig. 2 Examples of SodSAR imagery of backscatter (in dB) of a forested site. Imaging direction from left to right. Corner reflectors used for calibration appear as bright objects in the images.

Collaborator: Harp Technologies Ltd.

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The SVC-FMI spectro-albedometer continuously measures spectral albedo in the solar wavelength range (350-2500 nm). It is built to operate in polar weather conditions.

Continuous measurements of snow spectral albedo

The snow albedo feedback process shows large variability in the climate models. Snow albedo is therfore one of the key climate variables which need more observations

The spectro-albedometer is part of Arctic climate observation aparatus installed in the Sodankylä field station, Finland (Fig. 1).
This prototype spectro-albedometer (Fig. 2), built by Spectra Vista Corporation in collaboration with FMI, has been calibrated, tested and then installed in Sodankylä to provide ground truth for satellite optical measurements. Raw data are collected every 2 minutes, (Fig. 3). Processed data stored in netCDF format will be openly accessible from FMI.

Fig. 1 Deployment of the spectro-albedometer in the field.

The data will be used to validate/calibrate satellite-based radiances, radiative transfer codes and snow albedo schemes. These unique data will integrate and increase the value of the large collection of in situ surface and atmospheric variables measured at Sodankylä.

Site description and link to in situ and satellite data are available online (https://fmiarc.fmi.fi)

Fig. 2 View of the SVC instrument left) and its internal components (right) where it is connected to the optical tube and the two integrating spheres.

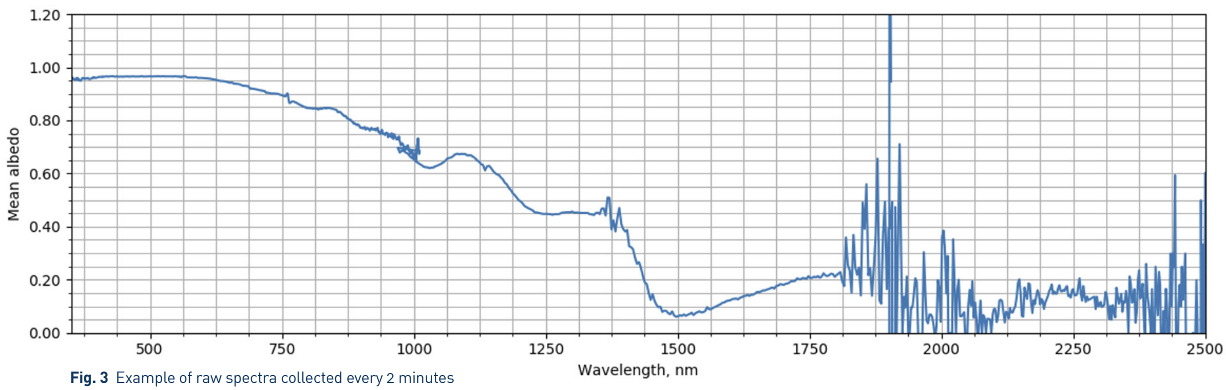

Fig. 3 Example of raw spectra collected every 2 minutes

Contributors: Henna-Reetta Hannula, Petri Räisänen and Rostislav Kouznestov (FMI).

FMI

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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The Polish polar station in Svalbard

The Polish Polar Station Hornsund (77°00′N, 15°33′E) is situated in Hornsund fjord in the south-western part of Spitsbergen. It is a modern interdisciplinary scientific station performing research projects to better understand the functioning of the Arctic climate and ecosystem changes.

The station conducts year-round scientific observations and is the northern-most permanent Polish scientific station. The meteorological station no. 01003 has been working continuously under WMO since 1978. The station is managed by the Institute of Geophysics, Polish Academy of Sciences. Data are collected in a number of scientific disciplines: Meteorology, hydrology, oceanography, glaciology, seismology, earth magnetism, ionospheric research, atmospheric physics and optics, and other environmental research. The data have been collected over many years and contribute to many international networks. The Hornsund station is a member of the Svalbard Integrated Arctic Earth Observing system (https://sios-svalbard.org/)

Fig. 1 Map of Svalbard with location of Hornsund station

Inter-seasonal weather fluctuations are determined by the changing Arctic climate system and atmospheric circulation. Weather conditions are crucial factors that have local feedback on many environmental components. Meteorological variables collected at Hornsund help to characterize the climate variability in this part of the Arctic and for a long time have been the background for multiple studies conducted in Southern Spitsbergen. Long-term in situ measurements in the Arctic are rare. Therefore, data from the Hornsund station are very valuable for weather forecasting and climate monitoring.

Link to the station
https://hornsund.igf.edu.pl/en/

Fig. 2 Photos of the Hornsund station in winter (upper picture) and summer (lower picture)

Contributors: Piotr Głowacki and Tomasz Wawrzyniak, (IG-PAS).

Institute of Geophysics
Polish Academy of Sciences

HORNSUND
POLSKA STACJA POLARNA

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Polish Academy of Sciences

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Meteorological data series collected at the Hornsund station

A major activity at the Polish Polar Station Hornsund is to collect meteorological data as input to weather foreacssting and climate monitoring. The Hornsund weather station works is part of the Norwegian station network and is registered by the WMO (World Meteorological Organisation) as number 01003. Basic meteorological parameters are measured and observed here systematically following WMO standards.

The meteorological parameters measured in Hornsund include:

- Air temperature, humidity, wind speed, wind direction, atmospheric pressure, dew point, solar radiation;
- Precipitation rain gauges;
- Ground temperatures;
- Snow cover, snow water equivalent and spatial distribution in the nearby catchment;
- Cloudiness, cloud types, cloud base (using 2017 ceilometer);
- Visibility and other weather phenomena.

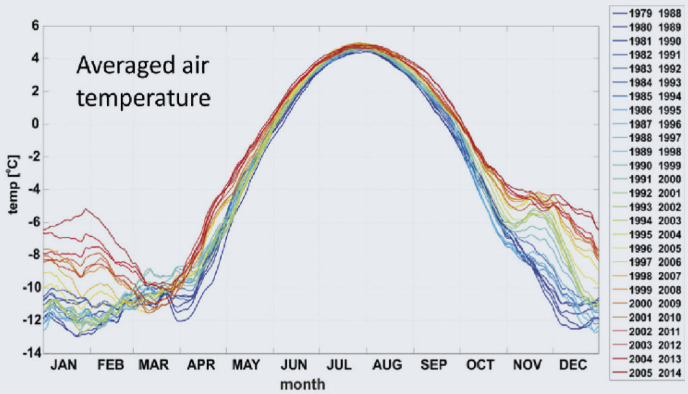

Fig. 1 Average air temperature at Hornsund from 1979 to 2014

Meteorological variables collected at Hornsund are important for monitoring the climate variability in this part of the Arctic. The data have for a long time been used in climate studies in the region. Statistical analysis of long time series indicates a significant positive trend of air temperature for almost every day throughout the year. The largest changes in precipitation are found from August to early November.

Link to the station
https://hornsund.igf.edu.pl/en/

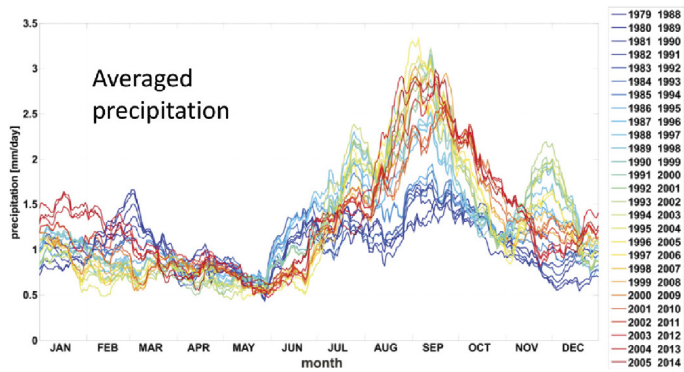

Fig. 2 Average precipitation at Hornsund from 1979 to 2014

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Snow, permafrost and atmospheric observations in the Canadian Arctic

Arctic permafrost is thawing, with the potential of releasing large amounts of CO_2 and CH_4 from the decomposition of frozen organic matter. Projections of the rate of thawing and gas release are uncertain because of poorly understood feedbacks. Monitoring of snow, permafrost and atmosphere are used to understand processes and detect feedbacks.

The observing sites (Fig.1) include Kuujjuarapik and Umiujaq in southeastern Hudson Bay and Bylot Island north of Baffin Island. Data until August 2021 were retrieved and analyzed.

The data from these sites contributes to the monitoring of Arctic climate change. Holistic snow, atmosphere and permafrost data sets are invaluable for model forcing and evaluation.

Bylot Island data are available at https://doi.org/10.5885/45693CE-02685A5200DD4C38

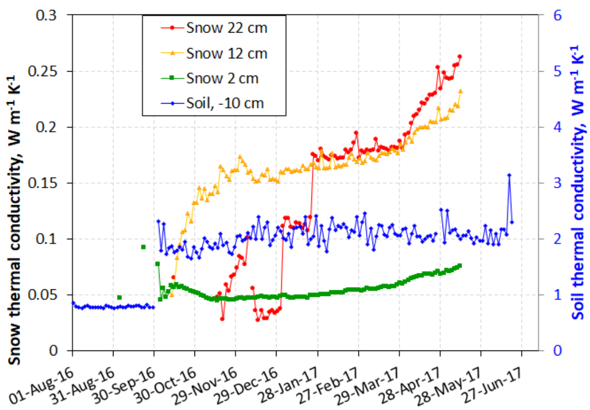

Fig. 2 Snow and soil thermal conductivity data from Bylot Island.

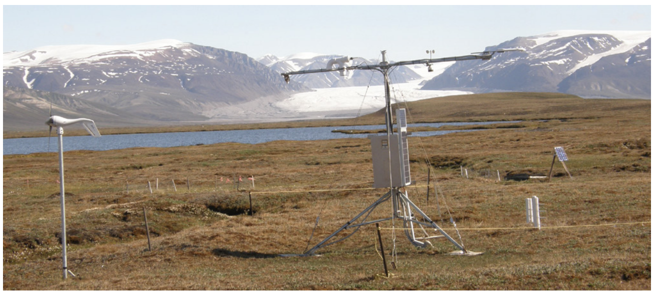

Fig. 3 Photo of the observing station at Bylot Island.

TAKUVIK UNIVERSITÉ LAVAL cnrs

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Geological Survey of Denmark and Greenland

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Automatic weather stations on the Greenland Ice Sheet

The objective is to provide accurate measurements of the surface and near-surface atmospheric conditions, important for present and future assessment of mass changes of the Greenland ice sheet.

The automatic weather stations contribute to the long-term in situ observations as part of PROMICE – Programme for Monitoring of the Greenland Ice Sheet.

Automatic weather stations (AWSs) provide hourly transmissions of weather and ice data from more that 20 sites on the Greenland Ice Sheet.

The AWS data is used for:

- Validating satellite data
- Validating regional climate models
- Improving weather prediction
- Improving sea level rise models

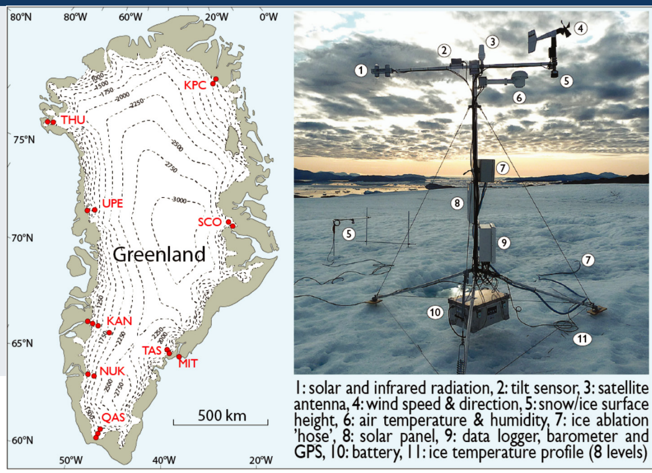

Fig. 1 Map of the Greenland Ice Sheet with location of some AWSs and photo of an AWS with all the sensors

Upgrading the PROMICE AWSs

The snow water equivalent (SWE) of a snowpack in Greenland is a major mass budget term. The new data quantifies the mass accumulation as snow during the winter season.

Data access:
https://doi.org/10.22008/promice/data/aws

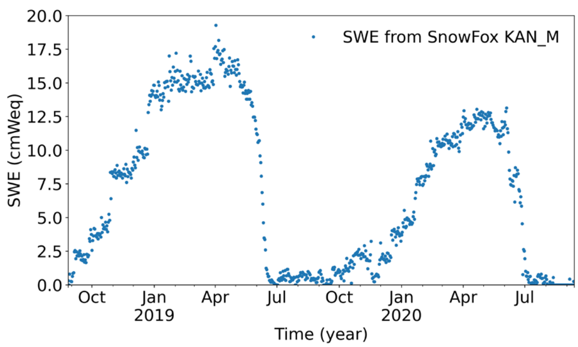

Fig. 2 Example of SWE data from SnowFox and KAN_M

Fig. 3 Photo of the SnowFox system.

Danish Ministry of Climate, Energy and Utilities

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Solid ice discharge from the Greenland Ice Sheet

Geolgical Survey of Denmark and Greenland

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The objective of this work is to calculate solid ice discharge from the Greenland Ice Sheet on weekly scales using an automated and reproducible procedure. The work is part of PROMICE – Programme for Monitoring of the Greenland Ice Sheet. The next step is to combine the solid ice discharge with the runoff and basal mass loss to estimate the total ice sheet mass balance.

Solid ice discharge at all Greenland Ice Sheet outlet glaciers is calculated using a combination of ice velocity maps, bed topography, surface elevation and surface elevation change. Fig. 1 shows fast-moving ice in orange, with inserts showing the gates at the eight top-discharging glaciers located using criteria for fast flow (> 100 m/yr) and 5 km distance from the current glacier front.
Fig. 2 shows the total solid ice discharge from the ice sheet since 1986 to present. The time series is updated continually as new data become available. Long time series of solid ice discharge are important for researchers as well as policymakers.

Data is available from www.promice.dk

Reference:
Mankoff, K. D.,et al. Greenland Ice Sheet solid ice discharge from 1986 through 2017, Earth Syst. Sci. Data, 11, 769–786, https://doi.org/10.5194/essd-11-769-2019, 2019

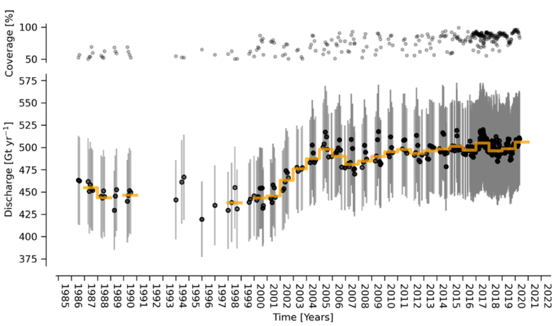

Fig. 2 Time series of total solid ice discharge.

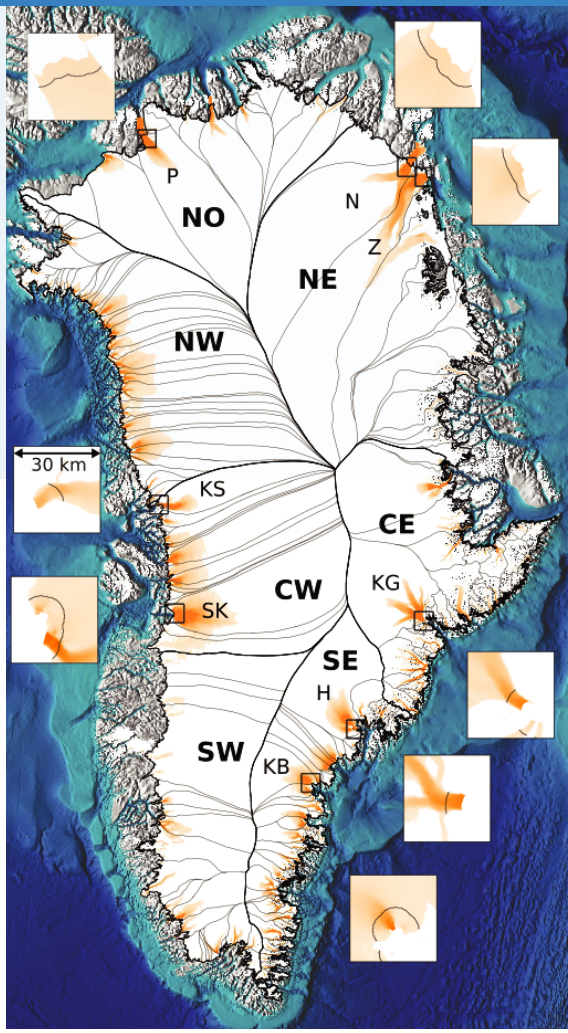

Fig. 1 Overview showing fast-flowing ice (orange, greater than 100 m/yr) and the gates for the top eight discharging glaciers.

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Changes in the extent of the tidewater glacier as a component of frontal mass balance assessment

Fluctuations of the glacier front are essential components contributing to the changes in the tidewater glacier mass. Glaciers extent is sensitive to environmental changes within the ocean-atmosphere-glacier system. Remote sensing monitoring of front positions significantly contributes to the development of methods of assessing mass changes of glaciers and ice sheets. The objective of the work is to collect remote sensing data on the Hansbreen front positions and combine them with field observations to understand air-glacier-ocean interactions.

Remote sensing data are used for the long-term and seasonal observation of front fluctuations of Hansbreen, a tidewater glacier in Hornsund, Svalbard. Front fluctuations between 1992 and 2015 are studied based on a remote sensing dataset and are compared to air temperature, precipitation, sea temperature, sea ice cover, glacier surface velocity, surface mass balance and seawater depth at the terminus.

The glacier retreated considerably throughout a bedrock overdeepening in the very warm period 2012–2014. The long-term retreat was interrupted by glacier advances in colder years, regardless of the water depth at the front. The duration of the retreat and advance periods are strongly correlated with the sea surface temperature.

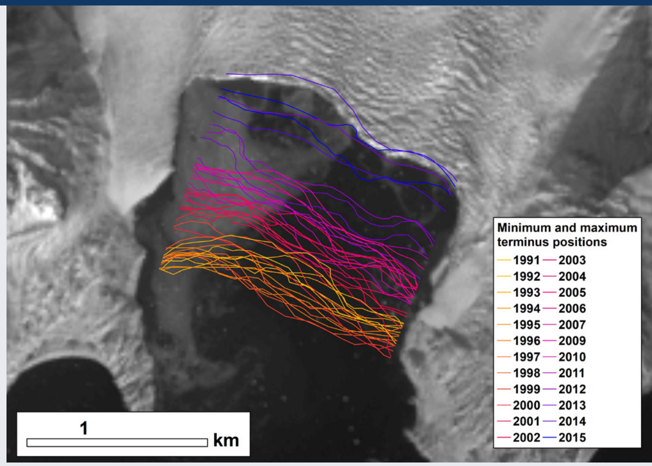

Fig. 1 Minimum and maximum terminus positions of Hansbreen, Spitsbergen.

Front fluctuations data:
http://ppdb.us.edu.pl/geonetwork/srv/eng/catalog.search#/metadata/77c6fbd4-1a07-47b1-a663-559970517841

Other glaciological datasets available at:
http://ppdb.us.edu.pl/geonetwork/srv/eng/catalog.search#/home

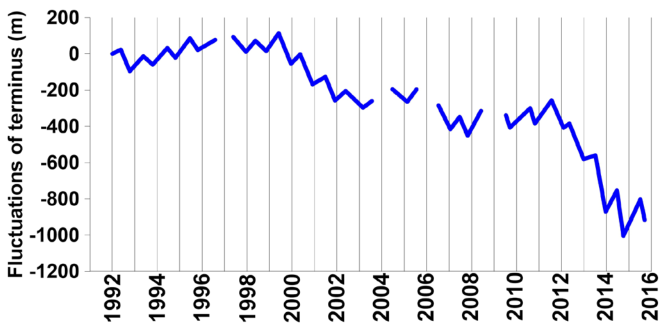

Fig. 2 Fluctuations of Hansbreen terminus position 1992 - 2016.

References
Błaszczyk, M., Jania, J. A., Ciepły, M., Grabiec, M., Ignatiuk, D., Kolondra, L., et al. (2021). Factors controlling terminus position of Hansbreen, a tidewater glacier in Svalbard. Journal of Geophysical Research: Earth Surface, 126, e2020JF005763. https://doi. org/10.1029/2020JF005763

Contributors: University of Silesia in Katowice, Institute of Geophysics PAS, Institute of Oceanology PAS, Svalbard Integrated Arctic Earth Observing System, University of Gdansk, NORBIT-Poland, Gdynia Maritime University

UNIVERSITY OF SILESIA IN KATOWICE

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INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Ice discharge split into solid iceberg production and submarine melt

The overall objective is to develop a coupled glacier-fjord model allowing the separation of the ice discharge to the ocean into iceberg production and submarine melting at the glacier front. It will be applied as a test case to the Hansbreen-Hansbukta system in Svalbard.

With the increasing impact of the ocean on the glaciers, our model is a good tool for estimating the **share of submarine melting and iceberg production (calving) to the Frontal Mass Loss:** calving 54%, submarine melt: 46%. Datasets used in the model are glacier velocity and thickness, temperature and salinity in the fjord obtained in collaboration with the Hornsund station.

The model components:

GLACIER MODEL (ELMER/ICE) → ICEBERG PRODUCTION → FJORD MODEL (MIT GCM) → SUBMARINE MELT → GLACIER MODEL (ELMER/ICE)

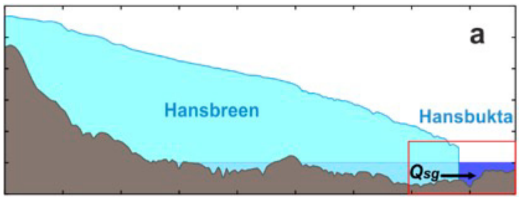

Fig. 2 Section of the modelled glacier-fjord system, and the location of the subglacial discharge current (Qsg) entering the fjord waters from underneath the glacier

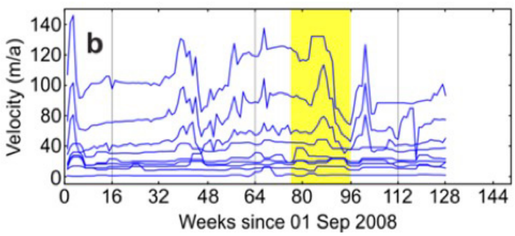

Fig. 3 Ice velocity data at the glacier surface, for the stakes at the central flowline. The highest velocities corrrespond to the stakes closer to the glacier front.

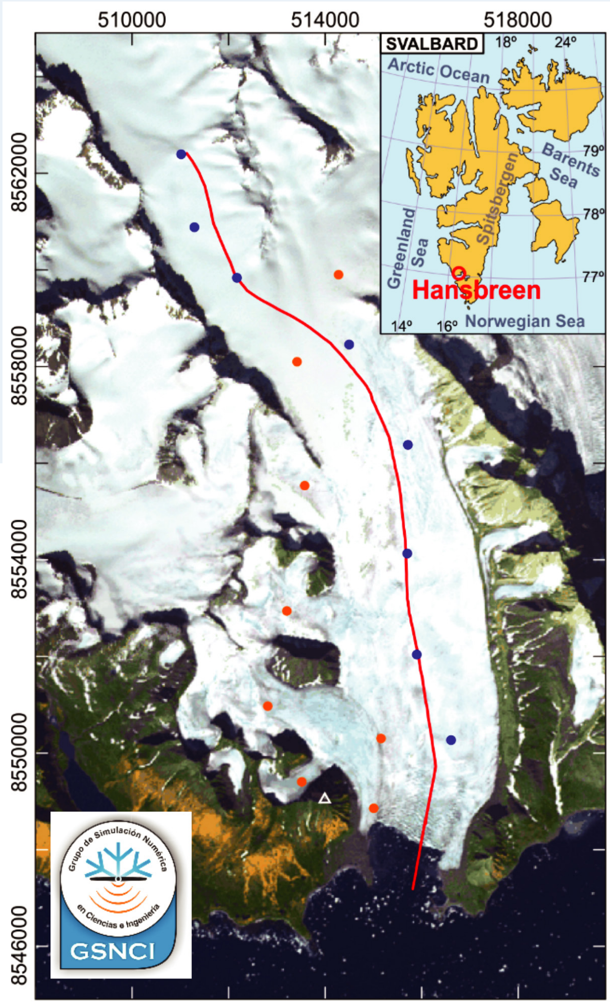

Fig. 1 Hansbreen glacier with location of velocity and mass balance stakes and the modelled central flowline.

Contributors: Eva De Andrés (UPM), Jaime Otero (UPM). Waldemar Walczowski (IOPAN), Bartek Luks (IGPAN). Mariusz Grabiec (Un. Silesia)

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INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Ground-penetrating radar system development

The main aim is to develop a new ground-penetrating radar system, remotely controlled from a helicopter cabin. Airborne radar profiling is fundamental to be able to measure the ice thickness near the highly-crevassed areas of marine-terminating glaciers, where the crevasses make it impossible to acquire radar data from the glacier surface. Accurately knowing the glacier thickness near the marine-terminating fronts is essential to estimate the ice discharge from glaciers to the ocean.

The radar system components and its deployment for fieldwork are shown in figure 1 and 2.
Two fieldwork tests of the equipment have been done in Livingston Island, Antarctica, during 2016-2017 and 2018-2019 campaigns (Fig. 3).

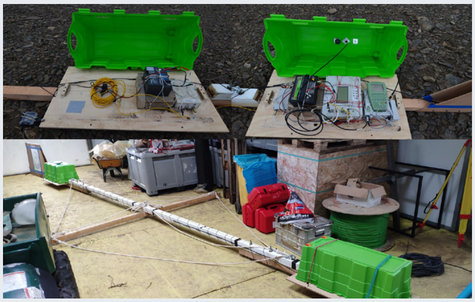

Fig. 1 The radar system consists of a transmitter, a receiver and a control unit that also includes the digital recording system, together with transmitting and receiving antennas.

Fig. 2 Operating the radar system from a helicopter.

In the two field campaigns we performed helicopter-borne radar profiling, retrieving the glacier thickness along more than 200 km of radar survey lines. An example is shown in Fig. 3 where the vertical axis represents the radar wave travel time. The uppermost reflection corresponds to the glacier surface. The image reflects the difficulties of processing and interpretation, as reflections from surrounding mountain outcrops overlap the surface and bed reflections, and multiple reflections are also observed.

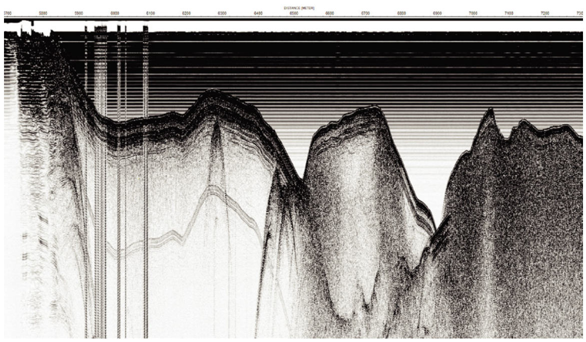

Fig. 3 Example of a radar profile along a 1.5 km transect

Contributors: Javier Lapazaran (UPM) and Evgeny Vasilenko (Uzbekian Acad. Sci.).

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

GFZ German Research Centre for Geosciences

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Airborne observation of turbulent fluxes

The objective of the airborne observations was to provide regional-scale heat and GHG flux estimates and evaluate the representativeness of stationary monitoring sites in the Arctic.

The AWI research aircraft Polar 5 was used to collect a range of atmospheric data during campaigns in the Arctic. For this study the aircraft data provided spatially extensive temporal snapshots of surface-atmosphere heat and greenhouse gas (GHG) fluxes. The data were processed into gridded flux maps in combination with in situ data, numerical simulations, satellite remote sensing data and machine learning [1,2].

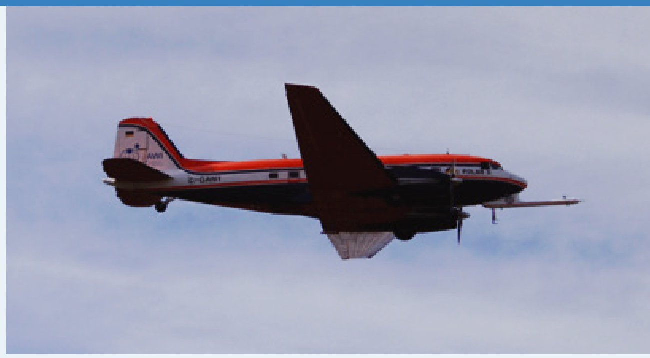

Fig. 1 Research aircraft Polar 5 (AWI)

The gridded maps of sensible and latent heat flux, CO_2 flux, and CH_4 flux were produced in 100 m x 100 m resolution for discrete periods in the summers of 2012, 2013, and 2016 (Fig. 2).
The airborne data are important for field researchers and modelers to analyze and evaluate field site or grid cell spatial heterogeneity, patterns, and representativeness.

Data access:
https://catalog-intaros.nersc.no/dataset?q=GFZ

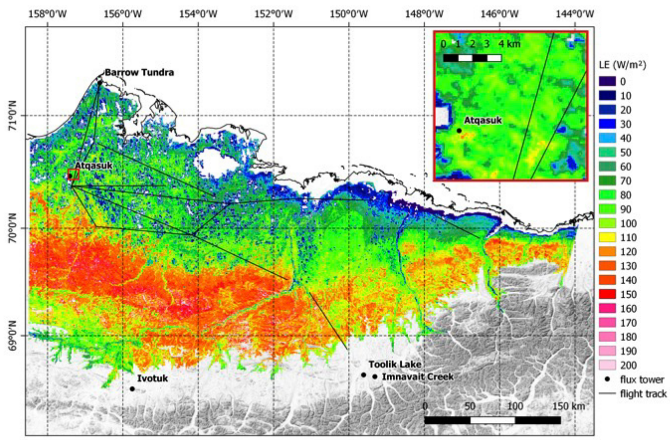

Fig. 2 Latent heat flux on the North Slope of Alaska at the end of June / beginning of July 2012 as derived from airborne eddy covariance flux measurements.

References:
[1] Hartmann et al. (2018), Atmos. Meas. Tech. https://doi.org/10.5194/amt-11-4567-2018
[2] Serafimovich et al. (2018) Atmos. Chem. Phys. https://doi.org/10.5194/acp-18-10007-2018

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Cold season carbon loss in the Arctic

The objective is to improve the estimation of greenhouse gas fluxes in the Arctic and understand the spatial and temporal variability of the fluxes.

Arctic tundra exhibits a large spatial and temporal variability. A continuous record of CO_2 and methane (CH4) fluxes from three eddy covariance (EC) towers within 1 km from each other, allowed us to describe the integrated dynamics of landscape type, vegetation development, moisture regime, and seasonality affect C budget variability, and suggest the number of sites needed to capture the landscape variability.es.

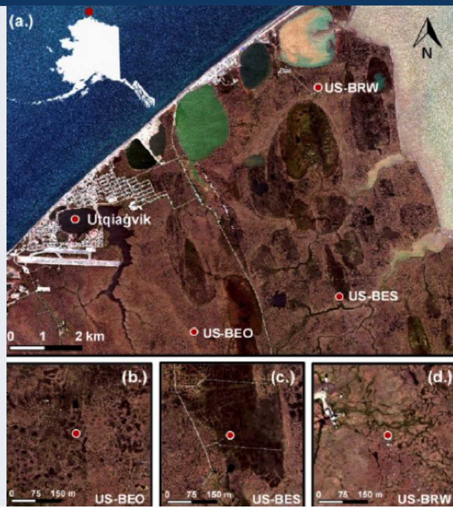

Fig. 1 Location of the three EC towers in Barrow, Alaska (Hashemi et al., in review).

The amount of autumnal CO_2 emissions corresponds to the magnitude of growing season net ecosystem exchange (NEE), reducing variability in annual budgets due to landscape type. The combination of CO_2 and CH_4 fluxes shows that the Alaskan Arctic tundra has a net warming effect, and vary substantially in sites within the same grid cells used by model estimat

Data access: see Arctic Data Center, doi:10.18739/A2X34MS1B. (Donatella Zona, 2019).

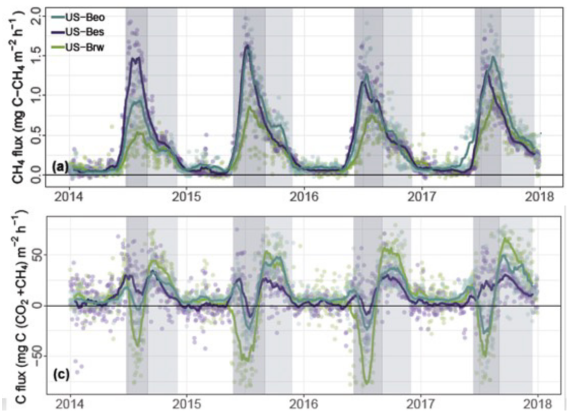

Fig. 2 Yearly flux rates (daily average) of (a.) CH_4, and (c.) CO_2 + CH_4 (with CH_4 expressed as CO_2 equivalent) at the three EC sites. The darker shaded portion represents the growing season, while the lighter shaded portion represents the zero-curtain period (Hashemi et al., in review).

The University Of Sheffield.
UNIVERSITY OF EXETER

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Automated flask sampling of atmospheric trace gases in the Arctic

Measurements of minor trace gases and isotope signatures in the atmosphere help to understand the origin of air masses, and the sources and sinks on the ground they interacted with. New data from remote locations can thus help us understand better what controls the surface-atmosphere exchange fluxes over oceanic and terrestrial Arctic regions, and how signals are affected by the environment.

The automated flask sampler will facilitate air mass characterization at regular intervals (2-3 times per week). This will improve the identification of air mass origin and carbon sources. A targeted sampling mode will allow to focus on e.g. air masses with high carbon content.

The sampler will close key gaps in the Arctic monitoring network, and new information on minor trace gases and isotopes will improve our ability to constrain carbon emissions through atmospheric inverse modelling.

Fig. 1 Automated flask sampling device.

Location:
Station North, Greenland

Observations:
trace gases (e.g. N_{20}, SF_6, CO, O_2/N_2)
isotopes signatures (e.g. ^{13}C-CO^2, 180)

Sampling scheme:
Fixed intervals (weekly)
Targeted samples (e.g. GHG peaks)

Data access:
MPI-BGC data repository
ICOS database

This new data product specifically targets the atmospheric transport modelling community.

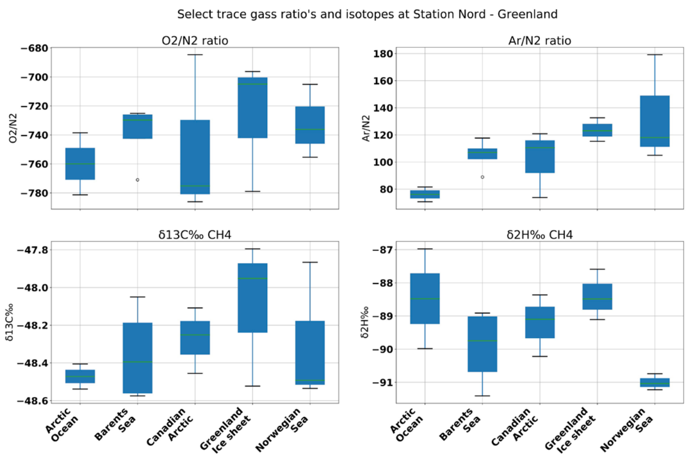

Fig. 2 Example of trace gas ratio's and isotopes in different Arctic regions.

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Marine-based Observations

"Sustained marine-based observations are essential for knowledge of the ocean itself and the abundant and diverse life in it. The ocean is also a fundamental component of the Earth's climate system. To understand the Earth we must measure the ocean."

- Geir Ottersen, Institute of Marine Research, Norway.

Stockholm University, Swedish Polar Research Secretariat

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Shipborne Arctic atmospheric observatory on the Swedish icebreaker Oden

The objective is to develop an atmospheric "super-site" observatory, operated either unattended or with minimum staff to provide extensive atmospheric observations at a much higher frequency than previously. The observatory is developed for the Swedish icebreaker Oden, but can also be adapted for other vessels operating in the Arctic.

The observatory was first deployed in 2018 and now provides:

- surface fluxes of energy and trace gases, in situ weather information including visibility, vertical profiling of winds and atmospheric thermodynamics, cloud vertical distribution and cloud properties,
- surface energy budgets, Cloud-Net retrieval of cloud properties and radio-soundings.

The data are primarily for research use.
Some data are transmitted on the GTS for weather forecasting and reanalysis.

Fig. 1 Examples of observing systems onboard icebreaker Oden.

The observatory is intended to improve the situation with lack of data in the central Arctic. The data are needed to understand atmospheric processes and develop realistic models of the central Arctic atmosphere. Users are primarily the atmospheric research community.

The data follow standards for atmospheric parameters including MODF-files. All data will be directly open after a QC. Data are stored at the Bolin Centre for Climate Research database at University of Stockholm: http://www.bolin.su.se/data

Fig. 2 The observing systems are mounted in different placed onboard icebreaker Oden.

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Polar Research Institute of China, National Marine Forecasting Centre and Finnish Meteorological Institute

Snow and Ice Mass Balance Array (SIMBA)

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The objective of the SIMBA ice mass balance buoys is to measures high-resolution (2cm) vertical temperature profiles (4 times a day) through the air-snow-sea ice-ocean column.

The temperature data is used to derive snow depth and ice thickness. The SIMBA buoy uses GPS module to measure positions. The Iridium satellite is used for data transmission.

A total 15 SIMBA buoys have been deployed in the Arctic Ocean during the Chinese National Arctic Research Expedition (CHINARE) 2018 and the Nansen and Amundsen Basins Observational System (NABOS) 2018 field expeditions in late autumn. In 2019 17 SIMBA buoys were deployed during the CAATEX and MOSAIC expeditions. The cluster of SIMBA buoys is an important method to monitor temporal and spatial variations of snow depth and ice thickness as they drift around in the Arctic Ocean.

Fig. 1 The Chinese icebreaker Xuelong during the CHINARE Arctic expedition in 2018.

The data are available at

- https://simba.srsl.com/fmi
- https://simba.srsl.com/pric
- https://simba.srsl.com/nmefc

Fig. 2 Deployment of a SIMBA buoy

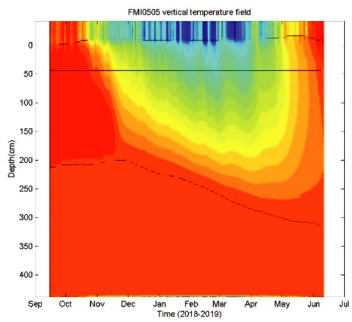

Fig. 3 SIMBA data collected from one buoy over a seasonal cycle, showing the vertical temperature field (deg. C), snow depth and ice thickness. The black lines mark the snow surface (top), the initial freeboard (middle) and the ice bottom.

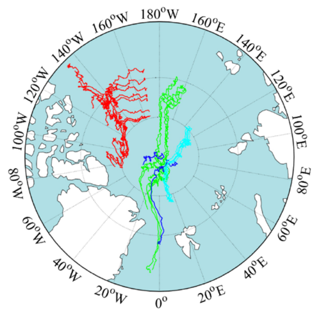

Fig. 4 Trajectories of SIMBA buoys deployed in the Arctic in the period 2018-2019. Red: CHINARE(10), green: NABOS(5), dark blue: CAATEX(2), and light blue: MOSAiC(15).

Contributors: Ruibo Lei (PRIC), Zhongxiang Tian (NMEFC), Mario Hoppmann (AWI), Phillip Thompson (SAMS)

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

INTAROS

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Oceanographic moorings north of Svalbard

The main purpose of the INTAROS moored array north of Svalbard is to monitor the inflow of warm and salty Atlantic water into the Arctic Ocean in the key area where strong ocean-atmosphere-sea ice interactions result in significant heat loss and water mass transformations before Atlantic water continues to circumvent the Arctic Ocean.

The INTAROS array consists of 3-5 oceanographic moorings deployed since 2017 across the shelf break and continental slope north of Svalbard at 500, 850 and 1500 m depth (Fig 1). The mooring are equipped with Seabird and RBR instruments, McLane profiler and acoustic doppler current profilers (ADCP) for collecting measurements in the entire water column. Additional observations of sea ice drift and draft are obtained concurrently with the upper ocean currents with ADCP.

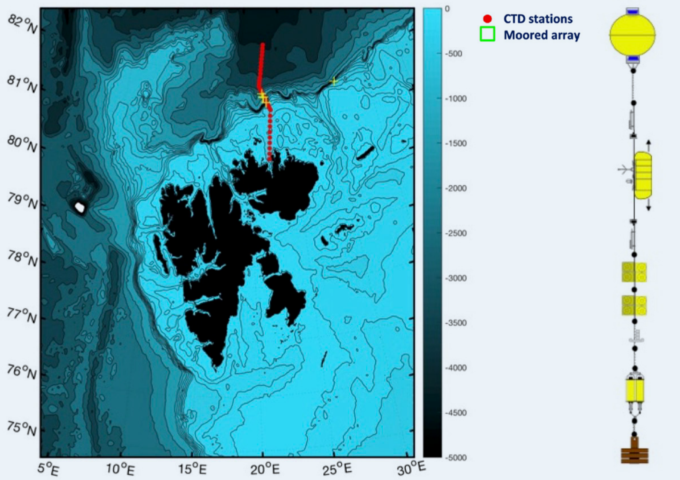

Fig. 1 Location of the INTAROS moored array north of Svalbard along 22°E and complementary CTD section (left) and schematic drawing of mooring instrumentations (right).

Time series of temperature (Fig. 2), salinity and ocean currents are needed to study Atlantic inflow and dynamic events in the entrance to the Arctic Ocean and understand their impact on ocean-air heat fluxes and sea ice cover. Mooring observations also provide data for studies of biogeochemical and biological processes.

Data from the moorings will be freely available from the eCUDO (IOPAN data base) and SEANOE data repository (LOCEAN data).

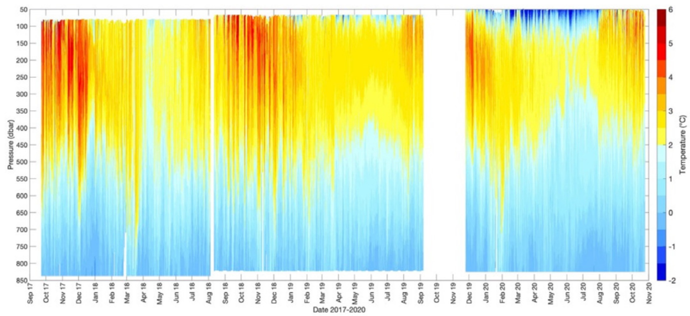

Fig. 2 Time series ocean temperature from 2017-2020 at the INTAROS mooring at 850 m water depth.

Contributors: Marie-Noelle Houssais (CNRS-LOCEAN).

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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AREX long-term monitoring program

The main aim of the long-term monitoring program AREX and annual summer cruises, carried for over 30 years in the Nordic Seas and Fram Strait by RV Oceania, is to study processes responsible for changing ocean climate and marine ecosystems along the poleward Atlantic water flow in the sub-Arctic and Arctic regions.

Every summer since 1987 large-scale surveys have been carried out by RV Oceania in the area shown in Fig. 1. In situ data are collected on physical oceanography, air-ocean interaction, ocean biogeochemistry and ecology. A repeated regular grid of more than 200 stations covers the Atlantic water inflow through the eastern Norwegian and Greenland seas, into the Fram Strait up to the southern Nansen Basin in the Arctic Ocean. Additionally, an extensive observational campaign takes place every year in the western Svalbard fjords. The data will be freely available from the eCUDO (IOPAN data base).

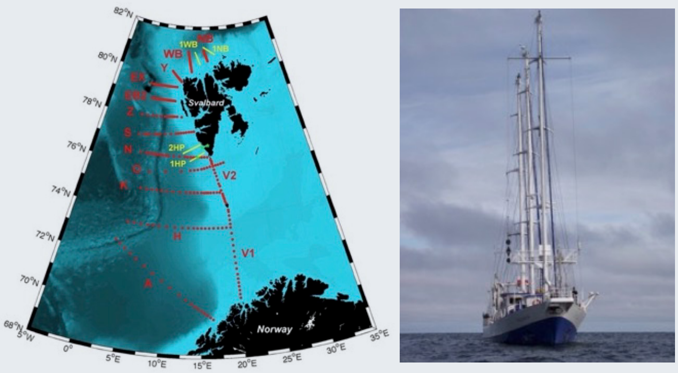

Fig. 1 Data are collected every year in the regular station grid (left) by RV Oceania (right).

Time series of key ocean variables from the AREX program, allow monitoring of changes in the Arctic physical and biological environment and improving numerical simulations of ocean, sea ice and climate in the Arctic region.

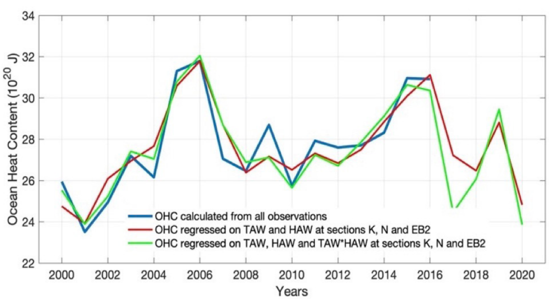

Fig. 3 Time series of ocean heat content (OHC) in the Atlantic domain.

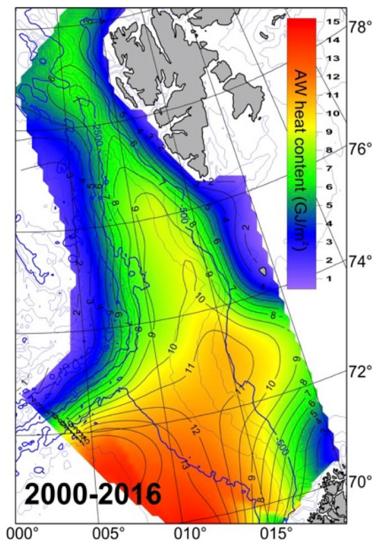

Fig. 2 Mean ocean heat content of the Atlantic water from the summer surveys of RV Oceania.

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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The Norwegian Argo Infrastructure (NorArgo)

NorArgo is an ocean observing system for the Arctic that monitors, in near real-time, essential physical and biogeochemical variables. NorArgo operates an array of ~30 autonomous vertical profiling floats, Argo floats.

NorArgo will deploy approximately 13 floats per year to keep the target of ~30 floats operated by Norway active at any time. Argo floats with different equipment and properties will be used. These include floats with standards sensors (pressure, temperature and salinity), additional biogeochemical sensors, and for the deep ocean.

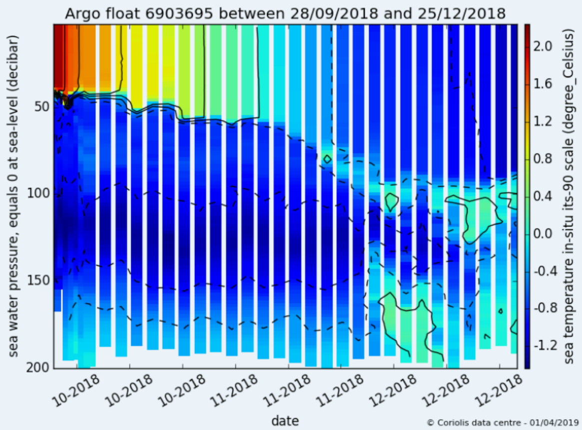

Fig. 1 Vertical temperature profile from Argo float WMO 6903695 deployed by Finland and drifting east of Svalbard during September-December 2018.

NorArgo is funded by the Norwegian Research Council for 2018-2023 through the infrastructure project NorArgo2. NorArgo is part of Euro-Argo https://www.euro-argo.eu and the international Argo program http://www.argo.ucsd.edu

NorArgo provides data that is essential for the monitoring and understanding of processes related to climate variability and impacts on the marine ecosystem.

The NorArgo data are freely available to all from the NorArgo operational web site http://www.imr.no/forskning/prosjekter/norargo/map and the Coriolis Data Centre, France (http://www.coriolis.eu.org)

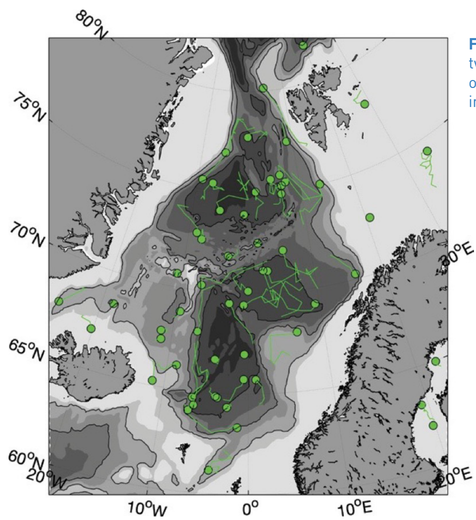

Fig. 2 Locations and two months drift of operative Argo floats in the Nordic Seas.

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

CNRS-LOCEAN

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Endurance glider lines in Fram Strait

Endurance glider lines are useful to monitor the inflow of Atlantic Water to the Arctic. Glider measurements provide detailed information on the dynamics and variability of the circulation, including the impact of mesoscale features and recirculation on the transports to the Arctic.

Underwater gliders equipped with sensors measuring ocean physical and biogeochemical properties from the surface down to at most 1000 m are operated every summer (not in 2021) for approximately 2 months in ice-free waters of eastern Fram Strait. The remotely operated vehicles glide up and down along sections across the Atlantic Water current, providing profiles with horizontal resolution on the order of 4 km. Deployments/recoveries are carried out from open ocean or coastal ships. Data are transmitted in near-real time to the Coriolis data base.

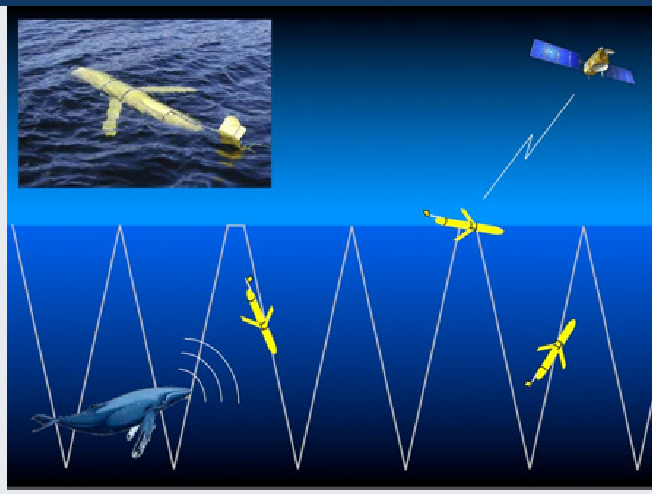

Fig. 1 Glider operational mode.

Data from the glider sections going in west-east direction shows how the Atlantic water flowing northwards in the eastern Fram Strait varies from year to year (Fig. 3).

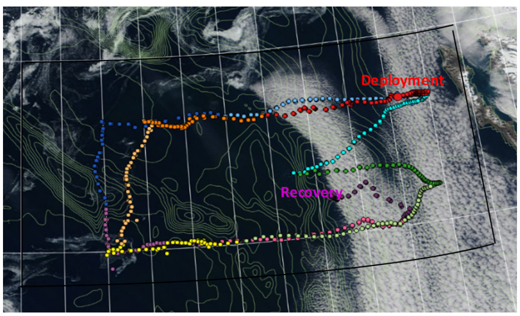

Fig. 2 Example of a glider mission performed in July-August 2017 overlaid on a MODIS image showing the sea ice distribution. Deployment/recovery done from RV Oceania (IOPAN)

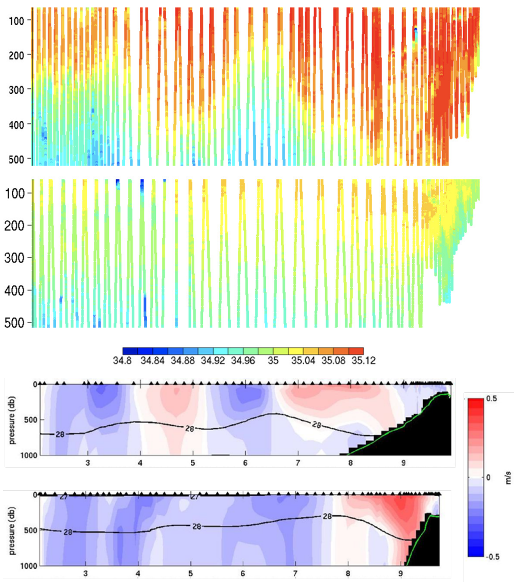

Fig. 3 Salinity distribution along a glider section at 78°40'N carried out between 27 July- 4 August 2017 (upper figure) and 17-23 July 2019 (lower figure).

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Takuvik CNRS and University of Laval

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Biogeochemical Argo floats in Baffin Bay

The objective of the biogeochemical (BGC) Argo floats is to study the dynamics of phytoplankton blooms, year-long high-frequency time series of phytoplankton phenology and its drivers in Baffin Bay.

The BGC Argo floats are the complementary tool to remote sensing and oceanographic cruises for these studies.

Takuvik is deploying a fleet of PRO-ICE floats (biogeochemical Argo floats) dedicated to navigating in ice-covered waters: 4 floats in 2016, 7 in 2017, 2 in 2018, 2 in 2019 and 4 in 2021 (2020 deployments were postponed because of COVID pandemic).
Some are re-fitted floats after recovery. When drifting under ice the floats avoid hitting the ice and come to surface only when in open water (Fig. 1). The floats transmit the data via Iridium when surfacing. Data collected are available (open access) in real time in the Argo database (ftp://ftp.ifremer.fr/ifremer/argo/dac/coriolis) or https://fleetmonitoring.euro-argo.eu/dashboard

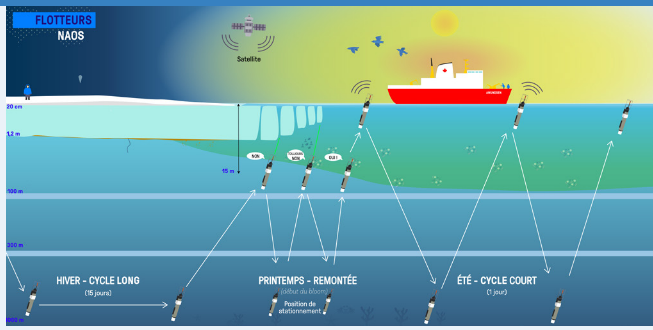

Fig. 1 Illustration of the annual pattern of BGC Argo floats (PRO-ICE) in Baffin Bay.

The unprecedented data collected by the PRO-ICE floats provide in situ data for physical observations, modelling, and also biology (pressure, temperature, salinity, chlorophyll a fluorescence, CDOM fluorescence, particle back scattering, nitrate concentration, O2 concentration and radiometry). All this will contribute to long-term initiatives.

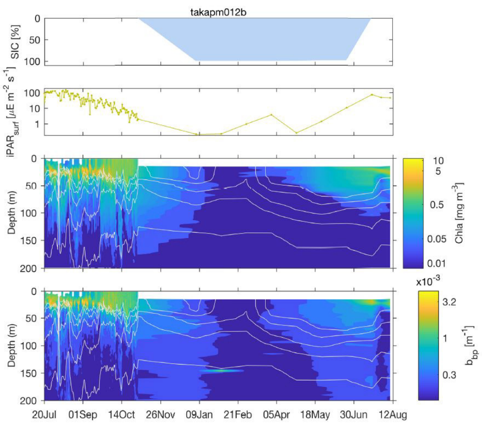

Fig. 2 Example of a one-year time series (July 2017 to August 2018) for chlorophyll a and particle back-scattering (Credit L.Lacour).

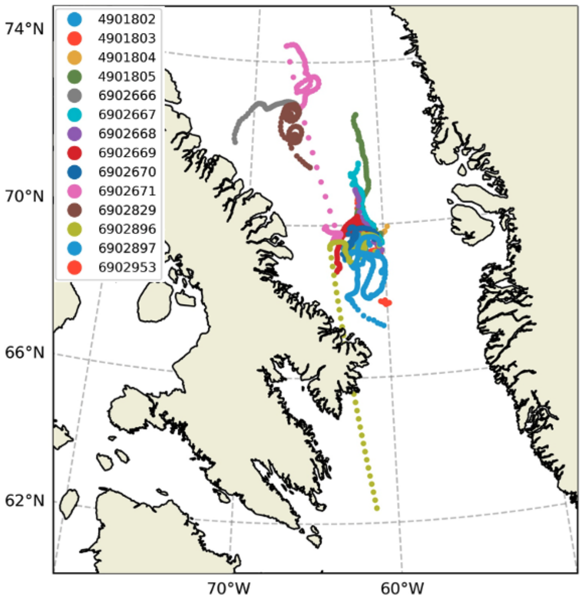

Fig. 3 Trajectories of floats collected from 2016-07-09 to 2019-10-12. Missing (under-ice) GPS fixes have been linearly interpolated as a visual aid. (credit A.Randelhoff).

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Aarhus University and Greenland Institute of Natural Resources

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Coastal studies around Greenland

The aim is to extend, improve and complement the long-term coastal research efforts in the Greenland Ecosystem Monitoring (GEM) Programme (www.g-e-m.dk)

The observing systems will improve the existing efforts by:

- Extending observation beyond the monitoring sites (blue dots)
- Developing an ecosystem model for one of the monitoring sites (Disko Bay)
- Adding new instruments to existing moorings (Young Sound)
- Extending CTD profiles in collaboration with the Danish Navy (Young Sound)

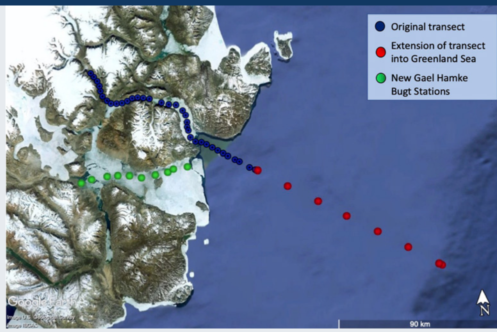

Fig. 1 The repeated transect in Young Sound.

Results will provide a scientific basis for better-informed decisions and better-documented processes for stakeholders, managers and policy-makers, such as Arctic Council working groups, governmental institutions, ICES, OSPAR, fishing industries and local hunters.

Fig. 2 Instruments used for the work in Young Sound.

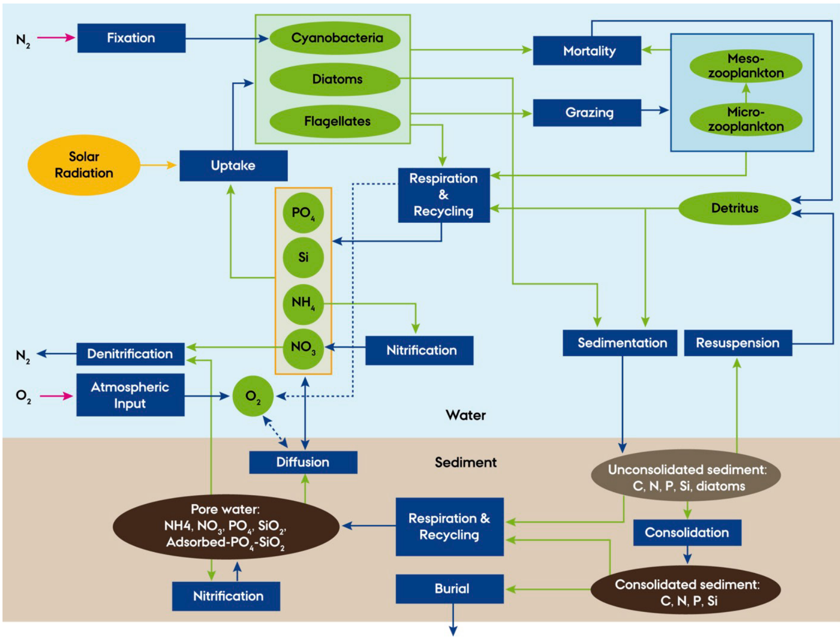

Fig. 3 Components of the Ecosystem model set up for the GEM sites in Disko Bay.

Contributors: M. Maar, J. Holding, E. Friis Møller (Arhus University) and M. Winding (GINR)

GREENLAND CLIMATE RESEARCH CENTRE
ARCTIC RESEARCH CENTRE

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Demonstration of environmental management in Disko Bay, Greenland

The objective is to demonstrate how an iAOS can improve marine ecosystem modelling in data-poor areas and thereby increase our knowledge on how environmental change will affect local productivity as input to stakeholders.

The local fine-scale ecosystem model for Disko Bay, west Greenland, was improved by using:

- Sea ice data (CICE, DMI)
- Regional model data (HYCOM, ERSEM)
- Freshwater discharges (PROMICE, GEUS)
- Remote sensing data (COPERNICUS, DTU)
- Monitoring data (GEM) and other field data

Fig. 2 Picture from Disko Bay

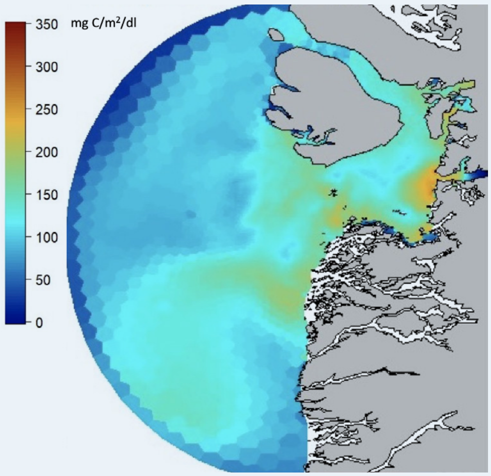

Fig. 1 Primary production (mg-C/m2/d) estimated for the Disko Bay in 2010 with early sea ice break-up.

On the bay scale, sea ice cover is the most important factor, and decreasing sea ice cover leads to higher primary production.

The freshwater discharge has an impact on the timing and level of primary production near the source; more discharge leads to higher primary production.

The model results improve our current understanding of the environmental effects on the productivity of Disko Bay that is considered an Arctic biodiversity hot-spot.

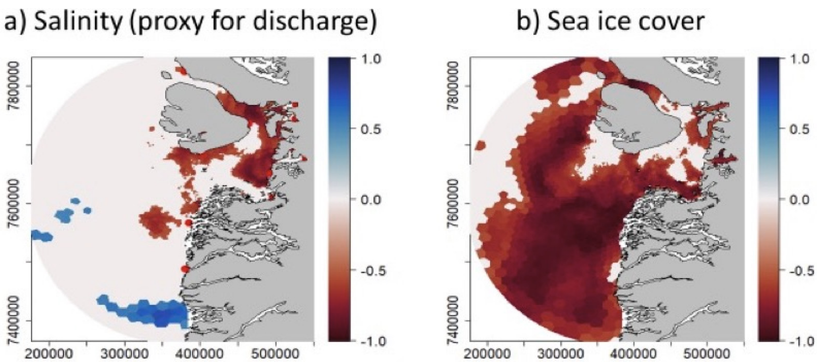

Fig. 3 Correlations between primary production and a) salinity and b) sea ice cover from 2004 to 2018.

Contributors: Eva Friis Møller, M Sejr, J Larsen (Aarhus University), A Christensen (DTU), K Mankoff (GEUS), MH Ribergaard (DMI)

AARHUS UNIVERSITY
DEPARTMENT OF BIOSCIENCE

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Barents Sea ecosystem survey

The joint Norwegian/Russian autumn ecosystem survey in the Barents Sea and adjacent waters (BESS) monitors the status and changes in abiotic and biotic variables, providing background for environmental and fisheries advice.

BESS is based upon in situ measurements from scientific vessels (normally three). It provides a broad range of inter-disciplinary observations by means of demersal and pelagic trawls, vertical phyto- and zooplankton nets, CTD probes with water bottles rosette, and more. The survey is run each August-October since 2004. It is an extension of earlier IMR surveys, in particular the 0-group survey initiated in 1965.

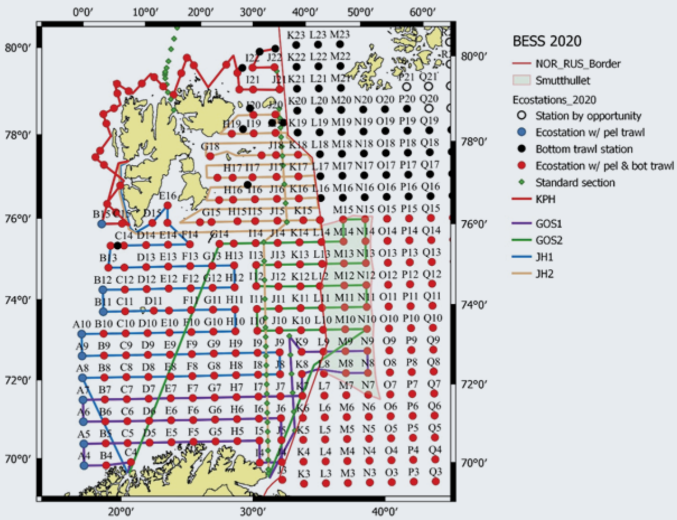

Fig. 1 Norwegian part of BESS autumn 2020 Trawl sampling stations and vessel tracks.

Information from BESS is used extensively as a basis for advice to environmental and fisheries management and various applied and more basic research projects. Results are published in scientific papers and in IPCC's 2019 Special Report on the Ocean and Cryosphere in a Changing Climate.
Data are handled by the Norwegian Marine Data Centre and stored in a national repository.

Reference:
https://www.hi.no/resources/IMR-PINRO-Report-2019-survey.pdf

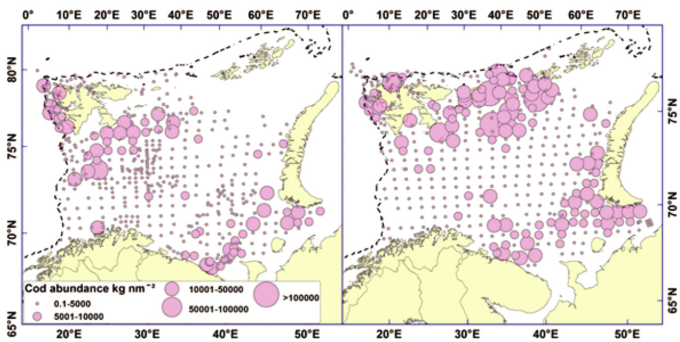

Fig. 2 Major ecosystem changes in the Barents Sea. Spatial distribution of cod in 2007 (left panel) and 2013 (right panel).

Contributor: The Russian Polar Branch of FSBSI VNIRO (PINRO).

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

The Norwegian Institute of Marine Research

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Barents Sea Opening Mooring Array

The main purpose of the Barents Sea Opening Mooring Array is to monitor the main currents flowing in from the southwest, which are of great importance for the oceanographic and ecological state of the Barents Sea.

The Barents Sea Opening Mooring Array consists of fixed moorings along a section across the western Barents Sea. Surface and subsurface ocean temperature and current velocity are recorded every 20 minutes by means of Aanderaa RCM7 current meters. The number of moorings deployed (now 5), and the number of instruments attached to each mooring, has varied. Instruments are typically placed at 50, 125, 225 meters and close to the sea floor.

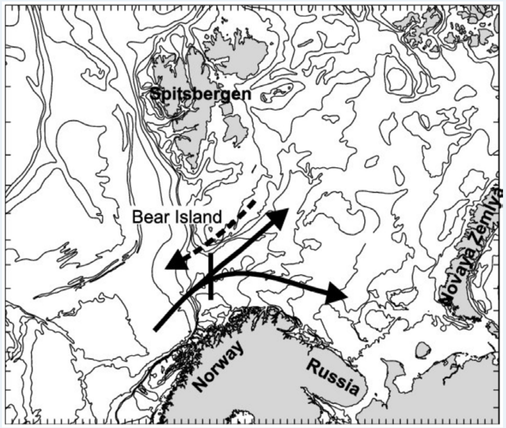

Fig. 1 The Barents Sea. The solid line indicates the section where the moorings were deployed, the solid and dashed arrows the flow of Atlantic and Arctic water, respectively.

The first mooring was deployed 20 August 1997 and the platform has been operating consistently since then. The data are handled by the Norwegian Marine Data Centre and are now available in the INTAROS data catalog together with more information: Mooring data from the Barents Sea Opening – Atlantic Water inflow - Datasets - INTAROS Data Catalogue (https://catalog-intaros.nersc.no/).

The mooring network is supported by funding to IMR from the Norwegian government ensuring long-term operation and sustainability.

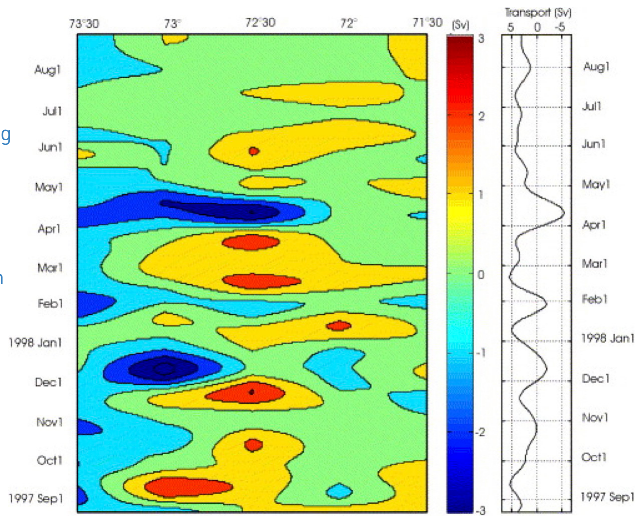

Fig. 2 Time series of transport through the BSO based on 30 days low-pass filtered and vertically integrated currents (left panel), and the total transport in Sv through the section (right panel). Ingvaldsen et al. (2002).

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Barents Sea FerryBox System

The objectives of the Barents Sea Ferrybox system are to (1) Improve our understanding of short/long-term variability in physical, chemical, and biological ocean processes, (2) Provide in situ measurements for validating remote sensing observations and biogeochemical models including carbon cycling, and (3) Develop new sensors and instruments for measuring ocean acidification, inherent optical properties, and microplastics.

The Barents Sea FerryBox system is a suite of sensors that are on a ship of opportunity, the M/S Norbjørn, that makes ~30 roundtrip voyages between Tromsø, Norway and Longyearbyen, Svalbard. Some voyages make stops at Bear Island, Svalbard and Ny Ålesund, Svalbard. The ship is outfitted with a seawater pump system that brings seawater from ~5 m depth into an assembly of physical, biological, and chemical sensors.

Fig. 1 The cargo vessel M/S Norbjør.

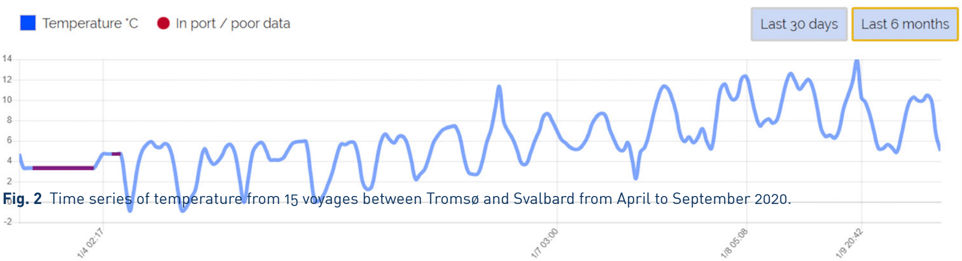

Fig. 2 Time series of temperature from 15 voyages between Tromsø and Svalbard from April to September 2020.

The FerryBox system on Norbjørn is part of NorSOOP: Norwegian Ships of Opportunity Program for marine and atmospheric research. It supports research and monitoring of ocean acidification for the Norwegian Environment Agency. Data are also provided to Copernicus and EMODnet for use in models and satellite validation.

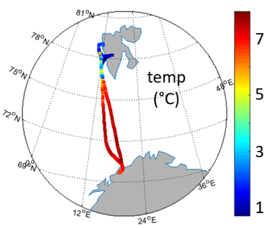

Fig. 3 The sailing route with surface temperature from two of the transits.

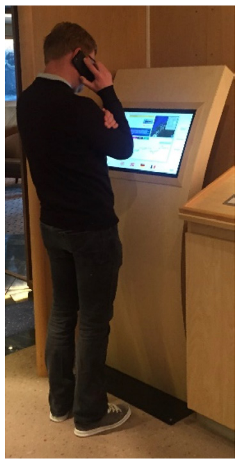

Fig. 4 The data from the FerryBox is also presented in touchscreen consoles located at various public venues.

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Armines and Terradue

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Application of RGeostats on oceanographical data

The objective is to build and deploy a new geostatistcal library as a service for scientists analyzing, interpolating and presenting oceanographic data

This work demonstrates a case study on:

- Analysis of oceanographical data from an Institute of Marine Research (IMR) database
- Presentation of spatial and temporal correlations
- Mapping multiple variables
- Combining different data sources.

Powered by RGeostats

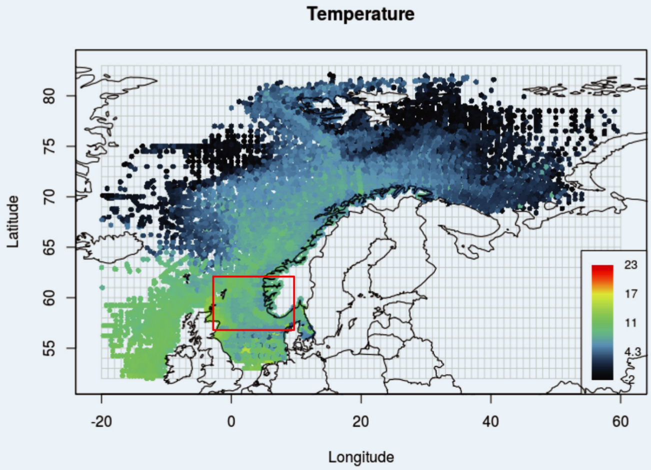

Fig. 1 Example of temperature map from an IMR database.

Examples of applications of RGeostats:

- Temperature interpolation map at a given depth and time interval (Fig. 1)
- Estimation of salinity
- Probability of exceeding a given sea ice thickness
- Evolution of fish density in time
- Seasonal plankton concentration

Users include:

- Scientists, companies, NGOs, national and EU agencies working with climatology, meteorology, biology, oceanography, pollution, tourism and environmental management.

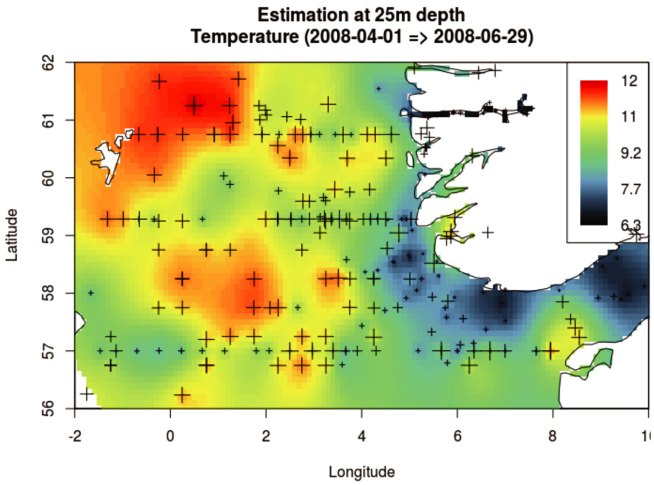

Fig. 2 Example of temperature interpolation map of ocean temperature at 25 m depth.

Contributor: Hervé Caumont (Terradue)

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Nansen Environmental and Remote Sensing Center and Scripps Institution of Oceanography

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Acoustic observations from the Fram Strait

The objectives are 1) Use acoustic thermometry to observe the mean ocean temperature along sections criss-crossing the Fram Strait. 2) Collect baseline information about the 'ocean sound' in the region.

Fram Strait is the only deep water connection between the Arctic Ocean and the world oceans, and an important area for water-mass and sea-ice transports into and out of the Arctic Ocean.

Acoustic thermometry is used to observe the large scale ocean temperature variability. The data can be used by the ocean and climate modelling community to validate and ultimately to constrain their models. **Passive acoustic** data can be used to observe how in the ocean sound characteristics are sensitive to environmental changes due to climate change and increased human activities. The seasonal variability in vocalization of marine mammals can be used to indicate migration patterns. **Ocean Sound** is recently approved as an essential ocean variable.

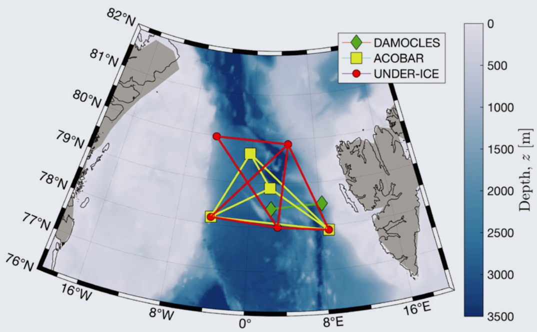

Fig. 1 Data collection from three experiments: DAMOCLES 2008-2009: one location (Green) ACOBAR 2010-2012: three locations (Yellow). UNDER-ICE 2014-2016: five locations (Red).

Data product:

- Acoustic travel times, inverted to range-depth averaged sound speed and converted to mean ocean temperature.
- Passive acoustic data presented as spectrogram.

Example of two years of mean ocean temperature across the Fram Strait is derived from the acoustic travel times obtained under the ACOBAR project.

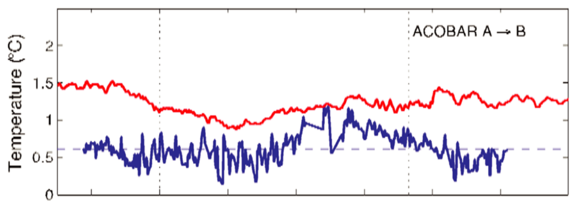

Fig. 2 One year temperature data from the Fram Strait from empirical acoustic data (blue) and an ocean model.

Fig. 3 Photo of an acoustic source used in the experiments.

H. Sagen, B. D. Dushaw, et al. 2016, J. Geophys. Res., 121, http://dx.doi.org/10.1002/2015JC011591.
H. Sagen, P. F. Worcester; M. A. Dzieciuch; et al. (2017) J. Acoust. Soc. Am., 143.

Contributor: Peter Worcester (Scripps).

NERSC

SCRIPPS INSTITUTION OF OCEANOGRAPHY

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Alfred-Wegener-Institute Helmholtz Center for Polar and Marine Research

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Autonomous Arctic Free Ocean Carbon Enrichment (arcFOCE) observing system

AWI developed and implemented an experimental system enabling scientists to study impacts of ocean acidification on (benthic) marine organisms. The mobile, autonomous system allows to conduct acidification experiments with different settings (e.g. different pH levels and exposure times in the mesocosms). arcFOCE (Fig. 1) was designed for one-year installations and re-deployments at different locations and water depths down to 4000 m – even after completion of the INTAROS project.

During the RV Maria S. Merian expedition MSM77 in 2018, the first deployment of arcFOCE was done in the Fram Strait at 1.500 m water depth (Fig. 3). During RV Polarstern cruise PS121 in 2019, an ROV was used to take sediment samples inside the mesocosms as well as next to the system as controls (Fig. 2). Samples will be analysed for bacterial and meiofaunal densities, biomass, and community composition as well as different background parameters (e.g., organic carbon content of the sediments, total benthic biomass).

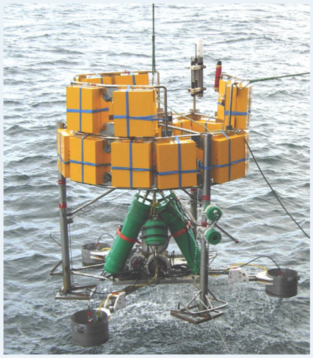

Fig. 1 Recovery of the arcFOCE experimental set-up one year after the initial deployment at HAUSGARTEN.

Fig. 2 Sampling of the arcFOCE mesocosms using an ROV.

arcFOCE enables us to generate data on the resistance of Arctic marine benthic organisms and communities to a reduction in ocean pH, thereby filling existing knowledge gaps and allowing predictions for future ecosystem functionality. The finally processed arcFOCE data will be freely available at www.pangaea.de.

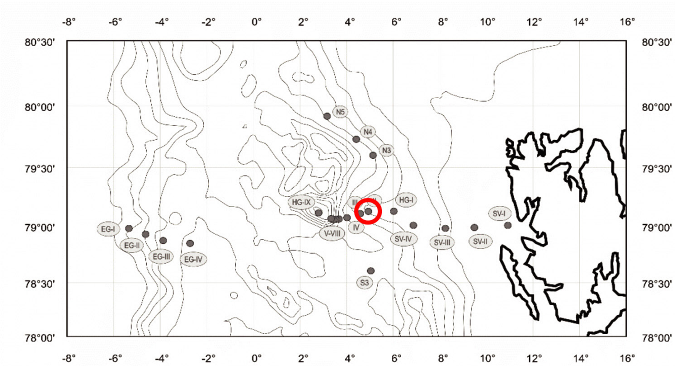

Fig. 3 The network of permanent sampling sites at the Hausgarten observatory. The red circle shows the arcFOCE deployment in 2018.

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Observing particles and zooplankton distribution north of Svalbard

Due to Atlantic water inflow and sea ice coverage, the region North of Svalbard is very dynamic in terms of particle production and plankton ecology. To shed a new light on the biological carbon pump and temporal plankton distributions in this area, we compiled a free-moving sensor package, which was connected to a biogeochemical mooring within the A-TWAIN mooring array at the continental slope North of Svalbard.

The system consisted of an Underwater Vision Profiler 6 (UVP 6), which acquires particle sizes and quantities as well as zooplankton and aggregate images. The fluorometric SUNA sensor measures nitrate concentrations, from which the Ecotriplet sensor acquires chlorophyll a, cDOM, and particle backscatter. The mooring was deployed at 50 m between August 2018 and September 2019. Deployment was conducted onboard KV Svalbard, and recovery was possible with RV Kronprins Haakon.

Images will be accessible on Ecotaxa (https://ecotaxa.obs-vlfr.fr); Image classifications and particle and sensor data will be accessible at (https://www.pangaea.de)

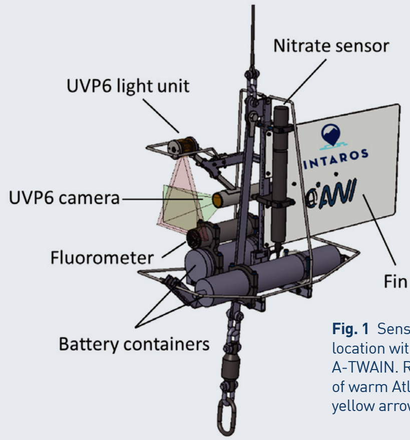

Fig. 1 Sensor package setup and its location within the study site of A-TWAIN. Red arrows indicate pathway of warm Atlantic water inflow, while yellow arrow marks sensor location.

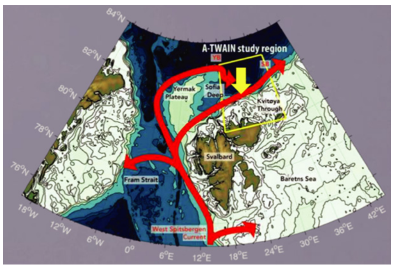

Fig. 2 Location within A-TWAIN mooring array (source: http://atwain.whoi.edu/php/index.php)

The combination with nutrient and fluorescence measurements, as well as other sensors of the mooring array will provide new knowledge about the impact of sea ice dynamics, as well as oceanographic properties on carbon export and zooplankton diversity and abundance in the Arctic.

Fig. 3 The method provides new insight into temporal zooplankton and particle distributions.

Kiel University
Christian-Albrechts-Universität zu Kiel
OCEAN FRONTIER INSTITUTE

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Institut Universitaire Europeen de la Mer

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Ecological monitoring using underwater acoustics

The objective is to 1) monitor how the increase of anthropogenic activities is affecting polar underwater soundscapes by changing habitat usage, and 2) provide long-term acoustic dataset to describe and quantify the features of soundscape contributors.

In order to monitor how anthropogenic changes are impacting polar ecosystems, the first step is to identify, describe and quantify the features of soundscape contributors. Since 2013, underwater acoustic recorders have been deployed for up to several months in several locations of the Arctic (Spitzbergen (2013, 2018-2020), Greenland (2015, 2016)).

Fig. 1 Acoustic recorder deployed by divers at 10m depth close to Kongsfjordneset point.

Data are used to describe the soundscape:
- Benthic fauna sounds,
- Marine mammals vocalizations,
- Ice sounds,
- Wind/wave noise,
- Boat noise (cruise ships).

Quantitative Soundscape

Metrics include:
- Overall sound levels: Long-term spectral averages are computed in several frequency bands.
- Sound pressure level and sound exposure level in decidecade bands , sound pressure kurtosis.
- Seasonal patterns in the acoustic data are investigated by analyzing daily median band levels in several frequency bands.
- Full acoustic dataset (since 2013) is stored at DATARMOR supercomputer facility in IFREMER research center in Brest.

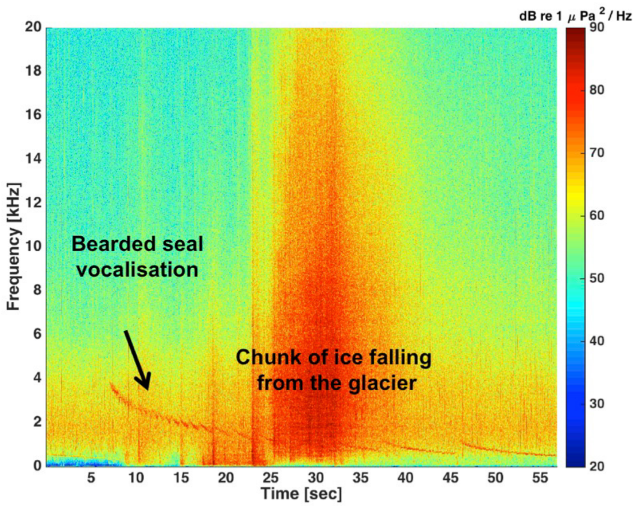

Fig. 2 Ice sounds and seal vocalisations close to London Glacier.

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Laboratoire d'Océanographie de Villefranche-sur-Mer

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High frequency measurement of CO_2 in seawater

The objective is to expand and continue the only high-frequency time-series of parameters of the carbonate chemistry system to document ocean acidification and air-sea CO_2 fluxes at the AWIPEV CO2 observatory in Ny-Ålesund, Svalbard.

In the subsea observatory water is pumped from 12 m depth to the AWIPEV research station in Ny-Ålesund. From the water samples O2, pH, salinity and temperature are measured every minute. Discrete measurements of dissolved inorganic carbon and total alkalinity are done weekly. The data are dissminated in near realtime to users. There is regular maintenance of the system twice per year. But due to COVID-19 the maintenance of the system in 2020 was delayed.

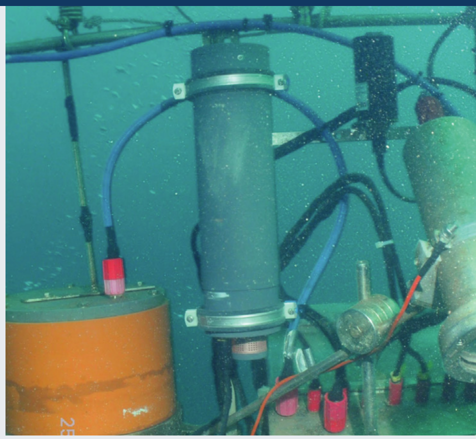

Fig. 1 Some of the instruments, including the pH sensor, mounted on the profiling platform (0 to 11 m).

There are very few high frequency data in the long-term. Yet, these data are essential to document air-sea CO_2 fluxes and the rate at which the Arctic Ocean acidifies, with major potential consequences on the ecosystem, including commercial species. These data mostly benefit the scientific community.

Fig. 2 Map of Kongsfjorden, showing Ny-Ålesund.

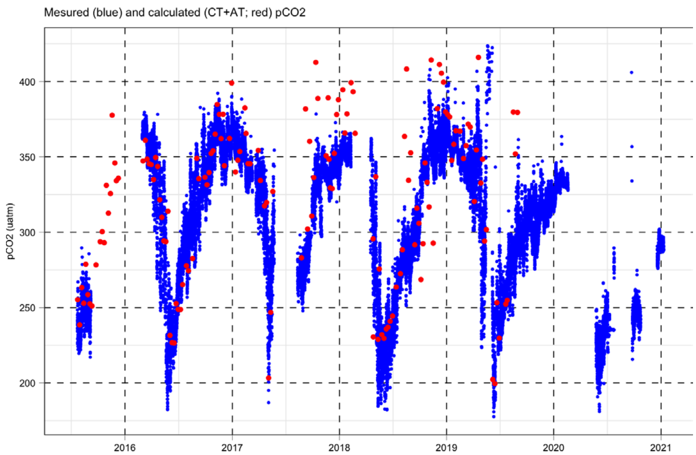

Fig. 3 Partial pressure of CO_2 in seawater Kongsfjorden.

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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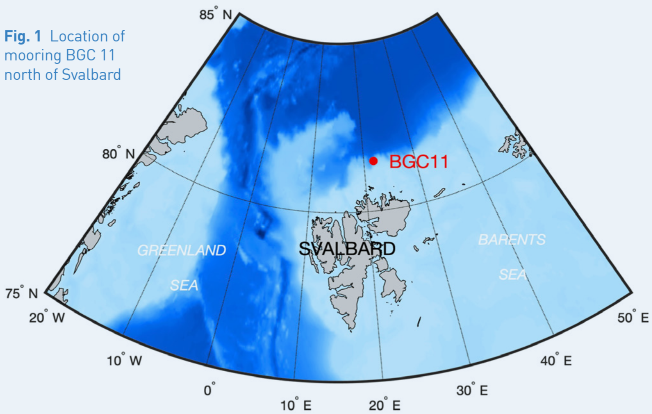
Biogeochemical mooring north of Svalbard: CO_2 system measurements

The objective is to identify and monitor changes in the Arctic marine carbon cycle by using a suite of biogeochemical measurements on a mooring. The ocean has absorbed ~30% of atmospheric CO_2 emissions causing ocean acidification. These changes and their impacts on ecosystems, are poorly understood in the Arctic due to sparse observations of key biogeochemical measurements. The observations from this mooring will provide the first year-long, high-resolution observations of the marine carbon cycle in the high Arctic.

The mooring was deployed from the Norwegian Coast Guard's ice breaker, KV Svalbard, on 12 August 2018 and recovered 13 months later by the Norwegian research vessel FF Kronprins Haakon. Data collection included 5 x CO2 sensors at three different depths, along with 2 x nitrate sensors, 2 x oxygen sensors, 2 x temperature and salinity sensors, and one current meter, successfully logged data at 3 hour intervals for a year.

The data will be included in the ICOS Norway network (https://no.icos-cp.eu/).

Fig. 1 Location of mooring BGC 11 north of Svalbard



The climate and ecosystem modelling community is the main user group. The data will contribute to the global carbon budget estimates, and to aid in our understanding of how ocean acidification will impact ecosystems in the Arctic. The data will help improve future forecasts of ecosystem changes.

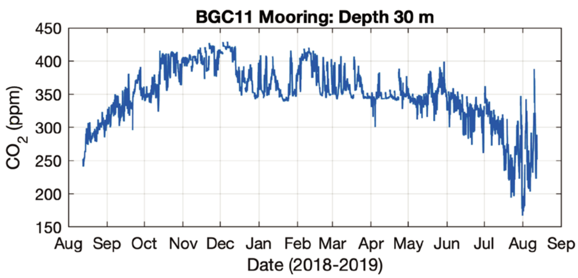


Fig. 2 Time series of CO_2 at 30 m depth

Fig. 3 KV Svalbard during the 2018 expedition

Contributor: Nick Roden (Geophysical Institute, UiB).

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Stable water isotopes of atmosphere, ocean, ice and snow north of Svalbard, 2018

Water isotopes in vapour, ice and precipitation reflect the condensation and transport history of water vapour.

Our in situ measurements provide a reference dataset for atmosphere and ocean model development validation.

The photos show the instruments used during the 2018 cruise: a laser instrument **(1)** measured δ18O and δD in water vapor through an air inlet **(2)**. Sea water was collected at the surface **(3)** and down to a depth of 1000 m **(4)**, **(5)**. Rain, snow **(6)** and sea-ice **(7)** were sampled on several occasions. Meteorological data were included in the datasets. All data are listed in the INTAROS catalogue and are made publicly available.

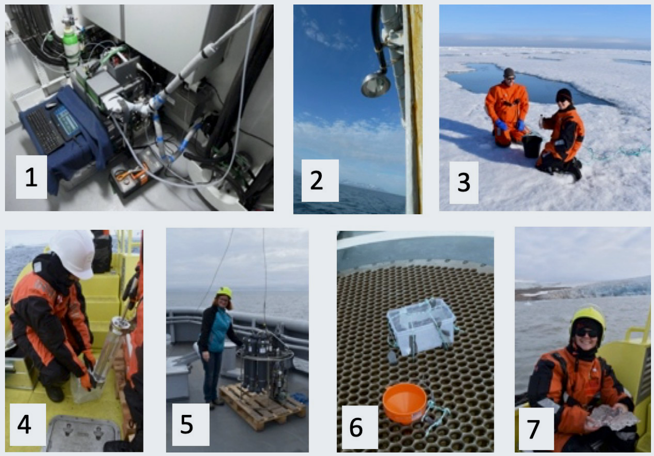

Fig. 1 Some of the instruments, including the pH sensor, mounted on the profiling platform (0 to 11 m).

Our water isotope reference dataset will be used by researchers to investigate air-sea interaction, and by model developers to improve processes representing the water cycle in Arctic regions.
On a longer perspective, including the water isotope composition in models will contributes to more reliable weather forecasts and future climate predictions in the Arctic.

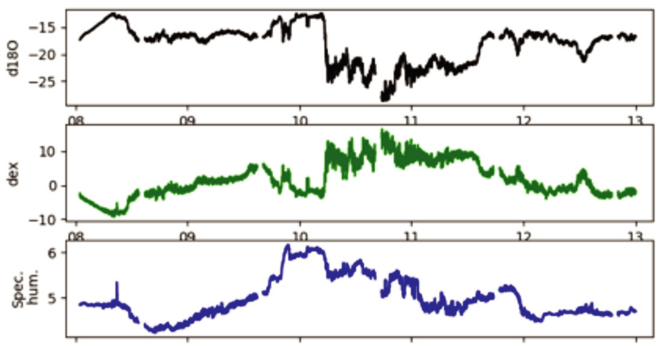

Fig. 2 The water vapour isotope time series (black, green) reflect the origin of cold, dry and moist, warm air (blue).

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Denmark Technical University, Space

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Arctic tide gauge, observed sea level and vertical land motion

Sea level observations from tide gauges are essential to observe local changes of sea level in areas where satellite altimetry is challenged by sea ice. Important for geodetic Arctic research and local communities. Data on relative sea level anomalies from tide gauges and Vertical Land Movement are presented.

The following data are used:

- Monthly Arctic Tide Gauge (TG) observations from PSMSL-Permanent Service for Mean Sea Level.
- 5-min resolution for 4 Greenland TG's
- Possible to adjust for Vertical Land Movement (VLM) to get Absolute Sea Level Anomalies (comparable with SLA from Altimetry)
- VLM (yearly 5x5 km) include model results from past (GIA, Caron et al (2018)) and contemporary ice loss (Ludwigsen et al, 2020).

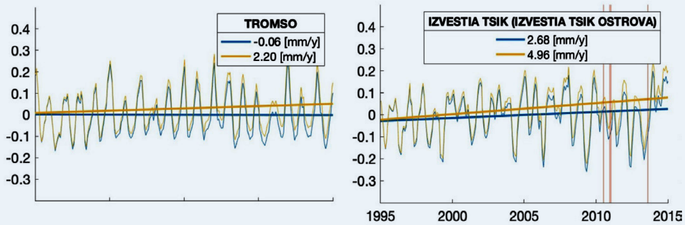

Fig. 1 Tide Gauge Observed relative sea level (blue) and VLM-corrected sea level (yellow) at 2 selected stations (in meter). Red bars indicate missing data.

Sea level observations from tide gauges are essential to observe local changes of sea level in areas where satellite altimetry is challenged by sea ice. Important for geodetic arctic research and local communities.

Tide-Gauge data:
https://catalog-intaros.nersc.no/dataset/tide-gauge-data
VLM-data: https://catalog-intaros.nersc.no/dataset/arctic-vertical-land-motion

Caron et al, 2018: www.doi.org/10.1002/2017GL076644
Ludwigsen et al, 2020: www.doi.org/10.1029/2020GL08800144

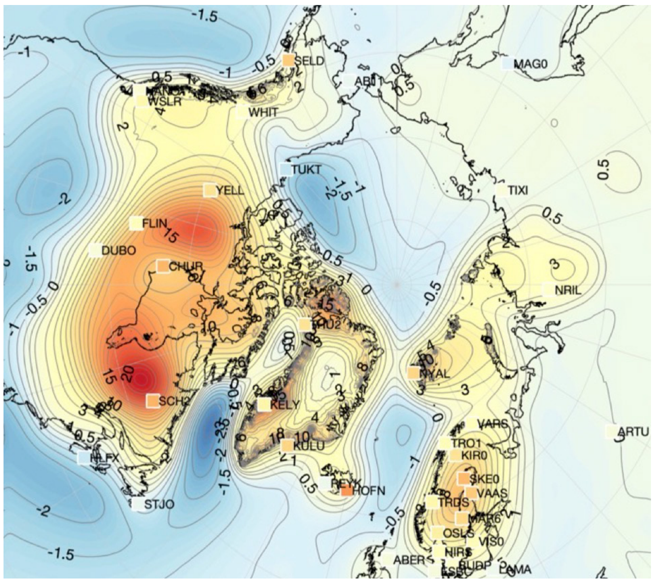

Fig. 2 Vertical velocity for modelled VLM and GNSS [mm/yr].

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Earthquakes in the Arctic

Observations of earthquakes and other natural hazards are essential for preparing and assessing the likelihood of future hazardous events, which can have dramatic impacts on people and infrastructure in the Arctic. Risk assessment for natural hazards requires that relevant data be provided by a number of different observing systems designed for earthquakes, landslides, erosion, snow avalanches, flooding and glacial events. For earthquake monitoring there are no observing sensors deployed in the ocean. It is therefore necessary to start deployment of ocean bottom seismometers in the Arctic Ocean.

Ocean bottom seismometers (OBS) have been deployed in the Arctic during three campaigns. This has allowed us to demonstrate how OBS monitoring in the region can close monitoring gaps and provide important insights into the potential for natural hazards.

Data will be made available through: https://eida.geo.uib.no/webdc3

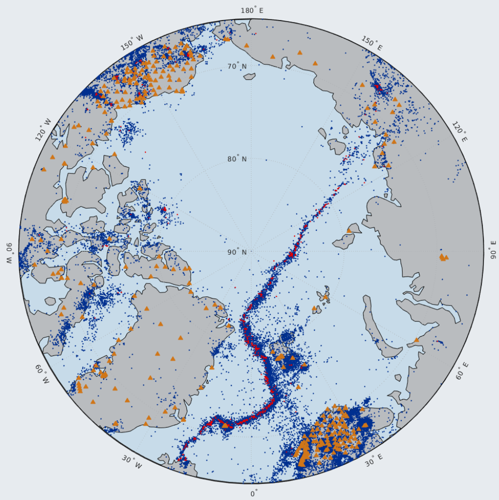

Fig. 1 Map of earthquakes in the Arctic region based on data from terrestrial seismometers.

UiB and GEUS have collected a catalogue of seismic events in the Arctic region, that consists of earthquakes, glacial events, landslides and snow avalanches: http://nnsn.geo.uib.no/intaros_eqcat

The collected data will help us understand how natural hazards are affected by climate change. Data will feed into future hazard and risk assessments, and thus contribute to increased safety in the region. This is of interest to the local communities and to anyone operating in the Arctic.

Fig. 2 The orange OBS is recovered from the ocean floor after almost one year of autonomously measuring seismic and acoustic signals traveling through the earth and ocean.

GEUS

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Satellite Observations

"Due to the hostile environment and vast area of the Arctic, satellite observations are the best suited for continuous and Arctic-wide observations. Satellite observations in many cases increase the value of in situ observations by allowing to expand them over the whole area."

- Georg Heygster, University of Bremen, Germany.

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Arctic mean sea surface and mean dynamic topography from satellite altimetry

Satellite radar altimeter data collected for more than 30 years provide a unique data source to estimate mean surface topography and sea level anomalies.

The radar altimeter data are provided by 5 polar orbiting satellites: ERS-1 (1991-1995), ERS-2 (1995-2003), Envisat (2003-2010), SARAL/AltiKa (2013-present); and CryoSat-2 (2010- present).

The data products from the merged data starting in 1991 are :

- DTU21 Mean Sea Surface (MSS) (1-min spatial resolution)
- DTU19 Mean Dynamic Topography (MDT) (1-min spatial resolution)

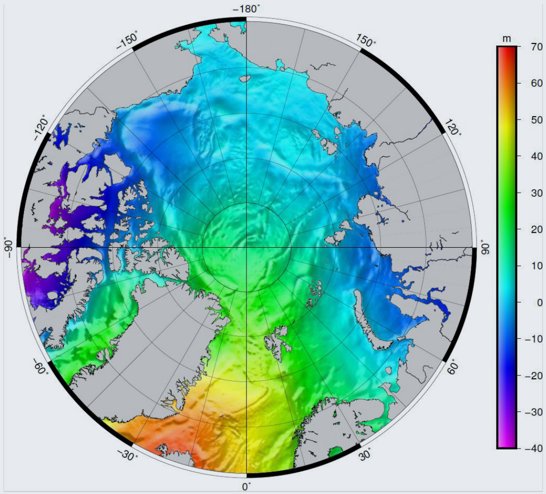

Fig. 1
DTU21 Mean Sea Surface

Vertical Offshore Reference Surfaces (VORF) for the Pan-Arctic mean sea surface (Mean sea level) and mean dynamic topography. The new DTU21MSS is fundamental for studies of sea level variations and the DTU19MDT for the study of Arctic surface geostrophic currents.

Link:
https://catalog-intaros.nersc.no/dataset/altimetric-sea-level

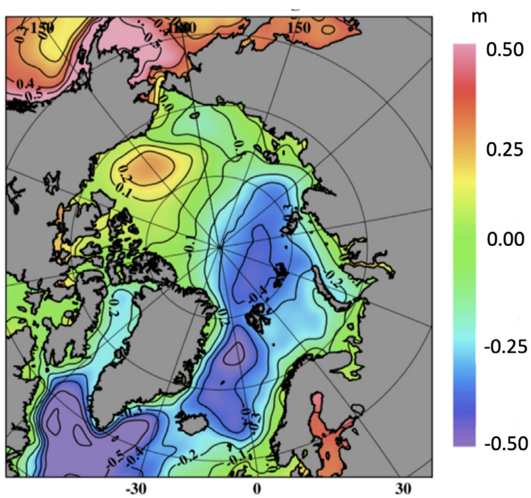

Fig. 2
DTU19 Mean Dynamic Topography

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

University of Bremen, Institute of Environmental Physics

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Daily maps of Arctic total sea ice concentration

Maps of total sea ice concentration (SIC) are produced daily in the Northern Hemisphere at 6.25 km resolution throughout the year.

Total sea ice concentration has been produced regularly from satellite passive microwave data for more than four decades and is one of the most important climate data records in the polar regions.

Total sea ice concentration (SIC) controls the exchange of heat, gases and momentum between ocean and atmosphere and has large impact on Arctic ecosystems and human activities like navigation in the polar seas. SIC is retrieved from microwave emission around 89 GHz at different polarisations where open water and sea ice behave very differently. Data are provided in near real time by satellite-borne radiometers from AMSR-E or AMSR2 (since 2002, UB), and in lower resolution from SSM/I or SSMIS (since 1991, Ifremer).

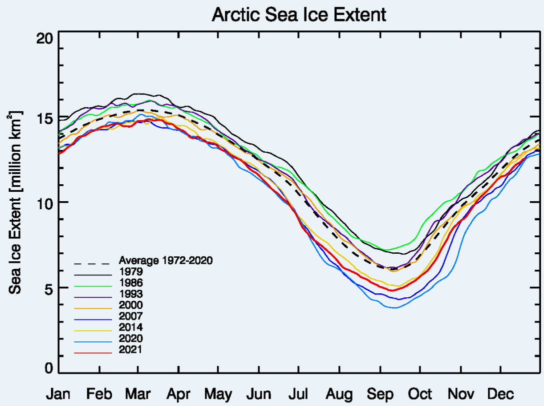

Fig. 1 Seasonal Arctic sea ice extent for recent years and the mean for the period 1972 - 2020

Daily SIC data are used for (1) initialisation of and assimilation into global climate models (GCM) and numerical weather prediction (NWP); (3) for shipping in polar seas, and (3) various climate and environment studies. Daily maps of SIC produced as images (PNG) and gridded data (NetCDF, HDF4).

Data available at:
https://seaice.uni-bremen.de/sea-ice-concentration/amsre-amsr2
ftp://ftp.ifremer.fr/ifremer/cersat/products/gridded/psi-concentration

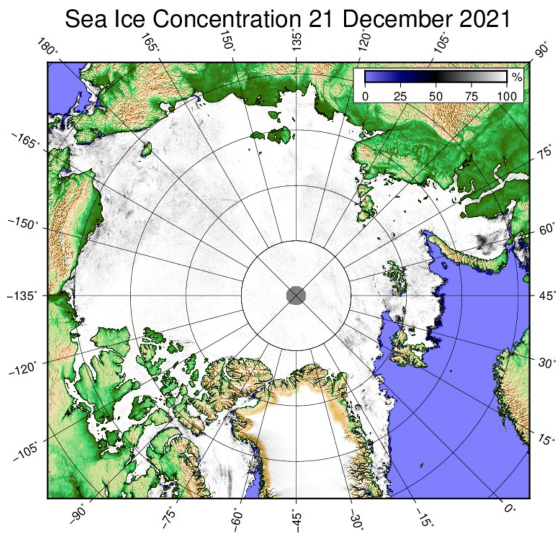

Fig. 2 Map of total SIC on 15 March 2021.

Reference:
Spreen, G., L. Kaleschke, and G.Heygster (2008), Sea ice remote sensing using AMSR-E 89 GHz channels J. Geophys. Res., vol. 113, C02S03, doi:10.1029/2005JC003384

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Daily maps of Arctic multiyear ice fraction

Multiyear ice concentration maps (MYIC) are produced daily at 12.5 km resolution during the freezing season in the Arctic (October to May).

The MY ice in the Arctic has decreased significantly in the last decade. In the 1980s MY ice covered most of the Arctic Basin, but presently the MY area is limited to the area north of Greenland and Canada (Fig. 1).

Multi-year ice is physically different from first-year ice and younger ice in terms of salinity, thickness, density, snow cover and mechanical properties. Data from MYIC is essential for understanding and modelling sea ice evolution from year to year. The data are also important for ice navigation and operations in ice. MYIC is retrieved from microwave emission and backscatter data between 5 and 37 GHz. Data come from satellite-borne radiometers AMSR-E or AMSR2 (since 2002), and from scatterometers ASCAT (on Metop) or Seawinds (on Quikscat).

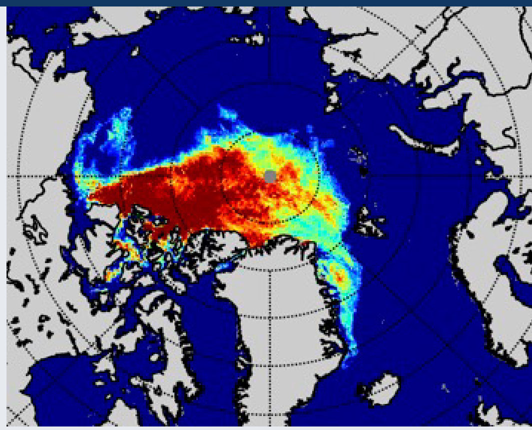

Fig. 1 Map of MYI in the Arctic om 01 Dec. 2020

Daily MYI data spanning more than 10 years are used (1) for validation or initialisation of ice-ocean-atmosphere models; (2) as ancillary data for other retrievals; (3) for locating possible old ice (navigation). Daily maps of MYIC are produced as images (PNG) and gridded data (NetCDF).

Data and maps are available at:
https://seaice.uni-bremen.de/

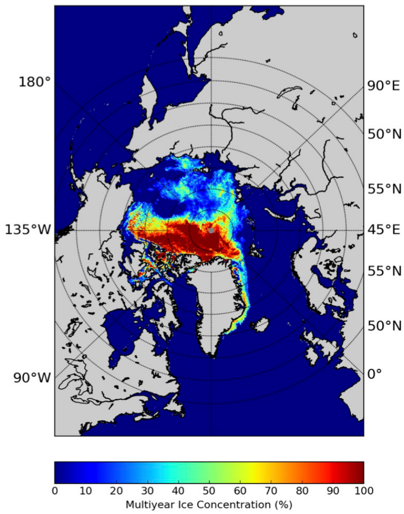

Fig. 2 Map of MYIC in the Arctic, 15 March 2021.

References:
Ye, Y., M. Shokr, G. Heygster, and G. Spreen (2016) Improving multiyear ice concentration estimates with ice drift. Remote Sens., 8(5), 397, doi:10.3390/rs8050397
Ye, Y., G. Heygster, and M. Shokr (2016) Improving multiyear ice concentration estimates with air temperatures. IEEE Trans. Geosci. Remote Sens., 54(5), 2602–2614, doi:10.1109/TGRS.2015.2503884.

Contributors: C. Melsheimer and G. Spreen (U. Bremen), Y. Ye and M. Shokr (Environment Canada)

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Environment Canada
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Thickness of thin sea ice in the Arctic

Daily maps of sea ice thickness up to 50 cm are produced in the Northern Hemisphere at 40 km resolution for the freezing season (October to April)

To observe sea ice thickness from satellites has been a major goal for several decades. By use of L-band microwave data, the thickness of thin sea ice (< 50 cm) has been be retrieved since 2010 using SMOS.

The thin ice thickness is derived from the polarization difference and the intensity of the L-band signal using an empirical method, which works well in the freezing season. Figure 1 shows the growth of ice thickness in the first three months of the freezing season.
The upper graph presents the total ice concentration and the lower graph the mean ice thickness. Figure 2 shows an example of ice thickness map for the whole Arctic Ocean in November when freezing is very active in the Russian shelf seas.

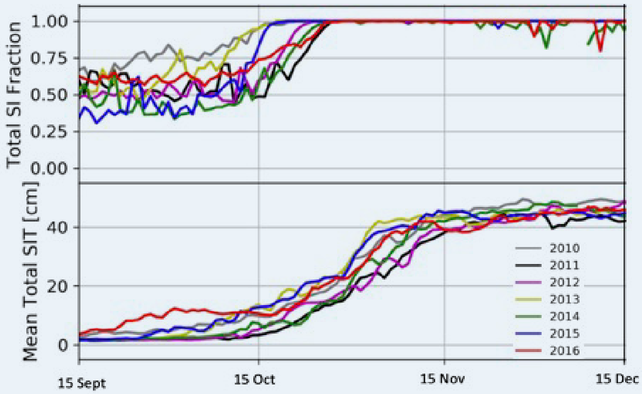

Fig. 1 Growth of ice concentration and thickness in the Laptev Sea for the years 2010 to 2016

The thickness data are used to improve weather and climate prediction in NWP and GCM models using data assimilation.

The data are also used directly to support ship navigation in ice-covered areas.

Maps of thin ice thickness are produced by combining data from the SMOS and SMAP satellites. The maps are updated daily with the near real time maps generated within 24 hours of the last observation.

Tha data are available in png, HDF and GeoTIFF formats at https://www.seaice.uni-bremen.de

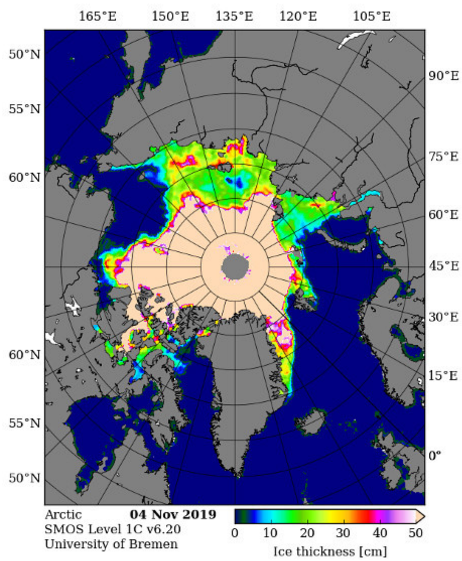

Fig. 2 Map of thin ice thickness on 4 November 2019.

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INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

French Institute for Ocean Science (Ifremer)

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Daily maps of Arctic sea ice drift from satellite observations

Sea ice drift is an important parameter to monitor and satellite data has been used to produce regular sea ice displacement maps for the winter months since 1992.

The CERSAT center at Ifremer provides long-term, homogeneous datasets of sea ice displacement and other products from passive & active satellite sensors.

The sea ice displacement data sets are produced from scatterometer and radiometer sensors onboard several satellites, which have been operating from 1992 to present. The sea ice displacement maps are produced at large & medium grid resolution (62 and 31 km) and are freely available at the CERSAT processing and archiving centre. The displacement data are derived from the QuikSCAT, ASCAT/MetOp, SSM/I, AMSR-E and AMSR-2 satellites.

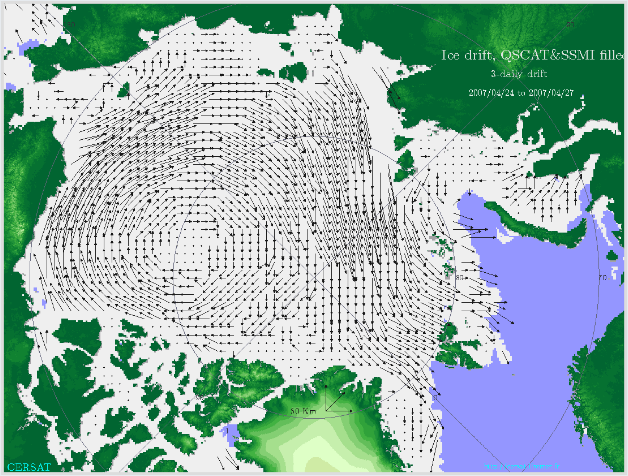

Fig.1 Arctic sea ice displacement map for 3 days at low resolution, 24-27th April 2007. Low resolution map using SSM/I and QuikSCAT data)

Daily sea ice drift data are used for

- Long-term analysis of ice displacement
- Estimate of sea ice area fluxes in the Fram strait
- Estimates of ice volume fluxes in ombination withice thickness data
- Assimilation in models
- Statistics for operations/risk estimate

Data are available at http://cersat.ifremer.fr/

Method and validation are published in
Girard-Ardhuin F. & R. Ezraty, Enhanced Arctic sea ice drift estimation merging radiometer and scatterometer data, IEEE Trans. Geosc. Remote Sensing, vol 50(7), July 2012, pp 2639-2648. DOI : 10,1109/TGRS,2012,2184124

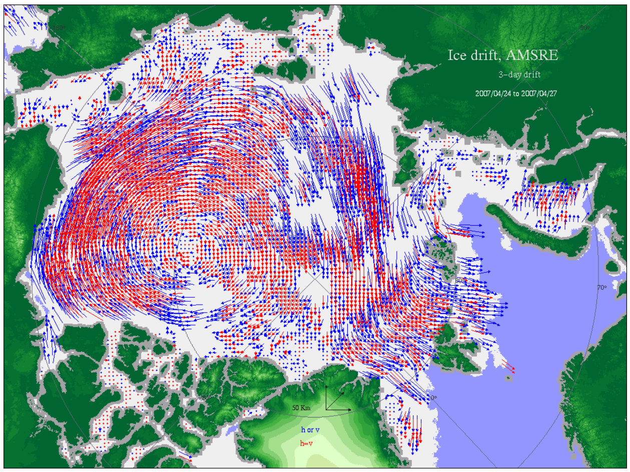

Fig. 2 Same as Fig, 1 at medium resolution (AMSR-E H & V data). Red vectors have higher confidence than blue vectors.

Contributors: JF Piollé, C. Prevost (Ifremer/CERSAT/LOPS)

Ifremer CERSAT LOPS

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Swedish Meteorological and Hydrological Institute and Stockholm University

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Assessment of satellite-based cloud climate data records over the Arctic

The objective of the study was to evaluate and inter-compare four cloud Climate Data Records (CDR) and assess changes in Arctic cloud properties.

Clouds play an important role in the Arctic surface energy budget. Yet very little is known about their climatological characteristics and their response to warming and decreasing sea ice.

Currently there exist 4 satellite-based global CDRs of cloud properties that cover a more than 30+ year time period. They are evaluated in this workpackage to understand commonalities and differences and their strengths and weaknesses.
The trends in cloudiness are also evaluated.

CLARA-A2:
https://www.atmos-chem-phys.net/17/5809/2017/
PATMOS-x: https://cimss.ssec.wisc.edu/patmosx/
ESA Cloud_cci: http://www.esa-cloud-cci.org/
ISCCP: https://www.ncdc.noaa.gov/isccp/

Figure 1 shows trends in total cloud fraction based on CLARA-A2 climate data (1982-2016). Cloudiness is increasing during autumn.

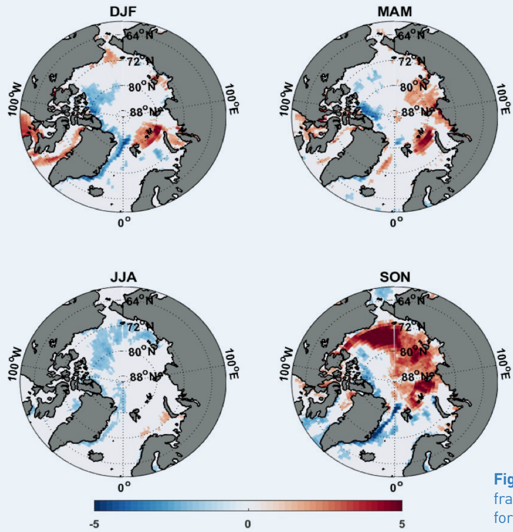

Fig.1 Trend in cloud fraction (%/decade) for each season.

The data are used for:

- Climate researchers at the universities and research institutes
- Agencies monitoring extreme events in the Arctic.
- Global and regional climate modeling community
- Energy and resources planning

Reference:
Devasthale A., Sedlar J., Tjernström M., Kokhanovsky A. (2020) A Climatological Overview of Arctic Clouds. In: Kokhanovsky A., Tomasi C. (eds) Physics and Chemistry of the Arctic Atmosphere. Springer Polar Sciences. Springer, Cham. https://doi.org/10.1007/978-3-030-33566-3_5

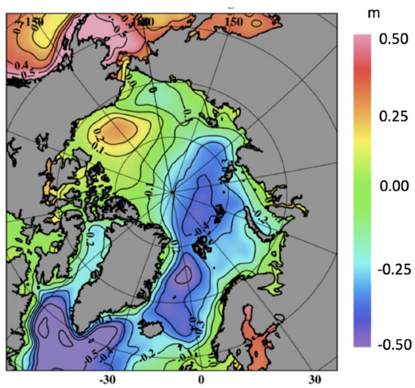

Fig. 2 Comparison of climatological mean cloud fraction in four CDRs (1982-2016).

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

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Total water vapor over Arctic sea ice, land ice and open ocean

A method for estimating vertically integrated water vapour (TWV) in polar regions has been developed. TWV datasets of 50km resolution have been produced since 2002, based on data from satellite microwave humidity sounders.

Water vapor (WV) is the most important greenhouse gas and the source of clouds and precipitation. Monitoring of water vapor in the Arctic in near real time and on long time scales is essential for predicting Arctic weather and understanding climate trends.

Standard methods to observe atmospheric water vapor do not work in polar regions where water vapor content is low.
By combining data from the microwave imagers AMSR-E/2 over open water and a new retrieval from the humidity sounders AMSU-B and MHS on-board the NOAA and METOP platforms, a data set of vertically integrated WV has been generated. Examples of monthly mean TWV are shown in Fig. 1.

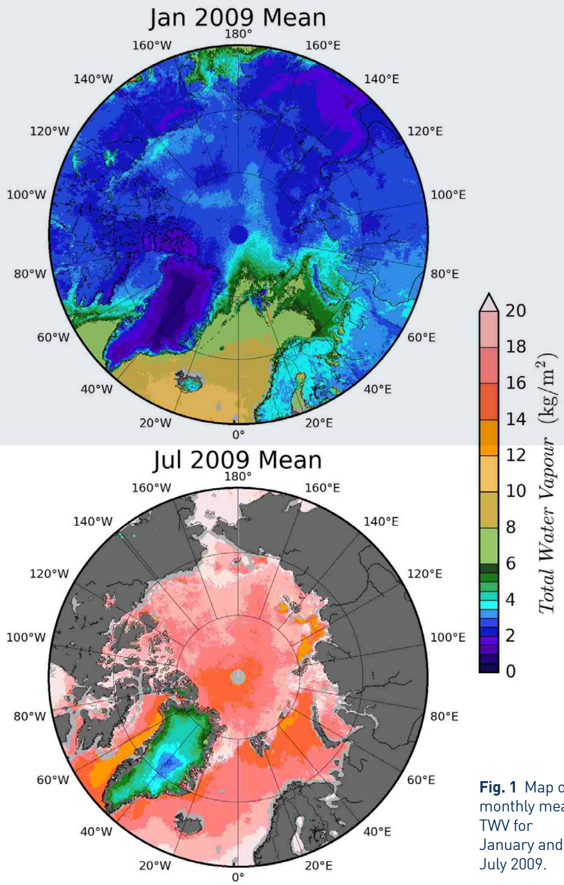

Fig. 1 Map of monthly mean TWV for January and July 2009.

The data set is used in a multi-disciplinary data assimilation study to characterize greenhouse gas mass transport and to explain greenhouse gas (GHG) patterns in the Arctic. This will help to reduce uncertainties in future climate simulations.

The data are available in NetCDF and png formats:

- https://catalog-intaros.nersc.no
- https://www.seaice.uni-bremen.de (including User Guide)

References
[1] Triana-Gómez, A. et al.: Improved water vapour retrieval from AMSU-B and MHS in the polar regions. Atmos. Meas. Tech. 13, 3697–3715, DOI: 0.5194/amt-2019-253
[2] Wentz, F. J. and T. Meissner. 2004. doi: https://doi.org/10.5067/AMSR-E/AE_OCEAN.002.

Contributors: Mathias Göckede (Max-Planck-Institute for Biogeochemistry), Mathias Arantxa Triana-Gomez, Christian Melsheimer, Gunnar Spreen (U. Bremen)

Universität Bremen
iup

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

Community-based Observations

"Changes in climate and nature are most often first detected by local community members. The locals can quickly report the changes they observe. If the observations they make are systematic, they can be a huge help for the management of the living resources."

- PâviâraK Jakobsen, Qeqertalik Municipality, Greenland

Qeqertalik Municipality, Greenland

PâviâraK Jakobsen
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Community-observing of natural resources in North-West Greenland

Qeqertalik Municipality and NORDECO with many partners are developing community observing in North West Greenland. The work builds upon existing informal community-based observation and management systems in the area.

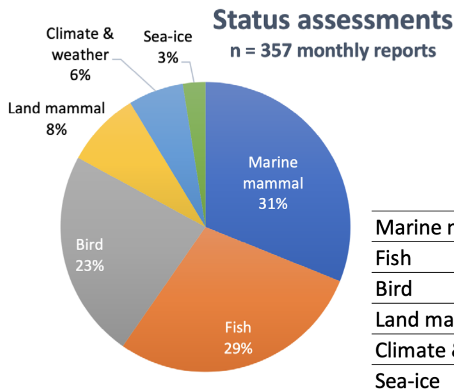
Qeqertalik Municipality and NORDECO with many partners pilot community observing in North-West Greenland. The work builds upon existing informal community-based observation and management systems in the area. The process of routinely observing the environment is led and undertaken by local natural resource experts, typically fishermen and hunters in their respective communities (Fig. 2). The work contributes to the Greenland Government's community observing network Piniakkanik Sumiiffinni Nalunaarsuineq (PISUNA).

PISUNA-net: https://eloka-arctic.org/pisuna-net/en
PISUNA: www.pisuna.org

Fig. 1 Registration of local resources (Photo: F. Danielsen).

By its nature, community observing tends to focus on issues of greatest concern to local stakeholders. The community observing documents living resources, promotes local discussion, and shortens the time from observation to decision.

Fig. 2 Communities who have been making resource observations.



Marine mammal	111
Fish	102
Bird	83
Land mammal	30
Climate & weather	22
Sea-ice	9

Fig. 3 The proportion of monthly records of the status of different taxa, climate, weather, and sea-ice from the PISUNA Natural Resource Committees in Akunnaaq, Attu, Kangarsuatsiaq, Kitsissuarsuit, and Qaanaaq, 2016-2019.

Contributors: Per Ole Frederiksen (Attu), Gerth Nielsen (Akunnaaq), Edvard Kristiansen (Kangarsuatsiaq), Tom Mølgaard (Kitsissuarsuit), Jens Danielsen (Qaanaaq), Michael K. Poulsen and Finn Danielsen, (NORDECO)

NORDECO
Nordic Agency for Development and Ecology

Kommune Qeqertalik

INTAROS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727890

The Republic Indigenous People Organization of Sakha Republic, Russia

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Piloting community-based observing among Evenk communities in Yakutia

The Republic Indigenous People Organization of Sakha Republic cooperate with other Indigenous Peoples organizations and NORDECO in developing capacity and piloting community observing among civil society organizations and community members in Sakha Republic, Russia. Community members keep track of changes in the environment, discuss their observations and propose management initiatives.

The community-based monitoring process has involved a wide range of workshops and meetings in the communities of Zhigansk and Olenek districts. The first workshops have introduced community-based monitoring and built the local capacity to undertake it. Subsequent workshops have focused on how concrete monitoring activities are being implemented. As of 2020, eight community groups are actively undertaking community-based monitoring. Key participants are local fishermen, hunters and herders, local indigenous peoples' representatives, various members of local authorities, and school students and teachers. The monitoring process fills important knowledge gaps. In the future, the monitoring may link to Arctic community observatory networks and the data may become broadly available.

Fig. 1 Visitor welcome ritual in Evenk community in Yakutia. Photo by M. Enghoff.

The community observing by the Evenk community members in Yakutia enables better ability to adjust management of the resources to changing conditions of the resources. At the same time, it contributes to improved dialogue between communities and authorities, and helps enhance local livelihoods within environmentally sustainable limits. Community observing has, for example, led to establishment of a traditional use area for fisheries. The data are stored within databases held by the Republic Indigenous People Organisation of Sakha Republic, and additionally the data collection is registered in the publicly available INTAROS Data Catalogue.

Fig. 2 Fish is an important food source in Yakutia. Photo by M. Enghoff.

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Geological Survey of Denmark and Greenland

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Cryo-seismological recordings from citizen science seismic stations

GEUS and UiB with partners pilot citizen science seismic stations for cryo-seismological recordings in West Greenland and Svalbard. The purpose is to collect data from the local seismic activity, in order to improve the accuracy of earthquake locations and detection thresholds and thereby gain new information on the earthquake hazard in the region. The data could potentially also provide new insight on seismic signals released in the cryosphere such as glacial events or icequakes.

Since mid-2018, the monitoring by permanent seismological networks in West Greenland has been complemented by citizen science monitoring seismometers in Disko Bay (Fig. 1 and 2).
The sensors are fully automatic; when they are connected to an Internet router and powered up they adjust their inner clock and start sending live data to the Internet server that collect data from more than 1000 similar sensors worldwide.

Fig. 1 Gerth Nielsen, Akunnaaq, with seismograph before connecting it to electricity and a router and placing it on the rock below his house. Photo: F. Danielsen.

The data are shared in real time at the website https://raspberryshake.org and are also included in the GEUS earthquake bulletin (https://www.geus.dk/natur-og-klima/jordskaelv-og-seismologi/registrerede-jordskaelv-i-groenland)

The data improve the detection and location of cryo-generated seismic events and earthquakes and other events that generate seismic signals. Furthermore, the data provide information on the magnitude of local ground motions during felt earthquakes.

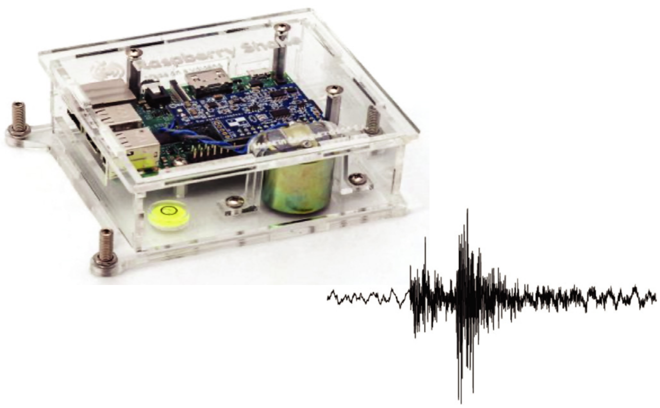

Fig. 2 Upper: photo of the Raspberryshake seismometer, Lower: a seismogram showing the recording of a magnitude 2.0 earthquake located 122 km South-West of Akunnaaq, May 21st 2018.

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Nordic Agency for Development and Ecology, and Nansen Environmental and Remote Sensing Center

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Testing environmental monitoring in the Arctic on expedition cruise ships

Many remote areas in the Arctic are hardly accessible by scientists or others, preventing data collection. A possibility to improve this is offered by cruise expedition vessels whose passengers can contribute to environmental data collection in remote areas through Citizen Science. Data from these programmes can be useful for scientists and contribute to environmental management.

A dialogue has been initiated with the expedition cruise industry (including AECO), scientists, and local authorities about environmental observing during cruises to remote Arctic areas. Four Citizen Science programs were tested among cruise operators in Disko Bay and Svalbard for one cruise season. A total of 165 people contributed observations.

An example is "Happywhale" where marine mammals are photo documented. In 2019 81 encounters of 13 species were reported from the Svalbard region into the website: https://happywhale.com/home (Fig. 1). The icons show records of polar bear, fin whale, humpback whale, bowhead whale, and harbor seal. The digits indicate numbers of encounters that are too close together to be shown on the map.

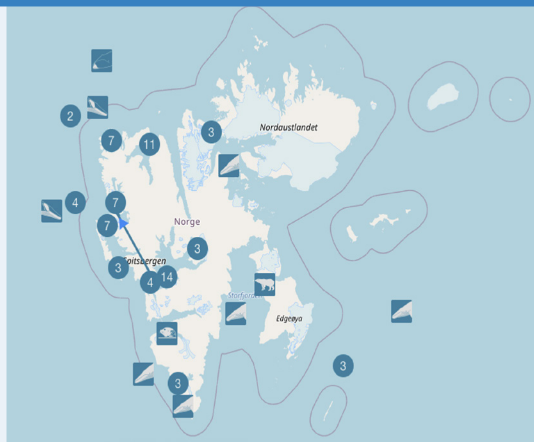

Fig. 1 Records of marine mammals in Svalbard in 2019 (from https://happywhale.com)

Cruise passengers and guides can contribute to large volumes of observations during the cruise season from April to September. Enabling factors include: (1) equipping cruise vessels with tablets that allow for easy upload of records, (2) prompt feedback to observers and decision-making bodies directly from the citizen science programs through the use of digital platforms, and (3) a well-funded intermediate organization facilitating communication.

Link to other Citizen Science programmes of relevance to Arctic cruise expeditions:

- eBird (https://ebird.org)
- Secchi Disk Study (www.secchidisk.org)
- Cloud Observations (www.globe.gov/web/s-cool)

Fig. 2 Photo by M.K. Poulsen.

Contributor: Lisbeth Iversen (NERSC).

NORDECO
Nordic Agency for Development and Ecology
NERSC
Association of Arctic Expedition Cruise Operators AECO

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Nansen Environmental and Remote Sensing Center

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Co-creating knowledge with the local community in Longyearbyen, Svalbard

Co-production of knowledge involves linking top-down, (non-) governmental programs with bottom-up initiatives at community level. This approach is necessary to build trust, develop a sustainable place-leadership and management, and to identify gaps in research needed for sustainable local planning and decision-making. Longyearbyen is one of the areas where INTAROS supports co-production of knowledge.

The Svalbard Social Science Initiative is an association of social science, humanities and arts-based researchers working with a wide range of issues on Svalbard. SSSI was established in 2019 with support from INTAROS. SSSI helps to coordinate research activities and communication with the local community in Longyearbyen. The SSSI website provides a venue for sharing research and publications as well as creating opportunities to coordinate with each other and local residents.

https://svalbardsocialscience.com
E-mail: svalbardsocialscience@gmail.com

Fig. 1 SSSI represented by Cecilie Vindal Ødegaaard, Zdenka Sokolickova, Lisbeth Iversen and Alexandra Meyer at the Local Council meeting in Longyearbyen, September 16 2019. Photo: Hilde Kristin Røsvik-Svalbardposten.

After the Covid 19 lock-down in 2020, SSSI have collaborated with Store Norske, LPO architects and the Local Council on the establishment of Longyearbyen Community Dialogues.

The dialogue meetings started in June 2020 where important topics for the community are discussed. Open meetings have been organised in Longyearbyen Culture House. Other inhabitants and local actors can participate digitally and follow the dialogues through streaming, and they can comment and contribute. This is planned to be a monthly event.

More information at https://svalbardsocialscience.com/longyearbyen-community-dialogue-about-tourism

Fig. 2 From one of the Longyearbyen Community Dialogue meetings.

NERSC SSSI
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Climate Modelling and Observations

"Climate models are invaluable tools to understand climate processes and to predict the future of climate. Climate models are providing unique input to assessments of climate change, to climate services and to climate impact research. Availability of observations is a necessity to develop, evaluate and initialise climate models from."

- Ralf Döscher, Swedish Meteorological and Hydrological Institute, Sweden.

Barcelona Supercomputing Center

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Climate impact of Arctic sea ice minima based on observational analysis

The objective was to characterize the Arctic sea ice minimum in spring 2018 in different data sets from sea ice concentration observations, reanalyses and modeling fields.

Observational Products used in the study included:

(1) Sea Ice Concentrations from CERSAT and HadISST,
(2) Geopotential at 500hPa (z500) from Japanese 55-year Reanalysis and
(3) Surface Air Temperature from EOBS v19.

Analysis included (Fig. 1)

- 6 analogous events to the Bering sea ice minima in 2018 are identified
- Composite maps averaging their related anomalies in z500 and SAT at subsequent months are computed
- Non-coherent signals across the individual events are stippled.

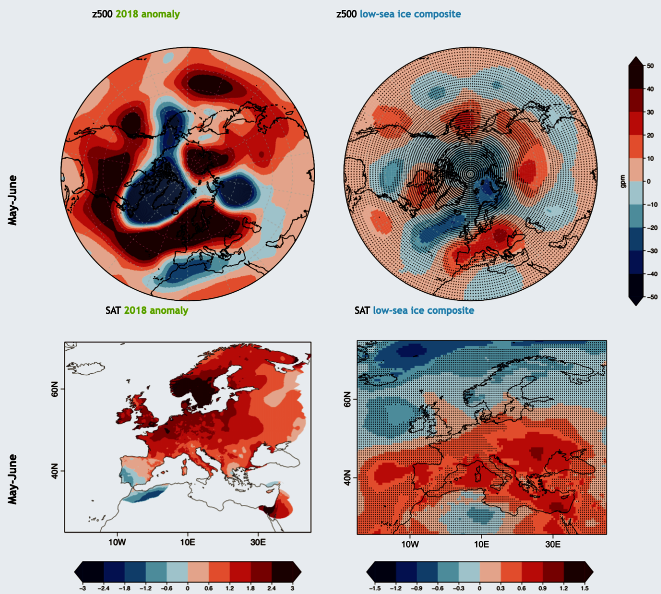

Fig. 1 Anomalies in the z500 Geopotential and Surface Air Temperature.

Main results:
Warm anomalies in western Europe during May-June and later might be associated with sea-ice driven changes in the atmospheric circulation. The identification of climatic responses in Europe to extreme events in sea ice can be useful for companies from different economic sectors like agriculture, tourism or energy production.

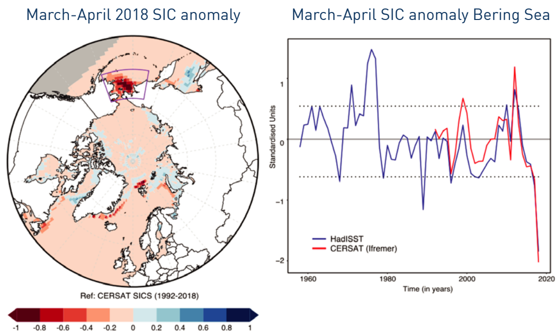

Fig. 2 The 2018 anomaly in SIC and SAT.

Reference:
Francis, J. A., and S. J. Vavrus, Geophysical Research Letters, 39 (6), doi:10.1029/2012GL051000, 2012.

Contributors: F. López, J. Acosta, S. Wild, M. Donat (BSC).

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

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Decadal climate predictions produced with EC-Earth3

The objective is to demonstrate application of iAOS for improving decadal climate predictions: usage of Sea Ice Concentrations from CERSAT.

- Decadal predictions with EC-Earth3 have been produced, initialized from ocean (ORA-S5) and atmosphere (ERA-Interim) reanalyses (reference system; collaboration with ARCPATH-project)
- iAOS to be used for
  a) independent verification
  b) assimilation/initialization yielding potentially improved decadal predictions

Mean SST-anomaly over Arctic Ocean

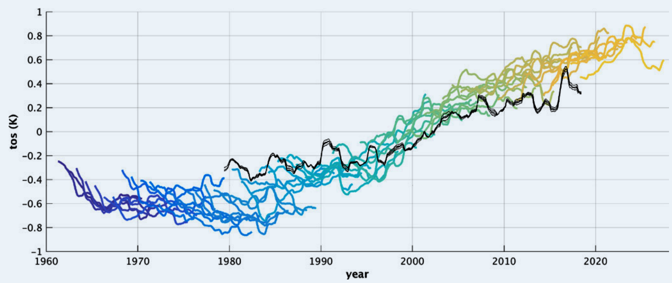

Fig. 1 Observed (black) SST-anomaly over Arctic Ocean (65°N-90°N) and respective retroactive decadal climate predictions (colored)

Decadal predictions produced with EC-Earth are global. iAOS will provide valuable data, that (i) allows for more thorough evaluation and verification of the predictions in a region highly important for the global climate but still underrepresented in existing observational products, and (ii) contributes to improving estimates of climate states, beneficial for the performance of decadal climate predictions initialized from these.

The EC-Earth3 decadal predictions demonstrate the application of iAOS data for the climate modelling community, other scientific actors and follow-up benefits for political and socio-economic stakeholders including local communities.

The climate prediction data are freely available from the Earth System Grid Federation (https://doi.org/10.22033/ESGF/CMIP6.4553 and links therein).

Surface temperature, Iceland-I

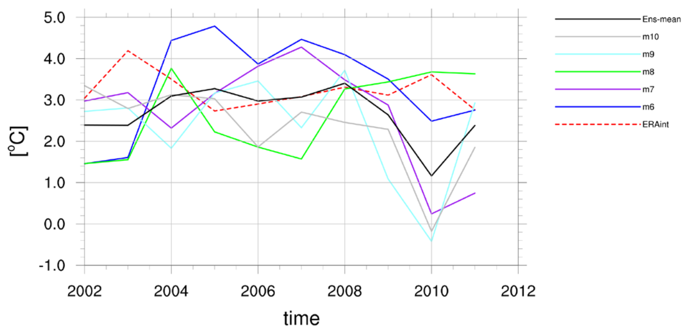

Fig. 2 Observed (red) 2m-temperature in Ísafjörður (Iceland) and retroactive decadal climate predictions (bluish & ensemble mean in black) initialized in November 2001

Contributors: Tim Kruschke, Mehdi Pasha Karami (SMHI).

SMHI

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University of Hamburg

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A 10-year Arctic Ocean reanalysis using the adjoint metho

The objective of assimilating in situ and remote sensing observations into an ice-ocean model is to 1) demonstrate the usefulness of improved Arctic observing system for process understanding; and 2) improve predictability of the ice-ocean environment.

The coupled ocean-sea ice data assimilation system builds on the MIT general circulation model coupled with a zero-layer thermodynamic-dynamic sea ice model. The model domain covers the entire Arctic Ocean north of the Bering Strait and the Atlantic Ocean north of 44N (Fig 1). The system has 50 vertical z-levels; a curvilinear grid with a resolution of ~16 km is used. The adjoint method adjusts the model initial conditions in the year 2007 and daily surface atmospheric states to make the model simulation consistent with the observations (Fig. 2 and 3).

Results:

- A 10-year Arctic Ocean reanalysis with all available data assimilated into the ice-ocean model.
- deliver information on where and what to observe to complement the current observing system.

Reference:
Lyu, G. et al., Q J R Meteorol Soc. 2021; https://doi.org/10.1002/qj.4002.

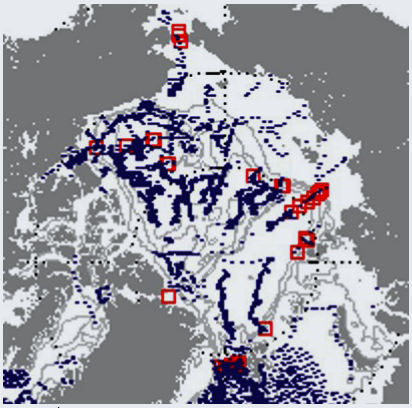

Fig. 1 Model domain and locations of moorings (red rectangles) and T/S profiles (blue dots, year 2008).

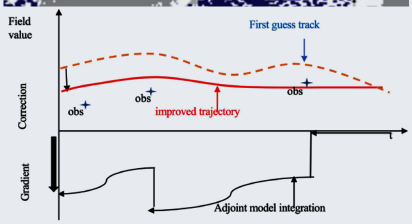

Fig. 2 4D variational data assimilation scheme.

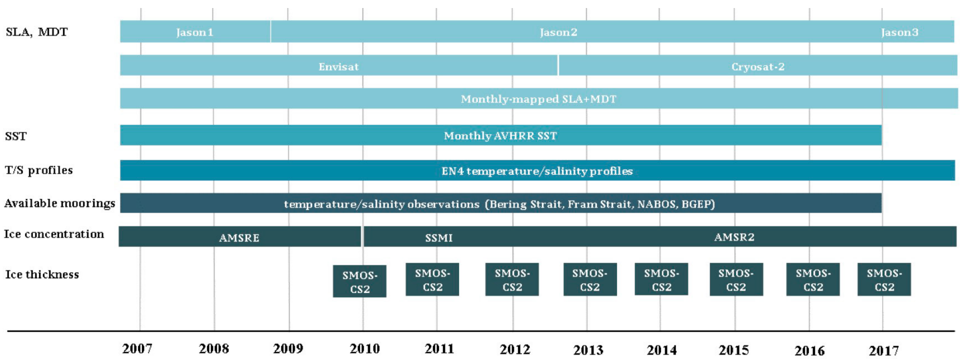

Fig. 3 Observations used in the reanalysis.

Contributors: G. Lyu, N. Serra, A. Koehl (U.Ham).

Universität Hamburg

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Nansen Environmental and Remote Sensing Center

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Enhancing the skill of seasonal prediction in the Arctic

Assimilating sea ice concentration data within the Norwegian Climate Prediction Model (NorCPM) **can greatly reduce error in the initial condition of sea ice thickness and enhances its prediction skill.**

NorCPM combines the Norwegian Earth system model with the Ensemble Kalman Filter (EnKF). The EnKF can successfully update jointly the ocean and the multi-category sea ice state.

We compare the performance of NorCPM assimilating ocean data only with one also assimilating sea ice concentration (HadiSST2).

Performance of the reanalysis and seasonal retrospective hindcast are assessed for the period 1980:2010 (Kimmritz et al. 2019).

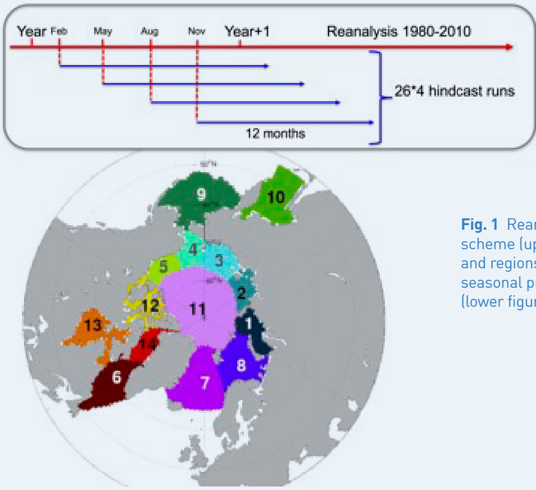

Fig. 1 Reanalysis scheme (upper figure) and regions for the seasonal prediction (lower figure)

The developments have been used in the CMIP6 Decadal Prediction Project (Bethke et al. submitted). The usefulness of the forecast for stakeholders in maritime transport is investigated in the Centre for Research-based Innovation Climate Futures.

We are now testing the added value of sea ice thickness from C2SMOS.

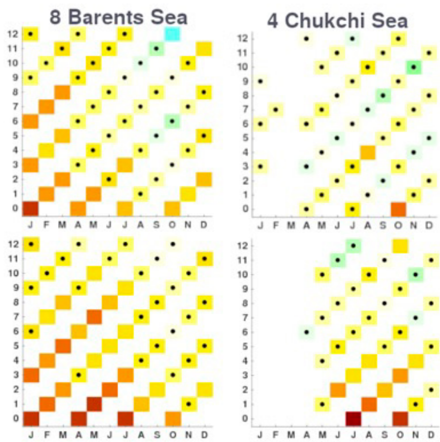

Fig. 2 Detrended correlations skill of sea ice extent in two regions of the Arctic. The x-axis is the starting month and the y-axis the lead month. Upper row with ocean data only and lower with ocean and se ice data. Dots mark insignificant correlations.

References:
Kimmritz, et al. (2019). Impact of ocean and sea ice initialisation on seasonal prediction skill in the Arctic. https://doi.org/10.1029/2019MS001825
Bethke et al., NorCPM1 and its contribution to CMIP6 DCPP, submitted to GMD

Contributors: M. Kimmritz and F. Counillon (NERSC).

NERSC

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Assessment of Arctic-HYCOS hydrological observation system and integration in the Arctic-Hype model

The Arctic-HYCOS project provides river discharge data at gauging stations representing freshwater flow-to-ocean and changes in Arctic hydrological regimes.

The Arctic-HYCOS project is part of the World Hydrological Cycle Observing System (WHYCOS) network in the transnational basin of the Arctic.
https://hydrohub.wmo.int/en/projects/Arctic-HYCOS

- Observations are integrated in the hydrological model Arctic-HYPE to provide estimates of flow in ungauged basins and Pan-Arctic forecasts of river discharge in near real time
- Arctic-HYCOS observation system was assessed with regard to spatial, temporal, and total water flow representation
- Data access enhanced by integration in the IAOS developed in INTAROS

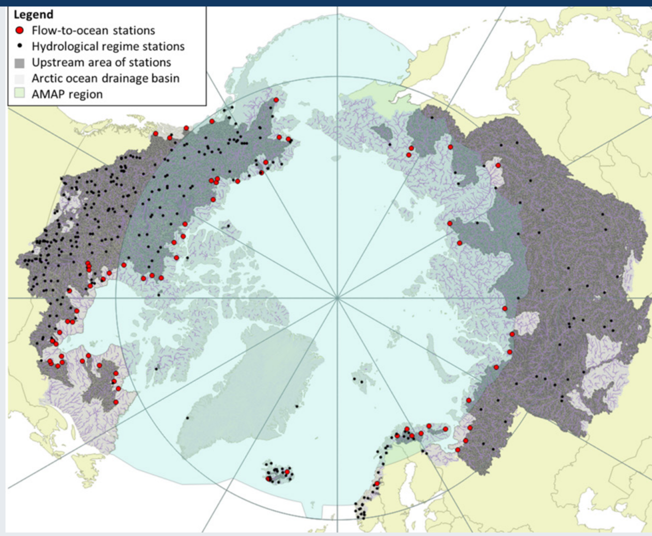

Fig. 1 Arctic-HYCOS hydrological station network.

Users of Arctic-HYCOS are

- Arctic communities (improved flood forecasting, freshwater resource management)
- Ocean and Climate modelers (improved estimates of freshwater inflow to ocean)
- Studies of climate change impacts on Arctic freshwater systems

Arctic-HYPE model analysis and forecasts are available from SMHI (http://hypeweb.smhi.se)

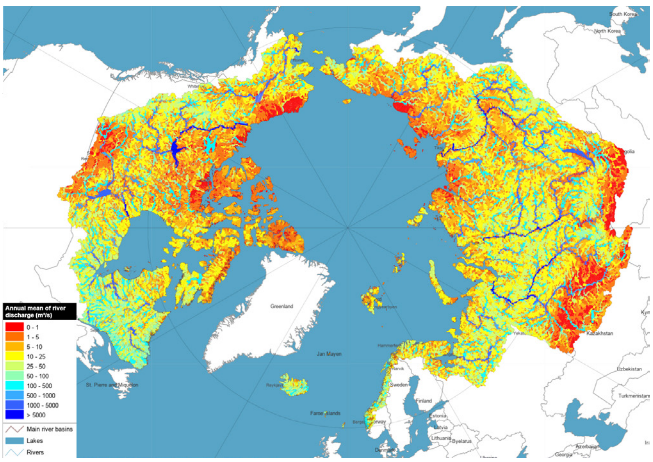

Fig. 2 River discharge by Arctic-HYPE model.

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