INTAROS General Assembly

Virtual Event, 20-21 January 2022

Integrating Arctic Observing Systems

INTAROS final synthesis report meeting

INTAROS

WP3 Enhancement of *in situ* observations in the Arctic

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INTAROS WP3 Enhancement of *in situ* observations in the Arctic

To develop an efficient integrated Arctic Observation System by extending, improving and unifying existing and evolving systems in the different regions of the Arctic

INTAROS reference sites and distributed observatories:

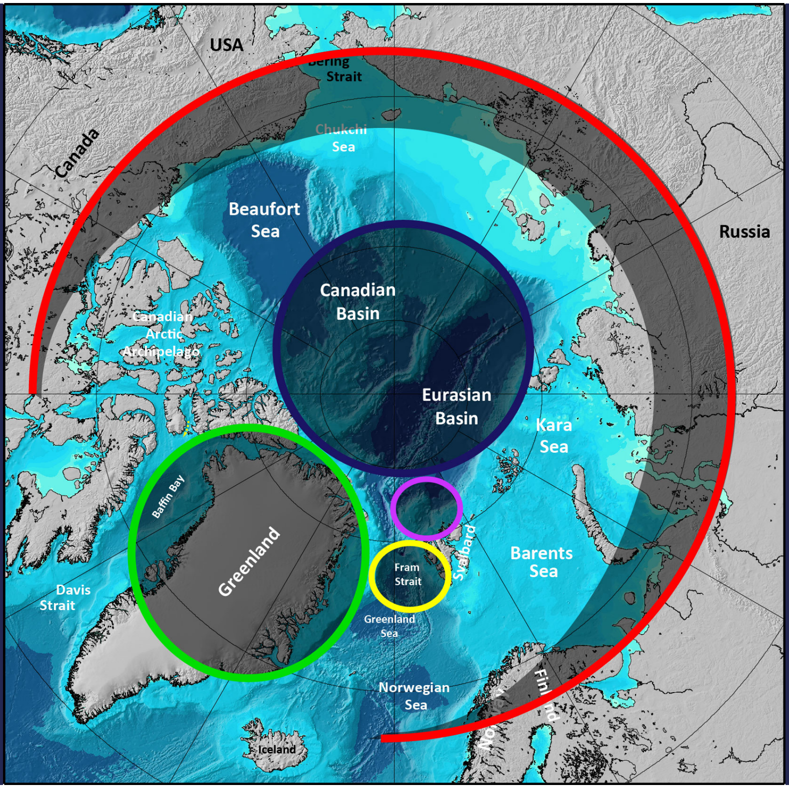
Coastal Greenland and Baffin Bay

North of Svalbard towards the deep Nansen Basin

Fram Strait and Kongsfjorden

Central Arctic distributed systems for ocean and sea ice

Pan-Arctic region distributed systems for atmosphere and land



WP3 objectives:

- make best use of existing reference sites and distributed observatories providing data for Arctic climate and ecosystems but missing multidisciplinary dimension or technical advancement
- extend temporal and geographic coverage of available infrastructures and add key geophysical and biogeochemical variables through implementing novel technologies integrated with standard observations

WP3 Enhancement of *in situ* observations in the Arctic

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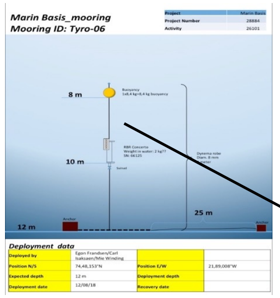
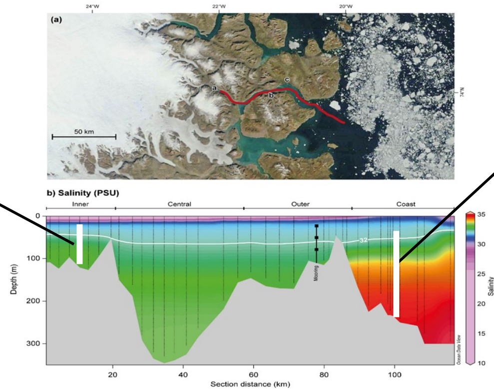
Marine and ice sheet observations in coastal Greenland

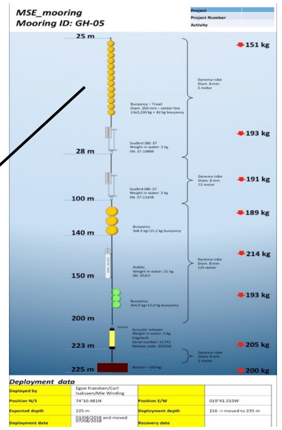
Ocean moorings with freshwater and snow on the ice focus in NE Greenland (AU)

- Two moorings in Young Sound: one in the inner fjord near the Ice Sheet and one in the outer fjord (coastal)
- Measurements of key physical parameters coupled to detailed biological measurements from existing monitoring program
- 3 years of consecutive data available at Greenland Ecosystem Monitoring Programme database



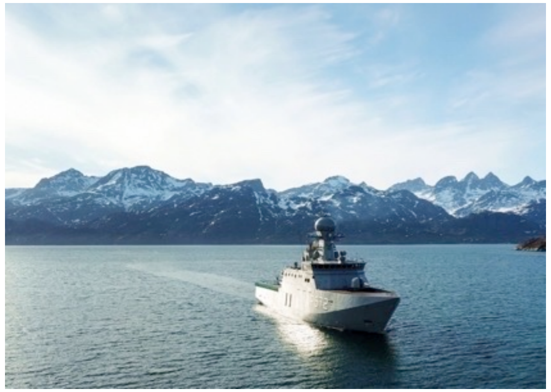
Two new moorings deployed under INTAROS

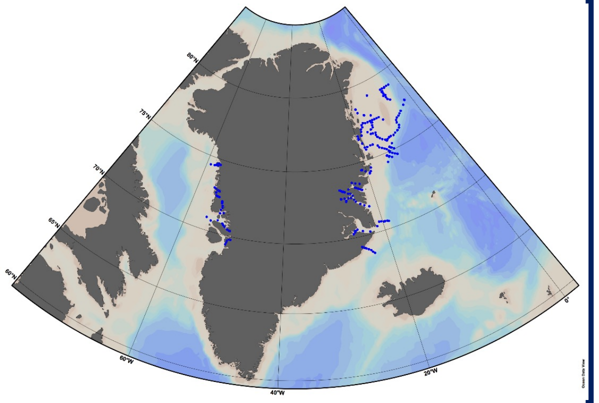




Collecting baseline dataset on surface pCO2 and OA in the entire Greenland coastal zone (AU)

- Data collected in coastal Greenland 2016-2018 (3 cruises)
- Provided 50+ CTDO profiles, pCO_2, nutrients etc.
- Joint work with stakeholder (Danish Navy) in 2018
- Data in public depository GEM data base after embargo





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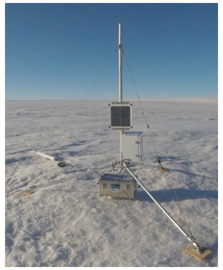
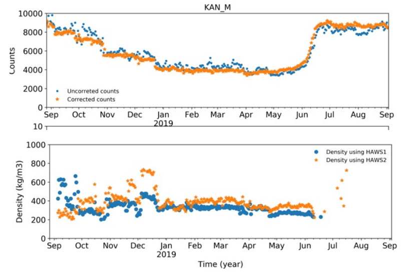
Marine and ice sheet observations in coastal Greenland

New *in situ* observations on the Greenland icesheet as contribution to PROMICE network (GEUS)

SWE measurements on ice sheet by SnowFoxes

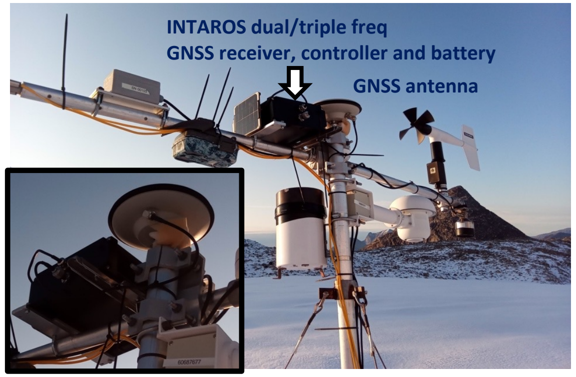
Five SnowFox instruments (water-equivalent of above-laying snow) deployed on the Greenland ice sheet in 2018-2020





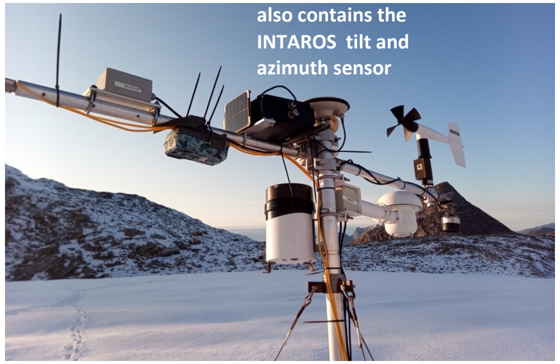
Precise AWS positioning on ice sheet with new GNSS

- In situ validation data for satellite SAR velocity & altimetry products
- Constrain elevation of barometer
- Support local strain network for ice dynamics
- Deployed since 2018, performance of new instruments significantly better than initial requirements



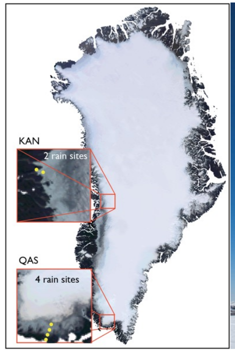
Radiometers with improved tilt and azimuth

- Improve correction for radiometer tilt for changes in azimuth and remove alignment error between radiometer and tilt sensors
- Provide accurate in situ validation data for satellite albedo products
- Deployed since 2019 with GNSS



Experimental rain gauges on ice sheet

- Experimental deployment of rain gauges since 2018 (three sites with new setup)
- Implementation of a new AWS system including a rain gauge at all >20 PROMICE locations starting in 2021



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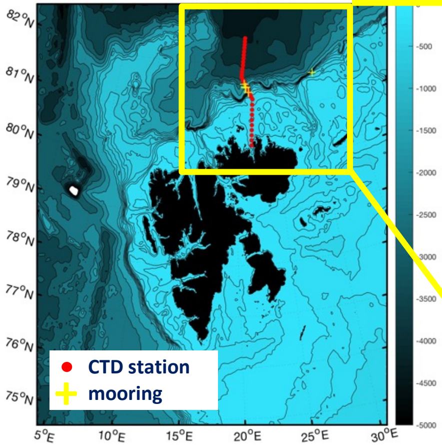
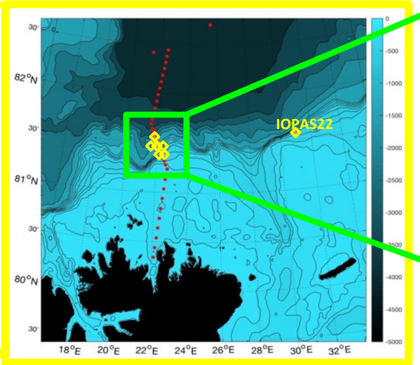
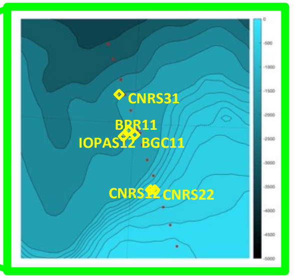
Moored observatory north of Svalbard towards the deep Nansen Basin

Moorings with profiling and point measurements of physical and sea ice variables (IOPAN, LOCEAN, UiB-GFI, NERSC)







INTAROS mooring cluster

Pilot experiment in 2017-2018: 2 moorings for physical obs

First deployment 2018-2019: 7 moorings with multidisciplinary

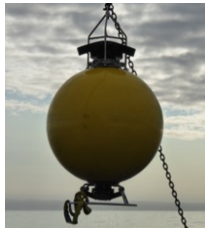
Second deployment 2019-2020: 4 moorings

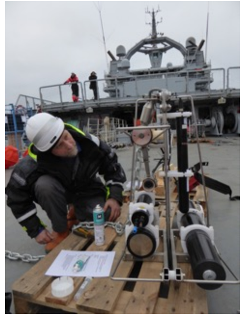
- Mooring operations in collaboration with CAATEX and the Norwegian Coast Guard (using the icebreaker KV Svalbard)
- CTD, optical, biogeochemical and turbulence measurements on stations during mooring cruises

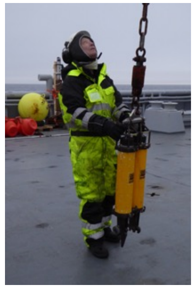
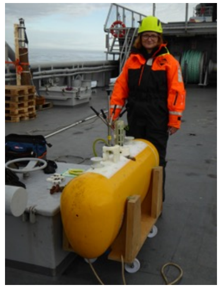
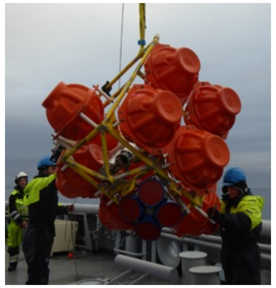
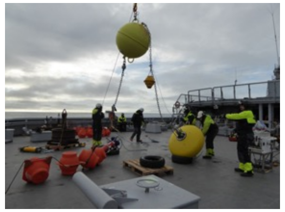
INTAROS moorings 2017-2021 instrumented with:

- Moored McLane Profilers (temperature, salinity, currents)
- TRDI QM and LR ADCPs (ocean currents)
- Signature 55 Dual Freq Nortek ADCPs (ocean currents, dual res./range)
- Nortek Signature 250 ADCPs (ocean currents, sea ice drift and draft)
- Microcats SBE37 CTD(O) sensors
- RBR and SBE56 temperature and pressure recorders







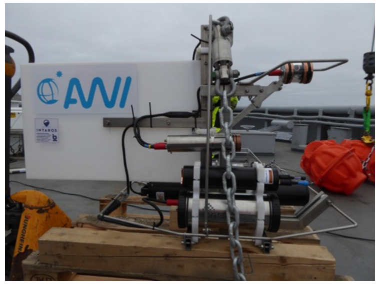
INTAROS WP3 Enhancement of *in situ* observations in the Arctic

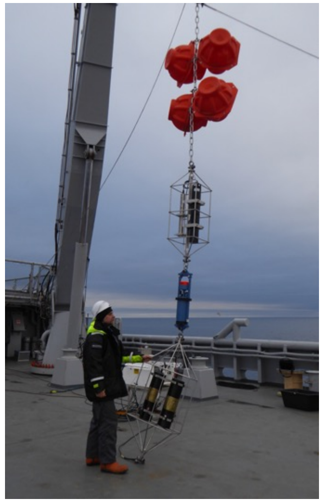
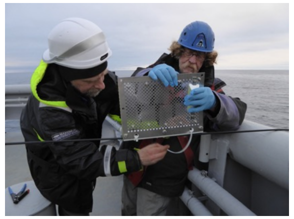
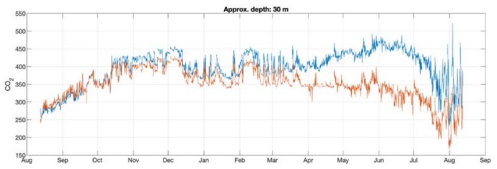
Moored observatory north of Svalbard towards the deep Nansen Basin

Multidisciplinary mooring for BGC and biological measurements (UiB-GFI, AWI, NIVA, IOPAN, NERSC)

- A suite of instruments for carbon system, biological and physical parameters: pH, pCO2, nitrate, CTDO sensors, Octopus package (UVP particle camera, nitrate sensor and ECO Triplet-w for chl a and FDOM fluorescence and backscattering, passive contaminant samplers)
- Deployed for 2018-2019 in cluster with the mooring at 850 m, measuring physical ocean and ice parameters

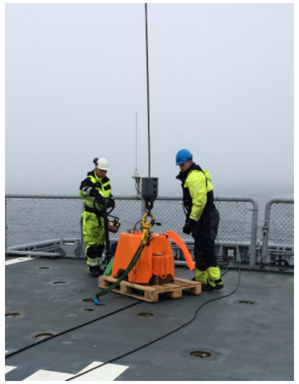


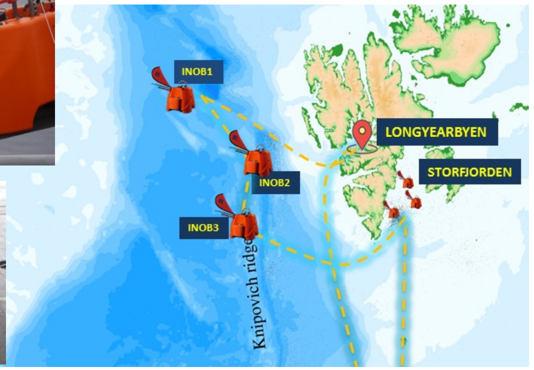


Ocean bottom seismometers in Fram Strait (GEUS, UiB-GEO) and BPR recorders (UNIS)

- Three OBS for for solid Earth processes and geohazards deployed in 2018-2019 and 2019-2020
- Deployment locations in deeper parts of Fram Strait, close to Mid Atlantic Ridge (seismically active regions) and in Storfjorden
- Data will be used to analyze earthquake sources to improve earthquake monitoring in the Arctic region



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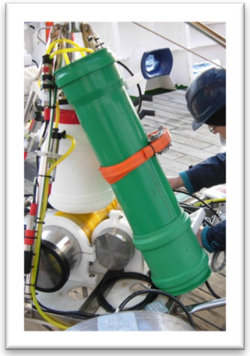
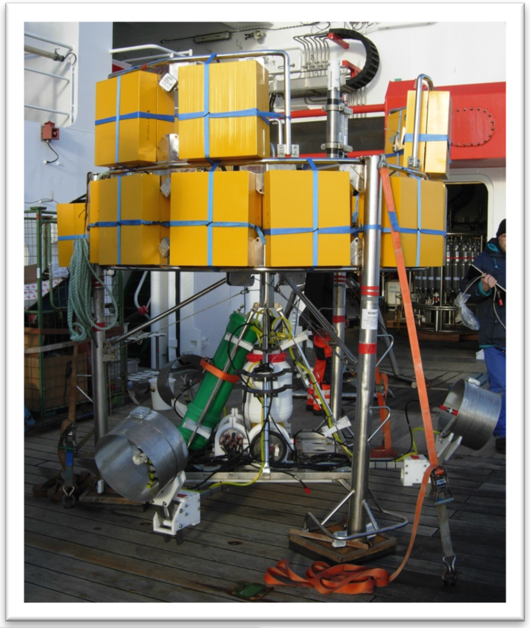
Marine observations in Fram Strait and Svalbard fjords

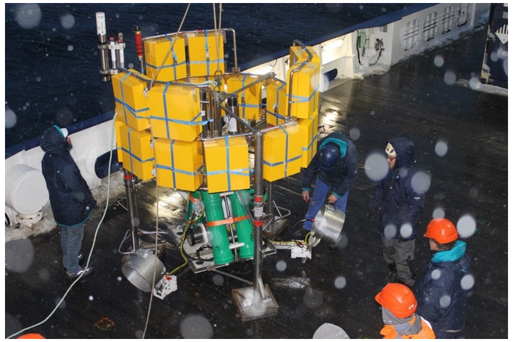
Autonomous arcFOCE (Arctic Free Ocean Carbon Enrichment) system (AWI)

Experimental set-up (based on a free-falling system - bottom-lander)

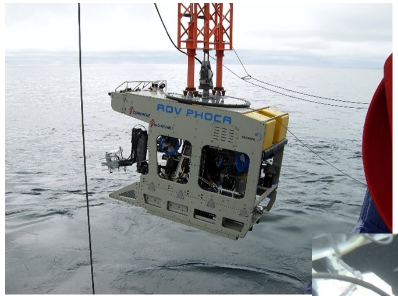
- **CO_2 storage** (discharge of CO_2 from pressure cylinders)
- **CO_2 enrichment unit** (CO_2 mixed with seawater)
- **Experimental chamber** (mesocosms)
- **Pump system** (seawater enrichment & feed into mesocosms)
- **pH sensors** (mesocosms, CO2-seawater mixing, reference sensor)
- **Energy supply** (batteries)
- **Electronical control unit**

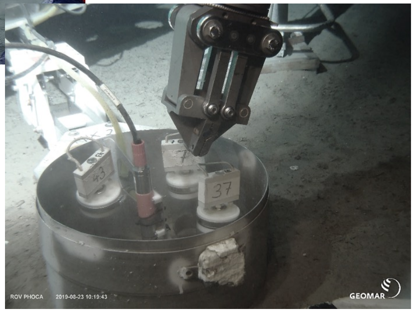




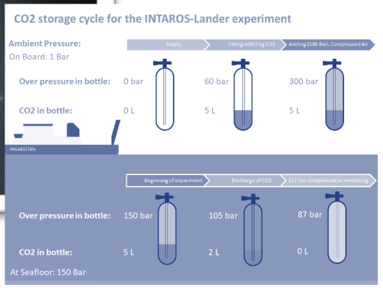


First long-term deployment from RV Polarstern for 2018-2019





Sediment sampling before recovery in summer 2019 using ROV PHOCA



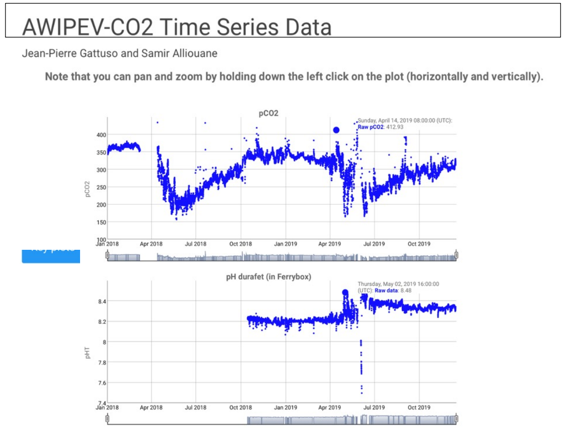
Redeployment in 2021 from RV Polarstern after reconfiguration of experimental setup

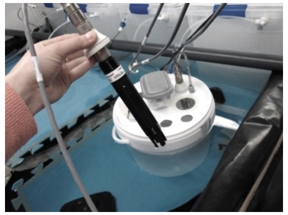
WP3 Enhancement of *in situ* observations in the Arctic

Marine observations in Fram Strait and Svalbard fjords

Real-time measurements of pCO2 and pH, monitoring of carbon cycle parameters in Kongsfjorden (CNRS-LOV)

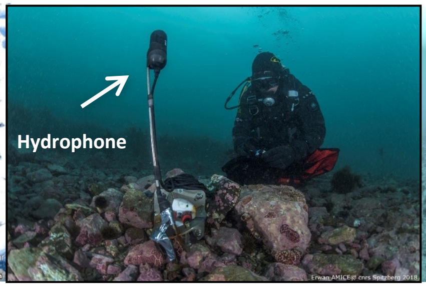
- AWIPEV observatory in Kongsfjorden, water pumped from 12 m water depth at Ny-Ålesund
- pCO2 (since 2015) and TA (since 2016) measurements
- Under INTAROS (since 2017) pH measurements:
  - Durafet pH sensor in the FerryBox
  - continuous measurements in fjord water (seaFET)
  - discrete pH samples once a month for calibration
  - regular maintenance twice a year





Ecological monitoring using underwater passive acoustics in Kongsfjorden (CNRS-IUEM)

- Monitor the soundscape diversity including benthic fauna sounds, marine mammals vocalisations, ice sounds, boat noise, wind/wave noise - antropophony (shipping noises) and biophony
- Long-term deployment at 10 m depth in the fjord entrance
- Instrument rotation by divers: up to 3 acoustic recorders, one pressure sensor
- 2020 summer acoustic dataset will allow comparing the ambient noise during the pandemic and associated reduced tourist shipping activity with previous years

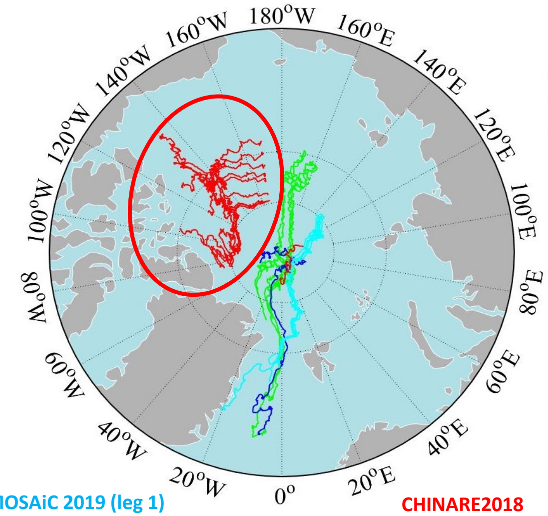


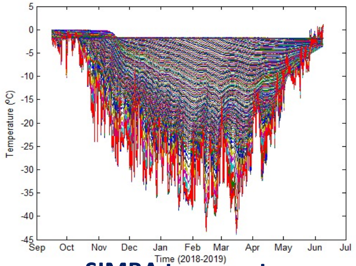
INTAROS WP3 Enhancement of *in situ* observations in the Arctic

Distributed observing systems for ocean and sea ice

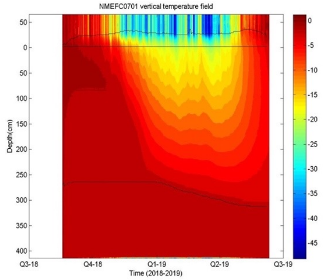
Snow and Ice Mass Balance Arrays (SIMBA) measurements (FMI)

- Up to 38 SIMBA ice mass balance buoys deployed by FMI during different field campaigns in 2018-2020 in the central Arctic Ocean
- Some of the buoys were in-kind contributions from collaborators (PRIC, NMEFC and AWI)





SIMBA temperature in air-snow-ice-ocean

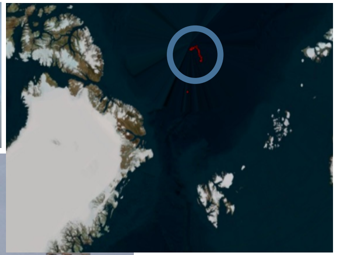


IAOOS ice-tethered platform (IAOOS Equipex for IOPAN) and deep basin mooring (IOPAN)

IAOOS platform deployed in the central Arctic in 2018 by the EQUIPEX IAOOS team

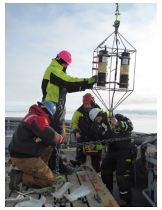
Data received for one month:

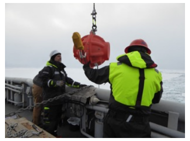
- Ocean temperature, salinity and oxygen profiles 5-600 m
- SIMBA temperature profiles (air, snow, sea ice and ocean)
- Air temperature and pressure
- Microlidar profiles

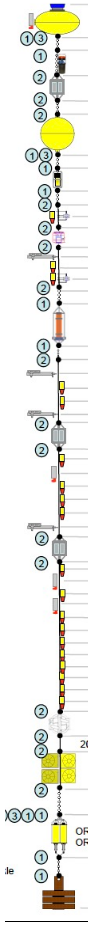


Multidisciplinary deep ocean mooring (2019-2020) in the central Nansen Basin

Deployed/recovered from KV Svalbard in collaboration with the CAATEX project







INTAROS WP3 Enhancement of *in situ* observations in the Arctic

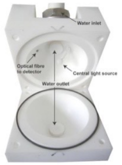
Distributed observing systems for ocean and sea ice

Autonomous sensors/samplers for FerryBoxes in the Arctic (NIVA)

- FerryBox on MS Norbjørn (Tromsø-Longyearbyen) with 25-30 roundtrips/year (northernmost regular shipping route in the world)

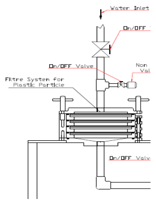
Novel sensors and samplers developed:

- Combined pH/CO_3^{2-} sensor: UV-Vis spectrophotometric detection
- Integrated sphere absorption sensor: cDOM, chl, and phytoplankton accessory pigments


- Microplastics sampler: 3 size fraction

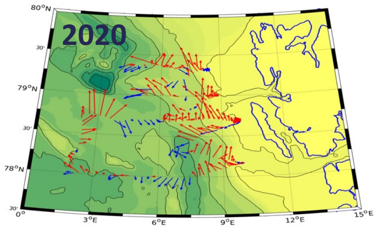


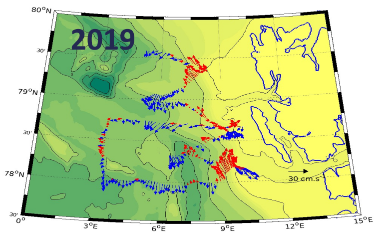


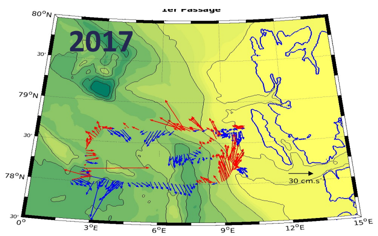
M/S *Norbjørn*: Bring A/S Marine Supply

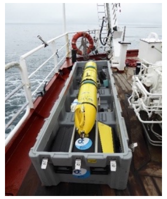
Endurance glider lines for high-resolution ocean measurements around Svalbard (CNRS-LOCEAN)

- Autonomous gliders deployed in 2017-2020 in the Atlantic water current in ice-free waters west and north of Svalbard
- Gliders equipped with Seabird T,C,P sensors, DO optode, chl-a and CDOM fluorimeters, optical backscatter
- High resolution profiles down to max. 1000 m at the repeated sections across in eastern and northern Fram Strait with with mission duration ca. 2 months










INTAROS **WP3 Enhancement of *in situ* observations in the Arctic**

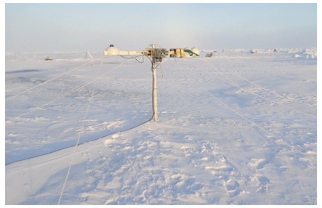
Distributed observing systems for ocean and sea ice

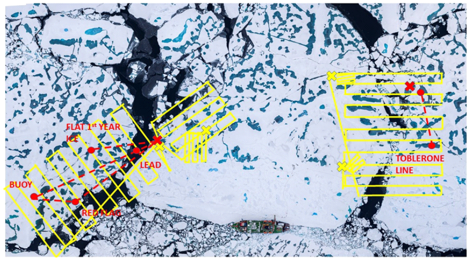
Under ice BGC Argo floats in the Baffin Bay Observatory (CNRS-Takuvik)

- Monitoring of the biogeochemical properties of the Baffin Bay with a fleet of BGC Argo floats dedicated to navigate in ice-infested waters (ProIce floats)
- 21 ProIce floats deployed in 2016-2021 collected physical (temperature, salinity) and biogeochemical (diss. oxygen, nitrates, chla and CDOM fluorescence, backscattering, underwater radiation and PAR) observations in all seasons, including under ice measurements
- New sensors (e.g. high-sensitive radiometer and optical profiler UVP6 for particles size and abundance) were implemented on BGC Argo floats

Fixed station and UAV-based radiation measurements in the Central Arctic during MOSAiC (FMI)

- Broadband radiation station installed in 2019-2020 on the MOSAiC main ice floe to measure surface shortwave and longwave radiative budgets
- Drone MAVIC2 equipped with camera performed photography mapping of the target fight area
- Drone SPECTRA equipped with broadband and spectral radiometers collected radiation measurements along repeated transects and albedo vertical profiles

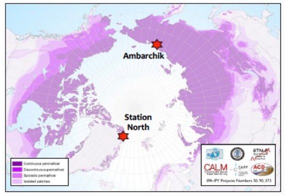




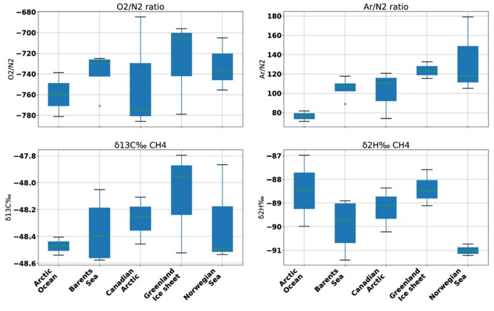
Distributed observing systems for land and atmosphere

Automated flask sampling system for greenhouse gases monitoring (MPG)

- Automated collection of air samples under standardized conditions for continuous monitoring of the atmospheric trace gases CO_2, CH_4 and H_2O
- GHG isotopes to separate emission sources
- Evaluate and improve atmospheric transport model results using multiple species fingerprints (SF_6, N_2O, O_2/N_2, ..)
- Developed and in 2019 installed in the Station North in Greenland, integrated into ICOS observation network



First results of selected trace gas patterns



De-icing system for atmospheric instruments, novel soil temperature and soil diffusivity systems (UNEXE, USFD)

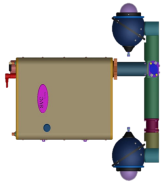
- Eddy-covariance towers with de-icing system (Barrow site cluster) and soil diffusivity system to estimate CO_2 and CH_4 soil concentration and contribution of different soil layers
- Ice-free instruments needed, but heating disturbs instrument performance so customized heating devices and 'smart' heating algorithm developed
- High-resolution temperature sensing systems for continuous measurements of water table and thaw depth with thermocouples located every 5 cm

WP3 Enhancement of *in situ* observations in the Arctic

Distributed observing systems for land and atmosphere

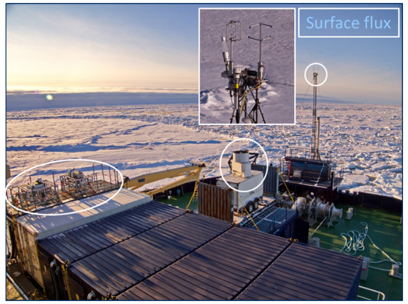
Novel albedo/surface measurements for radiation monitoring in boreal forest (FMI)

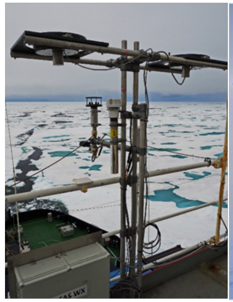
- Improved ground-truthing of satellite remote sensing products (spectro-albedometer, VNA-based radar system to monitor soil, snow and surface vegetation properties)
- Continuous observations with scatterometer together with passive microwave radiometers and an optical spectrometer since 2018 at IOA (Intensive Observation Area) at the FMI Sodankylä Arctic Space Centre
- Novel SVC-FMI automatic spectro-albedometer adapted to work in polar conditions and covering the full solar range (350-2500nm) at high temporal and spectral resolution



Semi-autonomous system for atmospheric observations in the central Arctic for icebreaker Oden (SU)

- A low-maintenance atmospheric observatory for IB Oden, first deployed during the Arctic Ocean AO2018 expedition
- Surface flux installation on the bow mast, advanced weather station on the 7th top deck (incoming broad-band radiation, surface temperature, and visibility and cloud-base lidars) and regular 6-hourly radiosoundings from helideck
- Doppler cloud radar and scanning microwave radiometer provided by other groups, planned in future
- Second deployment performed as a part of the 2019 Ryder expedition (AO2019)





Summary of WP3 main achievements

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Final implementation of observing systems in WP3 is described in detail in deliverables:

- D3.10 Final implementation: Greenland
- D3.11 Final implementation: North Svalbard
- D3.12 Final implementation: Fram Strait
- D3.13 Final implementation: ocean-sea ice distributed systems
- D3.15 Final implementation: atmosphere-land distributed systems

Implemented observations and technical recommendations from all WP3 observing systems are described in D3.16 'Synthesis and technical recommendations':

- Overview of collaborations with other programs and projects
- Summaries of observing assets and collected observations for individual systems
- Detailed technical recommendations for individual systems
- Overarching and cross-cutting technical recommendations
- Synthesis of WP3 main achievements and challenges
- Synthesis of technical recommendations for a future sustained Arctic observing system

Summary of WP3 main achievements

- New *in situ* observations collected across all Arctic domains: ocean, sea ice, atmosphere and land and delivered to open data repositories
- New instruments or platforms added to existing observing systems
- New sensors and technologies developed or adapted to polar conditions for long-term use in a sustained Arctic observing system
- New data processing algorithms and delivery chains developed for collected data
- Standarized data formats conform to requirements of modern databases and FAIR principle developed for different types of processed data
- Technical recommendations were elaborated based on first-hand experience in implementing in situ measurements during INTAROS field campaigns
- Majority of observing platforms, networks and reference sites will be operated beyond INTAROS with the long-term perspective to become important components of a future sustained integrated Arctic observing system

Expected WP3 impact

- New observations of key ocean, ice, atmospheric, and terrestrial variables delivered to open data bases for a wide use by different stakeholders
- Extension of long-term in situ time series of observations or establishing new time series
- Novel sensors and systems developed for collecting observations of new variables
- Existing systems improved and extended with new sensors or technologies
- Improved data delivery chain for different types of in situ measurements (from raw data processing to submission into open data repositories)
- Defining requirements and technical recommendations for a future observing system based on first-hand experience in implementing in situ measurements during numerous INTAROS field campaigns
- Building enhanced collaboration with different projects and programs and developing different models of shared observing infrastructure, field logistics and personnel resources that encourage interdisciplinary research
- …

Challenges in implementing *in situ* observations in WP3

Environmental challenges:

- Low temperatures (freezing conditions), long periods with limited or no daylight, harsh weather (storms, waves)

Technical challenges:

- Lack of standard instruments, ruggedized for Arctic conditions
- Unforgiving operating environment, extended development arc, high sensor/platform costs thus no redundancy
- Limited access to critical services (GPS positioning, satellite communication and data transfer), lack of NRT data
- Insufficient capacity of power supplies (batteries) for longer/more demanding deployments
- Environmental conditions not favorable for windmills or solar panels
- Instruments/platforms need evolve with changing environment (e.g. declining sea ice)

Logistic challenges:

- Difficult access to fieldwork areas (in particular under COVID-19 restriction)
- Access to icebreakers/ice capable vessels for marine operations
- Long deployment periods (risk for instruments and data recovery)
- Cost/scalability – difficult to sustain broad, long-term activities
- High logistic costs and complex operations in remote areas with no regular services
- Often limited support by trained technical personnel

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WP3 technical recommendations for a future iAOS

1. Facilitate a transition from regional and thematic measurement networks towards a sustained observing system by extending existing components with new instrumentation, to improve present-time measurements and add new observed variables.
2. Support and strengthen implementation of multipurpose observing systems, enabling multidisciplinary observations and providing additional services for different platforms and systems (e.g. acoustic geo-positioning or data telemetry in the ocean).
3. Promote development of relatively simple, low-cost and low-power sensors for measuring essential ocean, atmospheric, and terrestrial variables that could be deployed in larger quantities to improve spatial scales and representativeness of observations and mitigate data gaps.
4. Accelerate a development of robust and reliable sensors for biogeochemistry and biology to be routinely used for ocean observations in the Arctic environment.
5. Encourage development and wider implementation of autonomous systems for untended atmospheric measurements over land, sea ice and ocean, including radiative fluxes, winds, aerosols, and clouds.
6. Improve technical solution for adaptation of standard sensors for operating in the Arctic conditions, e.g. solutions for deicing of atmospheric and terrestrial instruments or innovative power supplies for surface instruments operating during polar night.

WP3 technical recommendations for a future iAOS

7. Encourage and promote development of new generation of power sources with high capacity, high performance and improved tolerance for low temperatures, possible also rechargeable, to enable longer and more efficient autonomous measurements in the Arctic.
8. Facilitate availability of reliable, broadband, and cost-efficient services for satellite data transmission and development of robust, low-power hardware for data transfer, in particular with respect to new satellite communication systems coming in near future.
9. Promote using ships of opportunity for autonomous collecting ocean, sea ice, and atmospheric observations in the Arctic Ocean.
10. Encourage and support development of publicly available best practice documentation for operating different in situ sensors, platforms and systems in the Arctic and open technical trainings available to professionals from different disciplines involved in Arctic observing.

The most needed technical developments for building a future sustained Arctic observing system encompass:

- standard sensors ruggedized for Arctic conditions and new, low-cost and low-power sensors,
- autonomous observing systems adapted to changing Arctic conditions,
- new generation of improved power sources,
- reliable, high bandwidth, and cost-effective services and hardware for satellite data transfer.

THANK YOU FOR ATTENTION

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Data collected during INTAROS field campaigns are registered in the INTAROS data catalogue: https://catalog-intaros.nersc.no and INTAROS observing systems in the ARCMAP: https://arcmap.nersc.no