Integrated Arctic Observation System

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Nansen Environmental and Remote Sensing Center, Norway

Deliverable 3.11

Final implementation and data: North of Svalbard

Data delivery and report on results of the observing systems north of Svalbard

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PU	Public, fully open	**X**
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified, information as referred to in Commission Decision 2001/844/EC	

EXECUTIVE SUMMARY

This document, Deliverable 3.11 'Final implementation of the observing system: Data delivery and report on results of the observing systems north of Svalbard', provides an overview of platforms, sensors, and samplers which were implemented north of Svalbard for various periods in 2017-2020, describes multidisciplinary data collected by different instruments, addresses the performance of the employed systems and their applicability for a future sustained observing system.

The main goal of Task 3.2 is to deliver in situ ocean and sea ice observations collected during two INTAROS field seasons (and partially also during the initial test field season) and to provide recommendations for future implementation of the moored observing system north of Svalbard that can be applied to define a roadmap for observing future changes in the Arctic. The aim is to make comprehensive observations of the ongoing climate and environmental change that can be also applied as a validation tool for conceptual and three-dimensional modelling.

The first implementation of the observing system North of Svalbard was deployed successfully in August 2018 using the Norwegian Coast Guard icebreaker *KV Svalbard* and retrieved with *KV Svalbard* in August/September and with the research icebreaker *RV Kronprins Håkon* in September and November 2019. All recovered instrument and sensor provided full data return therefore a full annual cycle of multidisciplinary data was obtained for 2018-2019.

The second field deployment took place in 2019-2020 (one mooring remained until 2021) and included mostly moorings instrumented for measurements of ocean physical variables (and dissolved oxygen) at the main INTAROS line north of Svalbard and additional instruments and sensors for biogeochemical measurements at the deep INTAROS mooring in the Nansen Basin (deployed under Task 3.4). INTAROS moorings north of Svalbard were deployed from the research icebreaker *RV Kronprins Håkon* in November 2019 and recovered during the CAATEX cruises with the Norwegian Coast Guard icebreaker *KV Svalbard* in August and November 2020 and in June 2021 as part of the UAK 2021. Field operations in 2020 and 2021 were extremely difficult in terms of logistics and ship access under the limitations due to COVID-19.

Deliverable 3.11 aims to address the following goals:

- Document the performance of instruments and systems selected/integrated for measurements of key ocean physical variables on INTAROS moorings (subsurface temperature, salinity, and ocean currents) and describe the collected data and their analysis,
- Document the performance of instruments and sensors selected/integrated for measurements of key biogeochemical variables (dissolved oxygen, nutrients and carbonate system parameters) on the multidisciplinary BGC11 mooring and other INTAROS moorings, and describe the collected data and their analysis,
- Document the performance of novel instruments for sea ice measurements on the INTAROS moorings and describe the collected data,

- Document the performance of novel combination of ADCP with echo sounder selected for ocean currents and zooplankton/small fish abundance measurements and describe the collected data,
- Document the performance and the state of technical development for a moored multisensor Octopus system for biological measurements (with an Underwater Vision Profiler, nutrient sensor, and chlorophyll-a and CDOM fluorometer), and describe the collected data,
- Document the performance and technical development for microplastic samplers, and describe the collected data sets,
- Document the performance of technologies and deployment methodology for the sensors mounted at the seafloor, including Ocean Bottom Pressure sensors and Ocean Bottom Seismometers, and describe the collected data and their analysis,
- Describe the performance and fitness-to-purpose of the platforms, sensors and systems implemented during INTAROS under Task 3.2 for a future sustained Arctic observing system.

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1. Introduction

This deliverable aims towards the development of a robust prototype observation system of ocean physics-including sea ice cover and motion, biogeochemistry, biology, toxification and earth processes and geohazards. Considerable gaps of such observation in a harsh Arctic environment have been identified (WP2) and novel instrumentation are tested to obtain a more comprehensive dataset that can in time address question as the rate of *Atlantification* of the Arctic Ocean, changes in sea ice condition, uptake and advection of anthropogenic carbon, rate of change in ocean acidification, changes in biology – ecosystems, uptake and advection of contaminant and finally changes in seismic activity that can potentially lead to geohazards in an autonomous fashion.

Establishing such an advance and ambitious observation system is still in its infancy and if successful this approach can be used to study selected hot spot areas to monitor changes in the Arctic caused by climate changes as global warming and environmental changes caused by contaminants and ocean acidification as in the ongoing high CO2 world.

The following approach was used to establish a prototype observation system as addressed above and described in WP3.

We selected the area North of Svalbard towards the deep Nansen Basin and deployed an array of multidisciplinary moorings with profiling instruments and point measurements of ocean physical variables (IOPAN, CNRS-LOCEAN, UiB-GFI), pCO_2 sensors for carbon system variables (UiB-GFI), NO_3^- sensors for nutrients and carbon cycle studies (UiB-GFI, AWI), autonomous passive contaminant samplers (NIVA), octopus system for biological measurements with underwater vision profiler (UVP) and ECO triplet (AWI), upward-looking dual use ADCPs/sonars for currents and sea ice draft and drift (IOPAN, UiB-GFI), bottom pressure recorders (UNIS), combined ADCP-echosounders for currents and zooplankton (IMR), and ocean bottom seismometers for solid Earth processes and geohazards (GEUS/UiB-GEO) deployed first in the Fram Strait and then later in the Storfjorden area.

With the support from the Norwegian projects CAATEX and UAK, we managed to some degree to keep up the field work and cruise activity despite of the COVID-19 situation. In summary, all planned field work as recovering and deployment of moorings and instrumentation has been done, but with some delays. The most suffering part has been the synthesis work, because of delays in data processing and analyses, etc.

As the following contribution to D3.11 proves, the majority of advanced constructing a robust prototype observation system as described above, have been tested throughout and as partners report for the most been successful. In other words, the majority of significant advances and innovations has been obtained constructing an Arctic system of observations.

2. Final implementation and operational use of the observing system north of Svalbard

The following work has been performed by partners responsible for Task 3.2.

2.1. UiB-GFI

Contributors: Truls Johannessen, Nicolas Roden, Tor de Lange, Alexandra Touzeau, Harald Sodemann

2.1.1. Results of the final implementation of the observing system

Biogeochemical and physical observations at INTAROS moorings (Truls Johannessen, Nicolas Roden, Tor de Lange)

UiB contributed both biogeochemical and physical oceanographic instruments to three moorings north of Svalbard (Table 2.1.1). The first fieldwork campaign, between 20 September 2017 and 22 February 2019, deployed an upward looking Nortek Signature 250 ADCP (Acoustic Doppler Current Profiler) as part of the ATWAIN 200 mooring (81°24.588’N 31°14.508’E). This mooring deployment was a joint effort between INTAROS and the A-TWAIN/Nansen Legacy projects. The Signature 250 measured the current profile from 40 m to the surface as well as sea ice draft and drift direction. More than 60% of data was lost due to the instrument’s SD card being corrupted.

The second fieldwork campaign measured pCO2 and nitrate over a yearlong deployment on the BGC11 mooring between 11 August 2018 and 21 September 2019 (81° 28.6308'N 21° 53.201'E). SAMI-CO2 instruments measured pCO2 at three separate depths using sensor technology based on a colorimetric pH indicator contained in a gas permeable membrane. The instruments were calibrated by the manufacturer before deployment to the expected annual range in temperature and pCO2 for the region. A single SAMI-CO2 was deployed at 297 m on the mooring, whilst duplicate sensors were deployed at both 174 m and 30 m. All SAMI-CO2 instruments stopped recording data after 1 year of deployment, the performance and reliability of these data will be discussed later. SUNA V2 instruments measured nitrate concentrations at two depths on the mooring by using an ultraviolet spectrophotometer. One sensor was located at 30 m and the other at 172 m. Both sensors recorded data for the entire mooring deployment. A CTD profile and accompanying validation samples were collected near each sensor a few days after deployment. This process was repeated shortly after the mooring was retrieved.

Table 2.1.1: Description of UiB instruments on INTAROS moorings between 2018 and 2020.

Mooring	Mooring position and water depth	Instrument type	Measurement type Nominal sensor depth	Measured variables	Sampling period (s)	Start and stop of sampling (UTC)
BGC11	81° 28.6308'N 21° 53.201'E 850 m	SUNA V2 (1126)	Point measurement 30 m (depth)	Nitrate Temperature	10800 10800	11.08.18 21:00 21.09.19 18:00
		SAMI-CO2 (C0177)	Point measurement 31 m (depth)	pCO2 Temperature	10800 10800	12.08.18 12:00 12.08.19 09:00
		SAMI-CO2 (C0178)	Point measurement 31 m (depth)	pCO2 Temperature	10800 10800	12.08.18 12:00 12.08.19 09:00

		SBE37 (16959)	Point measurement 32 m (depth)	Temperature Salinity Pressure Oxygen	10800 10800 10800 10800	12.08.18 12:00 21.09.19 18:01
		SUNA V2 (1125)	Point measurement 172 m (depth)	Nitrate Temperature	10800 10800	11.08.18 21:00 21.09.19 18:00
		AADI Seaguard (1751)	Point measurement 173 m (depth)	Temperature Salinity Pressure Turbidity Current velocity Current direction	3600 3600 3600 3600 3600 3600	12.08.18 13:00 29.07.19 06:00
		SAMI-CO2 (C0176)	Point measurement 174 m (depth)	pCO2 Temperature	10800 10800	12.08.18 12:00 12.08.19 09:00
		SAMI-CO2 (C0175)	Point measurement 174 m (depth)	pCO2 Temperature	10800 10800	12.08.18 12:00 12.08.19 09:00
		SAMI-CO2 (C0174)	Point measurement 297.5 m (depth)	pCO2 Temperature	10800 10800	12.08.18 12:00 12.08.19 09:00
		AADI Seaguard (2027)	Point measurement 299 m (depth)	Temperature Salinity Pressure Oxygen Current velocity Current direction	3600 3600 3600 3600 3600 3600	12.08.18 13:00 21.09.19 18:00
NERSC4	81°47.094'N 22°00.280'E 3458 m	SAMI-CO2 (C0042)	Point measurement 59 m (depth)	pCO2 Temperature	10800 10800	09.09.19 12:00 24.07.20 15:00
		SAMI-PH (P0050)	Point measurement 59 m (depth)	pH Temperature	10800 10800	09.09.19 12:00 25.07.20 09:00
		SAMI-CO2 (C0043)	Point measurement 164 m (depth)	pCO2 Temperature	10800 10800	09.09.19 12:00 24.07.20 15:00
		SAMI-PH (P0051)	Point measurement 164 m (depth)	pH Temperature	10800 10800	09.09.19 12:00 25.07.20 09:00
		SAMI-CO2 (C0065)	Point measurement 316 m (depth)	pCO2 Temperature	10800 10800	09.09.19 12:00 24.07.20 15:00
		SAMI-PH	Point measurement 316 m (depth)	pH Temperature	10800 10800	Instrument destroyed.
ATWAIN 200	81°24.588'N 31°14.508'E ? m	Nortek Signature 250 (100396)	Profile 40 m (depth) 2 m bin size	Current velocity Current direction Sea ice drift and draft Pressure (point) Temperature (point)	1800 1800 225 1800 1800	20.09.17 13:23 22.02.19 03:00

The third fieldwork campaign measured both pCO2 and pH on the NERSC4 mooring, deployed between 6 September 2019 and 24 July 2020 (81°47.094'N 22°00.280'E). Three SAMI-CO2 sensors measured pCO2 for the entire mooring deployment at three depths: 59 m, 164 m and 316 m. SAMI-pH sensors were also deployed at each of these depths, measuring pH using a similar colorimetric method as the CO2 sensors. Two of the SAMI-pHs recorded data for the entire mooring deployment, however the third sensor was destroyed when its pressure housing ruptured. All sensors were deployed using pre-deployment factory calibration coefficients. A CTD profile and validation samples were collected near each sensor shortly after the mooring was retrieved.

Ship-based stable isotope measurements in atmospheric water vapour (Alexandra Touzeau, Harald Sodemann)

During two cruises, a cavity ring-down spectrometer (CRDS; L2130-i, Picarro Inc., Sunnyvale, USA) with suitable inlet and calibration system was installed on board of the ice-going *KV Svalbard*. The CRDS analyser quasi-continuously measured the stable isotope composition in terms of δ^{18}O and δD in atmospheric vapour. The first cruise took place from 30th of July 2018 to 20th of August 2018. The second cruise took place from 17th of July 2019 to 6th of September 2019. The first part, from mainland Norway to Svalbard, was without instrument operator, whereas the second part, CAATEX cruise (starting 13th Aug), was with instrument operator. For the second cruise, the instrument was moved to a more elevated room on the port side to avoid contamination from ship air observed during the first cruise. The spectrometer was left alone for 4 weeks after installation, and ran without interruption (and without surveillance), and with successful calibration during the entire time. This performance indicates that these instruments are reliable enough to be set up and left alone on cruises of similar duration. In addition, water samples were taken from ocean, precipitation, and sea ice during both cruises (Table 2.1.2). A particular focus was placed on CTD samples on the first cruise, and sea-ice samples on the second cruise. In particular for sea-water samples, there had been very few, if any reported samples with both δ^{18}O and δD analysed. All data have been finally processed, and are in the process of being published, and to be made accessible with an open-access data base in a standardised format that was developed as part of this workpackage (https://erddap.bcdc.no/erddap/index.html, see below).

Table 2.1.2: Summary of water isotope samples taken during the two cruises in 2018 and 2019.

Campaign name	INTAROS2018	CAATEX2019
Campaign period	July-August 2018	August-September 2019
Total number of samples	177	248
Precipitation samples	8	31
Surface snow (over sea-ice)	13	60
Surface sea-water	30	
Sub-surface sea-water (25 m)	19	32
Deep CTD samples	90	0
Sea-ice samples	14	125
Glacier ice	3	0

3 different weather stations were set up during the CAATEX cruise to collect weather information at the level of the inlet (local vapour content, temperature, humidity). In addition, the ship weather station data was retrieved for both campaigns through the Norwegian Meteorological Institute. During the CAATEX cruise, an automated camera was installed on port-side to take regular pictures of the water surface and horizon (every 5 minutes) to monitor sea ice state and weather conditions.

2.1.2. Lessons learned and technology challenges identified during the project

Biogeochemical and physical observations at INTAROS moorings

Lessons learnt and technological challenges encountered with biogeochemical instruments during the INTAROS mooring campaigns largely relate to difficulties in getting co-located validation samples during mooring deployments. It was determined that pre-deployment factory calibrations, particularly for SAMI instruments, could not be relied upon for their entire deployment period. Post-deployment calibrations were done on functioning SAMI sensors, however this is only useful if drift within each sensor is a linear function of time.

Duplicated CO2 sensors on the BGC11 mooring indicated that this assumption could not be reliably made. Therefore, we determine that it is necessary to have regular co-located validation samples for each CO2/pH sensor on future mooring deployments. Due to the difficulty and expense in accessing moorings after they have been deployed (particularly in the Arctic), the best way to achieve this is with automatic water samplers co-located with each sensor on the mooring. Technical challenges and difficulties associated with the mooring operations themselves are discussed elsewhere in this report.

Ship-based stable isotope measurements in atmospheric water vapour

During the CAATEX cruise we have demonstrated that stable isotope measurements in atmospheric water vapour can be performed as a routine, automated measurement, typically requiring no in-situ or remote interaction by an operator. However, live transfer of data and remote access will be highly valuable in the cases of instrument problems, either with the analyzer, or with the calibration system. The CRDS instrument thereby needs to be well protected against sea state and accidental physical damage by limiting other activity in the room, ideally with a water-proof, ventilated casing. Outside installation can be done in a way that minimizes the impact of sea spray and contamination from ship air. However, regular meteorological probes will corrode quickly in the sea air, and appropriate filter systems are required to protect the inlet and analyzer from salt buildup, that potentially can increase memory inside the tubing, or in the worst case destroy the analyzer.

A still-camera for sea-ice observations be automated (some manual action was needed to clear the memory card). In contrast to that, the sampling of surface snow, rainfall and snowfall, ice and sea-ice, and sea-water currently require manual operation. For CTD samples, these can be easily incorporated into routine sampling from CTD stations. Processing of sea ice samples is particularly labour-intense, since samples need to be cut and melted on-board before packing for laboratory analysis elsewhere.

2.1.3. Description of processing and analysis of the obtained data

Biogeochemical and physical observations at INTAROS moorings

Data was recovered from the Signature 250’s corrupted SD card by using “testdisk” utility. The recovered data from this, and other physical oceanographic instruments belonging to UiB, were processed using the same procedures outlined elsewhere in this report. Nitrate data from SUNA V2 instruments and pCO2/pH data from SAMI instruments were processed according to standard procedures recommended by the manufacturers. Post-deployment calibration of SAMI-CO2 sensors was done by running instruments in a lab-based seawater tank alongside UiB’s General Oceanics pCO2 system (calibrated using 4 standard gases). The mean pCO2 offset of each SAMI against the General Oceanics system was calculated and then applied to each SAMI data set as a linear function of time from the date of the pre-deployment factory calibration. A comparison of duplicated sensors however, showed significant non-linear drift, indicating that this post-deployment calibration could not be reliably used after such long deployment times. Pre- or post-deployment pCO2/pH validation samples were calculated from in situ water samples of DIC, TA and nutrients using the dissociation constants of Mehrbach et al. (1973) refit by Dickson and Millero (1987). In lieu of reliable instrument calibrations, these validation samples are used as offset corrections.

Ship-based stable isotope measurements in atmospheric water vapour

The dataset consists for the vapour in time series of isotopes during the 2 *KV Svalbard* cruises. The main variables are therefore $\delta^{18}O$ (and δD), d-excess, and specific humidity. All processing was done with a set of vapour calibration routines in development at FARLAB, UiB. A flag for data quality is also be included. The standard deviations are 0.27 for $\delta^{18}O$ (and 1.5 for δD), 1.4 for d-excess, and 0.026 for specific humidity at 10 min resolution. The series are quasi-continuous, except for 1h per day dedicated to calibration (and 8h missing on the 6th of August 2018). For both cruises, calibrations with the secondary water standard DI provided by FARLAB, UiB, was more stable, with the more depleted standard GSM1. This was caused by bubbles in the calibration system tubing, indicating the need of other, more reliable calibration devices. Overall instrument stability however allowed reliable calibration nonetheless, with 60% of the calibrations of sufficient quality.

All water samples have been analyzed for stable water isotopes at FARLAB (University of Bergen) according to established laboratory routines. The variables measured are $\delta^{18}O$, δD, and d-excess with typical standard deviations of about 0.2 for δD, 0.08 for $\delta^{18}O$ and 0.6 for d-excess. Liquid measurements have been complied with their metadata in a standard format that serves all encountered sample types. Metadata include a unified structure for date and time, duration, location, sample type, sample depth, campaign, and collection method. Some samples from the first cruise showed signs of evaporation from the stable isotope analysis (very low d-excess), supported by salt deposits in the vials. Based on this dual criterion, it was possible to exclude these samples as compromised from the final data set.

During CAATEX, the attempted monitoring of pressure, temperature and humidity directly at the inlet failed quickly due to the corrosive atmospheric conditions that lead to malfunction of the sensor within days. Instead, regular ship atmospheric data are used. The still-camera was working very reliably. We expect the image time series to provide objective information on sea-ice state (ice floe size, sea-ice cover), after further image processing (contrast; shape detection), supplementing the other sea ice observations, and supporting the interpretation of the vapour isotope data.

From a qualitative point of view, the vapour measurements from both cruises indicate that variations in vapour isotope composition are related to air mass origin, with higher $\delta^{18}O$ (and lower d-excess) in the air from the SE (Barents Sea, Atlantic) and lower $\delta^{18}O$ (and higher d-excess) in the air from the NW (inner Arctic, northern Greenland, Canada).

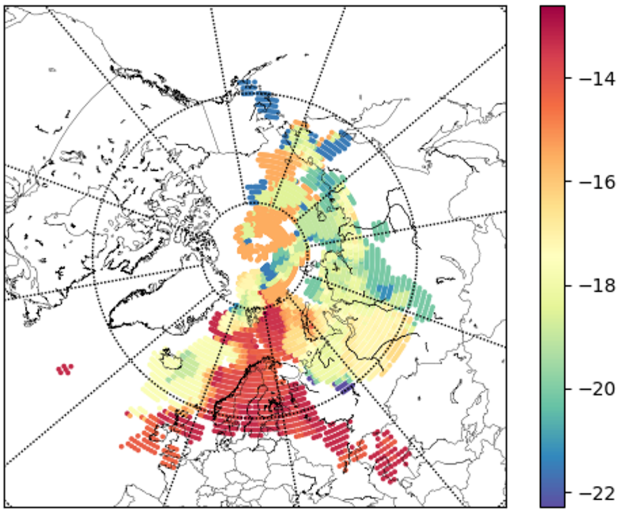

Figure 2.1.1: *Lagrangian backward projection of vapour isotope measurements (d18O, permil, colour) on board* KV Svalbard *during the INTAROS2019 cruise. Red areas indicate low-depletion vapour transported from land evaporation in central Europe, transported towards the Arctic.*

A more qualitative analysis has been performed using back-trajectories from the Lagrangian particle dispersion model FLEXPART and a moisture source diagnostic to identify the origin of water vapour. This combination of numerical model calculations with observations allowed us to assess links between isotope composition and vapor sources spatially. An interesting result is that relatively high delta values (δ^{18}O >-15‰) are observed at the ship location in summer 2018, associated with transport from and moisture sources located in Central Europe and the Barents Sea (Fig. 2.1.1). This probably reflects high land evaporation during the European heat wave in 2018. Interestingly, moisture sources were very different during the CAATEX cruise in 2019. Here, moisture sources were mostly from open ocean, and the highest values of isotope composition measured at the ship were more negative (δ^{18}O ~-16‰). However, the ship track during CAATEX 2019 was leading to the North Pole, and thus sampled air in a different region.

2.1.4. Accessibility of the obtained data sets and repositories used

Biogeochemical and physical observations at INTAROS moorings

Processed data from all UiB instruments on INTAROS moorings will be archived in netCDF format with accompanying metadata. The structure and content of metadata in netCDF files and variable structure is currently under development by the dedicated INTAROS working group and will be soon established for all types of measurements collected by moored instrumentation. When ready, data from UiB instruments will be archived in NMDC with an individual DOI number. Data will be publicly available after publication of planned INTAROS papers in the INTAROS Ocean Sciences Special Issue.

Ship-based stable isotope measurements in atmospheric water vapour

All data have been finally processed, and are in the process of being published towards the end of the project period. The data will be made accessible at an open-access data base in a standardized format that was developed as part of this work package (https://erddap.bcdc.no/erddap/index.html) and is hosted at the Bjerknes Centre Data

Centre at UiB. The ERDDAP system at the basis of this data repository allows flexible filtering and plotting of both geospatial data (https://coastwatch.pfeg.noaa.gov/erddap/information.html). The server can either be used to download data, or to retrieve data through DAP (Distributed Access Protocol) access. In addition, data that are included with forthcoming publications with be DOI minted.

2.1.5. Future plans for operation of the observing system, including data provision

Biogeochemical and physical observations at INTAROS moorings

As yet, there are no plans for continued biogeochemical measurements beyond the INTAROS project. When data from these activities are available, the following ECVs/EOVs will be included: inorganic carbon, nutrients, oxygen, sea ice, subsurface temperature, and subsurface salinity.

Ship-based stable isotope measurements in atmospheric water vapour

In continuation from the work performed during INTAROS, we will take the successful experience with continuous ship-based vapour isotope measurements further and develop and integrated surface water and water vapour isotope measurement system. A first installation of such a setup had been planned for March 2021 using the R/V Helmer Hansen (University of Tromsø, Norway), but needed to be postponed due to the COVID-19 pandemic. Remote access for monitoring, data transfer and intervention will be included in such a setup. It may thereby be possible to synergize with other INTAROS-related efforts in this further development, for example regarding the continuous measurement of water properties during ship cruises.

2.2. IOPAN

Contributors: Agnieszka Beszczynska-Möller, Waldemar Walczowski, and Agata Grynczel

2.2.1. Results of the final implementation of the observing system

IOPAN contributed to the moored observatory north of Svalbard with two moorings dedicated to measurements of physical ocean properties and sea ice in the key region of Atlantic water inflow to the Arctic Ocean in 2017-2020. One mooring (IOPAS1x, where x stands for the deployment number) was deployed at the INTAROS line at 22°E over the upper continental slope at the water depth of 850 m. The second mooring, labeled IOPAS2x (x for the deployment number) was deployed as a part of the A-TWAIN mooring line along 31°E over the mid-slope at the depth of 1200 m and complemented Norwegian moorings deployed in the frame of the A-TWAIN/Nansen legacy projects.

The IOPAN mooring measurements during INTAROS comprised three deployment periods, including the pilot phase (2017-2018), the first fieldwork period (2018-2019), and the second fieldwork period (2019-2020).

The first two deployments (2017-2018 and 2018-2019) and specifications of instruments and measured variables are described in detail in the previous deliverable D3.7 ‘First implementation of the observing system north of Svalbard’. To summarize shortly, the mooring IOPAS11 deployed for 2017-2018 and the mooring IOPAS12 deployed for 2018-2019 at the INTAROS line (22°E) carried the McLane Moored Profiler (MMP) for measuring temperature and salinity profiles in the entire water column (except the surface layer of about 50 m), additional point temperature and salinity sensors, and upward- and downward-looking Nortek ADCPs for ocean current measurements (additionally the upward-looking ADCP measured drift and draft of sea ice). The mooring IOPAS21 (2017-2018) and IOPAS22 (2018-2019) deployed at the A-TWAIN line at 31°E both carried the upward- and downward-looking Nortek and TRDI ADCPs for ocean current measurements (additionally the upward-looking ADCP measured drift and draft of sea ice). IOPAS21 was equipped with the MMP profiler for measuring temperature and salinity profiles while IOPAS22 carried several point-measuring temperature and salinity sensors instead the profiler.

For the second fieldwork period (2019-2020) two moorings were deployed during the *RV Kronprins Haakon* cruise in November 2019. The mooring IOPAS13 was deployed on November 24, 2019 at the position 81°29.16’E 21°56.27’E at the water depth of 855 m. IOPAS13 was equipped with the McLane Moored Profiler (MMP) for measuring temperature and salinity profiles between 53 and 822 m depths and two additional temperature and salinity sensors SBE37 above (at 52 m) and below (at 823 m) the MMP and two temperature sensors at the top float (at 46 m) and 10 m above the bottom. For the ocean current and sea ice measurements IOPAS13 was equipped with two Nortek ADCPs, the downward-looking Signature 55 and the upward-looking Signature 250, both installed in the upper flotation located at the nominal depth of 46 m. IOPAS13 was recovered in July 2020 during the CAATEX 2020 cruise with the Norwegian coastguard icebreaker *KV Svalbard.* Due to the COVID-19 limitations, nobody from IOPAN could participate in this cruise thus the recovered data and instruments were available only in the late 2020. All instruments delivered data as programmed (the data from Nortek Signature 250 could not be retrieved after recovery due to the instrument failure and they were read out by the manufacturer when the instrument was sent for repair). The second mooring IOPAS23 was deployed on November 20, 2019 at the A-TWAIN line at 31°E, at the water depth of 1800 m. Unfortunately, due to the ship equipment failure (the mooring winch leading rope) the top float was not properly deployed (including the upward-looking ADCP) and the mooring did not stand upright after deployment. Therefore, IOPAS23 could not be recovered (including the MMP profiler and downward-looking ADCP) and its data could not be retrieved.

The instruments distribution for the moorings IOPAS13 and IOPAS23 deployed in 2019 is shown on Fig. 2.2.1

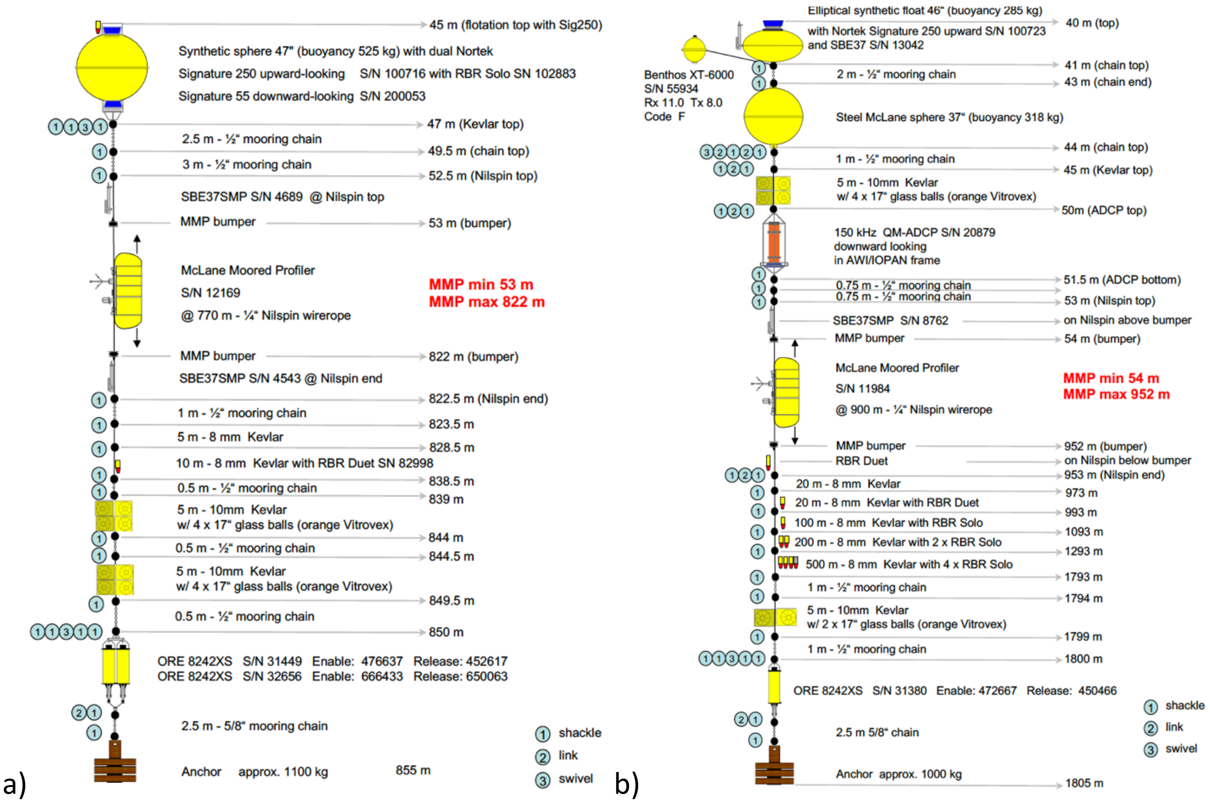

Figure 2.2.1: *Schematics of the instruments distribution and mooring design for (a) mooring IOPAS13 and (b) mooring IOPAS23 deployed for the second INTAROS deployment period in 2019-2020.*

During three years of continuous measurements at two IOPAN moorings at the INTAROS line (at 22°E) and A-TWAIN line (at 31°E) new time series of ocean pressure, temperature, salinity, components of ocean current vectors and sea ice drift and draft were collected. Summary of measured variables and their details (depth, temporal and vertical resolution, and temporal coverage) are listed below in Table 2.2.1.

Table 2.2.1 Distribution of instruments and details of measured variables at the IOPAN moorings north of Svalbard in 2017-2020.

Mooring	Mooring position and water depth	Instrument type	Measurement type Nominal sensor depth Profiling range Bin size for profiles	Measured variables	Sampling period (s)	Start and stop of sampling (UTC)
IOPAS11	81° 29.387'N 22° 00.230'E 854 m	Nortek Signature 250	Profile 75 m (depth) 8-66 m (range) 2 m bin size	Current velocity Current direction Sea ice drift and draft Pressure (point) Temperature (point)	3600 3600 1 3600 3600	22.09.17 14:00 04.08.18 07:00
		Nortek Signature 55	Profile 77 m (depth) 84-846 m (range) 6 m bin size (high res) 12 m bin size (low res)	Current speed (high res) Current direction (high res) Current speed (low res) Current direction (low res) Pressure (point) Temperature (point)	3600 3600 10800 10800 3600 3600	22.09.17 14:00 04.08.18 07:00
		SBE37 SMP	Point measurement 80 m (depth)	Temperature Salinity Pressure	900 900 900	22.09.17 14:00 04.08.18 07:00
		Moored McLane Profiler	Profile 81-829 m (range) 2 m bin size	Temperature Salinity Pressure	2 profiles per day	22.09.17 14:00 04.08.18 07:00

		SBE37 SMP	Point measurement 830 m	Temperature Salinity Pressure	900 900 900	22.09.17 14:00 04.08.18 07:00
IOPAS21	81°34.508’N 31°00.301’E 1210 m	Nortek Signature 250	Profile 77 m (depth) 8-68 m (range) 2 m bin size	Current velocity Current direction Sea ice drift and draft Pressure (point) Temperature (point)	3600 3600 1 3600 3600	21.09.17 00:00 04.08.18 21:00
		SBE37 SMP	Point measurement 78 m (depth)	Temperature Salinity Pressure	900 900 900	21.09.17 00:00 04.08.18 21:00
		TRDI QM-ADCP 150 kHz	Profile 100 m (depth) 112-424 m (range) 8 m bin size	Current velocity Current direction Pressure (point) Temperature (point)	3600 3600 3600 3600	21.09.17 00:00 04.08.18 19:00
		SBE37 SMP	Point measurement 103 m (depth)	Temperature Salinity Pressure	900 900 900	21.09.17 00:00 04.08.18 21:00
		Moored McLane Profiler	Profile 104-984 m (range) 2 m bin size	Temperature Salinity Pressure	2 profiles per day	21.09.17 00:00 04.08.18 21:00
		SBE37 SMP	Point measurement 985 m (depth)	Temperature Salinity Pressure	900 900 900	21.09.17 00:00 04.08.18 21:00
		SBE37 SMP	Point measurement 1195 m (depth)	Temperature Salinity Pressure	900 900 900	21.09.17 00:00 04.08.18 21:00
IOPAS12	81° 29.189'N 21° 59.561'E 861 m	Nortek Signature 250	Profile 70 m (depth) 8-63 m (range) 2 m bin size	Current velocity Current direction Sea ice drift and draft Pressure (point) Temperature (point)	3600 3600 1 3600 3600	11.08.18 11:00 06.09.19 12:00
		Nortek Signature 55	Profile 72 m (depth) 80-780 m (range) 6 m bin size (high res) 12 m bin size (low res)	Current speed (high res) Current direction (high res) Current speed (low res) Current direction (low res) Pressure (point) Temperature (point)	3600 3600 10800 10800 3600 3600	11.08.18 11:00 06.09.19 12:00
		Moored McLane Profiler	Profile 76-824 m (range) 2 m bin size	Temperature Salinity Pressure	2 profiles per day	11.08.18 12:00 06.09.19 12:00
IOPAS22	81°34.489'N 30°59.530'E 1228 m	Nortek Signature 250	Profile 78 m (depth) 8-70 m (range) 2 m bin size	Current velocity Current direction Sea ice drift and draft Pressure (point) Temperature (point)	3600 3600 1 3600 3600	09.08.18 14:00 19.11.19 14:00
		SBE37 SMP	Point measurement 78 m (depth)	Temperature Salinity Pressure	900 900 900	09.08.18 14:00 19.11.19 14:00
		TRDI QM-ADCP 150 kHz	Profile 93 m (depth) 105-420 m (range) 8 m bin size	Current velocity Current direction Pressure (point) Temperature (point)	3600 3600 3600 3600	09.08.18 14:00 19.11.19 14:00
		RBR Solo	Point measurement 100 m (depth)	Temperature	5	09.08.18 14:00 19.11.19 14:00
		SBE37 SMP	Point measurement 150 m (depth)	Temperature Salinity Pressure	900 900 900	09.08.18 14:00 19.11.19 14:00
		RBR Solo	Point measurement 200 m (depth)	Temperature	5	09.08.18 14:00 19.11.19 14:00
		RBR Solo	Point measurement 250 m (depth)	Temperature	5	09.08.18 14:00 19.11.19 14:00

		RBR Solo	Point measurement 300 m (depth)	Temperature	5	09.08.18 14:00 19.11.19 14:00
		SBE37 SMP	Point measurement 350 m (depth)	Temperature Salinity Pressure	900 900 900	09.08.18 14:00 19.11.19 14:00
		RBR Solo	Point measurement 400 m (depth)	Temperature	5	09.08.18 14:00 19.11.19 14:00
		RBR Solo	Point measurement 450 m (depth)	Temperature	5	09.08.18 14:00 19.11.19 14:00
		SBE37 SMP	Point measurement 500 m (depth)	Temperature Salinity Pressure	900 900 900	09.08.18 14:00 19.11.19 14:00
		RBR Solo	Point measurement 550 m (depth)	Temperature	5	09.08.18 14:00 19.11.19 14:00
		RBR Solo	Point measurement 600 m (depth)	Temperature	5	09.08.18 14:00 19.11.19 14:00
		RBR Solo	Point measurement 700 m (depth)	Temperature	5	09.08.18 14:00 19.11.19 14:00
		RBR Duet	Point measurement 800 m (depth)	Temperature Pressure	5 5	09.08.18 14:00 19.11.19 14:00
		RBR Solo	Point measurement 1000 m (depth)	Temperature	5	09.08.18 14:00 19.11.19 14:00
IOPAS13	81°29.160'E 21°56.270'E 855 m	Nortek Signature 250	Profile 45 m (depth) 8-63 m (range) 2 m bin size	Current velocity Current direction Sea ice drift and draft Pressure (point) Temperature (point)	3600 3600 1 3600 3600	25.11.19 00:00 24.10.20 10:00
		RBR Solo	Point measurement 45 m (depth)	Temperature	5	25.11.19 00:00 24.10.20 10:00
		Nortek Signature 55	Profile 47 m (depth) 60-780 m (range) 6 m bin size (high res) 12 m bin size (low res)	Current speed (high res) Current direction (high res) Current speed (low res) Current direction (low res) Pressure (point) Temperature (point)	3600 3600 10800 10800 3600 3600	25.11.19 00:00 24.10.20 10:00
		SBE37 SMP	Point measurement 53 m (depth)	Temperature Salinity Pressure	600 600 600	25.11.19 00:00 24.10.20 10:00
		Moored McLane Profiler	Profile 54-822 m (range) 2 m bin size	Temperature Salinity Pressure	2 profiles per day	25.11.19 00:00 24.10.20 10:00
		SBE37 SMP	Point measurement 823 m (depth)	Temperature Salinity Pressure	600 600 600	25.11.19 00:00 24.10.20 10:00
		RBR Duet	Point measurement 830 m (depth)	Temperature Pressure	5 5	25.11.19 00:00 24.10.20 10:00
IOPAS23	81°36.132'N 30°25.302'E 1823 m	Due to technical failure during deployment, mooring did not stand upright. Mooring could not be recovered and data were not retrieved.				

2.2.2. Lessons learned and technology challenges identified during the project

Moorings deployed by IOPAN during INTAROS comprised a mixture of matured technology and newly available instrumentation. In general, well-proved sensors provided data as expected with battery capacity being the limiting factor for the length of time series. Albeit the moored profilers were used on IOPAN moorings in both locations to obtain temperature and salinity profiles with high vertical resolution, for the long-term deployments and sustained monitoring the point sensors at fixed depths would be better solution as more robust and less prone to technical failure. Movement of a mobile profiler introduces additional risk factor and when instrument fails or gets stuck, the full profile of data in the water column is lost. Moored profilers have excellent vertical resolution but relatively low temporal resolution (sampling rate of the full profile) while fixed sensors provide time series of much lower vertical coverage but also significantly higher temporal resolution.

Due to seasonal sea ice cover, all moorings deployed north of Svalbard are subsurface moorings with the top located at the depth of about 50 m. Therefore, there is no access to the uppermost layer which is critical to ocean-ice-air interactions and exchanges. No robust and cost-efficient technology is currently available to address this challenge (solutions as winched profilers on the mooring top, tube moorings, or sacrificial subsurface sensors with data logger in the lower part of a mooring exist but are not commercially available or/and did not prove their value for long-term deployments). This still remains the main challenge in the ice-covered waters. The lack of surface float (buoyancy element) also results in the significant pull-down of a mooring when deployed in the strong current regime (as in the case of moorings north of Svalbard). It can be partially remedied by a mooring design that takes mooring dynamics into account but in future better streamlined (less drag) mooring components, in particular flotation and large instruments, should be considered.

Significant technical challenges are related to mooring operations (deployments and recoveries) in ice-covered waters. They require access to the vessel with not only ice breaking capabilities, but also equipped with a system of winches and cranes that can be used for the deployment of a deep ocean mooring anchor first if necessary. Availability of ship time on such vessels is very limited and annual turnaround of INTAROS moorings was only possible through a close collaboration with other projects and programs, using icebreakers in the same Arctic region (e.g., *KV Svalbard* cruises of the CAATEX project or *RV Kronprins Haakon* cruises of the Nansen Legacy programme). This highlights a need for collaboration and coordination of efforts related to complex field operations in the marginal ice zone and ice-covered waters. A lesson learned from mooring operations in the ice calls attention to appropriate recovery aids, including acoustic transponders, Argo or Iridium beacons, and avalanche beacons which can be critical in finding the mooring (or its components) when surfacing under or in the ice.

Due to the COVID-19 limitations in travels and ship access, it was not possible to deploy IOPAN mooring for the 2020-2021 period. This experience suggests that even if the planned deployment period is one year, moored instrumentation should be programmed (and equipped with enough battery capacity) to last at least for a doubled period (two years) in case of unexpected unavailability of ship time or extremely difficult environmental (e.g. ice) conditions. This highlights the importance of an increased safety margin for operating moored platforms in the remote and generally inaccessible areas.

2.2.3. Description of processing and analysis of the obtained data

All IOPAN moorings at the INTAROS line (at 22°E) and the first and last mooring at the A-TWAIN line (at 31°E) were equipped with McLane Moored Profiler (MMP), carrying SBE52MP CTD sensor and FSI ACM current meter. MMP was set up to provide two profiles per day (3 profiles in 2019-2020), covering the water column usually between 50 and 750-800 m depth. The MMP acquires data at a speed of 25 cm/s (with 1 Hz sampling rate) along one-way profiles separated in time by 12 h intervals. The processed data are interpolated to a 2 m fixed vertical grid. Processed data from all profiles from a single MMP are aggregated into single Matlab-format files. Each file contains the following variables: DPDT (array of profiling speeds cm/s), S (salinity), SIGTH (potential density sigma-theta), T (temperature), THETA (potential temperature), TIME (time of each measurement in Matlab format), U (east velocity), V (north velocity), W (measured vertical velocity that includes profiling velocity), dates (vector string with profiler start date), location (string with location of mooring), name (dataset name), number (vector of profile number), and pgrid (vector of pressure grid).

The workflow for MMP data processing follows the procedure, described in the technical manual ‘McLane Moored Profiler Data Reduction and Processing Procedures’ by Toole (2006). The details of the procedure for downloading, processing, and archiving the MMP data include following steps:

- Retrieving MMP binary data files,
- Unpacking binary data to ASCII,
- Converting ASCII data to raw Matlab format files,
- Determining ACM heading angle and adjusting velocity biases,
- Pre-filtering, applying CTD and ACM corrections, and gridding,
- Removing spurious temperatures and salinities and adjusting to fixed reference layer,
- Interpolating to regular pressure grid,
- Archiving processed data as Matlab files and finally as netCDF files, including the full metadata set.

Calibrations steps require additional input from SBE37 sensor deployed on the same mooring and/or pre- and post-deployment CTD casts, and ACM compass calibration information. This is used to determine and apply velocity bias corrections and to calibrate and quality control the CTD conductivity data.

SBE37 raw time series of temperature, conductivity and pressure are processed according to the standard procedure that includes data conversion into engineering units, despiking, averaging onto 1 hour interval, and calculating derived variables (salinity and potential density). Processed data are archived as Matlab files and finally as netCDF files, including the full metadata set. Each netCDF file contains processed data from all SBE37 instruments located on a single mooring.

Similar procedure is applied to RBR temperature sensors Solo3 or temperature and pressure sensors Duet3. Data processing steps include data conversion into engineering units, despiking, averaging onto 1 hour interval, and calculating derived variables (depth, only for Duet). Processed data are archived as Matlab files and finally as netCDF files, including the full metadata set. Each netCDF file contains processed data from all RBR Solo and Duet instruments located on a single mooring.

Processing of ADCP data from the IOPAN moorings starts with the steps specific to different types of ADCPs (Nortek Signature 250, Nortek Signature 55, and TRDI QM-ADCP), including extraction of data from the ADCP binary files and conversion to engineering units. Further steps are similar for all ADCPs and include correction for magnetic declination, quality control procedures and re-mapping on the constant depth levels. The workflow for ADCP data post-processing and quality control consists of following steps:

- Magnetic declination correction and direction test,
- In and out the water test,
- Calculating distance from the surface to the center of each depth cell,
- Tilting angle and side lobe test,
- Coarse outlier removal,
- Tests of additional parameters (echo intensity, correlation magnitude, percent of good, error velocity and vertical velocity) to identify potentially bad data,
- Re-mapping data on uniform depth levels,
- Archiving processed data as Matlab files and finally as netCDF files, including the full metadata set.

Processing of sea ice drift and draft (ice keel depth) data from Nortek Signature 250 is still under development, using the instrument capability of automatic 'ice tracking' using the acoustic surface tracking (AST) by finding the range of the acoustic echo indicating the water-ice interface (ice cover) by locating the leading edge of the peak of the return acoustic signal. In general, the measurement of ice thickness is made by subtracting the location of the leading edge of the AST peak from the mean depth determined from a pressure measurement (also made onboard the Signature 250) after all the corrections which include corrections for atmospheric pressure fluctuations, temperature and salinity, sound speed, and instrument tilt.

Data analysis is ongoing and in the first step focuses on describing variability of the vertical structure of the water column and ocean dynamics at the locations of IOPAN moorings on temporal scales from daily and sub-seasonal to seasonal and interannual. In addition to measured quantities, derived parameters include temperature and salinity averaged in different water masses, Atlantic water layer thickness, ocean heat content, stratification index, mixed layer depth, water transport, mean and eddy kinetic energy, and other. The example of the temperature and ocean heat content variability in 2017-2020 from the IOPAN mooring at the INTAROS line at 22°E and nominal water depth of 850 m is shown on Fig. 2.2.2.

In the second step of data analysis, the concurrent measurements from different INTAROS and A-TWAIN moorings will be used to address the spatial structure and variability of ocean circulation, volume and heat transports, vertical heat fluxes, generation and fate of mesoscale eddies and ocean-sea ice interactions in the key region north of Svalbard.

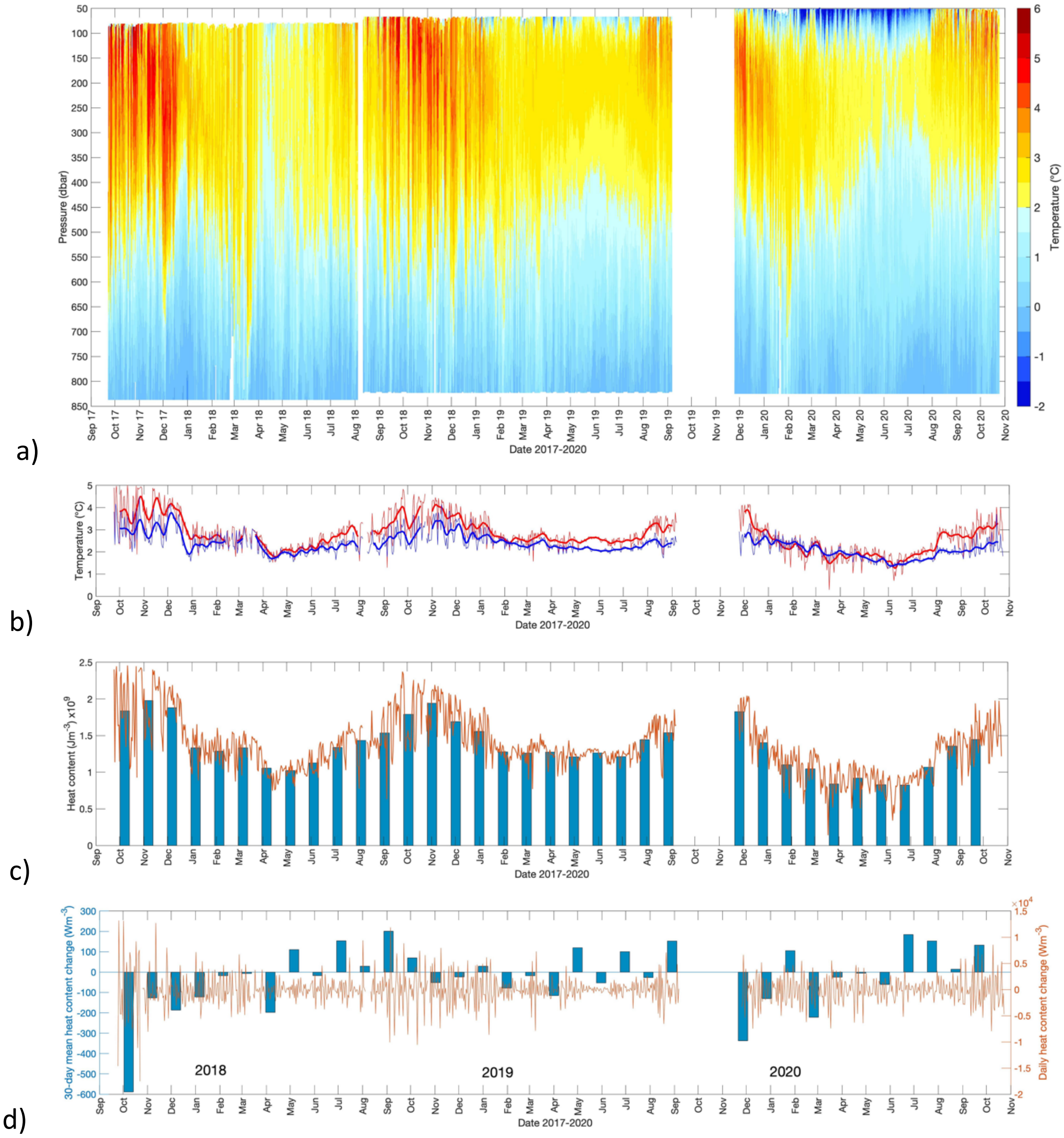

Figure 2.2.2: *(a) Ocean temperature evolution between 50-830 m in 2017-2020 at the water depth 850 m at 22°E (INTAROS line), (b) temperature averaged in 80-200 m (red) and 80-600 m (blue), (c) ocean heat content in the upper layer 80-200 m (red line – daily values, blue bars – 30-day means), and (d) heat content change in the upper layer 80-200 m (red line – daily values, blue bars – 30-day means).*

Data collected with moorings north of Svalbard will be used in further research activities. Planned publications include a paper on variability of the Atlantic water properties and flow north of Svalbard and a paper on the Atlantic water lateral exchanges, heat fluxes and interactions with sea ice in the Arctic boundary current in the Nansen Basin. Time series of variables measured by moored instruments can be also used to provide derived products for other research and development activities, industrial sectors, decision makers and NGOs focused on climate and environment. Potential users include scientists across a wide range of different disciplines, modelers working with ocean and climate forecast and prediction, companies focused on exploration of natural resources, fishery management, tourism, shipping, etc.

2.2.4. Accessibility of the obtained data sets and repositories used

Processed data from all instruments at the IOPAN moorings will be archived in the netCDF format with full metadata set. The structure and content of metadata in netCDF files and variable structure is currently under development by the dedicated INTAROS working group and will be soon established for all types of measurements collected by moored instrumentation. When data processing and conversion into netCDF files is finished, data from IOPAN moorings will be archived in the Oceanographic Data and Information System eCUDO (Polish national data base for oceanographic data) with an individual DOI number for each netCDF file. Data will be publicly available from eCUDO after publication of planned INTAROS papers in the INTAROS Ocean Sciences Special Issue at the end of 2021 or early 2022.

2.2.5. Future plans for operation of the observing system, including data provision

Two IOPAN moorings, one at the INTAROS line at 22°E and one at the A-TWAIN line at 31°E will be deployed again in November 2021 during the Nansen Legacy/A-TWAIN cruise of *RV Kronprins Haakon*. Instrumentation on two moorings will be similar with those deployed during INTAROS (with moored profiler on IOPAS14 at 22°E and only fixed depth temperature and salinity sensors on IOPAS24 at 31°E). These moorings, planned originally for two years, will ensure continuation of measurements beyond the INTAROS period, and contribute to building a sustained observing system north of Svalbard. They will provide Essential Ocean Variables, including physical (subsurface temperature, subsurface salinity, subsurface currents, sea ice) and biogeochemical (oxygen) EOVs from the key region in the Arctic Ocean boundary current.

2.3. CNRS-LOCEAN

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2.3.1. Results of the final implementation of the observing system

CNRS-LOCEAN has contributed to implementation of the INTAROS mooring array which has been maintained at 22°E off northern Svalbard to monitor the properties of the Atlantic Water boundary current at its entrance into the Nansen Basin. Two sites on the upper and mid slope have been instrumented, one in 500 m water depth (based on a couple of mooring, CNRS1 and CNRS2) and the other one in 1500 m water depth (CNRS3) (Table 2.3.1). These two sites were complementary to other sites instrumented by INTAROS partners on the slope (in 850 m water depth (IOPAS1 and BGC moorings) and farther offshore in 3450 m water depth (NERSC4 mooring). While LOCEAN's focus was on measuring physical ocean properties, additional sensors installed on CNRS1 (a bottom pressure recorder maintained by UNIS) or CNRS2 and CNRS3 (microplastic sampler maintained by NIVA) complemented the set of measurements (see Table 2.3.1).

At the upper slope site, a bottom frame mooring (CNRS1) hosted an upward looking 75 kHz Acoustic Doppler profiler measuring ocean current velocities at different depths between the near bottom and the near surface (note [1] in table 2.3.1). A few nautical miles away from the frame, a mooring line was deployed (CNRS2), equipped with CTD sensors distributed every

20-40 m along the line. While the line was maintained more or less continuously (depending on sensor performance) through the course of the project (summer 2017 to summer 2021), the bottom frame could only be operated for two years (summer 2017 to summer 2019) due to lack of favorable ice conditions or ship time for redeployment.

At mid-slope, CNRS-LOCEAN maintained a mooring line (CNRS3) equipped with an upward looking 75 kHz Acoustic Doppler profiler measuring ocean current velocities at different depths between the instrument depth (ca. 500 m) and the near surface. The line was additionally equipped with CTD sensors distributed every 50-200 m from the surface to the bottom, with enhanced vertical resolution in the upper 500 meters. This mooring line could only be maintained between summer 2018 and summer 2020, yet only a subset of the CTD sensors have been operational throughout the full deployment period.

Table 2.3.1. Description of CNRS-LOCEAN moorings maintained during the INTAROS projects

Mooring	Nominal position Bottom depth	Sensor nominal depth	Instrument type	Measured variable	Sampling period (s)	2017-18	2018-19	2019-20	2020-21
CNRS1	81°23'N 22°14'E 500 m	500 m	SBE SMP37-ODO	Pressure Temperature Conductivity Diss. Oxygen	1800	17-09-17 to 03-08-18	10-08-18 to 20-08-19	-	-
		500 m	SBE 26 Operated by UNIS	Pressure		-	10-08-18 to 24-11-19	-	-
		500 m Profiler [1]	RDI-WH-LR ADCP	Current velocity	1800	25-09-17 to 03-08-18	10-08-18 to 29-08-19	-	-
CNRS2	81°23'N 22°16'E 500 m	30 m	SBE SMP37	Pressure Temperature Conductivity	600 (300[2])	17-09-17 to 04-08-18	10-08-18 to 24-11-19	25-11-19 to 11-06-21	
		50 m	RBR Duet (Wisens TD[2])	Pressure Temperature	5 (300[2])	25-09-17 to 03-08-18	10-08-18 to 24-11-19	25-11-19 to 15-06-21	
		50 m	Microplastic sampler Operated by NIVA	Microplastics	continuous	-	10-08-18 to 24-11-19	-	-
		90 m	RBR Duet (Wisens TD[2])	Pressure Temperature	5 (300[2])	25-09-17 to 03-08-18	10-08-18 to 24-11-19	25-11-19 to 15-06-21	
		130 m	RBR Solo (Wisens TD[2])	Pressure [2] Temperature	3 or 5 (300[2])	25-09-17 to 03-08-18	10-08-18 to 24-11-19	25-11-19 to 15-06-21	
		170 m	RBR Duet (Wisens TD[2])	Pressure Temperature	5 (300[2])	25-09-17 to 03-08-18	10-08-18 to 24-11-19	25-11-19 to 15-06-21	
		210 m	RBR Solo (Wisens TD[2])	Pressure [2] Temperature	3 or 5 (300[2])	25-09-17 to 03-08-18	10-08-18 to 24-11-19	25-11-19 to 15-06-21	
		250 m	SBE SMP37	Pressure Temperature Conductivity	600 (300[2])	-	10-08-18 to 24-11-19	25-11-19 to 15-06-21	
		290 m	RBR Solo (Wisens TD[2])	Pressure [2] Temperature	3 or 5 (300[2])	25-09-17 to 03-08-18	10-08-18 to 24-11-19	25-11-19 to 15-06-21	
		290 m	Microplastic sampler Operated by NIVA	Microplastics	continuous	-	10-08-18 to 24-11-19	-	-
		330 m	RBR Duet	Pressure Temperature	5 (6[2])	25-09-17 to 03-08-18	10-08-18 to 24-11-19	24-11-19 to 15-06-21	

		370 m	RBR Solo (RBR 1050²)	Temperature	3 or 5 (60²)	25-09-17 to 03-08-18	10-08-18 to 24-11-19	24-11-19 to 15-06-21	
		410 m	RBR Duet (RBR 1060²)	Pressure³ Temperature	5 (30²)	25-09-17 to 03-08-18	10-08-18 to 24-11-19	24-11-19 to 15-06-21	
		450 m	RBR Solo (RBR 1050²)	Temperature	3 or 5 (60²)	25-09-17 to 03-08-18	10-08-18 to 24-11-19	24-11-19 to 15-06-21	
		490 m	SBE SMP37	Pressure Temperature Conductivity	600 (300²)	17-09-17 to 21-06-18	-	25-11-19 to 15-06-21	
CNRS3	81°33’N 21°47’E 1500 m	50 m	SBE SMP37	Pressure Temperature Conductivity	300	-	10-08-18 to 23-07-20		-
		60 m	Microplastic sampler	Microplastic sampler Operated by NIVA	continuous	-	10-08-18 to 25-07-20		-
		100 m	SBE 56	Temperature	30	-	10-08-18 to 25-07-20		-
		150 m	SBE 56	Temperature	30	-	10-08-18 to 25-07-20		-
		200 m	SBE SMP37		600	-	10-08-18 to 07-02-19	-	-
		250 m	SBE 56	Temperature	30	-	10-08-18 to 25-07-20		-
		300 m	SBE 56	Temperature	30	-	10-08-18 to 25-07-20		-
		350 m	SBE SMP37	Pressure Temperature Conductivity	600	-	10-08-18 to 07-10-19	-	-
		400 m	SBE 56	Temperature	30	-	10-08-18 to 25-07-20		-
		450 m	SBE 56	Temperature	30	-	10-08-18 to 25-07-20		-
		500 m	SBE SMP37	Pressure Temperature Conductivity	600	-	10-08-18 to 23-02-19	-	-
		600 m	SBE 56	Temperature	30	-	10-08-18 to 25-07-20		
		700 m	RBR 1050	Temperature	60	-	10-08-18 to 01-10-19	-	-
		800 m	RBR 1050	Temperature	60	-	10-08-18 to 01-10-19	-	-
		810 m	Microplastic sampler	Microplastic sampler Operated by NIVA	continuous	-	10-08-18 to 25-07-20		-
		900 m	RBR 1050	Temperature	60	-	10-08-18 to 01-10-19	-	-
		1100 m	RBR 1050	Temperature	60	-	10-08-18 to 01-10-19	-	-
		1300 m	RBR 1050	Temperature	60	-	10-08-18 to 01-10-19	-	-
		1310 m	Microplastic sampler	Microplastic sampler Operated by NIVA	continuous	-	10-08-18 to 25-07-20		-

		1490 m	SBE SMP37	Pressure Temperature Conductivity	600	-	10-08-18 to 21-05-19	-	-
		500 m Profiler [1]	RDI-WH-LR ADCP	Current velocity	1800	-	10-08-18 to 16-07-19	-	-

[1] Upward looking profiler: according to instrument set-up, one velocity measurement every 16 meters from 24.25 m depth above instrument depth to the near surface (signal in the undersurface layer is often not exploitable)

[2] Only during 2019-2021

2.3.2. Lessons learned and technology challenges identified during the project

The biggest challenge we had to face was related to the feasibility of mooring deployment/recovery operations. The INTAROS mooring array was located within the seasonally ice-covered waters. Ice conditions require to operate from a vessel with ice breaking capabilities and often hamper safe mooring deployment or recovery.

A particular difficulty for CNRS-LOCEAN was the necessity to rely on the support of project partners to benefit from ship time for our mooring operations. These were only possible thanks to the support from the Nansen Center and the Norwegian research/coastguard fleet and the help from IOPAN partner who had to carry out these operations for us when it was not possible for us to be part of the cruise. The experience gained during the project demonstrated the exceptional added value of scientific cooperation at the European level for increasing the potential of observations at sea in these particularly extreme environments.

Regarding implementation, we were successful in retrieving all our equipment. Sensor autonomy was often much less than indicated by the manufacturer due to decreased battery lifetime under cold environment. Only a few sensors failed.

2.3.3. Description of processing and analysis of the obtained data

The variables measured by LOCEAN sensors are essentially water pressure, temperature, conductivity (CTD), dissolved oxygen (at the bottom) and current velocity.

For each time series of a given CTD or TD sensor, data have been interpolated to a common depth level. For the T-only sensors, the measurement depth has been approximated based on depth variations measured other by pressure sensors available on both sides of the T sensor.

Current velocity measurements are processed following the QA/QC threshold recommended by the manufacturer. Magnetic declination is added to the current heading measured by the ADCP compass.

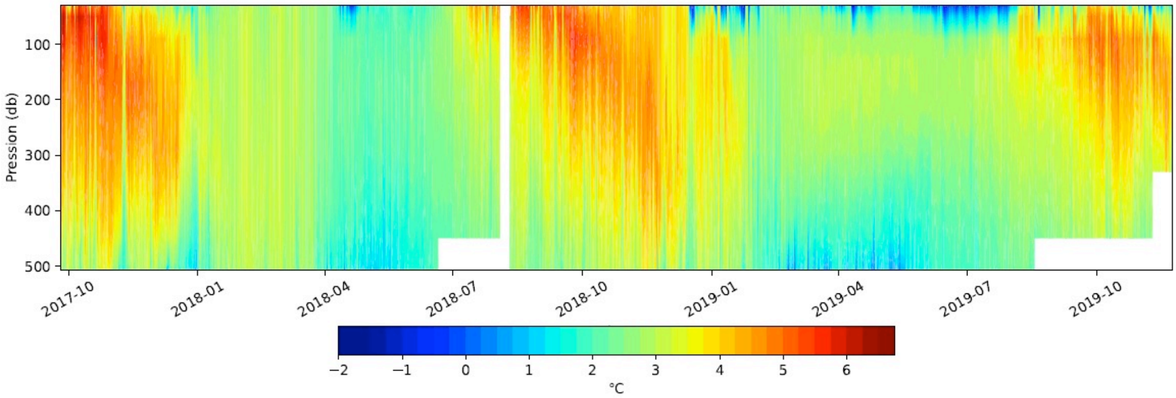


Figure 2.3.1: *Example of vertical temperature distribution at 81°23'N 22°16'E as a function of time over two annual cycles from 25/09/2017 to 24/11/2019. The Hovmöller diagram is based on sensors deployed on CNRS2 mooring line except at the deepest level in 2018-2019 where instead the SMP37-ODO deployed on CNRS1 bottom frame is used due to lack of near-bottom temperature sensor on the CNRS2 line.*

As a joint effort of the INTAROS partners, a mooring data format based on a set of commonly defined metadata information has been used to construct datafiles. This effort is ongoing and the final data files for all mooring sites/sensors should be available soon.

Measurements performed at both sites revealed to be extremely useful to describe the vertical structure of the water column and its variability from sub-seasonal time scales to the seasonal cycle (Fig. 2.3.1). Also, strong contrasts between measurements taken over different years highlighted the need for longer term time series in order to capture the nature and mechanisms of the interannual variability. Preliminary analysis of single site time series (CNRS1/CNRS2) already allow to calculate interesting metrics such as water column heat and freshwater contents, stratification index, Atlantic Water layer thickness and depth, transports, flow baroclinicity and kinetic energy. Concomitant observations collected at different sites of the INTAROS array will be used to address additional important characteristics such as volume, heat and freshwater transports, three-dimensional flow structure and coherency, eddy activity, … This will be particularly relevant in 2018-2020 when all mooring sites have been active simultaneously.

2.3.4. Accessibility of the obtained data sets and repositories used

We are still waiting for some of the data collected at sea since the equipment has not yet returned from field, Once the data have all been processed following the same format, the data will be sent to our national data repository (or other adequate repository) and a Doi assigned to the data.

2.3.5. Future plans for operation of the observing system, including data provision

CNRS-LOCEAN is willing to pursue its contribution to the mooring array to the north of Svalbard. Our recent analysis of model simulations (Herbaut et al., 2021) revealed that the location of the array is appropriate to capture the essentials of the variability of the Atlantic Current. In June 2021, thanks to the support of our Norwegian and Polish colleagues on board

KV Svalbard, the CNRS1 mooring frame was redeployed. We hope to have future opportunities to redeploy CNRS2 and CNRS3 to maintain the time series there.

The future plans also include the addition of an inverted echosounder at the top of at least one the mooring lines in order to monitor the sea ice draft. This will be achieved using the same instrumentation as that used on IOPAS mooring (a Signature 250 combining ADCP and vertical echo sounder). Joint measurements of sea ice and ocean properties will be very useful to study the ice-ocean coupling.

2.4. NIVA

Contributors: Ian Allan, Luca Nizzetto, Alfhild Kringstad, Marthe Jenssen, Andrew King

2.4.1. Results of the final implementation of the observing system

Sampling cages were designed for easy handling of the samplers and to minimise the potential for contamination during deployment and retrieval operations. Passive samplers can be mounted into solvent-rinsed cages as shown in Fig. 2.4.1, placed into a clean PTFE bag at -20 °C until deployment. These cages can hold up to 10 SR sheets (9 cm x 5 cm).

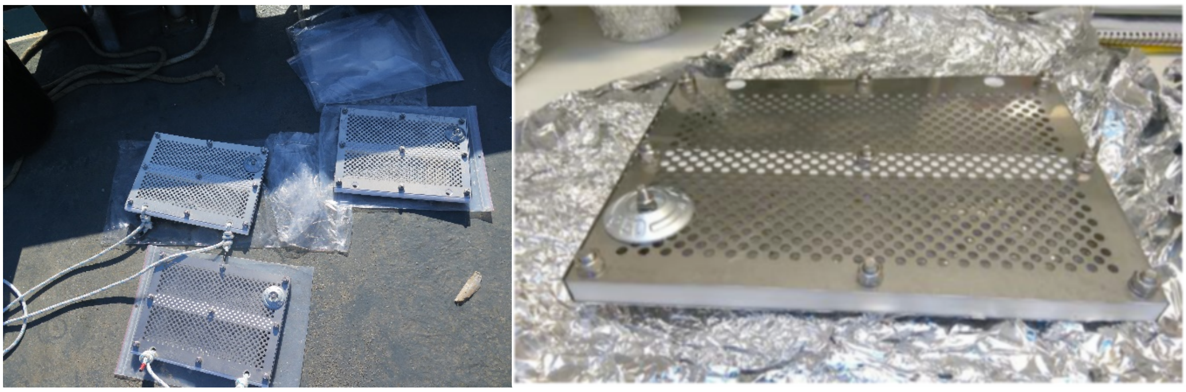


Figure 2.4.1: *Deployment cages for passive samplers used on the INTAROS moorings.*

Silicone rubber was from Specialty Silicone Products Inc and was purchase through Shielding Solution Ltd (UK). The SR was clean thoroughly using a Soxhlet extractor and ethyl acetate. This step was followed by further cleaning by soaking in methanol before loading performance reference compounds (PRCs) into the samplers. These PRCs are used to estimate the uptake rates of substances of interest in situ. These compounds are labelled analogues of chemicals of interest spiked into the membranes. Their dissipation during deployment and under isotropic exchange informs us on the kinetics of exchange of chemicals between water and the silicone. Once the samplers clean and spiked, these are stored in in the freezer. Quality assurance included the use of preparation blank samplers (stayed in the freezer), field blanks (sampler mounted into the cage and brought to the site), and samplers mounted into the cages but left stored in the freezer at NIVA. Analysis of sampler extracts after sample preparation and extract clean-up was by gas chromatography couple to a triple quadripole mass spectrometer. Samplers were analysed for polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorinated pesticide residues such as DDT, HCHs and hexachlorobenzene, polybrominated diphenyl ethers (PBDEs) and selected UV filter including UV-328 which is candidate substance for the Stockholm Convention list.

Deployment sites

Samplers were deployed on three moorings as shown in the table below (Table 2.4.1). In total, 4 cages were successfully retrieved from Mooring 1 (50 m) and Mooring 5 (from all depths).

Table 2.4.1. Details of the mooring sites and passive sampler deployments.

Mooring	ID/depths	Coordinates		Depths	Cage type(s)	Passive samplers
		longitude	latitude			
1	500 m	22° 16.00'E	81° 23.00'N	2 depths (50 m below surface, 300m)	Jerico-next Ptfe holder	SR
3	850 m	21°50.00'E	81°29.00'N	2 depths (50 m and 500m)	Jerico-next Ptfe holder	SR
5	1500 m	22° 15.00'E	81° 36.00'N	3 depths (50 m, 800 m and 1300 m)	Jerico-next Ptfe holder	SR

2.4.2. Lessons learned and technology challenges identified during the project

The deployment was efficient, and the samplers used for quality control and assurance showed that deployment procedures for most compounds did not contribute to elevated levels in blank samplers. This allowed measurement of concentrations down to fg L^{-1} level for some hydrophobic compounds. This technology can now easily be implemented on a wider scale and routine basis on more or less remote mooring locations.

2.4.3. Description of processing and analysis of the obtained data

Samplers for the Mooring noted 1 were recovered after one year while those installed on the Mooring 5 were left in position for two full years. Samplers were recovered and placed in the freezer until they were ready for extraction and analysis. Cleaning of the surface was done when dismantling the SR from the frames. This step was straightforward since samplers exhibited very minor amounts of biofouling even after two years of deployment.

A significant dissipation according to theory was observed for PRCs and allowed the estimation of sampling rates, R_s (Table 2.4.2). Sampling rates were in the range of 4-8 L d^{-1} for samplers with a sampling surface area of 360 cm^2 (4 sheets) or 720 cm^2 (8 sheets). These are in the range of sampling generally observed during such passive sampler exposures.

Table 2.4.2. Sampling rate estimation for the four samplers recovered.

	Sampler location	Depth (m)	Sampler mass (g)	$\log\beta_{sil}$	$\log\beta_{sil}$ SE	R_s at $\log K_{pw}$ = 5 (L d^{-1})
1	CNRS22	50 m	4.50	1.03	0.02	4.2
2	CNRS31	1490 m	9.25	1.08	0.04	4.8
3	CNRS31	50 m	9.57	1.28	0.07	7.7
4	CNRS31	700 m	9.18	1.04	0.05	4.4

A number of different chemicals were detected and quantified in extracts from the four passive sampling devices recovered (Table 2.4.3). One has to bear in mind, such measurements are very scarce.

Between 6 and 7 PAHs were consistently detected in passive sampler extracts and as can be expected from less remote passive sampling data, freely dissolved concentrations were highest for fluoranthene and pyrene (Allan et al., 2013). PAHs are generally at concentrations of tens of pg per litre. Concentrations of fluoranthene are in the range 0.009-0.021 ng L^{-1}. These concentrations are lower than those measured using the same methodology in 2009 and 2010 at Bear Island in the Barents Sea (0.6-0.95 ng L^{-1}), at Andøya on the Norwegian Coast (1.1 pg L^{-1}) or Jan Mayen in the North Atlantic (0.37 ng L^{-1}) (Allan et al., 2011; Allan et al., 2012). Booij et al. (2014) measured fluoranthene concentrations in water even lower with passive sampler deployments in deep and remote areas (e.g. Irminger Sea). These authors did not observe significant differences in fluoranthene concentration on a 3 km profile in the Irminger Sea with concentrations close to those we measured here.

Table 2.4.3. Freely dissolved concentrations of PAHs in water.

	Freely dissolved concentration (ng L^{-1})			
	CNRS22	**CNRS 31**	**CNRS31**	**CNRS31**
Compound	**50 m**	**1490 m**	**50 m**	**700 m**
Acenaphthylene	<10	<32	<4	<5
Acenaphthene	<2	<0.6	<0.6	<0.6
Fluorene	<0.4	<0.2	<0.2	<0.2
Dibenzothiophene	<0.2	<0.08	<0.08	<0.08
Phenanthrene	<0.7	<0.35	<0.35	<0.35
Anthracene	0.11	0.16	0.059	0.075
Fluoranthene	0.091	0.13	0.21	0.14
Pyrene	<0.02	0.055	0.043	0.037
Benzo[a]anthracene	<0.01	<0.005	0.012	0.0049
Chrysene	0.038	0.050	0.057	0.045
Benzo[b,j]fluoranten	0.027	0.021	0.031	0.018
Benzo[k]fluoranten	0.016	0.013	0.017	0.013
Benzo[e]pyren	0.012	0.019	0.015	0.016
Benzo[a]pyren	<0.003	<0.002	0.0038	<0.002
Perylene	<0.005	<0.003	<0.002	<0.003
Indeno[1,2,3-c,d]pyrene	0.013	0.0054	0.0082	<0.005

Dibenz[ah/ac]anthracene	<0.009	<0.005	<0.004	<0.005
Benzo[ghi]perylene	<0.009	<0.005	<0.004	<0.006

Legacy organochlorine pesticides and polychlorinated biphenyls (PCBs) are persistent and hydrophobic contaminants that have become widely distributed globally. We can see from Table 2.4.4, that many of them can be detected and quantified in extracts from all four samplers. For hexachlorobenzene, concentrations were in the range of 5 to 11 pg L^{-1} similar to data from the Irming Sea (Booij et al., 2014). These concentrations are also very similar to those measured by Lohmann et al. (2009) for the western Arctic Ocean in the East Greenland current. This is lower that the data we obtained from Bear Island, Jan Mayen or Andøya ten years ago. Concentration estimated here for p,p'-DDE and PCB 153 in the range of 0.5-5 and 0.06-0.8 pg L^{-1}, respectively are similar to those found for the Irminger Sea (Booij et al., 2014). The range of PCB concentrations measured here is higher than that observed for a cruise from 2001 (Carrizo and Gustafsson, 20). In general, concentrations of OCPs are highest for the samplers exposed to deep arctic waters. For example, the concentration of p,p'-DDE is close to 5 pg L^{-1} for the deepest exposure and a factor of 5-10 lower for samplers exposed in surface water masses. Concentrations of DDTs measured here are in line with previous measurements using high volume water sampling (Carrizo et al., 2017).

The only PBDE congener detected is BDE47. Concentration ranged from below LOQ at 40 fg L^{-1} up to a concentration of 160 fg L^{-1} (Table 2.4.5). These concentrations are lower than those reported previously (Salvado et al., 2016). The benzotriazole UV filter UV-326 was the only UV filter found above LOQ. Concentrations in the range 0.68-1.3 pg L^{-1} were estimated. This substance is registered within REACH with an annual import/production in the Eu of 1000-10000 tonnes. There are very few reports of detection of UV-326 in the Arctic environment and no measurements in the Arctic Ocean.

Table 2.4.4. Freely dissolved concentrations of PCBs and other chlorinated organics in water.

	Freely dissolved concentration (ng L^{-1})				
	CNRS22		**CNRS 31**	**CNRS31**	**CNRS31**
Compound	**50 m**		**1490 m**	**50 m**	**700 m**
Hexachlorobenzene	0.0055		0.0084	0.0089	0.011
HCH-alpha	0.17		1.31	0.26	0.57
HCH-beta		1.45	<0.5	<0.5	<0.5
HCH-gamma (Lindane)	<0.4		0.97	0.17	0.34
HCH-delta	<0.1		4.4	<0.05	1.7
o,p'-DDE		0.00013	0.0019	0.00017	0.0011
p,p'-DDE		0.00050	0.0047	0.00098	0.0018
o,p'-DDD		0.00050	0.0037	0.00084	0.0036

p,p'-DDD	0.0014	0.0083	0.0020	0.0080
o,p'-DDT	0.00022	0.0054	0.00040	0.0035
p,p'-DDT	0.00016	0.0053	0.00062	0.0031
PCB 31	<0.0004	0.0012	0.00045	0.0011
PCB 28	<0.0004	0.0011	0.00060	0.00081
PCB 52	0.000433	0.0030	0.00058	0.0024
PCB 44	0.000289	0.0023	0.00050	0.0018
PCB 101	<0.0002	0.0011	0.00029	0.0010
PCB 149	<0.00004	0.00067	0.00013	0.00055
PCB 118	0.000074	0.00068	0.00015	0.00056
PCB 153	0.000064	0.00080	0.00016	0.000608
PCB 105	<0.00004	0.00023	0.000055	0.000200
PCB 138	0.000098	0.00093	0.00019	0.00072
PCB 156	<0.00006	0.000035	<0.00003	<0.00004
PCB 180	<0.00004	0.00015	0.000030	0.00011
PCB 170	<0.00004	0.000072	0.000014	0.000053
PCB 194	<0.00004	<0.00003	<0.00002	<0.00003
PCB 209	<0.0004	<0.0003	<0.0002	<0.0003

Table 2.4.5. Freely dissolved concentrations of selected PBDEs and UV326 in water.

	Freely dissolved concentration (ng L^{-1})			
	CNRS22	**CNRS 31**	**CNRS31**	**CNRS31**
Compound	**50 m**	**1490 m**	**50 m**	**700 m**
BDE-49	<2.0E-05	3.9E-05	1.8E-05	3.8E-05
BDE-47	<4.0E-05	0.00016	3.8E-05	0.00014
UV-326	<0.0007	0.0013	0.00078	0.00067

2.4.4. Accessibility of the obtained data sets and repositories used

These data are currently with the authors of the report and have not yet been published. Data from these moorings as well as from previous deployments (e.g., at Jan Mayen, Bear Island…) will form a scientific publication to be drafted in 2022.

2.4.5. Future plans for operation of the observing system, including data provision

No plans currently. But such passive sampler deployments can easily put in place in the future. Different types of devices could easily be accommodated for in the sampling cages to increase the breadth of chemicals to be monitored. It could for example include compounds such the more mobile but still persistent perfluoro chemicals (PFAS).

2.5. IMR

Contributors: Angelika Renner, Geir Ottersen

2.5.1. Results of the final implementation of the observing system

To add biological observing capability to the observing system north of Svalbard, a Nortek Signature 100 combined ADCP/echosounder was purchased for deployment alongside the existing A-TWAIN mooring array. The instrument was tested successfully during a short-term deployment in January/February 2019, and then deployed at approximately 81.5N, 30.9E in November 2019. It was recovered in September 2020, and another instrument was deployed in the same place.

Upon recovery, it was discovered that the memory card was defect. The manufacturer confirmed this and the resulting data loss which meant that no data was recorded in this first deployment period. A new memory card had been installed prior to the 2020 deployment. The next mooring service with recovery and redeployment will take place in November 2021, when hopefully, a full year’s data record will be obtained.

2.5.2. Lessons learned and technology challenges identified during the project

The Nortek Signature 100 is a new sensor and there is limited prior experience regarding setup and use in polar regions. The malfunction demonstrated the vulnerability of any moored system that is serviced maximum annually or even biannually and the risk of data loss. It also prevented learning more about sensor capabilities regarding measurement range and duration in low scattering and low temperature environments. However, a second Signature 100 was deployed alongside and further up the water column as part of the Norwegian SIOS-InfraNor infrastructure project. This instrument successfully return data which could be used to develop processing and analysis routines. Preliminary results are promising and bode well for novel results if the current deployment is successful.

2.5.3. Description of processing and analysis of the obtained data

No data processing or analysis could be done due to instrument failure during the first deployment. New data will hopefully be obtained in November 2021, and processing will take place in 2022. Also, data from the neighboring Signature 100 (see above) can be analyzed jointly with the new INTAROS data.

2.5.4. Accessibility of the obtained data sets and repositories used

Any future datasets will be published in the Norwegian Marine Data Centre and made openly available.

2.5.5. Future plans for operation of the observing system, including data provision

The currently deployed INTAROS Signature 100 will be recovered and redeployed in November 2021. The new deployment is planned to last two years, and the new recovery will be done as part of the A-TWAIN/SIOS-InfraNor mooring service. The instrument is planned to become part of the A-TWAIN/SIOS-InfraNor array for long-term monitoring north of Svalbard. Variables measured include sea temperature, current speed and direction, and also more novel acoustic profiler measurements of biological production, up to larger animals at higher trophic level, like fish. Data will be processed upon each recovery and published in NMDC.

2.6. AWI

Contributors: Andreas Rogge

2.6.1. Results of the final implementation of the observing system

The horizontally free-moving sensor pack (Octopus system), hosting the latest prototype of the camera system Underwater Vision Profiler 6 (UVP 6; Hydroptic) has been developed and implemented for biogeochemical and biological (visual imaging) measurements on the INTAROS mooring north of Svalbard. The instrument harbors an intelligent camera, which automatically identifies and counts particles within a defined sample volume (0.65 L) and cuts and stores them as separated vignettes. The constructed mooring frame featured a fin and was thereby fully rotational and tiltable so that a pointing of the camera into the current was ensured. The sensor package also included a SUNA nitrate sensor (SeaBird), as well as an Ecotriplet fluorometer (SeaBird) for chlorophyll and cDOM to measure environmental conditions, such as nutrient supply and the bloom situation. An additional fluorescence channel for particle backscatter within the Ecotriplet further allowed quality control for the small particle fraction measured by the UVP6.

The system was connected to a biogeochemical mooring (BGC11) of the INTAROS mooring array at a depth of ~50 m at appr. 22 °E and 81.5 °N, deployed during the INTAROS2018 cruise on *KV Svalbard* in August 2018. The mooring also included several other biogeochemical sensors at several depths and was located in the inflow region of Atlantic water at the continental slope north of Svalbard with a depth ~800 m. It was deployed in the close cluster with the nearby mooring (IOPAS12), devoted to measurements of physical ocean and sea ice variables. The mooring BGC11, carrying the Octopus sensor system on was successfully recovered in September 2019 from *KV Svalbard*. All Octopus components were retrieved in good shape and minimal biofouling at the lens and the light unit, as observed during recovery, pointed towards complete field of view acquisition during the whole operation time.

The detailed description of the Octopus technical specification and implementation was provided in the deliverable D.3.7.

2.6.2. Lessons learned and technology challenges identified during the project

The first year-long field application of the newest UVP prototype on a mooring in the framework of INTAROS provided long-term optical data and hence, allows for the first time the consideration of the temporal dimension in plankton and particle dynamics. We thus expect new information regarding the annual cycle of particle dynamics and the interaction of sea ice, ocean currents, and plankton dynamics. All system components have worked reliably during one-year long deployment and the system was robust enough to survive recovery of the mooring from under the ice in difficult ice conditions encountered in 2019. The drawback of the first deployment of a prototype instrument was not optimal sensor setup (resulting in too long exposure time, blurry images etc.) but the collected data serve well as a proof of the principle for deployments of the UVP6 system on long-term moorings.

2.6.3. Description of processing and analysis of the obtained data

The raw particle data set consists of measured sizes and abundances of particles larger than ~70 µm, as well as stored images of automatically identified particles larger than ~500 µm. The time series of the particle size distribution, as well as particle volume per sample volume of all defined size classes will be calculated and checked for consistency and quality using particle backscatter from the Ecotriplet during the post-process period. Particle images were sorted semi-automatically using the web-based platform Ecotaxa (https://ecotaxa.obs-vlfr.fr; Picheral et al., 2017). Images were be grouped into plankton and detritus, whereas plankton images were further categorized into taxonomic groups based on the UniEuk taxonomic tree (Universal taxonomic framework and integrated reference gene databases for Eukaryotic biology, ecology, and evolution).

The time series of the nitrate data as well as fluorescence data of chlorophyll, cDOM and particle backscatter were checked for consistency and quality. Nitrate data were drift corrected using taken reference samples.

Particle size distributions and detritus images will be further used to estimate carbon flux, whereas plankton images will be used to calculate organism abundances throughout the annual cycle. In combination with environmental data from SUNA and Ecotriplet, as well as other sensors of the mooring array and satellite observations of sea ice coverage, we envisage to characterize particle flux and plankton dynamics with respect to sea ice coverage and Atlantic water inflow.

Methodology for data analysis and some results from the Octopus deployment are described in the paper by M. Picheral, C. Catalano, D. Brousseau, E. Leymarie, J. Coindat, F. Dias, S. Fevre, L. Guidi, J.O. Irisson, L. Legendre, F. Lombard, L. Mortier, A. Rogge, S. Thibault, T. Tixier, L. Stemmann, 2021, "UVP6: Underwater imaging sensor of particle size spectra and plankton, for autonomous and remote platforms" accepted for Limnology and Oceanology Methods.

2.6.4. Accessibility of the obtained data sets and repositories used

When data processing and analysis is completed, targeted image depository will be Ecotaxa, whereas particle data and image classification and plankton abundances will be available at Ecotaxa, as well as PANGAEA (https://www.pangaea.de). Biogeochemical variables measured concurrently with images collection by the Octopus system will also be available in PANGAEA (https://www.pangaea.de) when processed.

2.6.5. Future plans for operation of the observing system, including data provision

Following data download and maintenance in 2019-2020, another year-long field season in the INTAROS mooring array was originally planned, but due to COVID-19 restrictions and limitations in the field work opportunities, no INTAROS mooring could be redeployed in 2020. Currently there are no plans for system deployment on moorings north of Svalbard beyond the INTAROS period during the late 2021 deployment. However, the Octopus system can be used in future when any deployment opportunities occur in different regions of the Arctic Ocean. There is also a future possibility considered to put the system on a mooring in the Southern Ocean (for the purpose of comparison of performance in different polar areas).

2.7. UNIS

Contributors: Frank Nilsen, Marcos Porcires

2.7.1. Results of the final implementation of the observing system

Two bottom pressure recorders were deployed for one year from *KV Svalbard* during the INTAROS2018 cruise in August 2018. A bottom pressure recorder (SBE26) operated by UNIS was tied onto the frame of the CNRS12 mooring (81° 22.967’N, 22° 14.899’E) at 500 m depth. In addition to the tall BGC11 moorings, and in connection to the shallower bottom pressure recorder on CNRS12, a short bottom mooring BPR11 was deployed next to the cluster of IOPAS12 and BGC11 moorings. The BPR11 mooring was operated by UNIS and equipped with the Aanderaa SeaGuard WRL. The instrument was located at the bottom anchor (attached to it with a single acoustic IXI release) with a small package of four glass balls above to provide buoyancy for recovery. BPR11 was deployed on August 11, 2018 by free fall at the position 81° 29.1565’N, 021° 55.3338’E at the water depth of approx. 870 m. Both moorings carrying bottom pressure recorders (CNRS12 and BPR11) were successfully recovered from *RV Kronprins Haakon* in November 2019.

The BPR’s are currently not re-deployed, however, we hope to redeploy since the concept and scientific outcome from such measurements are proven to be valuable.

2.7.2. Lessons learned and technology challenges identified during the project

Due to technical issues with the SBE26 sensor, it has not been possible to calculate the geostrophic current time series as planned. Hence, the observatory set up is vulnerable since we are dependent on two sensors working together and operating in pairs. But there are large benefits and opportunities when this technology work.

2.7.3. Description of processing and analysis of the obtained data

Collected data from the WRL SeaGuard at 850m will be processed, analyzed, and made available from the national data repositories.

2.7.4. Accessibility of the obtained data sets and repositories used

Data will be published and accessible through the Norwegian Centre for Research Data and SIOS data portal.

2.7.5. Future plans for operation of the observing system, including data provision

We hope to redeploy the pair of BPR's when we have clarified the funding situation.

2.8. NERSC

Contributors: Hanne Sagen, Espen Storheim

2.8.1. Results of the final implementation of the observing system

NERSC did not operate any observing system North of Svalbard. NERSC supported INTAROS Task 3.2 with ship time, technical assistance, and CTD system. The support from NERSC to INTAROS was to organize and coordinate the INTAROS 2018 field experiment, CAATEX field experiments in 2019, 2020 and the UAK 2020 and 2021. All these field operations provided ship time, instrumentation, and technical assistance to INTAROS activities. The CAATEX experiment is a trans Arctic Experiment focused on the central Arctic (a short report is provided in D3.13) and UAK is the educational project (to be reported in WP7).

2.9. UiB-GEO and GEUS seismology

Contributors: Mathilde B. Sørensen, Zeinab Jeddi, Peter Voss

2.9.1. Results of the final implementation of the observing system

During INTAROS, three ocean bottom seismograph (OBS) monitoring campaigns have been completed (Table 2.9.1). The first two deployments were along the Arctic part of the mid-Atlantic ridge. Those deployments have been described in detail in Deliverables D3.2 and D3.7. Thorough processing and analysis of the data from the first deployment has provided new insights into how local seismicity affects the Loki's Castle hydrothermal vent field (Jeddi et al., in prep). Data recorded west of Svalbard has substantially improved the detection threshold and location uncertainty and provided new insight into the crustal structure in the region. Furthermore, that campaign clearly demonstrates the added value of even a single monitoring station on the ocean bottom (Jeddi et al., 2021).

Table 2.9.1. OBS monitoring campaigns completed during INTAROS

Location	Deployment period	Instrumentation	Deployment method	References
Loki's Castle	06.2017 – 01.2018	6 LOBSTER systems	ROV	INTAROS D3.2; Jeddi et al. (in prep)
West of Svalbard	08.2018 – 08.2019	3 NAMMU systems	Free fall	INTAROS D3.7; Jeddi et al. (2021).
Storfjorden	08.2019 – 06.2020*	3 NAMMU systems	Free fall *	INTAROS D3.7

**One instrument did not release as planned during the recovery mission in August 2020. The instrument was recovered with ROV in June 2021.*

In August 2019, three NAMMU OBS systems were deployed in Storfjorden (Table 2.9.2; Fig. 2.9.1) from the vessel ACC MOSBY. The deployment was a cooperation with the EPOS-Norway project funded by the Norwegian Research Council. Seismic activity in Storfjorden increased after a Mw 6.2 event on 21. February 2008. The seismicity is persistent until present and nearby continuous monitoring of the region is an interesting and important target in Norwegian territory. Deployment locations were chosen in the southern and central parts of Storfjorden, aiming at the best possible spatial coverage while staying clear of restricted areas and areas prone to trawling activity. The OBS systems were prepared on board the ship and dropped to the sea floor at pre-defined locations (Fig. 2.9.1).

The instruments were recovered during a cruise onboard *KV Svalbard* in June 2020 as part of the UAK 2019. The unit at site STOR2 did not re-surface although it was responding to acoustic signals. After several attempts of releasing the instrument, it was decided to leave it on the sea floor. The instrument was later recovered with the ROV Ægir6000 in June 2021 during a cruise on board *RV Kronprins Haakon* in cooperation with UiT – The Arctic University of Norway. The reason for the failure of the release mechanism is currently being investigated with the manufacturer (K.U.M. Umwelt- und Meerestechnik Kiel GmbH). Analysis of the dataset from the Storfjorden monitoring campaign is at an initial stage.

Table 2.9.2. Deployment positions of OBS systems in Storfjorden.

Station	Latitude (°)	Longitude (°)	Depth (m)
STOR1	77.5981 N	18.8531E	150
STOR2	77.162 N	19.186 E	150
STOR3	77.047 N	17.6764 E	120

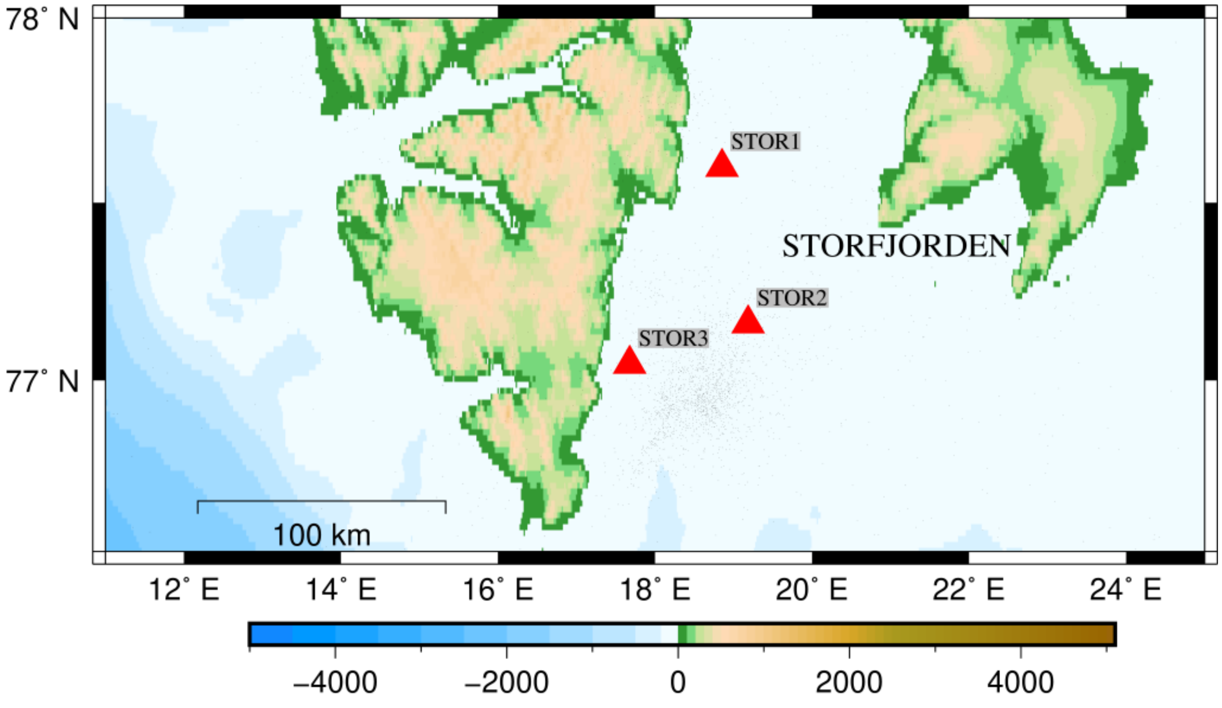


Figure 2.9.1: *Map of OBS instrument locations in Storfjorden.*

2.9.2. Lessons learned and technology challenges identified during the project

The OBS experiments carried out during INTAROS have clearly demonstrated the added value of seismological monitoring on the ocean bottom in detection and analysis of earthquakes in the offshore regions. Two approaches have been tested for OBS deployment: the traditional “free-fall” release with “pop-up” recovery and the more controlled deployment and recovery with an ROV.

Deployment and recovery with ROV allow one to know the exact location of the instrument on the ocean bottom, and it reduces the risk of losing an instrument as the location is known and the instrument is picked up directly on the ocean bottom. In ice-covered areas, deployment and recovery with ROV are required, as there is else a substantial risk of the instrument being trapped under the ice during recovery. The drawbacks of ROV deployment and recovery are that operations are much more costly and time consuming.

Free-fall deployment is fast and can be done even under rough weather conditions. There is a risk of the instrument drifting during the fall towards the ocean bottom, but there are efficient ways of determining the exact instrument location through triangulation. There is a higher risk associated with recovery, as one needs to locate the instrument when it appears at the sea surface. During the INTAROS deployment in Storfjorden we experienced a problem with the release mechanism of one instrument during recovery, and in such cases there is not much to be done while in the field. In that case, the ROV proved invaluable, as it allowed us to return to the deployment site, dive to locate the instrument at the ocean bottom and then carry the instrument to the surface for recovery.

Considering the added cost and logistical challenges, as well as the fairly high success rate of free-fall deployments, it is recommended to use the traditional free-fall deployment unless special conditions (such as presence of sea ice) require the use of ROV. However, the ROV is an important tool for locating and recovering lost instruments, and ROV-based rescue missions should always be considered in cases where instrumentation seems to be lost.

Two major limitations in seismological monitoring with OBS are the limited deployment period, usually of about 1 year, due to limitations in battery power, as well as the lack of real-time data since data only becomes available after recovery of the instrument. Operational use of seismological data requires that data is available in real-time as fast response is needed in many cases. Furthermore, long time series of data are needed to evaluate earthquake activity rates and associated parameters for seismic hazard assessment. Whereas the collected data still provides important insight into the mechanisms driving the seismicity in the deployment areas and may contribute to better understanding the crustal structure, long-term operation with real-time data transfer would expand the applicability of the collected data. Such operation would require a cabled system.

2.9.3. Description of processing and analysis of the obtained data

The seismometer is a sensor that is placed directly on the ground (preferably flat bedrock) and converts very small motions of the earth into digital recordings. The seismic waves which are generated by either earthquakes at depth or by man-made devices near the surface of the earth are travelling through the earth and recorded in these sensors. The information combined with precise timing, source location and the seismometer location, can provide details of seismic activity, the velocity and the geometry of the earth structure. In our experiments, we used two generations of OBS, LOBSTER and NAMMU, which are developed at K.U.M (Umwelt- und Meerestechnik Kiel, Germany) and the sensors were recording to four components: vertical, two horizontals and hydrophone channel.

Data processing procedures for OBS data are described in detail and with several examples in deliverable D3.7. After recovery, data needs to be time-corrected to compensate for time drift in the internal clock of the instrument during the deployment period. Data quality is then assessed in terms of station up-time (which should ideally be at 100%), as well as the noise level at the monitoring station. As instruments may have drifted while dropping from the surface to the sea floor, precise instrument locations need to be determined by triangulation on acoustic or active seismic sources.

After processing and quality assurance, data is made available through the UiB-NORSAR EIDA node (see next section). Data analysis includes improving the locations of events already recorded by the permanent seismic networks by adding data from the OBS instruments to the analysis, as well as improving the detection by scanning the continuous OBS data for new events that have not been captured by the permanent network. The OBS data can be used in the same way as data from land stations, to calculate earthquake location and magnitude, and to study e.g. source mechanisms and crustal structure.

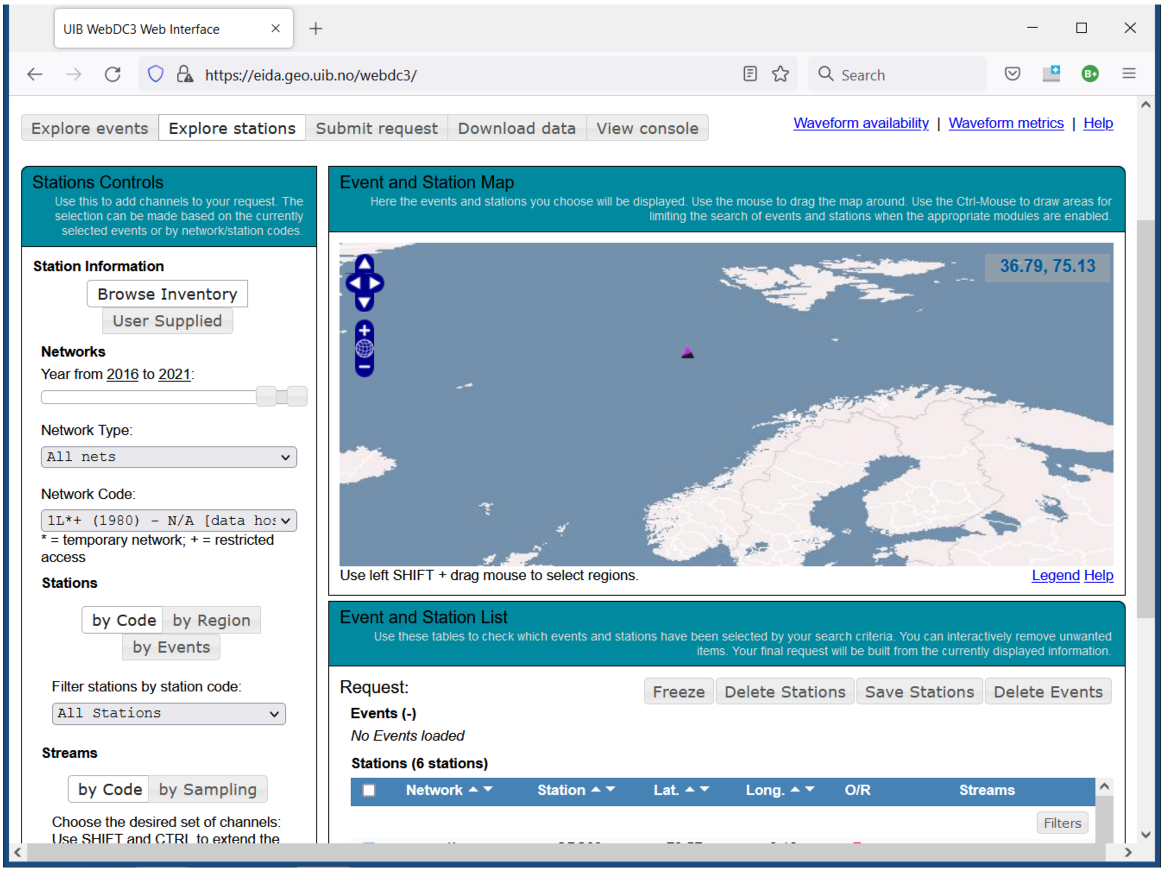
The hydrophones on the OBS instruments provide information about pressure changes at the sea bottom. The data from these instruments can be used to confirm detections of seismic signals. In addition, other signals from e.g. marine life can add to the multidisciplinary use of the recorded data.

2.9.4. Accessibility of the obtained data sets and repositories used

All OBS data collected through INTAROS are made available through the UiB-NORSAR EIDA node (https://eida.geo.uib.no/webdc3/; Ottemöller et al., 2021; Figure 2.9.2). The UiB-NORSAR EIDA node is part of the European Integrated Data Archive (EIDA; https://www.orfeus-eu.org/data/eida/; Fig. 2.9.3) which is the joint European repository for providing FAIR seismological data according to principles agreed by the wider, global seismological community. EIDA is a distributed federation of datacenters that securely archive seismic waveforms and metadata on a European level. EIDA organize and manage the operation of the archiving system.

2.9.5. Future plans for operation of the observing system, including data provision

Data collected through INTAROS will remain available through the UiB-NORSAR EIDA node. The OBS systems run on batteries and maximum deployment time with the standard NAMMU system is 1 year. By adding an extra battery pack, this period can be extended to 3 years. Deployment and recovery of the instruments is costly due to the offshore operations, and future deployments are thus subject to available funding.



Stations Controls

Use this to add channels to your request. The selection can be made based on the currently selected events or by network/station codes.

Station Information

Networks

Year from 2016 to 2021:

Network Type: All nets

Network Code: 1L*+ (1980) - N/A [data hos

* = temporary network; + = restricted access

Stations

Filter stations by station code: All Stations

Streams

Choose the desired set of channels: Use SHIFT and CTRL to extend the

Event and Station Map

Here the events and stations you choose will be displayed. Use the mouse to drag the map around. Use the Ctrl-Mouse to draw areas for limiting the search of events and stations when the appropriate modules are enabled.

Use left SHIFT + drag mouse to select regions.

Event and Station List

Use these tables to check which events and stations have been selected by your search criteria. You can interactively remove unwanted items. Your final request will be built from the currently displayed information.

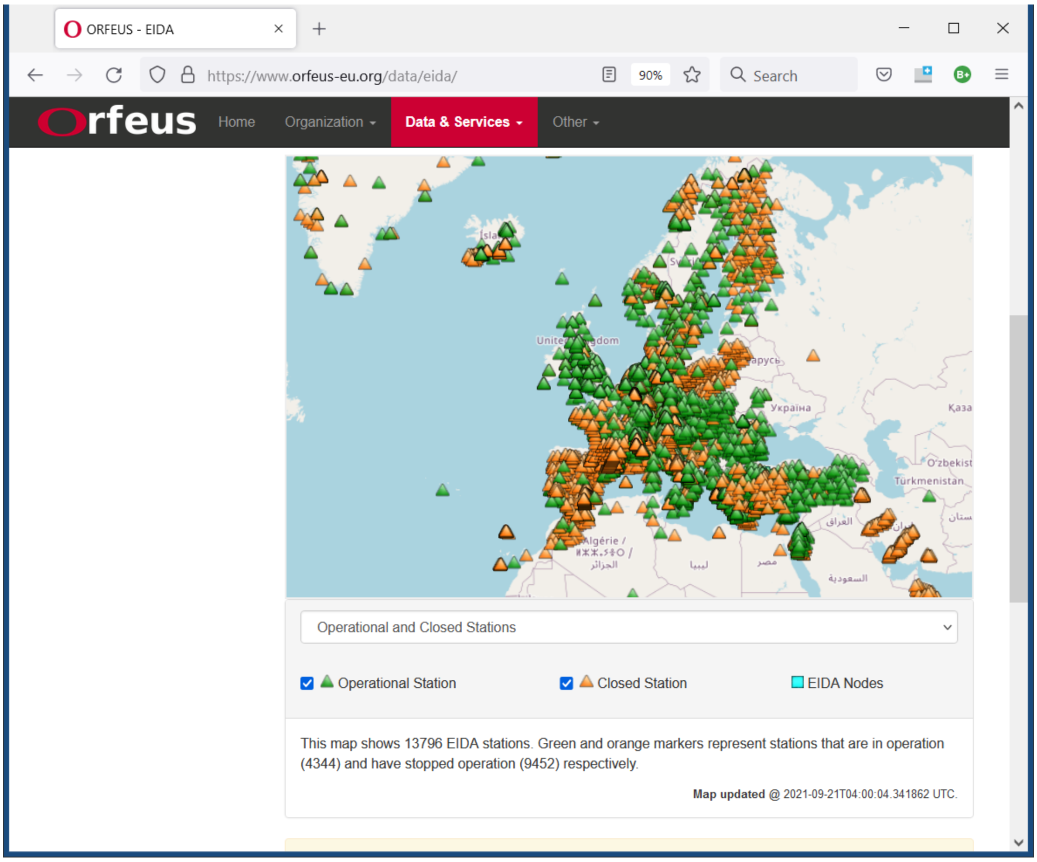
Request:

Events (-)

No Events loaded

Stations (6 stations)

Figure 2.9.2: *UIB-NORSAR EIDA node web interface.*



Operational and Closed Stations

☑ Operational Station ☑ Closed Station 🟦 EIDA Nodes

This map shows 13796 EIDA stations. Green and orange markers represent stations that are in operation (4344) and have stopped operation (9452) respectively.

Map updated @ 2021-09-21T04:00:04.341862 UTC.

Figure 2.9.3: *The EIDA website.*

3. Performance and fitness-to-purpose of the platforms, sensors and systems implemented during INTAROS for a future sustained Arctic observing system

3.1. UiB-GFI

Biogeochemistry

The aim for UiB-GFI where to implement advanced biogeochemical-, physical- and bio-optical sensors in collaboration with other Task 3.2 partners to produce a prototype biogeochemical mooring that could be implemented in extreme environment like the Artic Ocean. Are these sensors precise enough to measure trends in anthropogenic carbon uptake and transport, changes in pH and potentially in low oxygen areas trends in deoxygenation on a seasonal, annual, interannual and decadal time scale? Establishing such autonomous biogeochemical mooring sites is just in its infancy, so the focus in INTAROS is check the reliability, precision, accuracy, and duration of such sensor. If successful these mooring can be placed in "hot spot" areas selected to monitor future changes in climate (temperature, salinity and changing sea ice condition) and biogeochemistry (carbon uptake and transport, rate of change in ocean acidification, nutrient supply, and deoxygenation).

UIB-GFI was responsible for testing biogeochemical sensors, more specifically SAMIs for pH and pCO_2, SUNA for nitrate, and Aanderaa for oxygen (more detailed description in section 2.1.1).

Testing biogeochemical sensors for their reliability, precision, accuracy, and duration

Most of the sensors worked to some degree and gave comprehensive results. Their duration varied a lot from no-data to a couple to up to 6 months' worth of data for SAMI's measuring ocean pH and pCO_2. Their *precision and accuracy* are not on the scale needed to measure trends in anthropogenic CO_2 uptake and transport and changes for instance in ocean acidification. The typical standard deviation we obtained are in the order of ± 25 ppm. If these sensors are to be useful in the mentioned topic there is a need to improve the precession about 10 folds to ± 2.5 ppm. But they are useful to set the start, duration, and end of a phytoplankton bloom, and by the drop in pCO_2 the strength of the bloom. In contrast, based on experience oxygen and physical sensors work to the degree needed to measure changes in temperature, salinity, and water column oxygen content.

Conclusion: Depending on the question asked biogeochemical sensors are presently not very useful in studies of anthropogenic related changes in the carbon system variables and need to handle with care. Aanderaa Oxygen and SUNA Nitrate sensors did perform well and can be recommended for use on long-term mooring deployments. Still cruises and waters sampling is needed to get high precision and comprehensive data potentially answering question related to the changes in anthropogenic carbon and ocean acidification.

On the other hand, timing of phytoplankton blooms these sensors can be very useful as long as they measure a whole seasonal cycle. This was unfortunately not true for all sensors. The normal operation times for SAMI's were from 3-6 months.

In summary, promising advances in technology measuring carbon system variables and biogeochemistry in an autonomous fashion in general has been made, but the challenge is to improve the precision and reliability on long term deployment covering one annual cycle.

Upper looking ADCP for sea ice conditions and motion

An upward looking Nortek Signature 250 ADCP (Acoustic Doppler Current Profiler) was used (see section 2.1.1). More than 60% of data was lost due to the instrument's SD card being corrupted. This issue highlights a higher risk related to implementation of novel instrumentation which has not yet reached a high TLR. On one hand, newly developed (or newly adapted for polar regions) technologies are indispensable for improving and enhancing the capabilities of observing system, but on the other hand long-term in situ observations with fixed mooring in the remote Arctic areas require trusted performance of sensors and platforms to avoid large gaps in case of any instrument failure.

Stable isotopes in vapour and precipitation

Overall, the two cruises yielded a wealth of stable water isotope data from atmospheric water vapour, precipitation, sea ice, and sea water. The setup and maintenance required only limited efforts, with the vapour measurements working reliably in un-supervised mode. Discrete sampling activities required one operator on board of the ship. For the continuous analysis of water vapour, the used instrumentation (L2140-i, Picarro Inc., USA) worked reliably for the entire cruise periods of several weeks. Installation needs to be suitably protected from sea state and regular ship activities but can otherwise be done at various locations. Important aspects to consider during placement are the provision of a heated inlet line flushed with a manifold pump, and protected from sea salt aerosols, and placement to avoid contamination of the inlet from ship air. The used calibration system worked sufficiently most of the time, but it became obvious that more reliable means for calibration are needed for longer periods where no supervisor is on board. Remote access to the instrument for control of the measurements and remote data transfer is a highly desirable addition. Auxiliary information, such as a sea state and sea ice camera, and meteorological measurements near the inlet are highly valuable, but also need sufficient protection from sea spray.

Discrete sampling of water in liquid or frozen state required manual intervention and could only be performed during stops of the ship, small-boat operations, drilling of sea-ice cores, during CTD casts, and from CTD samples. While these actions could be seamlessly integrated into overall campaign operations, it is not easy to perceive how sampling can be automated for these. An important requirement for successful measurement operations are proper instructions both during and after sampling, and suitable storage containers to prevent leaks or evaporation until analysis. To ensure reliable isotope measurements, we recommend that (1) snow and ice samples be melted entirely in bags before being transferred to (glass) storage bottles with tight, sealed caps; (2) storage bottles should be filled with minimal headspace;

(3) samples be stored in a fridge for the remainder of the cruise, and (if possible) until the day of analysis. One technological development that should be pursued in the future is the continuous, combined analysis of liquid and vapour isotope composition. Potentially suitable commercial instrumentation exists to continuously vapourize sea water from the ship intake for water isotope analysis. If such an integration proves successful, discrete sampling will be limited to samples taken from CTD, sea ice, and precipitation.

3.2. IOPAN

Oceanographic moorings deployed in fixed locations for longer periods (and often arranged as a line of multiple platforms) are the only way to obtain year-round and high temporal resolution observations of subsurface physical, biogeochemical, and biological variables in the specific key locations situated in the seasonally ice-covered regions of the Arctic Ocean.

Sensors and instruments implemented under INTAROS on the moorings north of Svalbard and dedicated to measurements of physical variables as temperature, salinity, pressure, and ocean currents were represented the well-proved and robust technologies that worked with no significant failure during all year-long deployments in 2017-2020. Robustness is a key requirement for any long-term observing component of a sustained Arctic system, in particular for moored platforms which can be turned around only once a year (or sometimes more rarely). While new technical solutions are indispensable for improving and extending the capabilities of an observing system, they should be extensively tested until reaching a high TLR before operational implementation as a component of the long-term observatory. To ensure the continuous temporal coverage and coherence of sustained observations, the core set of sensors and platforms should be available at least in duplicate to allow for necessary calibrations and repairs between long-term deployments (this seems to be an obvious requirement but it is not always the case due to limited means). Additionally, development of the backup data storage system for instruments located at one mooring could be advantageous in the case of an instrument total failure (including data loss). Developing the acoustic or optical data transfer from self-recording moored instruments could in future enable easier data recovery from a vessel or even an autonomous mobile platform (as surface vehicle, underwater glider, or AUV/ROV) without a need to recover the entire mooring.

Spatial resolution of ocean physical observations with moored instruments and platforms should be optimized, taking into account the spatial scales of processes to be monitored by an observatory and the cost/efficiency ratio of obtaining the required measurements. In the key locations where the scales of spatial variability are relatively small (as in the case of the Arctic boundary current north of Svalbard), a moored array should be temporarily complemented by other components of an observing system, providing measurements with high spatial resolution (albeit obtained occasionally) that can be combined with data with high temporal resolution recorded at moorings.

The surface access is limited for moorings operated in the ice-infested waters where no instruments are placed in the surface/subsurface layer (of a few tens of meters) because of the high risk of damage or losing the equipment from ice collision. Acoustic profilers (as used in INTAROS) provide ocean current measurements up to a few/several meters from the surface but are limited by a physical principle of measurement. Moreover, they cannot deliver temperature and salinity measurements in the surface layer that are of key importance for studying the ocean-sea ice-atmosphere interactions. Several technical solutions have been tested in polar areas for surface access from fixed moorings but none of them reached the maturity level allowing its implementation for long-term observations in a sustained system. Therefore, there is a critical need for a dedicated effort to take advantage of currently emerging new technologies (miniaturized sensors/profilers, new ice-resistant materials, remote methods, etc.) for collecting the upper ocean measurements despite the ice presence.

Endurance time of all moored self-recording instruments and sensors is mostly limited by battery capacity. For one-year-long deployments and using the optimized sampling rate, all implemented instruments were able to deliver the full data record while is the case of longer deployments (not intentional but due to ship unavailability or ice conditions hindering the mooring recovery) measurements usually stopped prematurely. There is a significant progress in power usage of newer sensors (e.g., when comparing CTD sensors from different manufacturers) but in general battery lifetime in cold arctic waters is decreased (as compared to other regions) and instruments with higher energy consumption (e.g., active acoustic profilers) have limited endurance.

In a future sustained observing system where fixed moorings with multidisciplinary instrumentation should play an important role, the main challenges include development of more robust sensors for long-term deployments, availability of more efficient power supplies and possibility of remote data retrieval. For some sensors (mostly biogeochemical), sensor stability and calibration also pose a challenge.

Moorings that are operated in the ice-covered areas as INTAROS moorings north of Svalbard should be equipped to the maximum extent with the location and recovery aids, including satellite beacons, acoustic transponders, avalanche beacons, and possibly also strobe lights. All devices that can help to locate and follow a mooring under and in ice significantly lower the recovery risk and increase safe data and instrumentation return.

Since an access to ship time on ice-capable vessels equipped for mooring operations in ice-covered waters is very limited and often based on collaborations with and using opportunities of other programs and project, moorings should be designed, build and prepared in such a way that any trained mooring technician (with no specific knowledge of a specific mooring) should be able to recover and deploy it even if the mooring owner/operator cannot participate in a cruise. This includes the full technical documentation, certificates and manuals for mooring hardware and instruments, necessary soft- and hardware, and extensive personal communication.

3.3. CNRS-LOCEAN

Several recent studies on the ocean-sea ice variability in the Eurasian Arctic have highlighted the important role of the Atlantic Water boundary current in constraining the ocean heat and freshwater budget and the sea ice variability in the region, including during the wintertime.

Moorings so far are the only robust technology to monitor the ocean throughout the year in seasonally ice-covered regions. Yet, to fully address issues related to ocean-sea ice variability in the Arctic, it is necessary to continue the effort we have started during INTAROS through a long-term monitoring effort. This should include continuous measurements of basic physical properties such as those measured at CNRS moorings, but also other essential ocean-sea ice variables based on passive acoustic recorders, optical sensors, biogeochemical sensors, echo sounder for ecosystem monitoring, as well as combining mooring with other observing platforms (including AUV, gliders and buoys) to get a full understanding of climate change in the Arctic.

Mooring arrays are also essential in the Arctic as support to other platforms for data transmission and geographical positioning. Mooring implementation should therefore be thought in the wider context of a multi-platform Arctic OS. Also important is to optimize the geometry of an Arctic mooring system capable of addressing a wide range of spatial and temporal scales.

3.4. NIVA

The use of the passive sampling devices, specifically-designed exposure cages and sensitive instrumental analysis for the measurement of trace-level non-polar organic contaminants in polar waters was successful. The system was robust for deployments of 1 or 2 years, and considering the state the equipment was in after 2 years under water, it could have stayed longer. The system in place allowed us to estimate dissolved contaminant concentrations at depths in water as low as 1500m below the surface.

The procedures put in place to deploy and retrieve the samplers to minimizing possible contamination during manipulation of the samplers (on deck of the ship) were also successful. The build in calibration system (“PRCs”) provided robust estimates of sampler uptake rates even after a two year deployment. The platform that the designed exposure cages provide can easily be used to host other types of devices to target other types of contaminants. Routines and training in the handling of the samplers onboard would be relatively straightforward to put in place for future use.

3.5. IMR

Implementation of novel instruments always carries additional risks on top of the well-known risks of mooring loss or damage. Even though the IMR Signature 100 malfunctioned and therefore did not return data within the INTAROS project period, an adjacent deployed instrument of the same type showed the potential of this kind of novel observations shedding light on year-round biological activity (from large zooplankton to fish). This part of the Arctic marine system is otherwise still severely undersampled, especially outside the summer season. Implementation and integration of biological sensors on mooring systems therefore help towards closing a large gap in Arctic observing systems.

3.6. AWI

The mooring deployment of the Octopus system during the INTAROS field campaign turned out to be very beneficial for the improvement of the prototype. The system was easy to install and operate in the field with low power requirements and long acquisition periods. The cage construction was designed to rotate and tilt the camera field of view directly into the current which worked well. The prototype allowed data generation of chemical (nitrate, cDOM) and biological (chlorophyll, suspended and sinking particles, plankton) factors on an hourly basis for >1 year below sea ice cover, which represents a new opportunity for long-term observations especially during the Arctic winter.

After improvements of the weaknesses identified during the INTAROS field campaign (i.e. low light beam intensity coupled to long exposure times) the system has the potential to produce unique data also in areas of seasonally high current velocities, such as North of Svalbard, in the framework of a future sustained Arctic observing system.

3.7. UNIS

A pair of Bottom Pressure Recorders (BPR) spanning the Svalbard branch, together with temperature and salinity time series form other sensors on the two moorings, give us the opportunity to monitor the variation in fluxes of heat and salt into the Arctic Ocean. Although the observatory set up is vulnerable, since the instrument concept is dependent on two sensors working together and operating in pairs, there are large benefits and opportunities when this technology works.

3.8. UiB-GEO and GEUS

The ocean bottom seismographs (OBS) provided high-quality data with 100% up-time during the three deployments conducted under INTAROS. For one instrument, the release mechanism failed but the instrument could be retrieved manually using an ROV. In that regard, the OBS constitute a reliable means for collecting seismological data on the sea bottom, thereby reducing a large monitoring gap. Important limitations are the limited deployment period (dependent on battery power, usually about one year) and the lack of real-time data transfer. However, even with these limitations, future deployments are expected to provide important new insights on earthquake activity and natural hazards in the Arctic.

The main challenge in OBS monitoring is related to the logistics of deployment and recovery. In a standard deployment, instruments can be deployed and recovered from most ships with a winch on deck. The procedure becomes more complex in ice covered waters, where deployment and recovery must be done with an ROV to prevent the OBSs from being caught under the ice. Future deployments will require availability of funding for such operations.

4. Summary

The main goal of Task 3.2 was to implement the INTAROS multidisciplinary moored observing system north of Svalbard along 22°E for continuous measurements of physical, biogeochemical, and biological variables during two main field seasons (2018-2019 and 2019-2020). The INTAROS moored array built on and extended the existing infrastructure of the A-TWAIN oceanographic moorings deployed along 31°E. To extend capacity of platforms focused on specific measurements (mostly physical variables) towards multidisciplinary observations, a rich suite of multidisciplinary sensors and samplers have been developed or carefully selected from existing mature technologies and integrated in the moored array.

The main focus was on establishing a system of autonomous sensors and instruments installed on moorings and/or mounted at the seabed, quasi-continuously collecting year-round measurements. The mature sensors and instruments which have been integrated in the moored array could be deployed already in the early phase of the project for preliminary in situ deployments. Consequently, they have delivered multiyear time series of observed variables, covering two or even three full seasonal cycles. The sensors and samplers that have been newly developed or adapted during the project had to go through longer design, construction and testing phase before being ready for operational deployment. Therefore, time series of in situ observations provided by the sensors or platforms developed during the project cover shorter periods, usually one full year (in some cases two years).

The processing of collected data has been done (or is ongoing), according to the best practices documentation and methodology for each measured variable. All data were/will be quality-controlled and archived in standarized formats, dedicated to individual data sets. The full metadata sets for each type of measurement and recommended netCDF formats were developed by data producers in Task 3.2 together with WP5 partners. Derived data products were/will be obtained and stored together with measured properties.

Table 4.1 summarizes the main objectives, field deployments, challenges, and obtained results for all in situ observing activities and technical developments by the Task 3.2 partners.

Table 4.1. Final results obtained in Task 3.2.

Partner	UiB-GFI
Action	Year-round measurements of biogeochemical variables on INTAROS moorings
Objective	To collect year-round observations of biogeochemical variables (dissolved oxygen, pCO2, pH, nitrate) on INTAROS moorings deployed north of Svalbard and in the deep Nansen Basin
Field deployment	Deployments in BGC11 in 2018-2019 and on NERSC-4 in 2019-2020
Challenges	Stability of BGC sensors, availability of co-located samples for post-deployment calibrations taken during deployments and recoveries. Challenges in operating sensitive BGC sensors on moorings in the ice-covered waters.
Final results	Two years of year-round time series of measured physical (temperature, salinity, ocean currents) and biogeochemical (dissolved oxygen, pCO2, pH, nitrate) data in the key site north of Svalbard

Partner	UiB-GFI
Action	Ship-based stable isotope measurements in atmospheric water vapour
Objective	To collect automated ship-borne measurements of stable isotopes in atmospheric water vapour and auxiliary atmospheric and oceanographic data during two field campaigns north of Svalbard
Field deployment	Two cruises in July-August 2018 (INTAROS2018) and August-September 2019 (CAATEX2019) north of Svalbard
Challenges	No live transfer or remote access to instruments (in case of problems). Better protection against sea spray and contamination by ship air, and physical damage needed. Corrosion of regular meteo sensors, filter system required.
Final results	The dataset consisting of calibrated, continuous time series of stable isotopes in water vapour collected during two cruises with the main variables including δ^{18}O (and δD), d-excess, and specific humidity and auxiliary data (atmospheric data, images time series).

Partner	IOPAN
Action	Year-round measurements of ocean physical and sea ice variables on INTAROS and A-TWAIN moorings north of Svalbard
Objective	To deploy oceanographic moorings north of Svalbard and provide year-round measurements of physical and sea ice variables at fixed locations in the key region of the Atlantic water inflow to the Arctic Ocean
Field deployment	Three year-round deployments of two oceanographic moorings in 2017-2018 (test field season), 2018-2019 (first field season, three moorings, including BGC11), and 2019-2020 (second field season) at two moorings lines (INTAROS at 22°E and A-TWAIN at 31°E) north of Svalbard
Challenges	Difficult logistics for mooring operations in the remote, ice-cover region, recovery from under the ice, high risk mooring, no surface access. Limitation and restrictions due to COVID-19 in ship access and logistics.
Final results	Year-round time series of physical ocean and sea ice variables (ocean subsurface temperature, salinity, and dissolved oxygen at fixed depths and profiles of ocean currents, sea ice draft and drift) in the key region of the Atlantic water inflow to the Arctic Ocean north of Svalbard. Concurrent measurements with physical ocean variables collected at CNRS-LOCEAN moorings.

Partner	CNRS-LOCEAN
Action	Year-round measurements of ocean physical variables on INTAROS moorings north of Svalbard
Objective	To deploy oceanographic moorings north of Svalbard and provide year-round measurements of physical and sea ice variables at fixed locations in the key region of the Atlantic water inflow to the Arctic Ocean
Field deployment	Three year-round deployments of three oceanographic moorings in 2017-2018 (test field season), 2018-2019 (first field season), and 2019-2020 (second field season) at the INTAROS moorings line at 22°E north of Svalbard
Challenges	Difficult logistics for mooring operations in the remote, ice-cover region, recovery from under the ice, high risk mooring, no surface access. Limitation and restrictions due to COVID-19 in ship access and logistics.
Final results	Year-round time series of physical ocean variables (ocean subsurface temperature, salinity, and dissolved oxygen at fixed depths and profiles of ocean currents) in the key region of the Atlantic water inflow to the Arctic Ocean north of Svalbard. Concurrent measurements with physical ocean variables collected at IOPAN moorings.

Partner	NIVA
Action	Collection of passive contaminant samples on the moorings north of Svalbard
Objective	To collect year-round passive contaminants samples on moorings north of Svalbard
Field deployment	Clusters of 2-3 passive samplers deployed on three INTAROS moorings for 2018-2019 (one mooring recovered after 2 years in 2020)
Challenges	Access to moorings, post-recovery procedure (when recovered by other groups)
Final results	Data collection of concentrations of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorinated pesticide residues such as DDT, HCHs and hexachlorobenzene, polybrominated diphenyl ethers (PBDEs) and selected UV filter including UV-328 in the key locations north of Svalbard

Partner	IMR
Action	Implementation of a novel ADCP/echosounder instrument on the mooring north of Svalbard
Objective	To collect year-round measurements of the upper ocean currents and biological activity (from large zooplankton to fish) on selected moorings north of Svalbard
Field deployment	First deployment in 2019-2020 (instrument failure), second deployment for 2020-2021 (mooring to be recovered in November 2021)
Challenges	Malfunction of the instrument during the first deployment, delayed data delivery
Final results	To be yet obtained after recovery in late 2021, will include time series of ocean current profiles and high-resolution backscatter measurements for biomass in the upper ocean

Partner	AWI
Action	Deployment of the OCTOPUS sensor package for biogeochemical and biological observations north of Svalbard
Objective	To collect year-round physical, biogeochemical and biological observations with the prototype senor package (including the camera system UVP6, nitrate sensor, and Ecotriplet fluorometer) at the mooring in the Atlantic water inflow north of Svalbard
Field deployment	One-year deployment in 2018-2019 at the BGC1 mooring
Challenges	Collection of additional samples for calibration during deployment/recovery,
Final results	One-year time series of raw particles data (measured size, abundance) and analyzed visual images of particles in Ecotaxa. Time series of the nitrate data as well as fluorescence data of chlorophyll, cDOM and particle backscatter.

Partner	UNIS
Action	Year-round measurements with Ocean Bottom Pressure Recorders north of Svalbard
Objective	To collect time series of ocean bottom pressure and temperature on INTAROS moorings in key locations north of Svalbard
Field deployment	BPRs deployed on two INTAROS moorings in 2018-2019
Challenges	Delays in instruments purchase/delivery.
Final results	Year-round high resolution time series of pressure and temperature at the bottom to obtain the weight of the water column above the ocean sea floor

Partner	UiB-GEO and GEUS
Action	Deployment of the Ocean Bottom Seismographs (OBS) for year-round seismic observations around Svalbard
Objective	To monitor seismic activity in key locations around Svalbard
Field deployment	Three year-round deployments in 2017-2018 and 2018-2019 west of Svalbard in in 2019-2020 in Storfjorden

Challenges	High risk in recovery operations. ROV support recommended for operations in ice-covered areas. Limitations in battery power. Long-term operations with real-time data transfer needed for seismic hazard assessment
Final results	Year-round recordings of seismic waves with four components (vertical, two horizontals and hydrophone channel) with auxiliary data on precise timing, source location and the seismometer location. Time series of pressure changes at the sea bottom (from hydrophones).

The most of components that were considered in the initial system design, including the new technical developments of sensors and samplers have been implemented during the project and deployed over the 2018-2019 and 2019-2020 field seasons, with some deployments already in place for the test season 2017-2018. However, no new deployments could be made in 2020 and they had to be postponed to 2021. Results so far underline the challenges of operating in a severe and remote environment, with some instruments lost or damaged during field deployment, but also highlight retrieving the unprecedented data sets of key physical, biological, and biochemical variables with a novel combination of instruments.

The main challenge of Task 3.2 has been to retrieve or maintain instrumentation in the remote region north of Svalbard during the COVID-19 pandemic situation in 2020 and 2021, when access to planned cruises and field work opportunities were significantly limited. In some cases, moorings had to remain in water for extended period (two years instead of one year) while in other cases moorings could be recovered by other groups but not redeployed. Due to extremely difficult field work logistics under the pandemic restrictions, movement of instruments and equipment to and from the field was also delayed (sometimes for longer periods) what often resulted in significant delays in availability of new data sets collected during INTAROS deployments. However, all collected data will be ultimately submitted to open data repositories when their processing and preliminary analysis is completed.

Most of data sets and technical developments reported in this deliverable provide the basis for activities in WP6: *Applications of IAOS towards stakeholders*, which is focused on delivering demonstration products from the iAOS, more specifically under Task 6.3 Ice-ocean statistics and Task 6.5 Arctic greenhouse gases.

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