Integrated Arctic Observation System

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Report on present observing capacities and gaps: ocean and sea ice observing system

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EXECUTIVE SUMMARY

A major goal of WP2: “Exploitation of existing observing systems” is to analyze strengths, weaknesses, gaps in spatial/temporal coverage, and missing monitoring parameters of the existing observation networks and databases in relation to the requirements from different user groups. This report is prepared to assess the existing ocean and sea ice observing systems in the Arctic, primary those where the INTAROS partners have responsibilities, but also where the partners contribute to larger, international observing systems.

A core activity in the first 18 months of WP2 has been to conduct a survey where partners have responded to three sets of questionnaires: Questionnaire A: Existing Arctic In-situ Observing Systems, Questionnaire B: In-situ data collections, and Questionnaire C: Satellite Products. The survey has covered the scientific disciplines addressed in INTAROS, including atmosphere, ocean and terrestrial disciplines. The focus of the survey has been on in-situ observing systems, which is the priority of INTAROS, while satellite observing systems are treated more generally. This report therefore provides more details on selected in-situ systems and data collections than previous surveys and inventories. The reason or the detailed survey is that INTAROS will develop and demonstrate machine-to-machine operations between data repositories, following the FAIR data management principle (“Findable, Accessible, Interoperable and Re-usable”). An expected outcome of the survey is identification of selected observing systems and data collections that will be used further in the project, especially in WP5 (“Data integration and management”) and WP6 (“Application of iAOS towards stakeholders”).

A major part of the report is a status description of in situ observing systems that are operated by the partners (Section 2). In INTAROS we identify a set of data collected from the same types of instruments and platforms over time to be an observing system (for example CTD surveys by ships, network of moorings, glider surveys). An observing system is often defined programmatically, where many institutions agree to establish and operate a network of instruments collecting a set of standard measurements and agree on sharing and exploitation of the data (for example International Arctic Buoy Programme). We have also analysed selected in-situ data collections, which can be part of one or more observing systems, or can be a stand-along data set. This analysis has been more detailed, addressing spatial/temporal coverage, uncertainty characterisation and metadata description.

Requirements for observing systems is discussed in Section 3, where requirements to platforms, instruments and data management are central. For in-situ data, it is most important to focus on data at level 0 (raw data), level 1 and level 2 (physical, biological variables). These data are needed by different users along the downstream processing chain. Level 3 and level 4 data are gridded data, usually coming from satellite data and reanalysis fields, with input from in-situ data where these are available. Ocean modelling, reanalysis of forecasting are important users of data from level 2 and higher. Requirements to observational data are described in documents from programmes such as WMO, GCOS, Copernicus. Other users are marine ecosystem management, marine hazards and environmental monitoring.

The assessment of the observing systems is described in Section 4. The assessment criteria include the spatial and temporal coverage of the data collection, scientific-technical support,

sustainability of funding, data management, data usage, user feedback and others. The criteria are assessed on a scale from 1 (low maturity) to 6 (high maturity). The technical readiness level for all the instruments is generally high, showing that the observing systems are generally robust. For biogeochemical, observations there are fewer automated systems compared to physical observation systems. This is reflected in much less collection of biogeochemical data compared to physical data. For the ice-covered Arctic, there is a huge gap in collection in-situ measurements Uncertainty characterisation and metadata have mid to low maturity, while data management varies a lot. It is noteworthy that data management becomes a discipline in itself because the amount of data grows very rapidly. Therefore, data producers and data managers require experts and training to be able to do a good job.

Recommendations to develop and maintain in-situ observing systems are described in Section 5. There are significant efforts to build observing systems by many countries, organisations and projects in the Pan-Arctic region. The amount of data collected in the Arctic is growing and there are numerous initiatives to establish observing systems for collection of data in different disciplines. Many recommendations deal with technology development, collaboration and organisation. However, the funding of the observing systems is to a large extent dependent on time-limited research and observation projects. These systems are therefore not sustainable and there is a high risk that many will not be maintained in the future. Some satellite Earth Observation programmes, such as Copernicus, have long-term perspectives and funding plans for 5 – 10 years, but most of the observations from *in-situ* systems on ground and in water have no long-term funding. It is therefore essential to develop and maintain long-term *in-situ* observing systems to monitor trends, and to detect natural variations and human impacts on climate, environment, livelihoods and societies. This requires mechanisms for long-term funding to be established.

This report only provides preliminary results of the assessment, because organisations outside of the consortium are not yet included in the survey. It is therefore planned to update the assessment later in the project.

Table of Contents

1. Introduction

This report is prepared to assess the existing atmosphere observing systems, and is based on responses from INTAROS partners to a set of questionnaires. The survey addresses Arctic in-situ and satellite-based observations of the ocean, atmosphere and terrestrial parameters retrieved through established networks/observing systems as well as individual measurement campaigns and projects. In this report we analyse the responses covering the ice-ocean environment.

1.1. Links to previous assessments

Assessments of Arctic observations have recently been carried out in the framework of the EU project EU-PolarNet and of the ESA project "Polaris: Next Generation Observing Systems for the Polar Regions". Other assessments that focused on European data collections addressed also some datasets covering the Arctic region. This is the case for data maturity evaluations undertaken in the framework of CORE-CLIMAX and GAIA-CLIM projects. In the following paragraphs, these previous assessments are described, and their results summarized.

The deliverable D2.25 of the CORE-CLIMAX FP7 project (Schulz et al., 2015) reported the outcome of an assessment of Europe's capacity to provide climate data records for Essential Climate Variables (ECV) as defined by the Global Climate Observing System (GCOS). One of the scope of the assessment was to support the establishment of the Copernicus Climate Change Service. The assessment addressed satellite and in-situ climate data records (mostly gridded processed data) as well as weather prediction model-based reanalysis output, and was based on the System Maturity Matrix (SMM) method developed by the CORE-CLIMAX project. The applicability of the SMM for capacity assessment was well demonstrated by the 37 data records assessed. Among them, are satellite sea ice products (ESA CCI Sea-Ice-Concentration, Sea Ice volume flux through Fram Strait 79N), sea surface temperature products (ESA-SST-CCI-Analysis, ESA-SST-CCI-AVHRR), and ocean color products (ESA Ocean Colour CCI), plus sea surface temperature from a blended in-situ and satellite products (HadISST1) that have global coverage and, therefore, cover the Arctic.

Concerning other satellite data, selected ocean and sea ice products were addressed in the Polar View report on Gaps and Impact Analysis of the existing EO missions in Polar Regions (Polar View, 2016). The study focused on cryospheric products rather than ocean products, and gaps were identified with respect to the applicability of different groups of EO sensors to provide information on the addressed themes (Ocean, Sea ice, etc., see Fig 20 in Polar View, 2016). The final recommendation that emerged from the gap analysis was that future mission planning should focus on making optimum use of existing, rather than development of new, sensor technology. Furthermore, the Polar View report identified the primary gaps in existing environmental information in meeting user needs on the basis of literature review and consultations with representatives and user organizations (Table 5 in Polar View, 2016). The assessed data characteristics were spatial and temporal resolution, timeliness (the amount of delay between the data collection and its accessibility for subsequent use), data continuity, and coverage. The key environmental information gaps were divided into two groups: concerning Polar earth science, and concerning Polar operations. For Polar earth science, the identified key information gaps in the ocean and sea ice domain was Sea ice thickness, and the two parameters considered of most concern were "Extent" and "Surface structure/albedo" (of sea ice). For Polar operations, the identified key information gaps were: Sea ice thickness, Sea ice age/structure, Sea ice motion, Sea ice extent and topography, Snow cover on sea ice. Finally, a gap analysis of the Polar data value chain was performed, addressing the following points: data discovery, data access, data integration, data platforms, and training. Deficiencies were found in all the listed aspects (see Table

7, Polar View, 2016). The Polar View report, however, contains only very limited information on the characteristics of each product (mainly content and data availability (i.e. temporal coverage)), while keys information such as spatial and temporal resolution, timeliness, and uncertainty/validation are not provided (information on validation is provided only in few exceptional cases).

In-situ measurement networks were evaluated in the framework of the H2020 project GAIA-CLIM using the SMM approach developed in CORE-CLIMAX adapted to in-situ measurement series (Thorne et al., 2017). Although the addressed networks where almost exclusively from the atmospheric domain (with the exception of the ARGO buoy network), the method proved to be a valid, general tool to identify gaps in the in-situ observations from all domains.

A survey was made by the H2020 project EU-PolarNet to assess the data management of Polar observing systems (EU-PolarNet, 2016). The 58 addressed observing systems operate in either the Arctic or Antarctic region. Although the evaluated Arctic observing systems are too few to derive a conclusive picture on the Arctic data management, the results of the survey suggested that data interoperability would require the adoption of more advance data management practices, such as those developed for large multi-organizational system-of-systems.

These previous assessments form the foundation for the present and companion INTAROS reports on the existing observing capacity and gaps in the Arctic. To ensure continuity and comparability with the CORE-CLIMAX and GAIA-CLIM assessments, the ocean and sea ice satellite products and the in-situ observing systems were assessed in INTAROS using the SMM method developed by the CORE-CLIMAX and GAIA-CLIM projects, respectively. As most of the in-situ observing systems measure a large number of different variables that have different characteristics in accuracy, documentation, etc., the data collections measured by the observing systems were separately assessed. Additionally, in-situ and satellite data characteristics such as data coverage, resolution, timeliness, and accuracy were assessed with respect to user defined (and observing system-specific) requirements for most in-situ data, and with respect to WMO requirements defined in the OSCAR database (https://www.wmo-sat.info/oscar/requirements) for some in-situ and all satellite data.

1.2. The INTAROS survey and questionnaire

The existing observing systems were evaluated based on a standardized survey using three sets of questionnaires (Questionnaires A, B and C)[1].

The structure of the three questionnaires are defined as follows:

Questionnaire A: Existing Arctic In-situ Observing Systems.

Section 1: General information on the observing system and the respondent
Section 2: Observed variables and potential environmental impact
Section 3: Sustainability of the observing system
Section 4: Data usage

[1] More information about the questionnaires are found at https://intaros.nersc.no/node/651.

Section 5: Data management

Questionnaire B: In-situ data collections

Section 1: General information on the data collection and the respondent
Section 2: Sustainability of the data collection
Section 3: Data usage
Section 4: Data management
Section 5: Data coverage, resolution, timeliness and format
Section 6: Uncertainty characterization
Section 7: Metadata specification and documentation

Questionnaire C: Satellite Products

Section 1: General information on the data products and the respondent
Section 2: Data management
Section 3: Data coverage, resolution, timeliness and format
Section 4: Uncertainty characterization
Section 5: Metadata specification and documentation

1.3. Definition of the components of an in-situ observing system

An **in-situ observing system** consists of a data collection component (infrastructure) and a data management component (e-infrastructure). The data collection component is comprised of multiple sensors either belonging to a common fixed platform (such as cabled system, sea floor installation, mooring), which can be a single unit or a collection of units forming a network, or installed on a movable and temporary platform (ship, aircraft, gliders, floats, ice buoys). The data collection component stores the datasets internally or transmits them to the data management component. The data management component includes hardware and software for data repository, the data processing, data discovery and visualization services. The management can be centralized in a single institution or distributed among several national institutions, which have agreed on common standards for the data and metadata formats, documentation and management. An observing system can be multidisciplinary, focused on a specific discipline or designed for certain user requirements. Therefore, it usually serves identified scientific or operational purposes.

There are many types of in-situ observing systems, reflecting a large variety in technical solutions and different maturity and organizational levels of the in-situ measurements. For the atmosphere there are several mature observing systems, especially those organised in international networks supporting weather services and monitoring of air quality. These follow standardized procedures for data collection and management. In the marine sphere the observations are more diversified involving a wider range of scientific disciplines. This implies that more heterogeneous data with various degree of standardization need to be managed. The marine observing systems are usually identified on the basis of the utilized platforms (moorings, floats, gliders…). Observing systems supporting global challenges such as climate change are even more complex and diversified, which are described in in the GCOS 2016 Implementation Plan, a high level requirement document for climate observations (CGOS, 2016).

The different ocean in-situ observation systems are assessed through the responses to QA. The results from the QA are presented in **Section 4.2**.

1.4. In-situ data collections

In this report we distinguish between an **in-situ observing system** (as described above) and **in-situ data collection**, which has focus on specific data sets. An **in-situ data collection** is defined as a collection of data, or measurement series, that have common characteristics in terms of quality, resolution, and coverage. In most cases, the observation platform and its instrumentation used to collect the data determines the characteristics of the collection. In the present survey, the methods used to collect data range from human-operated instruments to semi-automated or fully automatized sensors, while the observation platform can be moving, drifting or fixed. Thus, a data collection generally includes all variables measured by a single instrument. In-situ data collections also include derived data products which result from processing of individual measurements or composition of multiple measurements. In-situ data collections can be surface-, subsurface-, and air-borne.

Each observing system in QA can produce a number of data collections. In QB single parameter datasets are assessed with respect to data characteristics such as coverage, quality, and resolution. The results from the QB are presented in **Section 4.3**. In general, the data collection in QB belongs to an observing system, but not always. In some cases, data sets come from research campaigns without any connection to an observing system.

We address three different kind of data collections:

1) data from established ocean in-situ networks with regional areal coverage and variable temporal coverage,
2) data from single stations with local areal coverage and variable temporal coverage,
3) data from time-limited field campaigns (ship-, aircraft-, etc.), with limited spatial coverage.

Most of the information required for the evaluation of the data collections is collected through Questionnaire B.

1.5. Satellite Earth Observation products

Satellite Earth Observations (EO) products are discussed in **Section 4.4**. The spatial and temporal coverage of satellite data products are very different from the in-situ observing systems. Assessment of satellite products have been done in other studies, such as the Gaps and Impact Analysis Report done by Polar View (2016). In this report we extend the analysis of gaps in spatial and temporal resolution, uncertainty, timeliness, and data value chain for selected EO products. The information needed for this assessment is collected through Questionnaire C.

1.6. Scope of the assessment

Observing system. The current assessment is limited to the responses to Questionnaire A (QA) provided by the INTAROS consortium. This means that several important ocean observing systems are not included such the Nansen and Amundsen Basins Observational Systems (NABOS), the moorings in the Baffin Bay Observatory and others, in particular systems operated by institutions outside of Europe. In order to include a wider range of observing systems, Questionnaire A is now open for external partners to fill in, and the opening has been announced widely through AMAP and the projects within the EU Arctic Cluster.

Data Collections. Questionnaire B (QB) was designed to evaluate important data sets, which potentially will be included in the iAOS for use in applications for different Stakeholders (WP 6). These datasets will be listed in the data catalogue and a subset will be made accessible for the iAOS.

Satellite products. This report does not intend to assess a wide range of satellite products available from the Earth Observation (EO) community. This is because assessment of satellite products is carried out by other projects and services, such as FP7 CORE-CLIMAX, EUMETSAT OSI-SAF and Copernicus Marine Services. Some satellite EO data products, which will be needed in the stakeholder dialogue (WP6), have been selected and assessed through Questionnaire C (QC).

1.7. Organization of the report

In Section 2 we describe each of the assessed in-situ observing systems, as well as the assessed in-situ and some EO datasets. In Section 3 some aspects of requirements used in the assessment are described.

For a comprehensive evaluation of the observational data, the assessment addresses general aspects of the in-situ observing platforms (Section 4.1), specific aspects of the in-situ observing systems (Section 4.2), specific aspects of in-situ data collections (Section 4.3), and the most relevant aspects of the satellite products (Section 4.4).

Recommendations for further development and operation of observing systems are described in Section 5.

2. The assessed Ocean and Sea Ice Observing systems

In this section the in-situ observing systems and data collections, mainly provided by the project partners, are presented to provide background information for the assessment.

2.1. NERSC (Nansen Environmental and Remote Sensing Center)

Contributors: Hanne Sagen, Torill Hamre, Mohamed Babiker, Asuka Yamakawa

2.1.1. Fram Strait Multipurpose Acoustic system

Multipurpose acoustic networks have several times been argued for as an important contribution to the development of a sustainable Arctic Ocean Observing System (e.g. Mikhalevsky et al. 2015). A network of fixed mooring systems with acoustic transceivers in the Arctic Ocean will provide an underwater geo-positioning system for all users in direct analogy with GPS positioning. The same system will provide ocean observation through acoustic thermometry, passive acoustic monitoring, and oceanographic point measurements. Passive acoustic monitoring of the sounds generated by marine life, ice, seismic, and other natural sources, as well as by anthropogenic sources. Moored multipurpose acoustic networks have been implemented in a sequence of year-long research experiments in the Fram Strait (Fig. 1) and in the Beaufort Sea (Mikhalevsky et al. 2015).

The *technological readiness level* of the instruments and methodologies used in these systems are high, while the data management of passive acoustics and acoustic thermometry is not very well developed. The acoustic data has not yet been included in the common data repositories because standards and formats have been missing. This is currently addressed and under development within the INTAROS project (Integrated Arctic Observation System).

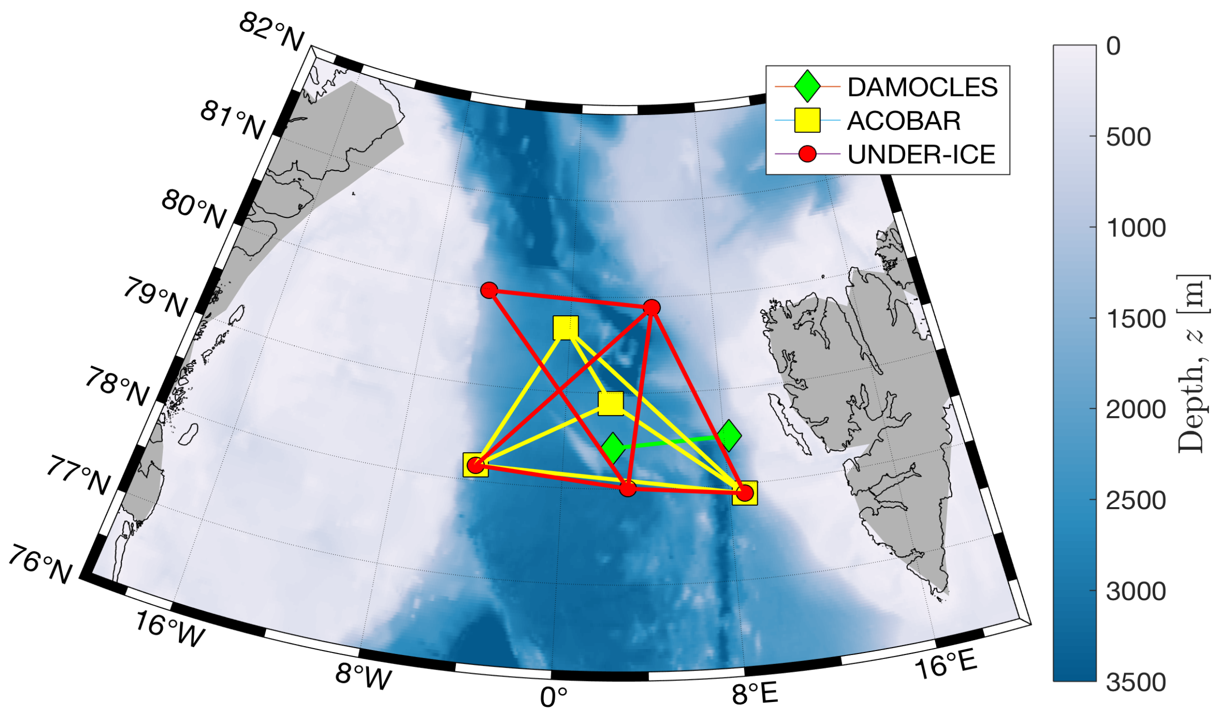

Figure 1. Green symbols mark the DAMOCLES (2008-2009), yellow marks the ACOBAR (2010-2012), and red marks the UNDER-ICE (2012-2014) experiment.

Goal of the observing system: The Fram Strait is of great importance in ocean climate monitoring, as it is the only deep-water connection between the Arctic and Atlantic Oceans. An extensive array of oceanographic moorings has been operated in Fram Strait since 1996 to monitor the transports through the Strait. The complex and highly variable ocean environment makes observations and modelling demanding.

As part of the DAMOCLES underwater acoustic methods were introduced to improve the monitoring of Fram Strait. The 2008–2009 single acoustic path experiment was followed by the implementation of a multipurpose acoustic network (2010-2012) with a triangle of acoustic transceivers for ocean acoustic tomography, ambient noise, and glider navigation (ACOBAR project). The measurements were continued during 2014–2016 in UNDER-ICE, with eight acoustic paths crisscrossing the Fram Strait.

The basic measurements is used for ambient noise monitoring and accurate measurements of acoustic travel times. A new inversion approach was developed under ACOBAR and UNDER-ICE projects to obtain depth-range averaged ocean temperature from the acoustic travel times. These derived data represent instantaneous mean ocean temperature over large ocean volumes/sections (90-300 km at an accuracy down to 50-75 m °C. In our case the measurements are repeated 8 times a day.

Geographical area: Fram Strait between 78-80 N, -4W - 8E.

Time: 2008-2009, 2010-2012, 2014-2016.

Observing platform: This system comprises fixed moorings carrying acoustic sources and/or acoustic receiver. During 2014- 2016 the system also carried oceanographic instrumentation, but these data are not assessed in QB.

General description: The number of moorings varies from 2 moorings in 2008-2009, 4 moorings in 2010-2012, 5 moorings in 2014-2016. One mooring was lost in 2010 a few weeks after deployment. The first experiment gave acoustic travel time measurements along 1 section, the second gave acoustic travel times along 4 sections, and the third gave 8 acoustic sections. Acoustic recordings can also be used for passive acoustics. UNDER-ICE experiment gave standard time series of oceanographic point measurements from all the moorings. Figure 1 give the overview of the moorings. The acoustic measurements were supported by XBT/XCTD profiles. Environmental assessment for all acoustic sources has been performed before implementation of the experiment (Spikes et al, 2010, Vigeness-Raposa et al., 2013, 2014).

Relevance of the observing system: The multipurpose acoustic system is used as an observing system but is also a prerequisite for geo-positioning of floats and gliders under the ice. The system delivers travel time data which can be used to derive depth-range averaged ocean temperature along fixed sections. These measurements are relevant for large scale ocean processes, validation/constraining of models and for monitoring and detection of ocean climate change. Acoustic recordings can also be used to analyse and characterize the soundscape/ambient noise which is important for the Marine Strategy through indicator 11 (MSFD Technical Subgroup on Underwater Noise, Part I-III, 2014) and input to environmental assessments.

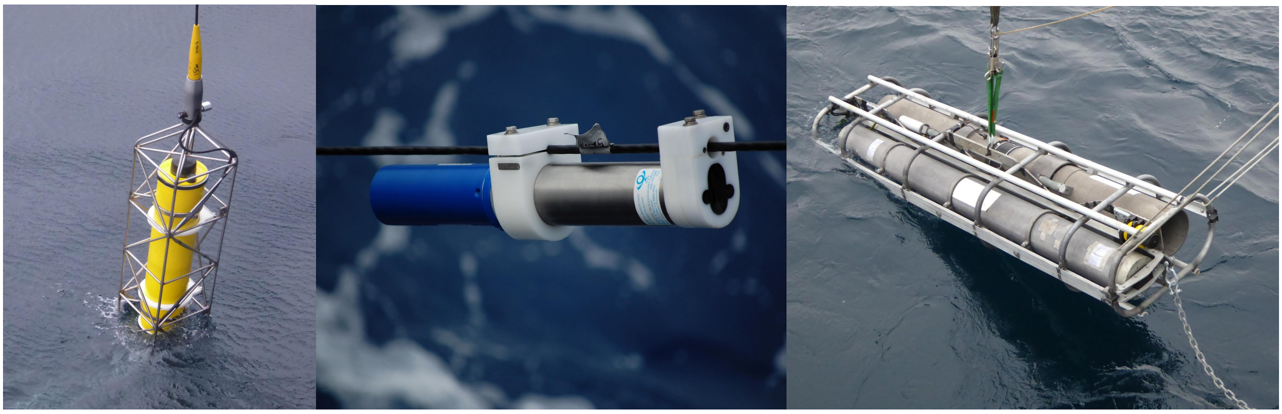

Figure 2. Instrumentation used in In-situ observing system: Fram Strait Multipurpose Acoustic system. From the left the STAR controller, the Hydrophone modules, and the Sweeper sources.

Sensors/instruments: Technical information is given in Sagen et al. 2013, 2017. The transceivers used in our DAMOCLES and ACOBAR used a Teledyne Webb Research swept-frequency acoustic sources that transmitted linear frequency-modulated (LFM) signals with bandwidths of 100 Hz and center frequencies of approximately 250 Hz. Each transmission lasted 60 s. The nominal maximum source level is 190 dB re 1 µPa at 1 m. In ACOBAR the source in A and C transmitted every 3 hours every other day; B transmitted every 3 hours every day. The transmission times were scheduled such that that the signals did not overlap at the receivers. The transmissions at A started at 0000, 0300,…, 2100 UTC. The transmissions at B started 420 s (7 min) after the hour, and those at C started 780 s (13 min) after the hour. In DAMOCLES the transmission schedule was the same as in ACOBAR A. Each transceiver incorporated a four-channel Simple Tomographic Acoustic Receiver (STAR) controller developed at the Scripps Institution of Oceanography. Small four-element receiving arrays with 9.0 m (~1.5 wavelengths at 250 Hz) spacing between the hydrophones allowed vertical arrival angles to be approximately determined and provided some angular resolution of arrivals that overlap in time.

Datasets from the observing system: Parameter(s) Observed: DAMOCLES & ACOBAR: Acoustic travel time and ambient noise. Both kind of data will be included in the INTAROS data catalogue.

Derived parameters: ACOBAR/DAMOCLES provided range averaged sound speed through inversion of acoustic travel times (D2.1). The sounds speed is converted to depth-range temperature. Depth-range ocean temperatures from acoustic thermometry are provided for 3 ACOBAR sections. The inversion methodology for ACOBAR and DAMOCLES is described in Dushaw et al. 2016 a, b, c, Sagen et al. 2016, Dushaw, 2017.

ACOBAR experiment produced acoustic travel time and ambient noise data. The data are formatted and further processed within UNDER-ICE and INTAROS (reported in D2.2).

Data management: In the ongoing Norwegian NorDataNet infrastructure project and the H2020 project INTAROS, NERSC has developed a new data format for the acoustically sensed ocean temperatures and ambient noise from the Fram Strait Multipurpose Acoustic system. This format is based on the NetCDF Climate and Forecast (CF) Metadata Conventions and the metadata structure developed by the OceanSITES program (OceanSITES, 2010). NERSC has developed a second format, also based on NetCDF/CF and OceanSITES, for the ambient noise data from the Fram Strait Multipurpose Acoustic system. The datasets from DAMOCLES and ACOBAR, as described above, have been converted to this format and stored at NERSC. During INTAROS, these datasets will be made available in iAOS as well as NMDC.

Acoustic data from the UNDER-ICE project will be prepared and made available in the same formats. This will be done as part of INTAROS; these datasets are therefore presented in Deliverable D2.2 (Report on exploitation of existing data: ocean and sea ice data).

Sustainability: No long-term funding. So far, the acoustic multipurpose acoustic system has been funded through a series of research projects: DAMOCLES (2005-2010), ACOBAR (2008-2013), and UNDER-ICE (2012-2014). Through these projects the instrumentation has proved to be robust and data quality has been good. It is planned to continue the observing system through follow-up research projects.

Funders: DAMOCLES and ACOBAR projects were supported by the EU, private sector, Research Council of Norway, and Office of Naval Research (US). The UNDER-ICE project is funded by Research Council of Norway.

Data owner: NERSC

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Sagen, Hanne Peter F. Worcester; Matthew A. Dzieciuch; Florian Geyer; Stein Sandven; Mohamed Babiker; Agnieszka Beszczynska-Möller; Brian D. Dushaw; Bruce Cornuelle (2017) Resolution, identification, and stability of broadband acoustic arrivals in Fram Strait. J. Acoust. Soc. Am., 143.(3).

Vigness-Raposa, Kathleen J.; Schroeder, Cheryl; Sagen, Hanne; Sandven, Stein; Worcester, Peter Francis; Livingston, Ellen; Simon, Malene; Walczowski, Waldemar. ACOUSTIC TECHNOLOGIES FOR OBSERVING THE INTERNAL OF THE ARCTIC OCEAN. D1.5 Environmental Assessment Report No. 2. Bergen: Nansen Environmental and Remote Sensing Center 2013.

Vigness-Raposa, Kathleen J.; Schroeder, Cheryl, Sagen, Hanne; Final environmental assessment report for the UNDER-ICE experiment. UNDER-ICE Project Report-1. Technical report 345, August, 2014.

Yamakawa A, Sagen H, Babiker M, Worcester PF, Furevik BR. Soundscape Characterization and the Impact of Environmental Factors in the Central Part of the Fram Strait. 2016.

MSFD Technical Subgroup on Underwater Noise (2014) JRC Scientific and Policy Reports - Monitoring Guidance for Underwater Noise in European Seas, Part I Executive Summary, ISBN 978-92-79-36341-2, ISSN 1831-9424, doi: 10.2788/29293.

MSFD Technical Subgroup on Underwater Noise (2014) JRC Scientific and Policy Reports - Monitoring Guidance for Underwater Noise in European Seas, Part II Monitoring Guidance Specifications, ISBN 978-92-79-36339-9, ISSN 1831-9424, doi: 10.2788/27158.

MSFD Technical Subgroup on Underwater Noise (2014) JRC Scientific and Policy Reports - Monitoring Guidance for Underwater Noise in European Seas, Part III Background Information and Annexes, ISBN 978-92-79-36340-5, ISSN 1831-9424, doi: 10.2788/2808.

OceanSITES (2010) OceanSITES User's Manual NetCDF Conventions and Reference Tables. Version 1.2. June 29th , 2010.

2.1.2.Canada Basin Acoustic Propagation Experiment (CANAPE 2016)

Geographical area: Beaufort Sea

Operational Time periods: 2016-2017.

Observing platform: This system comprises fixed moorings carrying acoustic sources and/or acoustic receiver. The system uses the same technologies as the multipurpose acoustic network in the Fram Strait.

General description: The Canada Basin Acoustic Propagation Experiment (CANAPE) consists of a yearlong experiment in the Canada Basin of the Arctic Ocean during 2016–2017, preceded by a short Pilot Study during summer 2015, in order to understand the effects of changing Arctic conditions on low-frequency, deep-water propagation and on the low-frequency ambient noise field. We plan to combine measurements of acoustic propagation and ambient noise with the use of acoustic remote sensing methods (i.e., ocean acoustic tomography) to help characterize the large-scale temperature and sound-speed fields in this difficult-to-measure region that is still ice covered during much of the year.

The goal of the CANAPE experiments is to determine the fundamental limits to signal processing in the Arctic imposed by ice and ocean processes. The hope is that these first few new steps will lead to a larger, permanent acoustic monitoring, navigation, and communications network in the Arctic Ocean.

Relevance of the observing system: CANAPE 2016 combines measurements of acoustic propagation and ambient noise with the use of an ocean acoustic tomography array to help characterize the oceanographic variability throughout the year in the central Beaufort Sea. The system is a multipurpose acoustic network which was used to monitor ambient noise and to geo-position the gliders for navigation.

Sensors/instruments: The tomographic array has six Teledyne Webb Research (TWR) swept-frequency sources that incorporate Distributed Vertical Line Array (DVLA) acoustic receiving systems with 15 Hydrophone Modules at 9-m spacing. In addition, all of the TWR source transmissions are being recorded by a stand-alone Distributed Vertical Line Array (DVLA) with 60 Hydrophone Modules at 9-m spacing to study deep-water propagation under the ice. Mooring configuration is shown in Figure 3.

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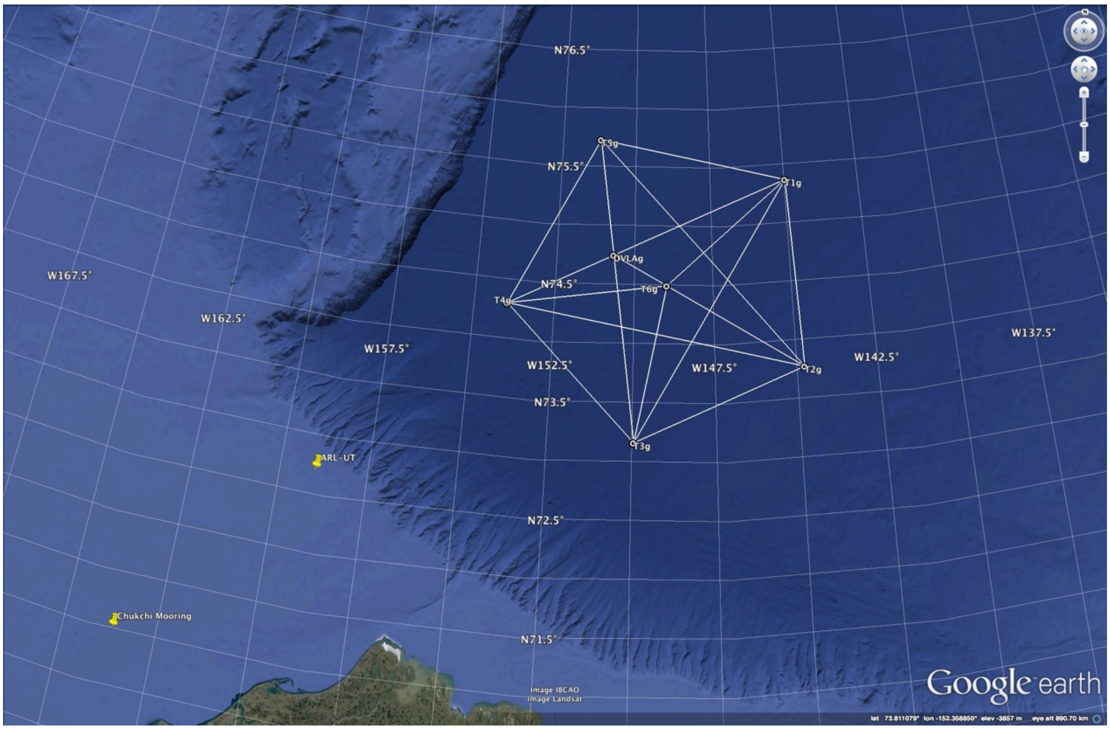

Figure 3. Mooring geometry for CANAPE 2016, consisting of six acoustic transceivers (T1, T2, … T6) and a DVLA receiver located at the intersection of the T1-T4 and T3-T5 paths.

Data management: Status of the data: Ocean temperature will be integrated into the iAOS when available from SIO. Data will be stored in the same data format as the acoustic data from the Fram Strait.

Sustainability: Not sustained – only one year of operation.

Funders: Office of Naval Research, USA

Data owner: Scripps Institution of Oceanography.

References: No publications yet

2.1.3. Data not part of any observing system (campaign data)

Drifting Acoustic Ice Station

Geographical area: Fram Strait

Time: 31. August – 3 September 2012, 31 August – 3 September 2013,

Technical platform: Drifting ice station with acoustic hydrophones.

Sensors: Four acoustic hydrophone modules with thermistors.

Datasets to be included in the Questionnaire B:

Pre-processed ambient noise data (D2.1)

Parameters observed: ambient noise

Derived parameters: percentiles.

Processing: Signal processing (D2.1) is described in Geyer et al. 2017.

Status: Data has been published and will be integrated into the iAOS.

Data management: Data format based NetCDF/CF has been developed and first version of the data is available through NORSTORE/NMDC. (D2.1, D2.2)

Sustainability: Time-limited research funding.

Funders: WIFAR project funded by Research Council of Norway.

References

Geyer F., H. Sagen, P. Worcester, G. Hope, and M. Babiker (2016). *Identification and quantification of soundscape components in the Marginal Ice Zone,* J. Acoust. Soc. Am. 139(4), 1873-1885.

2.1.4. Remote sensing datasets

NERSC has been processing and analysing sea ice data using data from various satellite sensors over the past three-four decades. One of the most important satellite sensors for sea ice observation is Synthetic Aperture Radar (SAR), which are well suited for monitoring Arctic regions, as they are not dependent on light and cloud conditions. NERSC has developed several algorithms for classification of sea ice types using SAR images. Two of these algorithms have been used to generate high-resolution ice edge maps in the MyOcean project and in CMEMS. This product is described in Section 2.1.4.1.

For long-term monitoring and climate research, passive microwave satellite sensors (SMMR, SSM/I, SSMIS) are used to estimate sea ice concentration (SIC) in both Arctic and Antarctica. NERSC developed the NORSEX algorithm in early 1980s to generate daily maps of SIC that have been published on the Arctic ROOS web portal, www.arctic-roos.org. This product is described in Section 2.1.4.2. During the last decades, a number of different algorithms have been developed and used to estimate ice concentration and produce daily sea ice extent and area maps in both hemispheres (e.g. Ivanova et al. 2015).

Synthetic Aperture Radar and passive microwave data are widely used by operational ice charting services and other service providers. A few examples of such products include daily sea ice concentration charts from the Svalbard area (Section 2.1.4.3), time series of global ocean sea ice concentration (Section 2.1.4.4), and sea and sea-ice surface temperature at high latitudes (Section 2.1.4.5).

2.1.4.1. NERSC: Arctic high-resolution ice edge from satellite SAR

Geographical area: Large parts of the Arctic sea ice areas are covered by Radarsat-2 and Sentinel-1 SAR data. In the MyOcean project and CMEMS, an ice edge product was prepared for the Fram Strait. Figure 4 shows two examples of ice edge maps from the MyOcean project.

Time: March 2013 – present for ice edge maps based on Radarsat-2 SAR data; April 2014 – present for ice edge maps based on Sentinel-1 SAR data.

Satellite product: Satellite radar image.

Sensors: C band Synthetic Aperture Radar, dual polarisation data are used to estimate sea ice type.

Parameter(s) observed: Radar backscatter.

Derived physical parameters: Sea ice type (ice, open water).

Data management: The Arctic high-resolution ice edge product was developed and delivered as part of the MyOcean product portfolio. This product was based on Radarsat-2 SAR data, generated at NERSC and transferred to the OSI-TAC Data Processing Unit at MET Norway for distribution to users through the MyOcean data catalogue. The Arctic high-resolution ice edge product based on Sentinel-1 SAR data was developed at NERSC in several RTD projects. This version of the product is managed by NERSC.

Sustainability: The satellite SAR data are available from different data providers. Radarsat-2 data were provided from the Norwegian Space Centre through the SATHAV programme for the Fram Strait and around Svalbard. Sentinel-1A and -1B data are available from the Copernicus Open Data Hub, as well as from the Norwegian Collaborative Ground Segment operated by MET Norway.

Funders: The algorithms for pre-processing and classification of sea ice type to produce the Arctic high-resolution sea ice products were developed under different projects, including, among others, FP7 MyOcean, RCN NORMAP and RCN SONARC. The main tool used is the Nansat tool which was developed at the NERSC (Korosov et al., 2016).

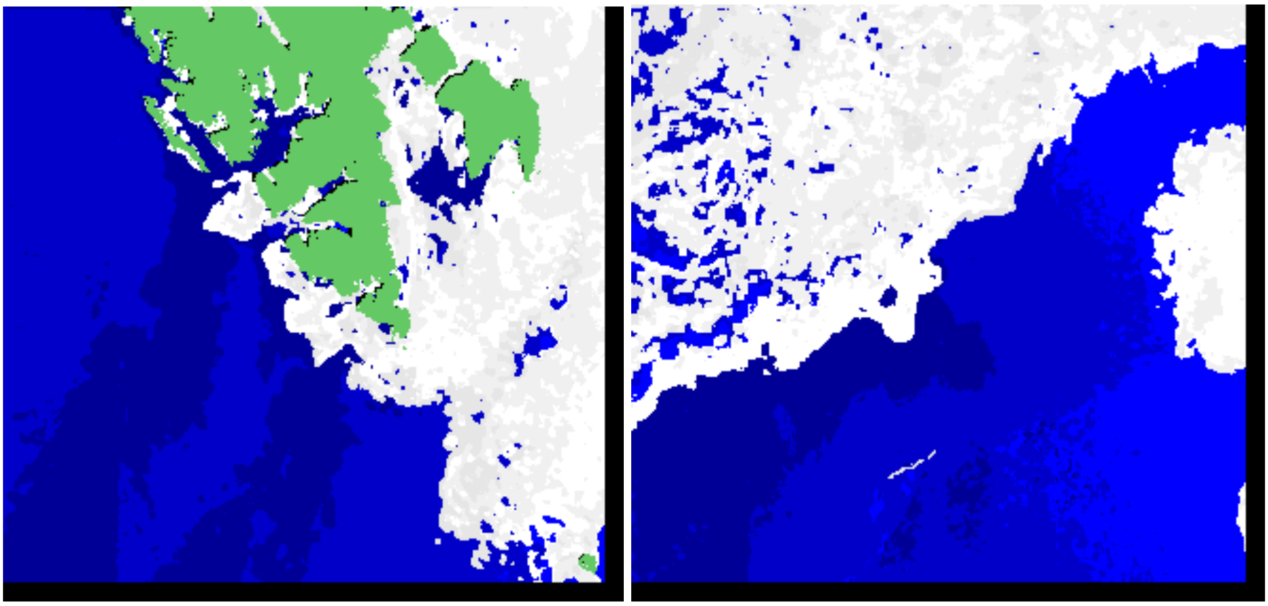

Figure 4. NERSC high-resolution ice edge maps estimated from Radarsat-2 SAR images during the MyOcean project (Zakhvatkina et al., 2017). Left: 13 March 2013. Right: 14 March 2013. Colour coding: grey-white – sea ice; blue – open water; red – no data; green – land mask.

References:

Korosov, A.A. et al., (2016). Nansat: a Scientist-Orientated Python Package for Geospatial Data Processing. Journal of Open Research Software. 4(1), p.e39. DOI: http://doi.org/10.5334/jors.120.

Zakhvatkina, N., A. Korosov, S. Muckenhuber, S. Sandven, and M. Babiker, 2017. Operational algorithm for ice–water classification on dual-polarized RADARSAT-2 images, The Cryosphere, 11, 33-46, doi:10.5194/tc-11-33-2017.

2.1.4.2. NERSC: Sea ice concentration and extent from passive microwave data

Geographical area: Arctic, (60-90N, -180-180E).

Time: Autumn 1978 – present.

Satellite product: Daily maps of sea ice concentration, area and extent (Fig. 5).

Sensors: Scanning Multichannel Microwave Radiometer (SMMR), Special Sensor Microwave Imager (SSM/I) and Special Sensor Microwave Imager/Sounder (SSMIS).

Parameter(s) observed: Passive microwave emission.

Derived physical parameters: Brightness temperature.

Data management: The SMRR/SSMI based sea ice concentration and extent dataset has been generated in a series of RTD projects at NERSC for nearly three decades. The dataset is hosted at an institutional server, and made publicly available through the Arctic ROOS web portal.

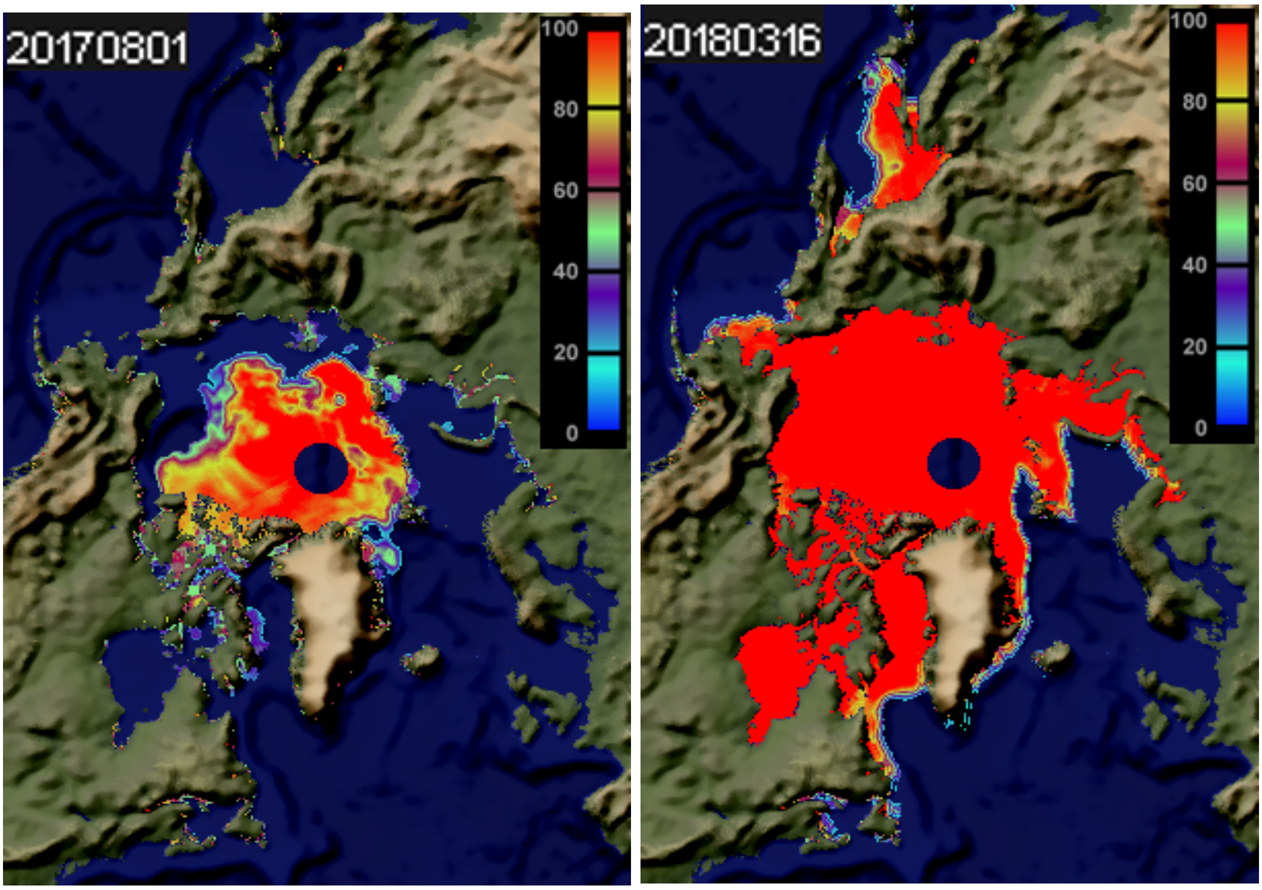

Figure 5. NERSC Sea Ice Concentration map for 1 August 2017 (left) and 16 March 2018 (right). (source: Arctic ROOS portal, www.arctic-roos.org)

Sustainability: Passive Microwave Radiometer (PMR) data from the SMMR, SSM/I, and SSMIS instruments have been provided operationally from 1979 to present. The data are downloaded from the National Snow and Ice Data Center (NSIDC). The data provision is sustainable.

Funders: The algorithm for estimation of brightness temperature and subsequent of sea ice concentration and ice coverage extent was first developed in the NORSEX program (Svendsen et al., 1983). Later development of the algorithm has been funded through research project from the Research Council of Norway. Operating of the Arctic-ROOS web site with daily products of ice charts is funded internally at NERSC.

References

Ivanova, N., et al., Inter-comparison and evaluation of sea ice algorithms: towards further identification of challenges and optimal approach using passive microwave observations. The Cryosphere, 9, 1797–1817, 2015, www.the-cryosphere.net/9/1797/2015/ doi:10.5194/tc-9-1797-2015

E. Svendsen, K. Kloster, B. Farrelly, O. M. Johannessen, J. A. Johannessen, W. J. Campbell, P. Gloersen, D. Cavalieri and C. Mätzler: Norwegian remote sensing experiment: Evaluation of the Nimbus 7 scanning multichannel microwave radiometer for sea ice research. Journal of geophysical research, vol. 88, p. 2781-2991, March 30, 1983. DOI: https://doi.org/10.1029/JC088iC05p02781.

2.1.4.3. CMEMS: Regional High-Resolution Sea Ice Charts Svalbard Region

Geographical area: Svalbard and Barents Sea region (60N - 80 N, -80 - 85 E). The sea ice concentration charts are made by manual interpretation of the most recent satellite data and covers an area from east Greenland to Novaya Zemlya.

Time: from 2012-04-30 to present.

Satellite product: Sea ice charts based on several satellites and sensors. These include SAR data from Envisat, Radarsat-1 and -2 and Sentinel-1 (since October 2014). In addition, visual and infrared satellite data from MODIS sensors on NOAA satellites are used in combination with the radar data.

Sensors: Synthetic Aperture Radar (SAR), visual and infrared sensors.

Parameter(s) observed: Radar backscatter, visual and infrared reflection.

Derived physical parameters: Sea ice concentration, presented in WMO code.

Data management: The sea ice concentration charts are stored and made accessible by the Norwegian Meteorological Institute (MET Norway). The charts are licensed with the CMEMS data license. Figure 6 shows an example of the SIC chart obtained from CMEMS through the OSI-TAC (Ocean and Sea Ice - Thematic Assembly Centre).

Sustainability: The satellite data used to generate the sea ice concentration chart are processed by MET Norway. Daily charts are produced during weekdays, and made available through the CMEMS service by 1500 UTC (Dinessen and Hackett, 2016).

Funders: The algorithms for satellite data processing were developed by MET Norway. This product has been developed as part of the Norwegian Ice Charting Service at MET Norway and CMEMS.

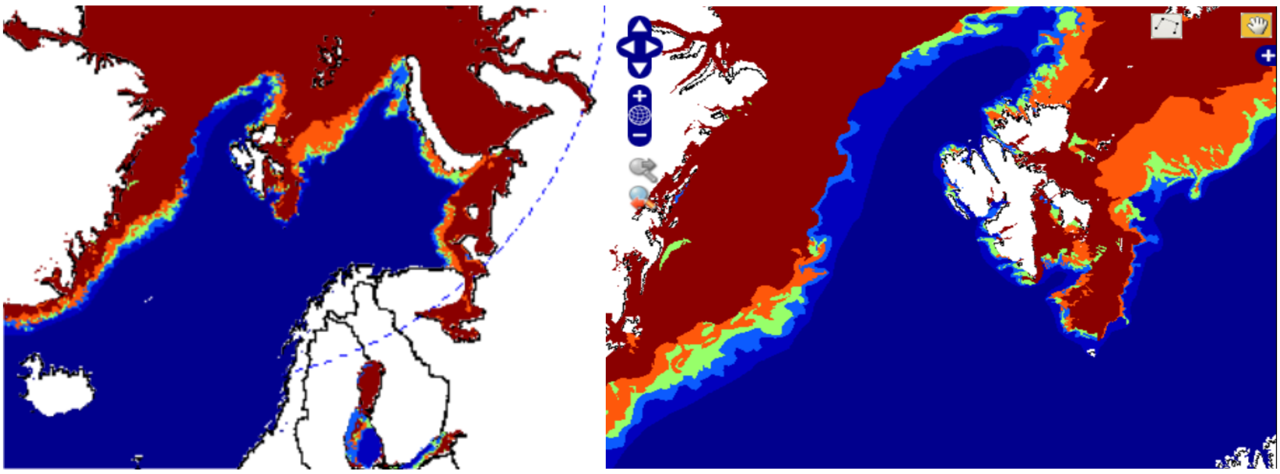

Figure 6. MET Norway Sea Ice Concentration Chart from 20 March 2018. Left: full coverage. Colour: blue - 0%, dark red - 100%. Right: zoomed in on the Svalbard - Fram Strait area.

References:

Dinessen, F. and B. Hackett, 2016. PRODUCT USER MANUAL For Regional High Resolution Sea Ice Charts Svalbard Region SEAICE_ARC_SEAICE_L4_NRT_OBSERVATIONS_011_002. Version 2.3, September 30 2016.

2.1.4.4. OSI-SAF Global Ocean Sea Ice Concentration Time Series Reprocessed

Geographical area: Global, (90S - 90N, 180W - 180E)

Time: from 1978-10-25 to present.

Satellite product: The sea ice concentration product is computed from atmospherically corrected brightness temperatures from passive microwave sensors (SSMR, SSM/I, SSMIS). The reprocessed sea ice concentration dataset generated by EUMETSAT OSI SAF (Eastwood et al., 2015), covers a period of near four decades (from October 1978 and onwards). The product contains an error estimate (uncertainty) for each grid cell.

Sensors: SMMR, SSM/I and SSMIS

Parameter(s) observed: passive microwave radiation

Derived physical parameters: Brightness temperature

Data management: The global sea ice concentration dataset is maintained and made available by the Norwegian Meteorological Institute. Figure 7 shows an example of the reprocessed sea ice concentration dataset from February 2016 for the Arctic and Antarctic regions. The products are available in NetCDF/CF format through EUMETSAT OSI SAF and CMEMS services.

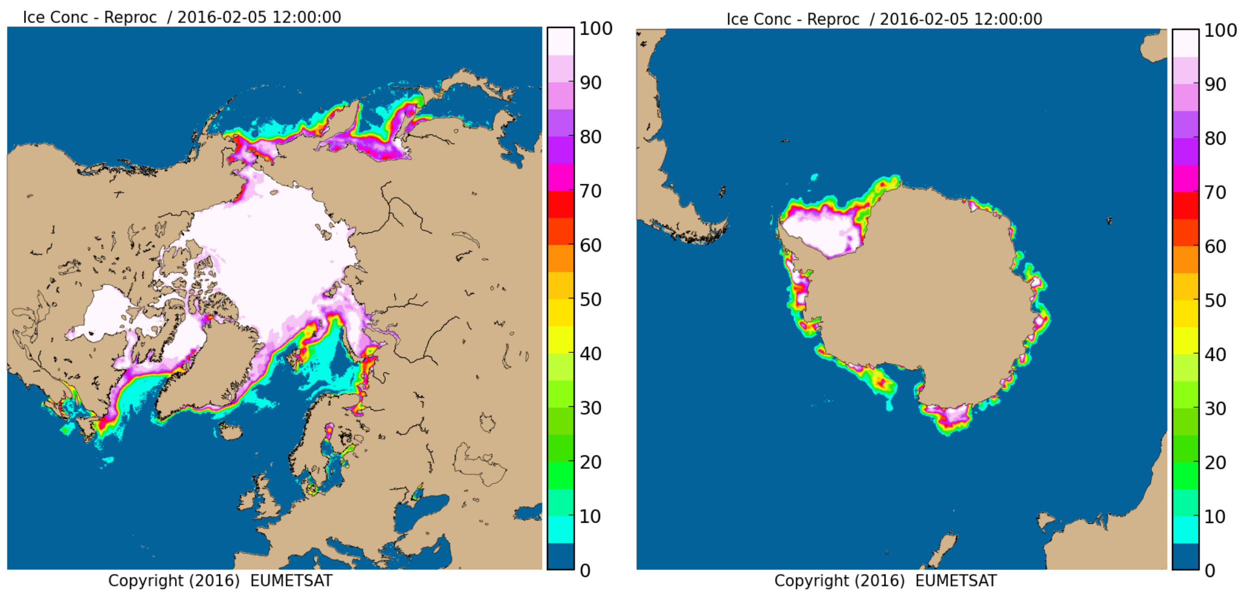

Figure 7. Example of the global sea ice concentration dataset from EUMETSAT OSI SAF and CMEMS. (source ftp://osisaf.met.no/reprocessed/ice/conc-cont-reproc/v1p2)

Sustainability: The reprocessed sea ice concentration dataset is sustainable because the input data from passive microwave sensors is sustainable and the products are generated by the Norwegian Meteorological Institute as part of CMEMS (Eastwood et al., 2016).

Funders: The algorithms for satellite data processing and estimates of global sea ice concentration were developed jointly by the Norwegian Meteorological Institute and the Danish Meteorological Institute.

References:

Eastwood, S., T. Lavergne, R- Tonboe, and B. Hackett, 2016. PRODUCT USER MANUAL For Reprocessed Sea Ice Concentration from EUMETSAT OSI SAF SEAICE_GLO_SEAICE_L4_REP_OBSERVATIONS_011_009. Issue: 2.6. 16 December 2016.

Eastwood, S., M Jenssen, T-Lavergne, A. M Sørensen, and R. Tonboe, 2015. Global Sea Ice Concentration Reprocessing Product User Manual Product OSI-409, OSI-409-a, OSI-430. Document version: 2.2 Data set version: 1.2 August 2015.

2.1.4.5. OSI SAF: High Latitudes L2 Sea and Sea Ice Surface Temperature

Geographical area: 50N-90N/50S-90S, 0-360E.

Time: from 2014-12-10 to present

Satellite product: Satellite data from the AVHRR instrument are combined with the OSI-SAF Sea ice Concentration Product (OSI SAF, 2014) and data from Numerical Weather Prediction models, to generate a combined sea ice surface and sea surface temperature product for the Arctic and Antarctic regions.

Sensors: AVHRR

Parameter(s) observed: Thermal emission.

Derived physical parameters: SST (Sea Surface Temperature) and IST (Ice Surface Temperature).

Data management: The sea ice surface and sea surface temperature dataset is prepared and made available by the Norwegian Meteorological Institute (MET Norway), as part of the EUMETSAT OSI SAF product suite. Figure 8 shows an example of the product, which can be downloaded in NetCDF/CF format.

Sustainability: The high latitudes Sea and Sea Ice Surface Temperature dataset is generated by the Norwegian Meteorological Institute, as part of the EUMETSAT OSI-SAF service (Dybkjaer, 2017).

Funders: The algorithms for satellite data processing and generation of the combined remote sensing and model product were developed jointly by the Norwegian Meteorological Institute and the Danish Meteorological Institute.

References

Dybkjaer, G., S. Eastwooed, R.-H. Pfeiffer and E. Howe, 2017. OSI SAF High Latitudes L2 Sea and Sea Ice Surface Temperature Product User Manual. OSI-205 Version 1.1, May 23 2017.

OSI SAF project team (2014). Low earth orbiter sea surface temperature product user manual. Version 2.6 Prepared by Météo France.

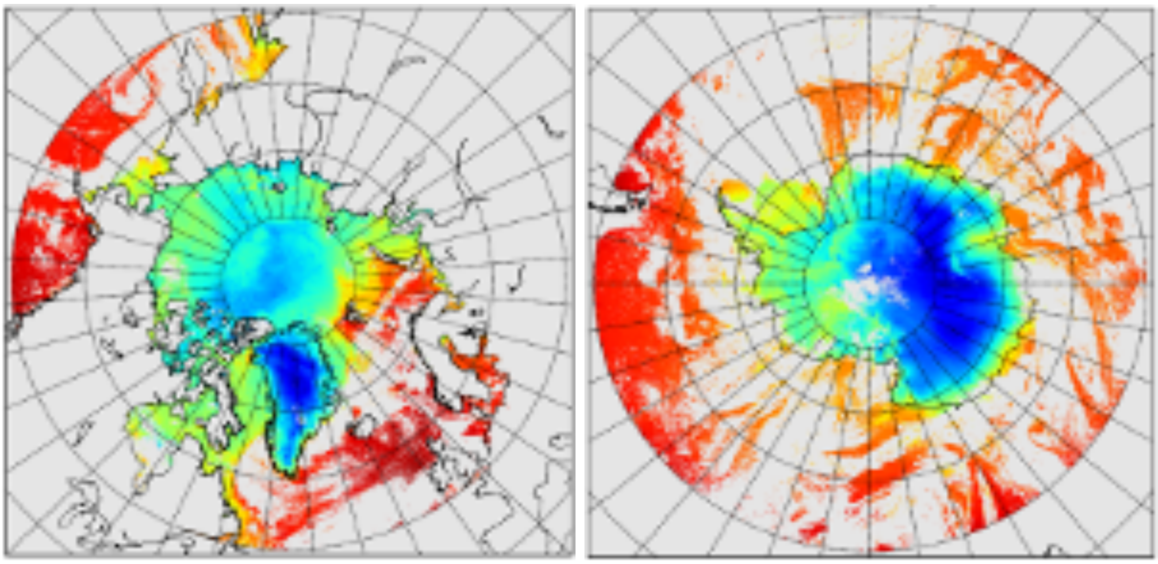

Figure 8. Example of the high latitudes L2 Sea and Ice Surface Temperature product from OSI SAF. (source http://osisaf.met.no/p/ice/index.html#sst-ist-l2)

2.2. UIB (University of Bergen)

2.2.1. Station Mike: biogeochemical sensors on mooring

Contributor: Truls Johannessen, Ingunn Skjelvan, Are Olsen, Nick Roden – Several providers

Geographical area: Norwegian Sea (station Mike) and the area north of Svalbard .

Time: Starting 1982-2018 at station Mike, start north of Svalbard in 2018 under INTAROS

Observing platform: Ocean buoys and moorings

Instruments and parameter(s) observed:

Surface air temperature, salinity, temperature, salinity, pressure, currents, fCO2, NO3 at selected depths on the mooring. NO3 will be introduced in the mooring north of Svalbard.

General description and relevance: The ocean buoy operated by UiB and Uni Research is the continuation of the weather ship located at Station M (OWS M), which has been an ocean weather station since 1948. In 2010 the weather ship was replaced by a mooring and a surface buoy which measures hydrography, O2, chlorophyll and carbon parameters. Located in Norwegian Sea with real-time and delayed mode capabilities. The site represents the longest existing homogeneous time series from deep ocean.

UiB and Uni Research have been the major supplier of carbon system data since 1987 and can today provide all carbon system variables including stable isotopes. The group have had several projects in the Greenland Sea, Storfjorden, Irminger Sea, Iceland Sea, Barents Sea and in the Nordic Seas and North Atlantic in general (Fig. 9).

Data management: The Bjerknes Centre of Climate Research, in cooperation with ICOS Carbon Portal (CP) https://www.icos-cp.eu/, provide a comprehensive data management team and have work out a data life cycle plan for all future data that will be collected under the umbrella of ICOS CP (Fig. 10) and ICOS Ocean Thematic Centre (OTC) https://otc.icos-cp.eu/.

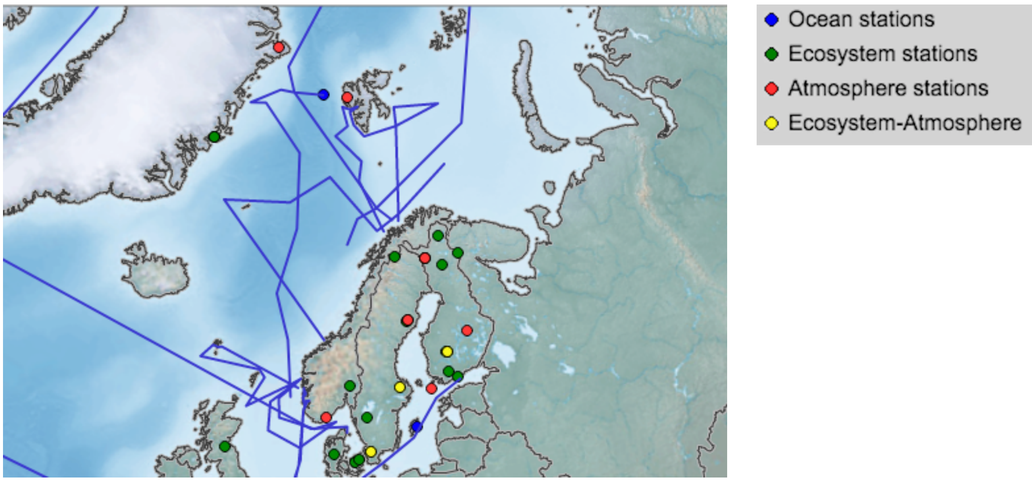

*Figure 9. The ICOS Carbon Portal is part of ICOS ERIC and offers access to research data, as well as easily accessible and understandable science and education products. This figure shows the ICOS station map for the norther part of Europe. The blue lines are shipping lanes where ICOS data are collected (*https://www.icos-cp.eu/).

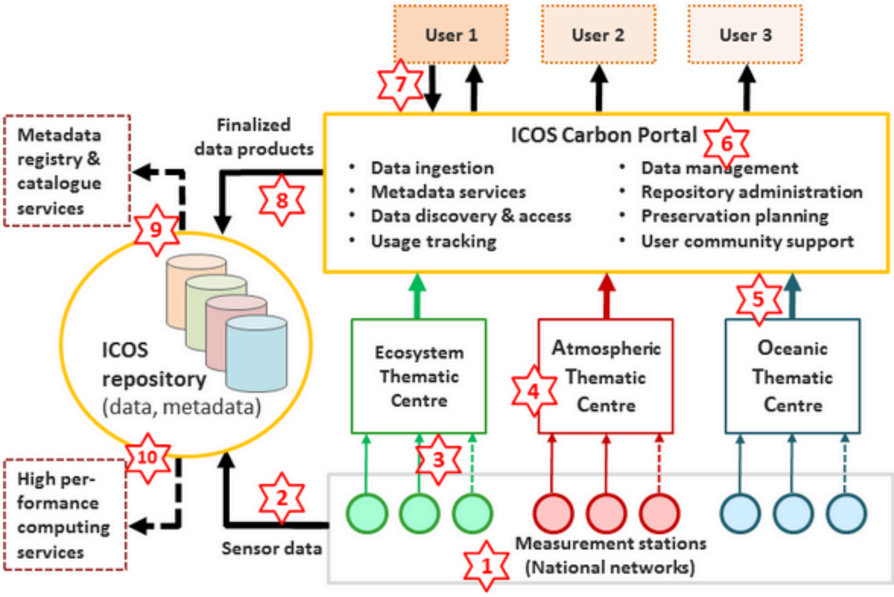

Figure 10. Diagram of the data flow in ICOS. The observing system produces 25-30 TB of sensor data per year, along with a bit under 1 GB of processed data products and 5-20 TB of elaborated data products. The ICOS processed data products are mostly time series of observed parameter values, for example carbon dioxide concentrations, given for every 30-minute interval. Every observation station delivers such time series for 50-100 parameters, representing the measurements made every day of every year (more information on https://www.icos-cp.eu/node/84).

Sustainability & Funding: UiB and UNI have presently sustained funding through the ICOS Norway and OTC funding provided by the Research Council of Norway (RCN) which last out 2020. Past funding is provided by RCN and EU in projects like ESOP, TRACTOR, CARBOOCEAN, CARBOCHANGE, RINGO and more. In addition, new funding to keep up the activity in the Arctic is provide through the INTAROS funding.

Data owners: Several providers, but mostly scientists at UiB and Uni when it comes to carbon system data.

2.3. IMR (Institute of Marine Research, Norway)

Contributors: Geir Ottersen, Angela Renner, Arnfinn Morvik

2.3.1. A-TWAIN mooring array north of Svalbard

Geographical area: 81-82° N, 31° E.

Time: 2012-ongoing.

Observing platform: 2-3 ocean moorings, turnover every 1-2 years

Instruments and parameter(s) observed:

- RDI & Nortek ADCPs (water velocity)
- Seabird Seacats and Microcats (temperature, salinity)

(other instruments mounted on the moorings varying by deployment)

General description and relevance: Mooring array from the shelf across the continental slope north of Svalbard. Main aim: long-term monitoring of the Atlantic Water inflow to the Arctic Ocean for climate research.

Data management: Data are available through the Norwegian Polar Data Centre at the Norwegian Polar Institute (https://data.npolar.no/home/).

Sustainability & Funding: Funding on project basis from the FRAM - High North Research Centre for Climate and the Environment, flagship "Sea Ice in the Arctic Ocean, Technology and Agreements".

Data owners: Norwegian Polar Institute and Institute of Marine Research.

References:

Våge, K., Pickart, R.S., Pavlov, V., Lin, P.G., Torres, D.J., Ingvaldsen, R., Sundfjord, A., Proshutinsky, A. (2016) The Atlantic Water boundary current in the Nansen Basin: Transport and mechanisms of lateral exchange. Journal of Geophysical Research-Oceans 121, 6946-6960.

Perez-Hernandez, M.D., Pickart, R.S., Pavlov, V., Vage, K., Ingvaldsen, R., Sundfjord, A., Renner, A.H.H., Torres, D.J., Erofeeva, S.Y. (2017) The Atlantic Water boundary current north of Svalbard in late summer. Journal of Geophysical Research-Oceans 122, 2269-2290.

2.3.2. Barents Sea Opening Mooring Array

Geographical area: Fixed moorings along a section across the western Barents Sea. 5 moorings located at:

(71.517 19.770), (71.982 19.625), (72.511 19.553), (72.995 19.550), (73.498 19.323)

Time: First mooring started 20 August 1997. Ongoing.

Observing platform: Fixed moorings.

Instruments and parameter(s) observed: Aanderaa Recording Current Meter 7 (RCM7). Surface and subsurface ocean temperature and current velocity. The number of moorings deployed, and the number of instruments attached to each mooring, has varied. Instruments typically at 50, 125, 225 and close to bottom depth. Data recorded every 20 minutes. Replaced annually.

General description and relevance: The data are mainly used for climate and environmental monitoring and research, including process-oriented research. The moorings are placed along a section across the western Barents Sea to cover the main inflow from the southwest.

Data management: Data are stored in a national repository according to legal constraints on their location. The data are handled by the Norwegian Marine Data Centre, Bergen, Norway. Most data are also shared with and stored at the International Council for Exploration of the Sea (ICES) in Copenhagen, Denmark. Data is available on supervised request through originator. Feedback from users is ad hoc. Updates to new measurements, including additional moorings irregularly.

Scientific and expert support: IMR makes sure that the measurements are conducted in the technically and scientifically best possible manner. Research and development is undertaken to ensure that the equipment is based on state of the art technology and are continuously upgraded.

Sustainability & Funding: The network is supported by national founding to IMR from the Norwegian government ensuring long-term operation and sustainability. Support for development of instrumentation and applied analysis of the observations is provided by IMR. Further, more ad hoc funding is provided to analyze and develop the measurement program.

Data owners: Institute of Marine Research.

References:

Ingvaldsen, R., Loeng, H., Asplin, L., 2002. Variability in the Atlantic inflow to the Barents Sea based on a one-year time series from moored current meters. Continental Shelf Research 22, 505–519.

Ingvaldsen, R. B., L. Asplin, and H. Loeng (2004), The seasonal cycle in the Atlantic transport to the Barents Sea during the years 1997–2001, *Cont. Shelf Res.*, 24, 1015–1032.

2.3.3. IMR-PINRO Ecosystem Survey

Geographical area: The survey covers the Barents Sea (Norwegian, Russian and international sectors). In more recent years (with less ice) also the area north of West-Spitsbergen has been covered (Figure 2.3.3.1). The extent is roughly from 68-82 N, 5-60 E.

Observing platforms: The survey is based upon in-situ measurements from scientific vessels (normally three). It provides a broad range of interdisciplinary observations and makes these available towards advice to fisheries management and various applied and more basic research projects.

Instruments and parameter(s) observed:

Numerous instruments and other types of equipment are used. Bottom trawl is central for the sampling of demersal fish (e.g. cod, haddock). The Technology Readiness Level must be considered low (TRL1) as compared to many physical measurement platforms.

The following measurements are routinely made (additional measurements may be done sporadically). CTD casts from surface to near bottom (temperature, salinity). Nutrients (Interior ocean concentrations of silicate, phosphate, nitrate). Primary production, secondary production, abundance, size, age, distribution of many fish stocks. Benthos – bottom dwelling flora and fauna. Marine mammal abundance and distribution. Biodiversity.

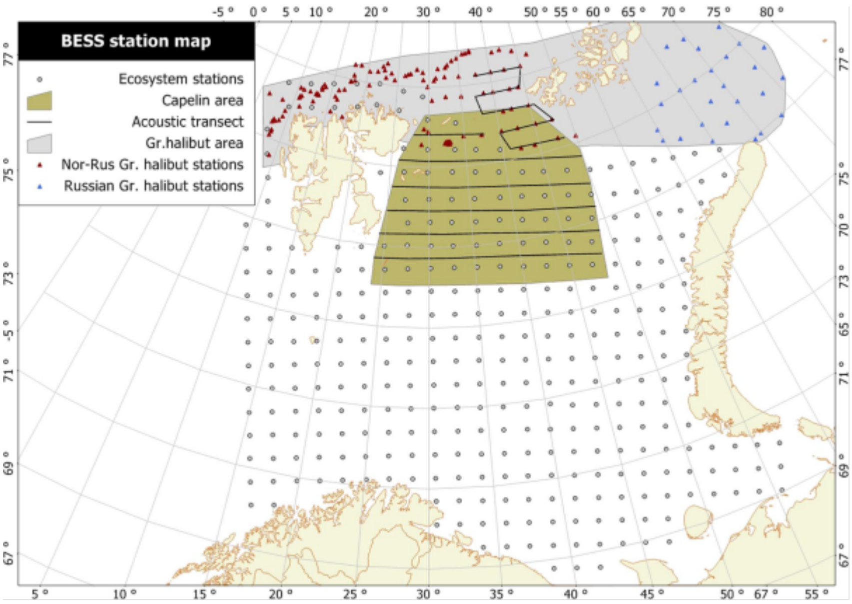

Figure 11. Map of the standard Barents Sea Ecosystem Survey. With ecosystem stations means stations where a demersal trawl haul, a pelagic trawl haul, one or more vertical phyto- and zooplankton nets, CTD probe with water bottles rosette were taken at same location. Capelin area shown with green area and additional acoustic transect shown with black lines. Depth stratified Greenland halibut station shown with triangles (brown for Norwegian-Russian, while blue for Russian stations; conducting of these stations varied between years (from Eriksen et al. in press).

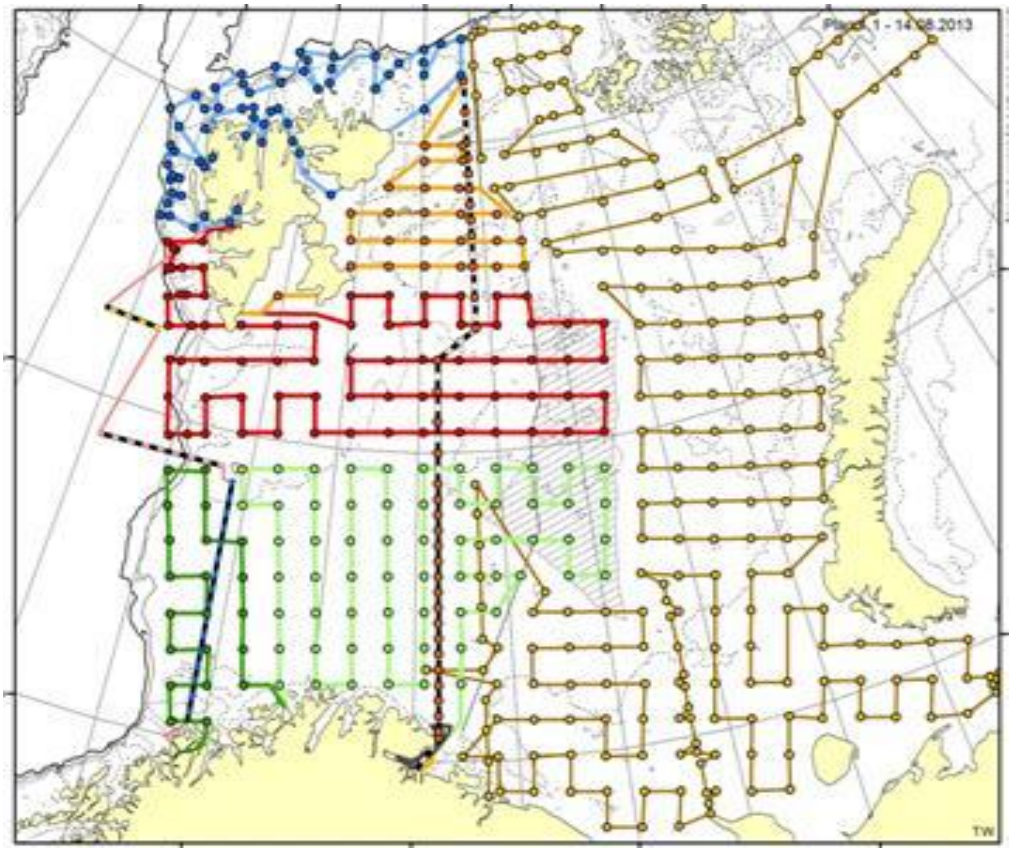

Figure 12. Cruise lines for the IMR-PINRO Ecosystem Survey August-September 2013. Different colours indicate different vessels.

Time: The Ecosystem Survey as such has been run annually in August-September 2004. It is an expansion of earlier IMR surveys, in particular the 0-group survey established in 1965.

Data management:

Data are stored in a national repository according to legal constraints on their location. The data are handled by the Norwegian Marine Data Centre, Bergen, Norway. Most data are also shared with and stored at the International Council for Exploration of the Sea (ICES) in Copenhagen, Denmark. Records are updated with new observations irregularly, but roughly annually. Data is available on supervised request through originator. Feedback from users is ad hoc.

Scientific and expert support:

IMR and PINRO make sure that the survey is conducted in the technically and scientifically best possible manner. Research and development is undertaken to ensure that the vessels and equipment are based on state of the art technology and are continuously upgraded.

Sustainability & Funding:

The IMR part of the survey is supported by national founding to IMR from the Norwegian government assuring long-term operation and sustainability. The PINRO part of the survey is supported by sustained national founding from the Russian government. Support for active research and development of instrumentation and applied analysis of the observations is routinely provided. Further, more ad hoc funding is provided to analyze and develop the measurement program. Funding is provided through IMR with sources from the Norwegian government and projects funded by the Research Council of Norway and the EU.

Data owners:

IMR and PINRO, Murmansk, Russia.

Further information:

For information on Barents Sea ecosystem monitoring the development of the Barents Sea Ecosystem Survey please see Eriksen et al. (2013 and in press).

References

Eriksen, E., Gjøsæter, H. (Eds.), 2013. A Monitoring Strategy for the Barents Sea. Institute of Marine Research Reports/Rapporter fra Havforskningsinstituttet Nr. 28–2013, pp. 73. Report from project nr.14256 “Survey strategy for the Barents Sea”.

Eriksen, E., et al. In press. From single species surveys towards monitoring of the Barents Sea Ecosystem. Progress in Oceanography

Eriksen E, Prozorkevich D. 2011. 0-group survey. In: Jakobsen T, Ozhigin VK, editors. The Barents Sea Ecosystem, Resources, Management. Half a Century of Russian Norwegian Cooperation. Trondheim: Tapir Academic Press, p 557569.

Michalsen et al. 2013. Marine living resources of the Barents Sea –Ecosystem understanding and monitoring in a climate change perspective, Mar Biol Res, 9: 932-947

2.3.4. Barents Sea Winter Survey

Geographical area: The survey covers the Barents Sea (Norwegian, Russian and international sectors, see Fig 13 and 14). The extent is roughly from 68-80 N, 7-56 E.

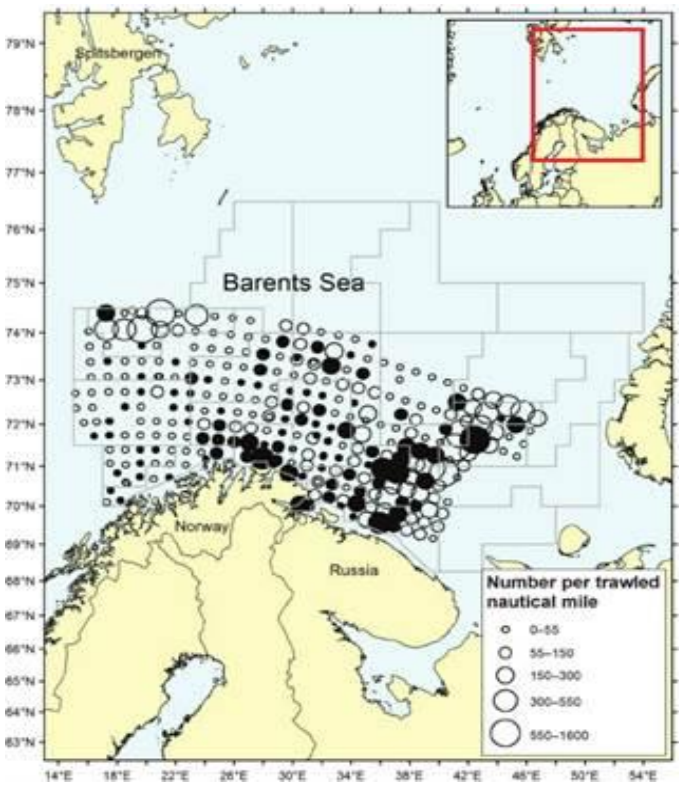

Figure 13. Catch (in numbers) of cod (the main target species) per nautical mile (1 n.mi. = 1.852 km) trawled during the joint Russian–Norwegian winter survey in the Barents Sea in 1991. Main areas used for swept area estimations and acoustic estimations at the time are shown. The coverage has now been expanded.

Figure 14. Norwegian research vessel "G.O. Sars" designed for multipurpose surveys and build in 2004.

Time: Annually in January-February from 1976 – ongoing.

Observing platform: The survey is based upon in-situ measurements from scientific vessels. It provides a range of interdisciplinary observations and makes these available mainly towards advice to fisheries management and various applied research projects. It is less broad than Barents Sea Ecosystem Survey and more focused on the main commercially harvested fish stocks.

Instruments and parameter(s) observed: Numerous instruments and other types of equipment are used. Bottom trawl is central for the sampling of demersal fish (cod, haddock,---). The Technology Readiness Level must be considered low (TRL1) as compared to many physical measurement platforms.

The following measurements are routinely made (additional measurements may be done sporadically). Hydrographic ctd casts from surface to near bottom (temperature, salinity). Nutrients (Interior ocean concentrations of silicate, phosphate, nitrate). Primary production, secondary production, abundance, size, age, distribution of many fish stocks.

Fish abundance is measured by acoustics and swept area (trawl-based). IMR has performed acoustic measurements of demersal fish in the Barents Sea since 1976. The acoustic equipment has been continuously improved. Since the early 1990s Simrad EK500 echo sounder and Bergen Echo Integrator have been used. The Simrad ER60 echo sounder and the Large Scale Survey System (LSSS, Korneliussen et al. 2006) took over on the last vessel in 2008. Details are given in Mehl et al. (2016). Swept area measurements are conducted with the standard research bottom trawl Campelen 1800. Since 1989 the trawl is now equipped with a rockhopper ground gear. Further details are given in Mehl et al. (2016).

Data management: Data are stored in a national repository according to legal constraints on their location. The data are handled by the Norwegian Marine Data Centre, Bergen, Norway. Most data are also shared with and stored at the International Council for Exploration of the Sea (ICES) in

Copenhagen, Denmark. Records are updated with new observations irregularly, but roughly annually. Data is available on supervised request through originator. Feedback from users is ad hoc.

Scientific and expert support: IMR makes sure that the survey is conducted in the technically and scientifically best possible manner. Research and development is undertaken to ensure that the vessels and equipment are based on state of the art technology and are continuously upgraded.

Sustainability & Funding: The survey is supported by national founding to IMR from the Norwegian government ensuring long-term operation and sustainability. Support for active research and development of instrumentation and applied analysis of the observations is routinely provided. Further, more ad hoc funding is provided to analyze and develop the measurement program. Funding is provided through IMR with sources from the Norwegian government and projects funded by the Research Council of Norway and the EU.

Data owners: IMR

References

Eriksen, E., et al. In press. From single species surveys towards monitoring of the Barents Sea Ecosystem. Progress in Oceanography http://dx.doi.org/10.1016/j.pocean.2017.09.007

Korneliussen et al., 2016. Acoustic identification of marine species using a feature library. Methods in Oceanography 17:187-205 DOI: 10.1016/j.mio.2016.09.002

Mehl, S. et al. 2016. Fish investigations in the Barents Sea winter 2016. IMR/PINRO Joint Report Series no 4. 79 p.

2.3.5. Fixed hydrographic (near coastal) station network

Geographical area: Network of point located hydrographic stations along the Norwegian coast of which three are in northern Norway/Arctic:

- Ingøy 71.13 N, 24.016E
- Eggum 68.367 N 13.633E
- Skrova 68.116 N, 14.533 E

Time: Started in 1936, still ongoing. Skrova observed ca 3-4 times per month, Ingøy and Eggum 1-2 times per month.

Observing platform: CTD profiler from small vessels.

Instruments and parameter(s) observed: Hydrography. Vertical profiles from surface to near bottom of temperature, salinity (conductivity), and depth (pressure). Before 1992 temperatures were measured with flip thermometer with an accuracy of about 0.01 °C. Salinity was before 1965 analyzed by titration and after 1965 with a salinometer. The accuracy was approximately 0.01 psu for both methods. After 1992 the stations were equipped with CTD-probes for the measurement of temperature, salinity and pressure (depth). Temperature and salinity are now calibrated respectively with flip thermometer and water sample analyses in the laboratory. After calibration the accuracy is about 0.01 for both salinity and temperature.

General description and relevance: Long-ongoing (1936-) network of single hydrographic stations at strategic places by the Norwegian coast. Used for oceanographic and climate monitoring and research. Used indirectly for monitoring of important fish stocks and fisheries management. Set up to monitor northwards flowing currents.

Data management: Data are stored in a national repository according to legal constraints on their location. The data are handled by the Norwegian Marine Data Centre, Bergen, Norway. Most data are also shared with and stored at the International Council for Exploration of the Sea (ICES) in

Copenhagen, Denmark. Records are frequently updated with new observations. Data is available on supervised request through originator. Feedback from users is ad hoc. Data are normally accessible within a week after acquisition.

Scientific and expert support: IMR makes sure that the measurements are conducted in the technically and scientifically best possible manner. Research and development is undertaken to ensure that the equipment is based on state of the art technology and are continuously upgraded.

Sustainability & Funding: The network is supported by national founding to IMR from the Norwegian government assuring long-term operation and sustainability. Support for development of instrumentation and applied analysis of the observations is provided by IMR. Further, more ad hoc funding is provided to analyze and develop the measurement program.

Data owners: Institute of Marine Research

References

Hydrografiske normaler og langtidsvariasjoner i norske kystfarvann mellom 1936 og 1992 (Hydrographical normals and long - term variations in Norwegian coastal waters from 1936 to 1992). Fisken og Havet, NR. 6 - 1993. 67s. Aure, Jan og Østensen, Ø. 1993. In Norwegian.

Skagseth, O., Slotte, A., Stenevik, E.K., Nash, R.D.M. (2015) Characteristics of the Norwegian Coastal Current during Years with High Recruitment of Norwegian Spring Spawning Herring (Clupea harengus L.). Plos One 10

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2.3.6. Fixed hydrographic sections

Geographical area: All sections sample multiple stations along a linear transect. Location of starting and ending points given below for each section.

- Gimsøy-NW (68.407, 14.078, 74.083, -3.667)
- Sem Islands N (69.083 37.333, 76.500 37.333)
- Vardø-N (70.400 31.217, 76.500 31.217)
- Fugløya-Bear Island (70.500 20.000, 74.250 19.167)
- Bear Island-W (74.500 18.500, 74.500 -15.000)
- Polhavet (80.500 31.000, 81.200 31.000)

Time: Temporal coverage, starting date for regular observations.

All sections have been observed irregularly earlier, some back to 1929.

- Gimsøy-NW 1957-
- Sem Islands N 1956-
- Vardø-N 1953-
- Fugløya-Bear Island 1953-
- Bear Island-W 1969-
- Polhavet 2012-

Observing platform: Research vessel

Instruments and parameter(s) observed: CTD, water bottles, plankton nets.

- Temperature, salinity (conductivity), and depth (pressure). Vertical profiles from surface to near bottom.
- Nutrients - interior ocean concentrations of silicate, phosphate, and nitrate
- Primary production
- Secondary production

General description and relevance:

Used for oceanographic and climate monitoring and research. Used indirectly for monitoring of important fish stocks and fisheries management. Set up to monitor across northwardly flowing currents. Hydrographic sections are a compromise between observing at a few positions with high frequency, and undertaking a spatially broader coverage with many measurement points with low frequency.

Data management

Data are stored in a national repository according to legal constraints on their location. The data are handled by the Norwegian Marine Data Centre, Bergen, Norway. Most data are also shared with and stored at the International Council for Exploration of the Sea (ICES) in Copenhagen, Denmark. Records are irregularly updated with new observations. Data is available on supervised request through originator. Feedback from users is ad hoc. Data are normally accessible within a week after acquisition.

Scientific and expert support

IMR makes sure that the measurements are conducted in the technically and scientifically best possible manner. Research and development is undertaken to ensure that the equipment is based on state of the art technology and are continuously upgraded.

Sustainability & Funding

The network is supported by national founding to IMR from the Norwegian government ensuring long-term operation and sustainability. Support for development of instrumentation and applied analysis of the observations is provided by IMR. Further, more ad hoc funding is provided to analyze and develop the measurement program.

Data owner: Institute of Marine Research

References

https://www.hi.no/temasider/oseanografi/tidsserier_faste_snitt/hydrografisk_snitt/datasett/nb-no (in Norwegian)

2.3.7. SI_Arctic vessel mounted ADCP system

Geographical area: Measurements are taken within the area expressed by the four corners 77.5N 3E, 77.5N 25E, 82.5N 3E, 82.5N 25E

Time: Annual RV cruises from August 2014 to 2018 with possible continuation.

Observing platform: Research vessel mounted ADCP system

Instruments and parameter(s) observed: Surface and subsurface current velocities

General description and relevance: Main applications are climate research and monitoring and environmental assessment.

Data management: Data are stored in a national repository according to legal constraints on their location. The data are handled by the Norwegian Marine Data Centre, Bergen, Norway. Records are irregularly updated with new observations. Data is available on supervised request through originator. Feedback from users is ad hoc.

Scientific and expert support: IMR makes sure that the measurements are conducted in the technically and scientifically best possible manner. Research and development is undertaken to ensure that the equipment is based on state of the art technology and are continuously upgraded.

Sustainability & Funding: The observation network is part of the SI Arctic /Arctic ecosystem survey and funded by SI Arctic, which is a Strategic Institute program awarded to IMR by the Ministry of Fisheries through the Research Council of Norway for January 1 2014- December 31 2018 (5 years). The research cruise including the ADCP observation network may be continued after this.

Data owner: Institute of Marine Research

2.3.8. NorArgo

Geographical area: The NorArgo float network is an ocean observation system for the Nordic Seas, roughly covering the area within the sector 60.00 °N 15.00 °W, 60.00 °N 10.00 °E, 80.00 °N 15.00 °W, 80.00 °N 10.00 °E.

Time: June 2012-

Observing platform: Argo autonomous profiling floats. NorArgo is a part of the international Argo network.

Instruments and parameter(s) observed: Surface and subsurface temperature, salinity, pressured and currents. Interior ocean oxygen concentration and fluorescence (chlorophyll-a).

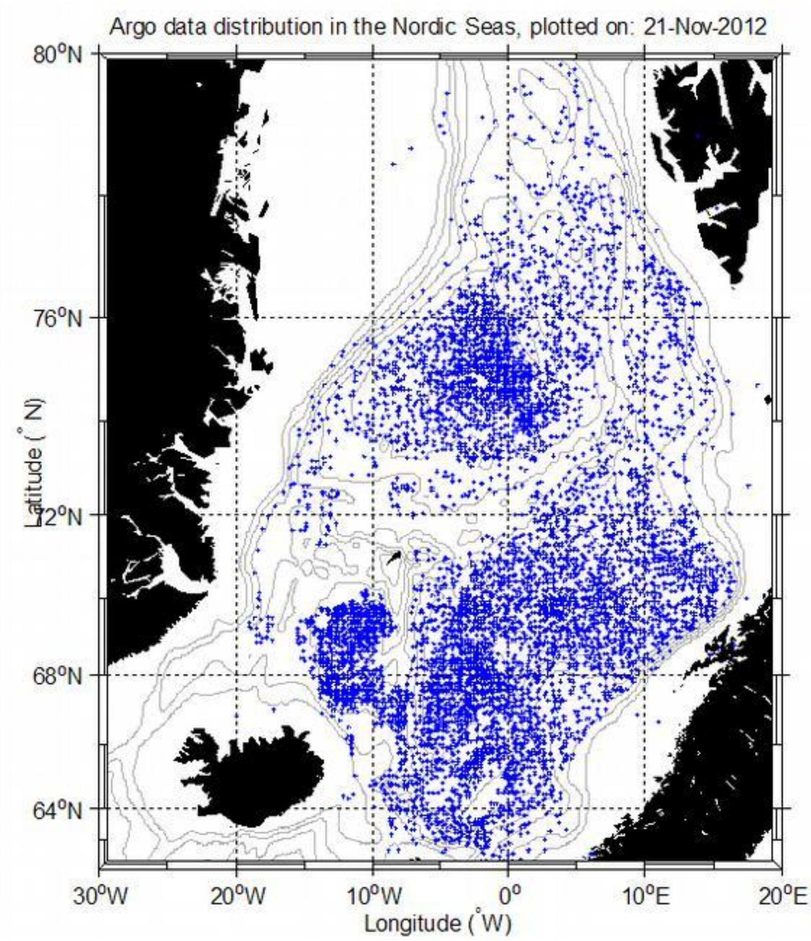

Figure 15. Dots represent locations of all Argo float profiles in the Nordic Seas from 2001-2012.

General description and relevance: The NorArgo network is applied for climate and environmental monitoring and research, process-oriented research and applied research supporting operational services. The main goal is to monitor:

- the ocean climate variability
- the water mass transformation
- the physical and biological variability of the upper ocean
- the deep currents, using the drift of the floats

Data management: The data are stored in international data depositories. Data access policy statement and documentation at ftp://ftp.ifremer.fr/ifremer/argo. Data records are systematically updated by a stable data provider when new observations become available. Updates periodically take into account methodological innovations that improve the utility of the measurement series. The observations are available on the internet for all users, in near-real time, i.e. within 24 hours after the measurements are taken.

Sustainability & Funding: Argo Norway represents the Norwegian contribution to the European and Global Argo infrastructure. It was originally funded by a project from Research Council of Norway for June 2012- June 2017 but has been continued. It is now funded by a RCN infrastructure project coordinated by IMR with Uni Bergen, NERSC, met.no, Akvaplan NIVA, and Uni Research as partners.

Data owners: Institute of Marine Research

References

Argo home page: http://www.argo.ucsd.edu/

Euro-Argo: http://www.euro-argo.eu/

Argo Information Centre: http://wo.jcommops.org/cgi-bin/WebObjects/Argo

http://www.imr.no/forskning/prosjekter/norargo/map

2.4. AWI (Alfred Wegener Institute)

2.4.1. FRAM Ocean Observing System at AWI

FRAM is implementing existing and next-generation sensors and observatory platforms, allowing synchronous observation of relevant ocean variables, as well as the study of physical, chemical and biological processes in the water column and at the seafloor. Experimental and event-triggered platforms complement observational platforms.

FRAM comprises amongst others the already existing **long-term observatories HAUSGARTEN** and '**79°N Oceanographic Mooring Array**'. Products of the infrastructure are continuous long-term data with appropriate resolution in space and time, as well as ground-truthing information for ocean models and remote sensing.

AWI contributes from the FRAM observing system, oceanographic and biogeochemical datasets from an area within the Fram Strait between 78 and 80.1 degrees latitude and -5.5 and 11.1 longitude. On a general basis AWI will also provide to the INTAROS iAOS a digital terrain model (DTM) of the central Fram Strait based on multibeam sonar survey data.

2.4.1.1. Data from the HAUSGARTEN longterm observatory

HAUSGARTEN observatory displays 21 permanent stations covering a water depth range of 250 to 5500 m water depth. Repeated sampling and the deployment of moorings and different free-falling systems which act as observation platforms has taken place since the beginning of the station in summer 1999 (Fig. 16). In this context AWI will provide data for:

- Biogenic particle flux from moored sediment traps parameters: Seston, CaCO3, POC, PON and Psi measured at fixed water depths [m]: -100; -300; -1000; -1250; -2250 with a temporal resolution of one or two weeks
- Inorganic nutrients measured on Fram-Strait water samples since 1997 on vertical water column profiles up to -5600m water depth
- parameters: phosphate, silicate, nitrate, nitrite
- Biogeochemical parameters from deep-sea sediments obtained at the permanent sampling stations
  parameters: Sediment porosity [% vol], sediment bound Chlorophyll a [μg/cm3], sediment bound Phaeopigments [μg/cm3], Esterase activity per sediment volume [nmol/ml/h], Phospholipid content [nmol/ml], sediment bound Protein [mg/cm3] measured once a year in summer at -1, -2, -3, -4, -5 centimetres sediment depth
- Benthic oxygen fluxes
- High resolution sea-bed photographs and footage from repeated long term surveys for epifauna and sea-bed pollution investigations

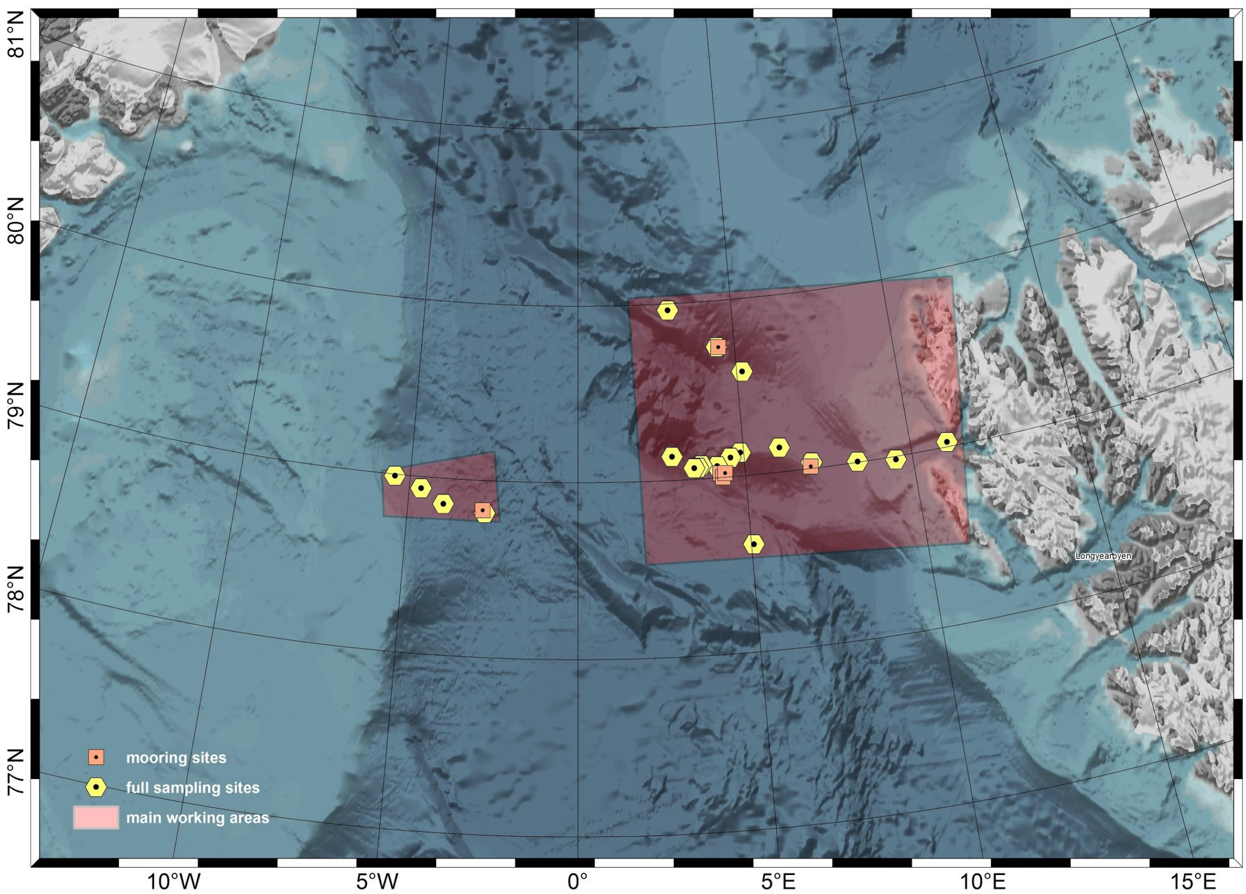

Figure 16. Position of HAUSGARTEN sampling sites and biogeochemical moorings

2.4.1.2. Data From the AWI 79°N Fram Strait Mooring Array

Data contribution to INTAROS: temperature, salinity, current velocity, oxygen.

The AWI Fram Strait mooring array between Svalbard and Greenland was established in 1997. It was designed to

- Monitor the temperature of the inflowing Atlantic Water
- Estimate the volume transport of the inflowing water
- Understand the ocean dynamics in Fram Strait
- Improve the understanding of the long-term observations
- Improve the understanding of the stratification in the upper 15 m
- Understand the coupling with biogeochemical parameters

Since 1997 a varying number of moorings is deployed along 79°N with instruments on the standard depth levels 75 m, 250 m, 750 m, 1500 m and near the bottom, with a mean exchange rate of two years. Additionally, moorings are deployed on changing positions (Fig. 17) in the central and western Fram Strait to, e.g., understand the pathways of warm Atlantic water into the cavities of the large East Greenland glaciers.

The velocity data were initially recorded with Aanderaa rotor current meters (RCM7/8, accuracy: ±1 cm/s) and Aanderaa Doppler current meters (RCM9/11, accuracy: ±0.15 cm/s). Today, the ocean current speed is recorded with RDI Teledyne Acoustic Doppler Current Profilers (ADCP, typical accuracies: ±0.3% ±3mm/s or ±1% ±5mm/s) with frequencies between 75 and 1200 kHz to measure a velocity profile of up to several 100 meters. The instrument that replaced the old Aanderaa current meters is the NORTEK Aquadopp acoustic profiler (accuracy: ±1% ±5mm/s) to measure the local velocity in a short range around the instrument (few centimetres).

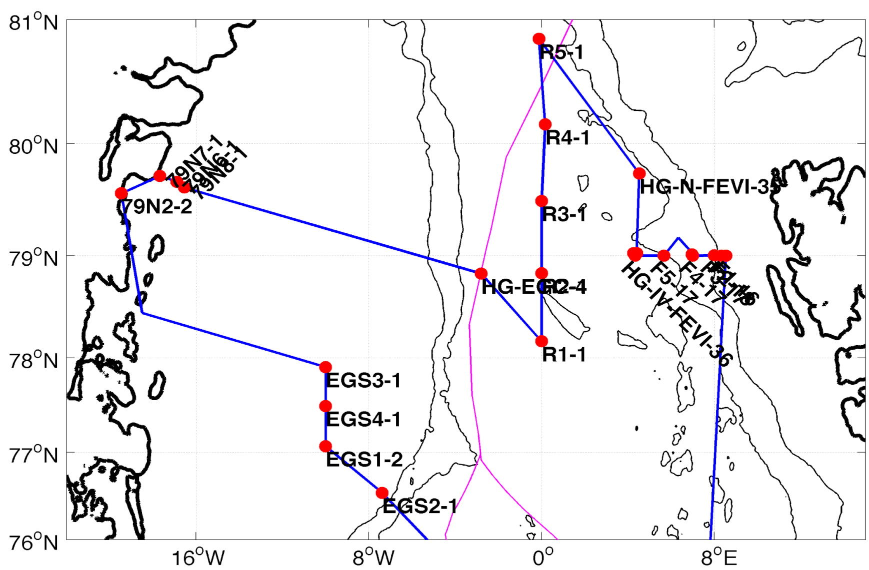

Figure 17. AWI mooring positions in Fram Strait (Summer 2017). In the early years, the 79°N section (right hand side) stretched further West across the central Fram Strait up to the East Greenland Shelf. Today it is maintained in the West-Spitsbergen Current.

Temperature and salinity (conductivity) were initially recorded with unpumped SeaBird SBE16 “SeaCat” CTD (temp. accuracy: ± 0.005 °C / cond. accuracy: ± 0.0005 S/m). Today, mainly the pumped CTD system SeaBird SBE37 “MicroCat” (temp. accuracy: ± 0.002 °C / cond. accuracy: ± 0.0003 S/m) is used. Some of the modern systems (SBE37 ODO) are equipped with additional oxygen sensors (accuracy: larger of ± 3 µmol/kg (0.07 ml/L, 0.1 mg/L) or ± 2%). A time series of 20 years of temperature data is shown in Fig. 18.

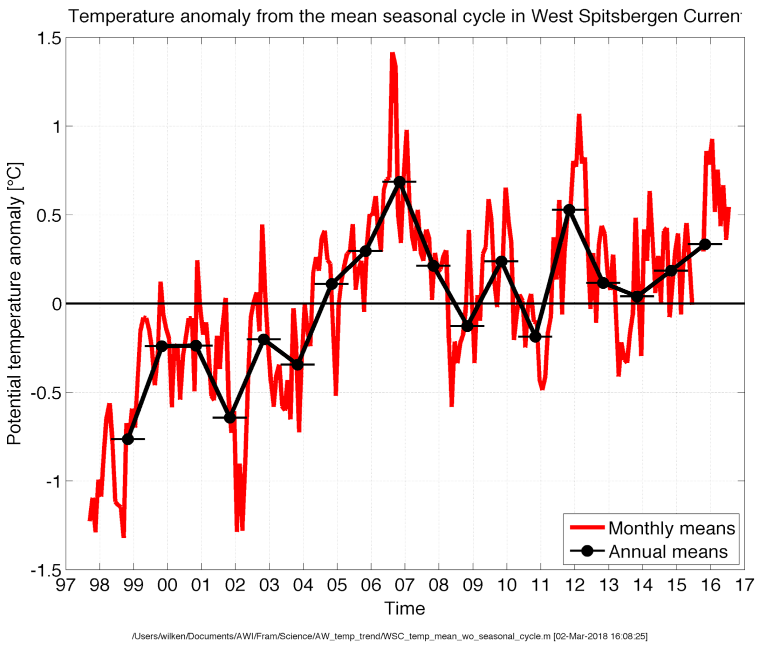

Figure 18. Time series (anomalies from 1997-2017 mean) of potential water temperatures in Fram Strait, averaged between 75 m and 250 m depth (source: AWI, Wilken-Jon von Appen).

Additionally, the moorings are equipped with SeaBird ECO triplet optical sensors to measure e.g. chlorophyll fluorescence, sensors for measuring pH and pCO_2, SUNA nitrate sensors and McLane water samplers.

Except for oxygen, the processing chain and the quality-checking procedures are well established, and the data are stored in the PANGAEA (https://www.pangaea.de/) data repository within 0.5-1 year after mooring recovery. Funding is maintained for at least one expert, who is responsible for mooring and cruise planning, data processing, data quality and data archiving.

2.4.2. CTD Measurements by RV Polarstern in Fram Strait

Data contribution to INTAROS: temperature, salinity, fluorescence, oxygen.

CTD surveys with RV Polarstern in the Arctic are conducted every year. These measurements are done in combination with water samplers (bottles) and are part of the multidisciplinary FRAM observatory (https://www.awi.de/en/expedition/observatories/ocean-fram.html). They represent an important contribution to the long-term ocean monitoring, to understand the warming and the changing freshwater inventory of the Arctic Ocean. CTD data from Fram Strait (Fig. 19 b) are the AWI contribution to INTAROS (data from 45 cruise legs with more than 2500 CTD profiles). The available data from the PANGAEA repository start in 1987 and are updated continuously.

A CTD (Fig. 19a) directly measures conductivity, temperature, and pressure of water during its down- and up-cast, resulting in a profile from the water surface to the bottom and back. Derived variables are salinity, density, and water depth. The CTDs onboard Polarstern were typically deployed in combination with a water sampler construction, holding 12, 24, or 36 bottles (named rosette or carousel, depending on the manufacturer. The CTD is mounted inside the frame of the water sampler in a way that the sensors measure the undisturbed water during the downcast. The downcast CTD profile is displayed on board in real time to allow the CTD operator to choose the water layers from which water samples for subsequent chemical and biological analyses are to be taken during the up-cast [Driemel et al., 2017]. The depth of a single profile depends on the cruise planning and scientific background. Most of the profiles reach down to several meters above the ocean bottom. Some profiles in deep ocean regions, however, stop at shallower depths (e.g. 1000 m).

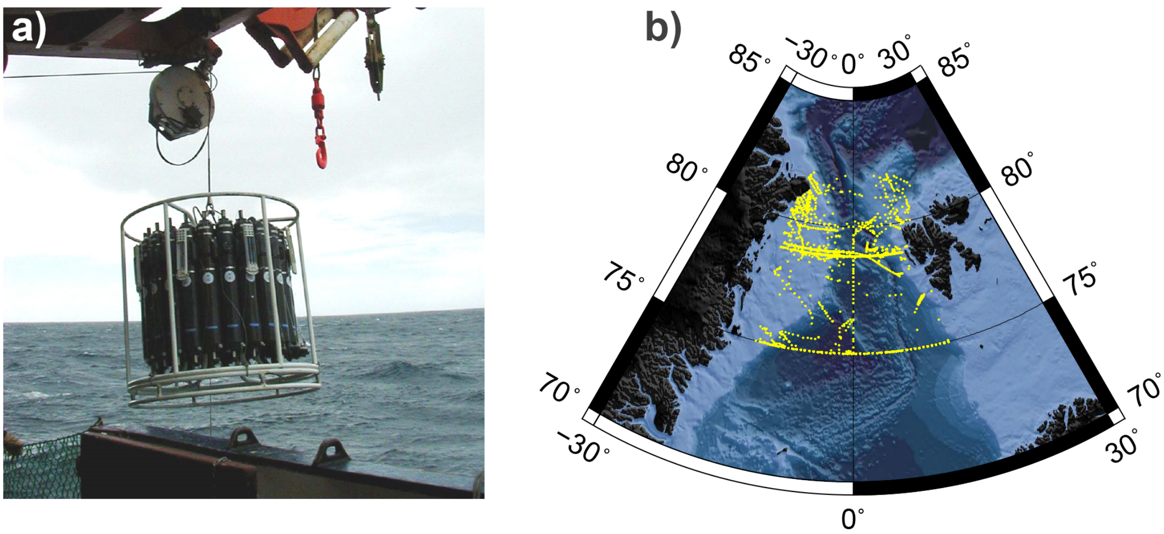

Figure 19 a) Typical CTD rosette system, equipped with a thermistor (temperature), conductivity cell (salinity), pressure sensor (depth), fluorometer (chlorophyll fluorescence), oxygen sensor and water sampling bottles [picture from Driemel et al., 2017]. b) Map of the measured CTD profiles in Fram Strait (domain of the FRAM project: 75-82°N and -15°W-15°E) between 1987 and 2015 (2236 profiles).

The initial instrument was the Neil Brown Instruments MarkIIIB CTD. Accuracies: ±6.5 dbar (pressure), ±0.005°C (temperature) and ±0.005 mS/cm (conductivity). Since 1992, a SeaBird SBE911plus CTD is operated onboard RV Polarstern. Accuracies: ±0.015% of full scale (0-6800 dbar), ±0.001°C and ±0.003 mS/cm. On 25 cruise legs since 1993, CTDs were equipped with a fluorescence sensor (e.g. WETLabs ECO FLRTD, sensitivity: 0.02 µg/l) and/or an oxygen sensor (e.g. SeaBird SBE43, accuracy: ± 2% of saturation, range: 120% of surface saturation).

Data management for temperature, salinity and oxygen is well established at AWI. Today, 1-2 scientists with permanent position are responsible for the full data flow: Data acquisition at sea, instrument calibration, data processing, quality control, depth homogenization, validation and archiving. The data are stored in the PANGAEA repository usually within 6 months after data acquisition. For a high quality of the oxygen data one person additionally needs to provide oxygen from bottle data by using the Winkler method. However, this does not happen on every single cruise.

The data management for fluorescence is not as well established. The data are available from PANGAEA, but were so far not calibrated against more precise laboratory measurements from water bottle samples. The calibration of fluorescence data is already initiated in the frame of the FRAM project and will hopefully be finished within 2018 (responsible person: Axel Behrendt).

References

Driemel et al.: From pole to pole: 33 years of physical oceanography onboard R/V Polarstern, Earth Syst. Sci. Data, 9, 211-220, https://doi.org/10.5194/essd-9-211-2017, 2017.

2.4.3. Vessel-Mounted ADCP on RV Polarstern

Data contribution to INTAROS: upper ocean current velocity.

The Teledyne RDI Ocean Surveyor 153.6 kHz VM-ADCP (Acoustic Doppler Current Profiler) is an acoustical instrument permanently installed on RV Polarstern. It measures a profile of the ocean current speed in the upper 320 m of the water column every two seconds, with a single-ping precision of 30 cm/s and a velocity accuracy of ±1.0% ± 0.5cm/s.

The data flow, quality checking and archiving is not very mature. For the FRAM domain data from only 10 cruises (between 1993 and 2017) are available from the PANGAEA data repository. These data are unprocessed raw data, which can not be readily used for scientific purposes. A few processed data sets exist only for the Southern Ocean. The person responsible for the VM-ADCP data is about to retire soon and it is not clear whether there will be personnel available to take over this task. However, it is planned to maintain the instrument.

2.5. IOPAN (The Institute of Oceanology of the Polish Academy of Sciences

2.5.1. AREX: Long-term large-scale multidisciplinary Arctic monitoring program

Geographical area: 70-81°N; 0-22°E (eastern Nordic Seas and Fram Strait)

Duration: 1988 - ongoing (annually repeated summer survey of 2 month duration); measurements on regularly repeated grid of sections/stations since 1997

Observing platform: IOPAN research vessel Oceania (open ocean RV, see Fig. 20)

General description and relevance: Institute of Oceanology PAS (IOPAN) contributes to improved understanding of Arctic climate processes with the strategic research initiative addressing the role of the ocean in changing climate and its effects on the European Seas. Its core activity, the long-term monitoring program AREX, is focused on multidisciplinary observations in areas such as physical oceanography, air-ocean interactions, ocean biogeochemistry and ecology to study the long-term changes of abiotic and biotic Arctic environment. Every summer since 1987 the large-scale field measurements have been carried out in the Nordic Seas and European Arctic from board of the IOPAN research vessel Oceania (Fig. 21). These data, collected under the observational program AREX every year in the same way, provide time series of key ocean variables which allow monitoring changes of the Arctic environment and improving numerical simulations of ocean, sea ice and climate in the Arctic region.

Instruments: The standard CTD system Seabird 9/11+ equipped with double pairs of temperature (SBE3) and conductivity (SBE4) sensors and pressure sensor Digiquartz 410K-105. Additionally CTD system carries two oxygen sensors (one standard SeaBird sensor SBE43 and Rinko optode, connected directly to the CTD registration system), fluorescence sensor SeaPoint and altimeter Benthos PSA-916. The CTD system is mounted on the SeaBird bathymetric rosette (carousel) equipped with 9 large Nansen bottles (12 l each and 3 small bottles (1.75 l each). Originally the rosette is designed to carry 12 large bottles but due to the mounting system for LADCP only 9 bottles can be use in the current configuration. RDI Teledyne Workhorse 300 kHz is used as Lowered Acoustic Doppler Profiler (LADCP), mounted in downward-looking configuration. Underway current measurements in the upper ocean of approx. 250 m are collected with Vessel Mounted Acoustic Doppler Current Profiler (RDI VMADCP Ocean Surveyor 150 kHz).

Seabird sensors accuracies: pressure ±0.015% of full scale (0-6800 dbar), temperature ±0.001°C and conductivity ±0.003 mS/cm

Seabird oxygen sensor: initial accuracy 2% of oxygen saturation, precision around 1 µmol/kg

Rinko oxygen sensor: resolution 0.01 to 0.04%, accuracy Non-linearity ±2%FS

LADCP: velocity accuracy: 0.5% of the water velocity relative to ADCP ±0.5cm/s, for processed data velocity errors < 3 cm/s (with bottom tracking) or <4.3 cm.s (without bottom tracking)

VMADCP: velocity accuracy (typical) ±1.0% ± 0.5cm/s (in High Precision Mode for 8m cell and range to 250m precision 8 cm/s)

Figure 20 IOPAN research vessel Oceania.

Data management and availability: Standard data flow includes data acquisition at sea, instrument calibration, data processing, quality control, depth homogenization, validation and archiving. Raw and processed measurements are stored in the IOPAN database (under development) and provided on request. Data are publicly available with the protection period of 2 years. It is also planned to submit the main CTD dataset to the PANGAEA database.

Sustainability and funding: AREX programme is supported from the IOPAN statutory funding provided by the Ministry of Science and Higher Education. Complementary funding for dedicated measurements is provided by a variety of national and international projects. Currently (the beginning of 2018) the statutory funding for the main AREX summer campaign is secured for the following years.

Data owner: Institute of Oceanology PAS, Sopot, Poland

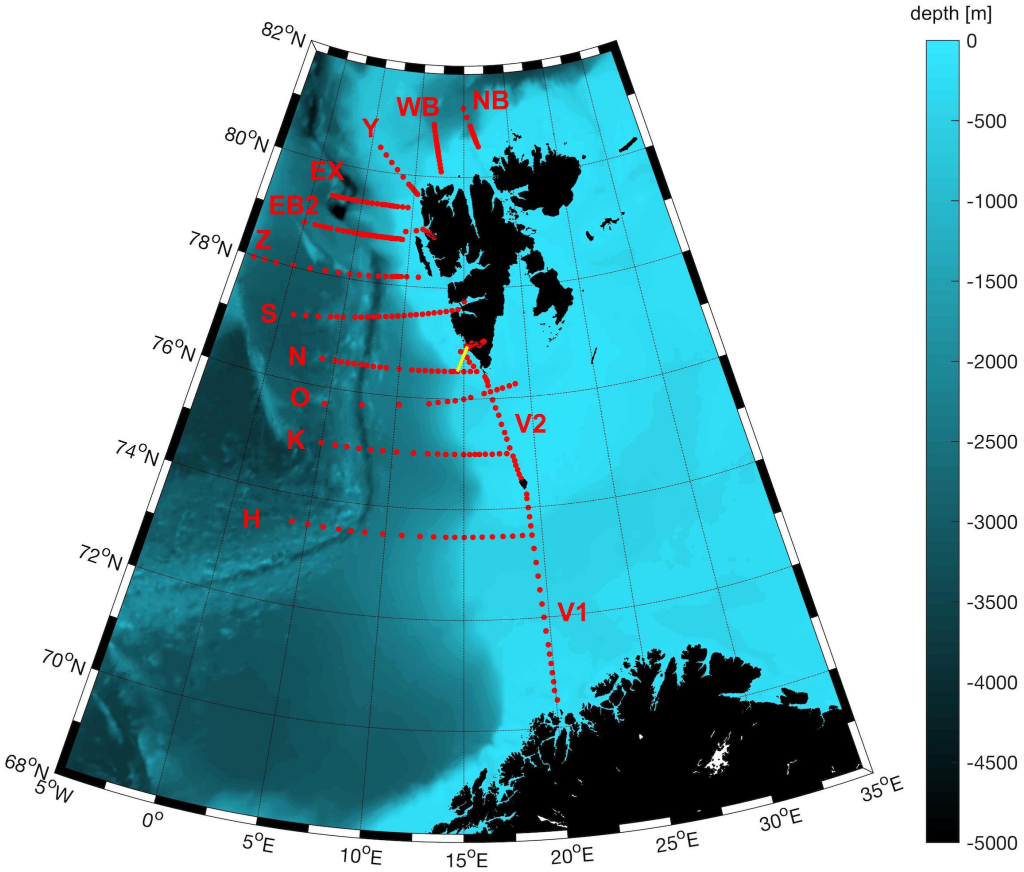

Figure 21. Station grid and location of regular sections, repeated every summer by RV Oceania.

2.5.2. A-TWAIN: Deep-ocean moorings north of Svalbard

Geographical area: 81-82°N, 22-32°E (the slope area northeast of Svalbard)

Duration: 2012 – ongoing

Observing platform: 1-2 deep ocean moorings redeployed each year

Instruments:

- McLane Moored Profilers with Seabird 52MP CTD and Falmouth Scientific ACM Current Meter
- TRDI Quatermaster ADCP 150 kHz for ocean currents measurements
- Nortek ADCP Signature 250 for ocean currents and sea ice measurements
- Nortek ADCP Signature 55 for ocean currents measurements
- SeaBird SBE37 Microcat temperature and salinity sensors

General description and relevance: The inflow of Atlantic water along the continental shelf slope of Svalbard constitutes the largest transport of heat, nutrients and biological energy to the Arctic Ocean and is likely an important pathway for introduction of new species in a warming climate. The Fram Strait Atlantic Water branch (FSAW) travels eastwards along the continental slope, encountering sea ice and colder, and fresher surface waters north of Svalbard. The heat transported in the FSAW has potential to melting sea ice even when overlain by fresher surface water. Since 2012 the A-TWAIN project, together with partners WHOI (2012-13) and IOPAN (2012-present), has maintained moorings over the upper slope, aiming to cover inflow both from the Svalbard and Yermak Pass Branches. One of the IOPAN moorings is usually a part of the main A-TWAIN array at 32°E while in some years the second IOPAN mooring was deployed upstream at 18 or 22°E to monitor Atlantic water transformation along the northern Svalbard slope. Under INTAROS the IOPAN moorings were augmented with new instruments measuring the profiles of ocean currents and sea ice drift and draft.

Data management and availability: Raw and processed measurements are stored in the IOPAN database (under development) and provided on request. Data are publicly available with the protection period of 2 years. It is also planned to submit the main CTD dataset to the PANGAEA database.

Sustainability and funding: IOPAN deep-ocean moorings were/are funded by several international projects including the PAVE project under the Polish-Norwegian Research Programme and the H2020 INTAROS project.

Data owner: Institute of Oceanology PAS, Sopot, Poland

2.5.3. ArgoPoland - deployments of Argo floats in the Nordic Seas

Geographical area: 73-80°N, 0-20°E (the eastern Norwegian and Greenland seas and eastern Fram Strait, see Fig. 22)

Duration: 2009 - ongoing (annual deployments of 2-3 floats)

Observing platform: profiling Argo floats deployed every year (2-3 floats): NEMO floats (2009-2012), APEX (2015), ARVOR (2016-2017)

Instruments: Argo floats with SeaBird SBE 41/41CP modules using the proven MicroCAT Temperature, Conductivity, and Pressure sensors

General description and relevance: The ArgoPoland is a component of the Euro-Argo ERIC (European Research Infrastructure Consortium), which allows active coordination and strengthening of the European contribution to the international global Argo programme. The main aim of Euro-Argo is to provide, deploy and operate an array of around 800 floats contributing to the global array (a European contribution of ¼ of the global array of temperature/salinity profiling Argo floats). Polish Argo floats are deployed in the subpolar North Atlantic to trace Atlantic water pathways and monitor transformation of Atlantic inflow during its northward transition towards the Arctic Ocean. The floats are set to parking depth of 1000 dbar and have profiling range from surface to 2000 dbar with a full cycle of 10 days.

Data management and availability: All ArgoPoland data are relayed and made publicly and freely available within hours after collection. Data are openly available from the CORIOLIS data center (main Argo GDAC).

Sustainability and funding: ArgoPoland is funded via the Polish Roadmap for Research Infrastructures developed by the Ministry of Science and Higher Education. Complementary in-kind funding (floats) is provided by the EU project MOCCA. Institute of Oceanology PAS is the national Argo operator and Distributed National Facilities of Euro-Argo infrastructure, Institute's vessel Oceania is the main Polish floats deployment platform. Funding is secured until 2020.

Data owner: Institute of Oceanology PAS, Sopot, Poland

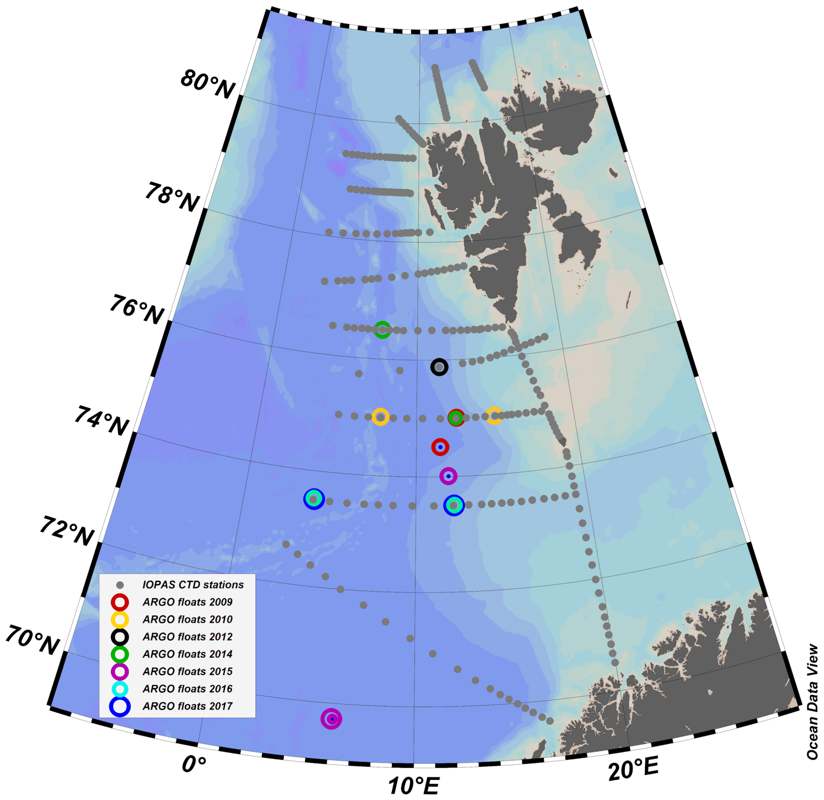

Figure 22. Deployment positions of floats launched by IOPAN in 2010-2017.

2.5.4. Long-term Monitoring in Svalbard Fjords

Geographical area: Hornsund (76°50' - 77°10'N, 15-17°E), Kongsfjorden (78°50'-79°05'N, 11-13°E) and shelf region next to the fjords' outlets (Fig. 23).

Duration: 1995 - ongoing (annually repeated summer surveys and spring and autumn measurements in selected years)

Observing platform: IOPAN research vessel Oceania and small boat operating from the Polish Polar Station in Hornsund

Instruments: Towed scan-fish CTD system with SeaBird SBE49 temperature and salinity sensors and Rinko optode (measurements from RV Oceania). Seabird CTD SBE 16plus V2 SeaCat, since 2016 turbulence profiler VMP250 (measurements from a small boat).

General description and relevance: Arctic fjords can be regarded as the link between the ocean and the land through cross-shelf exchange of water and the circulation dynamics of the fjord. The oceanographic conditions on the shelf set the fjord boundary conditions, and the fjords also exert change on the shelf environment. In the Arctic, the inshore boundary is usually dominated by glaciers and substantial seasonal freshwater input. The offshore boundary is influenced by relatively warm oceanic component. Long-term monitoring of hydrographic conditions is focused on two fjords with different location, geometry and hydrographic regimes, viz. relatively shallow and more influenced by Arctic waters Horsund located in the southwestern Spitsbergen, and deep and more 'Atlantified' Kongsfjorden in the northwestern Spitsbergen. A comparison of variability of physical and biological environment in two fjords accounts for northwards transformation of Atlantic water inflow and allows elucidating the effects of warming in two Arctic fjords with different regimes.

Data management and availability: Raw and processed measurements are stored in the IOPAN database (under development) and provided on request. Data are publicly available with the protection period of 2 years.

Sustainability and funding: Long-term monitoring of Svalbard fjords is supported from the IOPAN statuory funding provided by the Ministry of Science and Higher Education. Complementary funding was provided by several projects (AWAKE, AWAKE-2, GLAERE) under the Polish-Norwegian Research Programme.

Data owner: Institute of Oceanology PAS, Sopot, Poland

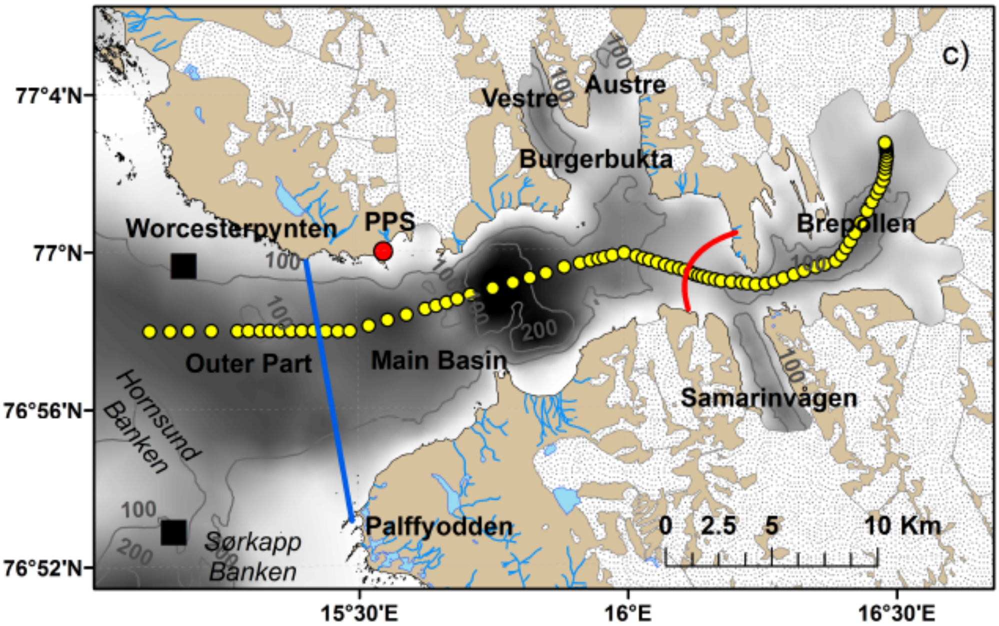

Figure 23. Map of standard sections and stations in Hornsund.

General description and relevance: Arctic fjords can be regarded as the link between the ocean and the land through cross-shelf exchange of water and the circulation dynamics of the fjord. The oceanographic conditions on the shelf set the fjord boundary conditions, and the fjords also exert change on the shelf environment. In the Arctic, the inshore boundary is usually dominated by glaciers and substantial seasonal freshwater input. The offshore boundary is influenced by relatively warm oceanic component. Long-term monitoring of hydrographic conditions is focused on two fjords with different location, geometry and hydrographic regimes, viz. relatively shallow and more influenced by Arctic waters Horsund located in the southwestern Spitsbergen, and deep and more 'Atlantified' Kongsfjorden in the northwestern Spitsbergen. A comparison of variability of physical and biological environment in two fjords accounts for northwards transformation of Atlantic water inflow and allows elucidating the effects of warming in two Arctic fjords with different regimes.

Data management and availability: Raw and processed measurements are stored in the IOPAN database (under development) and provided on request. Data are publicly available with the protection period of 2 years.

Sustainability and funding: Long-term monitoring of Svalbard fjords is supported from the IOPAN statuory funding provided by the Ministry of Science and Higher Education. Complementary funding was provided by several projects (AWAKE, AWAKE-2, GLAERE) under the Polish-Norwegian Research Programme.

Data owner: Institute of Oceanology PAS, Sopot, Poland

2.6. DTU (Technical University of Denmark)

Contributors: Carsten Ludwigsen, Ole Baltazar Andersen

2.6.1. IOC Tide Gauge Network for Greenland

Geographical area: 4 locations on Greenland (Nuuk (2014 -), Pituffik/Thule (2005 -), Qaqortoq (2005 -), Ittoqqortoormiit/Scoresbysund (2007 -). See Fig. 24.

Time: Daily data and high-frequency data (5 minutes)

Observing Platform: Tide-Gauge stations

General description: Daily measurements of relative sea level, including gps measurement. Corrected for atmospheric pressure.

Relevance of the observing system: Only consistent source of in-situ sea level measurements in a remote region.

Sensors/instruments: Tide Gauges (relative sea level), thermometer, barometer and GPS receiver.

Data available for download: http://www.ioc-sealevelmonitoring.org or by request to system administrator Ole Bjerregaard Hansen, obh@space.dtu.dk

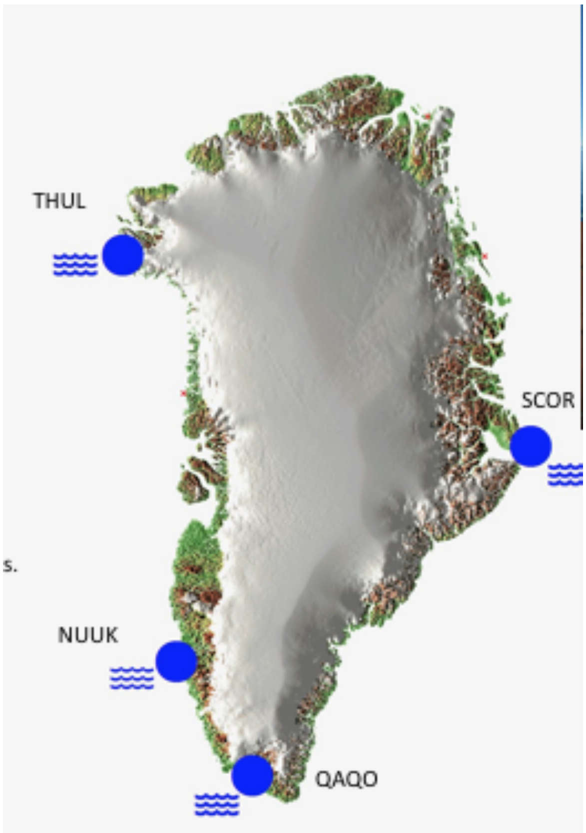

Figure 24. DTU Space IOC network stations.

2.6.2. PSMSL Tide Gauge Network

Name: PSMSL Tide Gauge Network

Geographical area: 38 locations in the Arctic (Fig. 25)

Time: Monthly data since 1990

Observing Platform: Tide-Gauge stations

General description: The Permanent Service of Mean Sea Level (PSMSL) is a monthly updated database of tide gauge measurements. From over 100 stations in the arctic area (above 60 deg North), 38 are meeting DTU's quality requirements, based on geographical location (no large tidal effects etc.) and amount of available data.

Relevance of the observing system: Only consistent source of in-situ sea level measurements in the arctic.

Sensors/instruments: Tide Gauges (relative sea level), thermometer, barometer and GPS receiver (on most stations).

Quality selected data available upon request (caanlu@space.dtu). All data (regardless quality) available for download at http://www.psmsl.org.

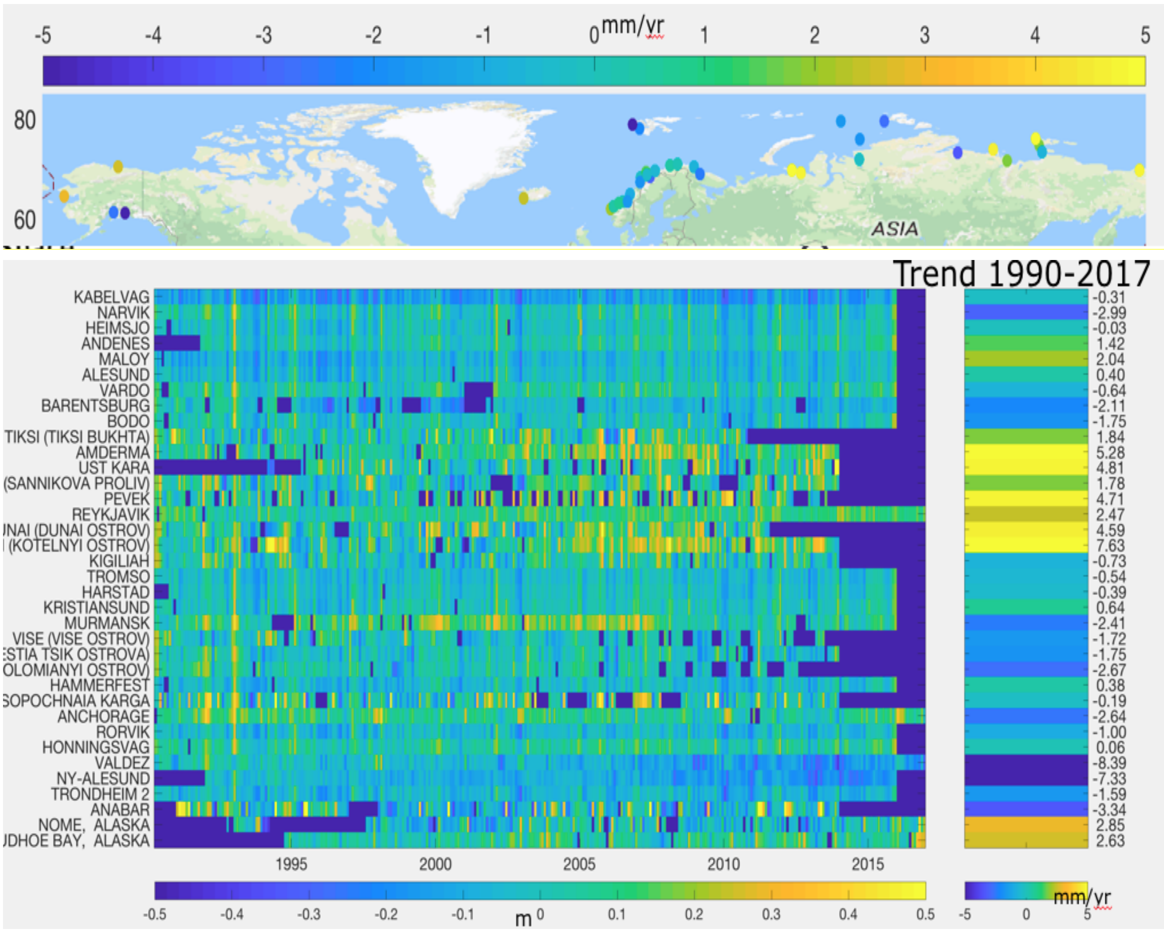

Figure 25. Geographical location (upper map) and sea level trend (lower graph) for 38 tide-gauge stations in the Arctic.

2.7. AU (Aarhus University)

2.7.1. Greenland Ecosystem Monitoring Programme

Geographical area: Coastal waters East Greenland (74 N 21 W) and West Greenland (64 N; 51 W).

Duration 2003- ongoing.

Observing platform: The system for physical ocean data consists of a fixed mooring combined with a repeated CTD transect every year in August.

Instruments: SeaBird 19 plus combined with SeaBird-37

General description and relevance: The Greenland Ecosystem Monitoring Program GEM) was established in 1994 with the aim of quantifying climate change and ecosystem responses in Greenland. It is run by a consortium of Danish and Greenland Institutions. The programme now includes 5 sub-programmes responsible for monitoring of atmosphere, terrestrial, marine, limnological and glacial systems with focus on two sites; a high Arctic site in East Greenland (74 N), and a sub-arctic site near Nuuk, West Greenland (64 N). The following relates to the marine component of the programme (MarineBasis) and will focus on physical parameters. The logistic constraints at the two sites are very different which is reflected in the measurement programme. In Nuuk, CTD profiles have been collected at monthly intervals since 2003. A SeaBird 19plus equipped with sensors for temperature, pressure, conductivity, PAR, fluorescence and turbidity is used and data are quality checked before being uploaded to the open GEM database. Each year in May, a repeated CTD transect in the fjord system (approximately 150 km, 20 stations) is conducted with the same instrument. In East Greenland access is only possible in summer. A CTD transect including 25-35 stations along the fjord system (approximately 120 km) is conducted every year in August (Fig. 26). To resolve seasonal variation a mooring with a SeaBird SBE-37 has been maintained at around 60 m since 2003. Sea ice is monitored by a camera system obtaining a daily image of the fjord.

To improve the marine monitoring programme the following upgrades was made under INTAROS:

1. Sea ice is a strong driver of light availability and thus marine production. From satellite images it appears that sea ice melt much earlier in the inner compared to the outer fjord, where the current sea ice camera is placed. A second camera has been deployed in the inner part of the fjord in August 2017.
2. The current mooring provides important knowledge of temperature and salinity. To expand the number of sensors on the mooring, we will add a new instrument from RBR, Canada with improved battery capacity, which allow us to obtain annual data on temperature, salinity, PAR, oxygen, fluorescence and turbidity in the fjord. This improves our capacity to measure biological relevant parameters to infer ecosystem responses to changes in climate. It also increases the vertical resolution, which improves our understanding of fjord circulation and freshwater export from the catchment.
3. Underwater light availability is a central parameter for marine production. In coastal Greenland it's a very dynamic parameter influenced by a combination of melting sea ice and increased runoff from land and the melting ice sheet. Two new PAR sensors including sensors for temperature, depth and salinity will be deployed in vicinity of the two sea ice cameras to link how seasonal and inter-annual changes in sea ice cover influence the light available for primary producers.

Data management and availability: Data are quality checked and available at the Greenland Ecosystem database (GEM database), see http://data.g-e-m.dk/

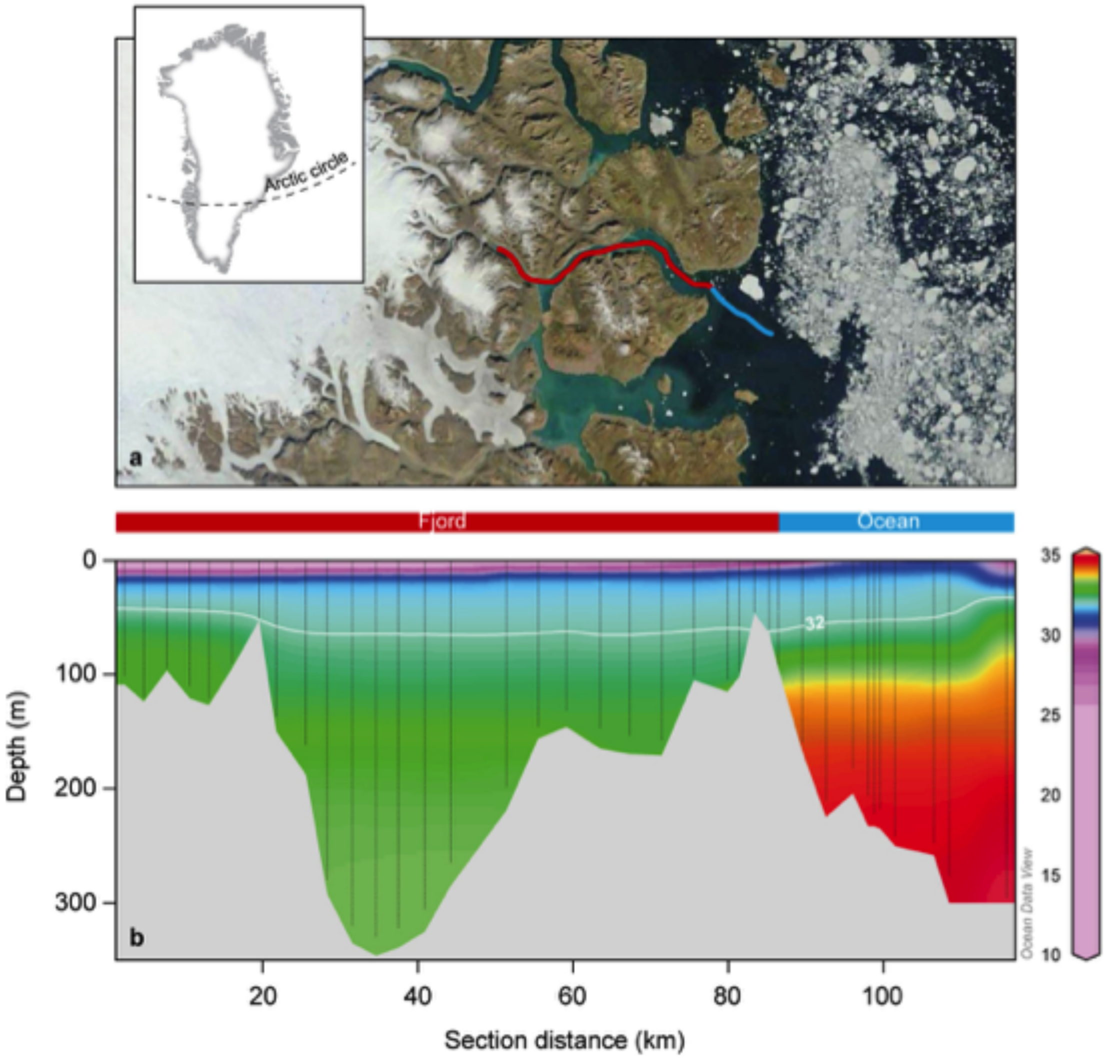

Figure 26. The repeated CTD transect measured every August since 2013 in Young Sound, East Greenland

2.8. IFREMER (L'Institut Français de Recherche pour l'Exploitation de la Mer)

Contributor: F. Ardhuin

2.8.1. Sea ice concentration using ASI algorithm with SSMI data

General description and relevance: The sea ice concentration is estimated using SSMI passive microwave radiometer data at 85 GHz, allowing to have 12.5 km grid resolution sea ice concentrations daily maps in Arctic and Antarctic since 1992 (Fig. 27). This time series is unique since other similar time series exist but at higher (or lower) resolution with less (or high) duration.

The maps are based on daily mean brightness temperature data from radiometer (SSMI series onboard DMSP, SSMIs) which are process using the Artist Sea ICe (ASI) algorithm (Kaleshke et al 2001, Spreen et al 2008).

The data are processed routinely, archived and distributed by the CERSAT at Ifremer and are easily accessible from (http://cersat.ifremer.fr/data/tools-and-services/quicklooks/sea-ice/ssm-i-sea-ice-concentration-maps). A User manual is available on the portal.

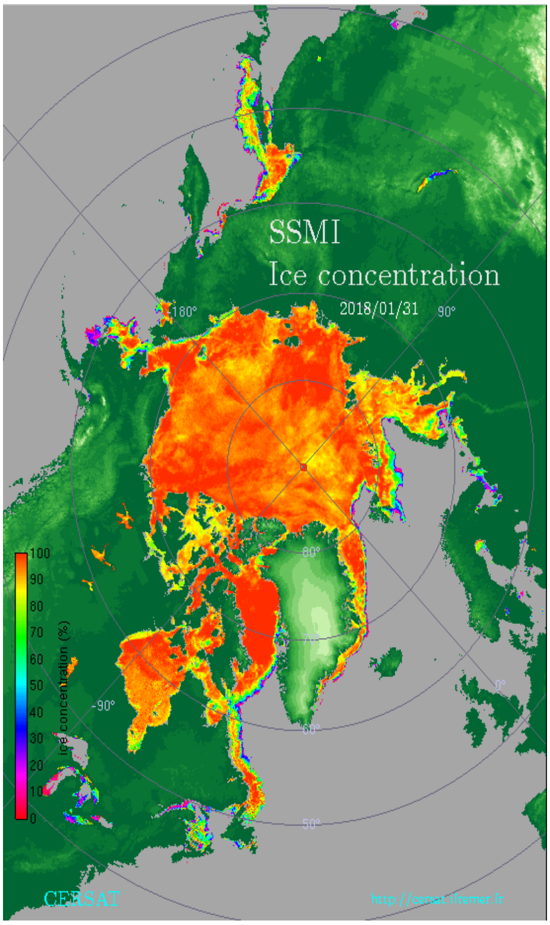

Figure 27. Arctic sea ice concentration on January 31th, 2018 using SSMIs data with ASI algorithm. From CERSAT portal

References

Kaleschke, L., C. Lüpkes, T. Vihma, J. Haarpaintner, A. Bochert, J. Hartmann, G. Heygster, 2001: SSM/I Sea Ice Remote Sensing for Mesoscale Ocean-Atmosphere Interaction Analysis. Can. J. Remote Sensing, 27, 5, 526—537.

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

2.9. UB (University of Bremen)

Contributor: Georg Heygster

2.9.1. Satellite data product ASI sea ice concentration data product

General description and relevance: Near real time (NRT) sea ice concentrations are needed at high horizontal resolution and high accuracy (1) in regions of low ice concentration for ship navigation, especially in low-frequented waters where no other ice information is available, and (2) in regions of high ice concentration to determine the heat flux for numerical weather prediction models.

The ARTIST Sea Ice (ASI) concentration algorithm, applied to the AMSR-E and AMSR2 data at 89 GHz are among the highest resolution sea ice concentration data which are currently available daily and globally. The ice concentration data have the resolution of the AMSR 89 GHz channels (5 km). The daily hemispherical maps are made available in a 6.25 km grid, the 20 regional maps in a 3.125 km grid. Figure 28 (left) shows an example. Together with the additional data products multiyear sea ice concentration (middle) and thickness of thin sea ice (right) presented in D2.2 (Exploitation of existing data) a detailed overview of the Arctic sea ice situation will be provided.

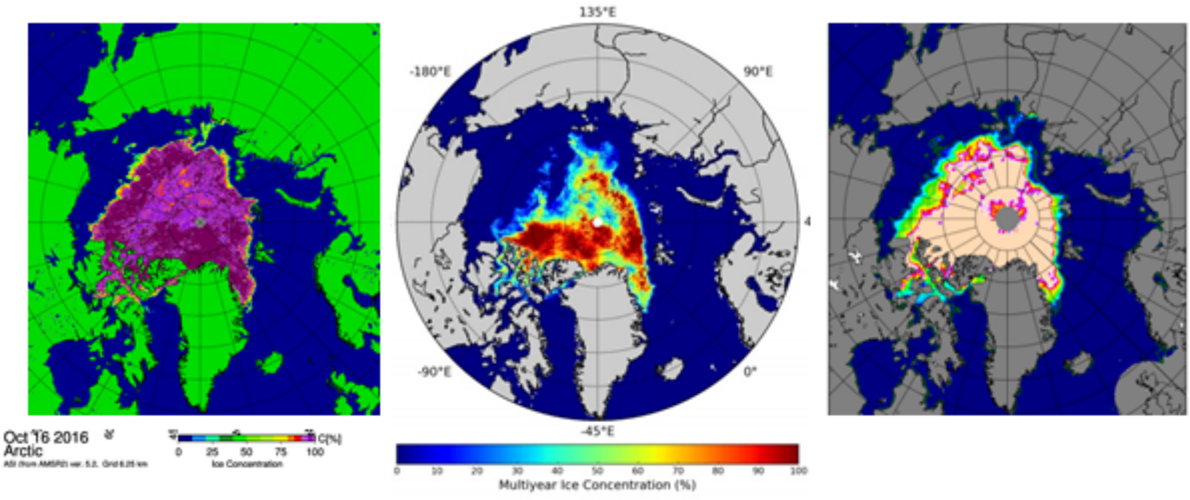

Figure 28. Sea ice concentration (left), multiyear ice concentration (middle) and thickness of thin sea ice (right) as of 16 Oct 2016).

The 89 GHz channels of the AMSR-E offer the highest resolution for passive microwave sea ice concentration retrieval currently available and exhibit reduced sensitivity to snow layering (Spreen et al. 2008). The ARTIST Sea Ice (ASI) algorithm was developed to benefit from the high spatial resolution of the 85-GHz channels of the SSM/I sensor for the mesoscale numerical modeling of the polar atmospheric boundary layer in the marginal sea ice zone as an enhancement of the Svendsen et al. sea ice algorithm for frequencies near 90 GHz (Kaleschke et al., 2001, Svendsen et al., 1987). The ASI algorithm has been well validated in particular in the marginal ice zone (MIZ) of the Greenland Sea and in the central Arctic (Andersen et al. 2006). Comprehensive validation efforts have been undertaken for the ASI algorithm during the ADEOS II 3rd RA projects (Heygster et al., 2009, Spreen etal., 2008) namely with ship-based observations in the Arctic (Barents and Greenland Sea, Central Arctic), with ETM+/Landsat scenes (Bering Sea), with SAR scenes (Davis Strait, Baffin Bay, Kara Sea and Greenland Sea). The improved resolution of the AMSR-E 89 GHz sea ice concentration products is especially suited for mesoscale studies in the MIZ and to observe coastal polynyas (Parmiggiani, 2006).

References

Andersen, S., R. Tonboe, S. Kern, H. Schyberg 2006: Improved retrieval of sea ice total concentration from spaceborne passive microwave observations using numerical weather prediction model fields: An intercomparison of nine algorithms, Remote Sensing of Environment, Volume 104, Issue 4, 374-392.

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Svendsen, E., C. Matzler, T. C. Grenfell, 1987: A model for retrieving total sea ice concentration from spaceborne dual-polarized passive microwave instrument operating near 90 GHz. Int. J. Rem. Sens. 8, 1479-1487.

2.10. NIVA (Norwegian Institute for Water Research)

Contributors: Andrew King

2.10.1. Barents Sea FerryBox system

General description and relevance: The Barents Sea FerryBox system is a suite of sensors that are on a ship of opportunity, the M/S Norbjørn, that makes ~30 roundtrip voyages between Tromsø, Norway (69.675 N, 18.9849 E) and Longyearbyen, Svalbard (78.1227 N, 13.9138 E). Some voyages make stops at Bear Island, Svalbard (74.4522 N, 19.1152 E) and Ny Ålesund, Svalbard (78.9235 N, 11.9099 E). The ship is outfitted with a seawater pump system that brings seawater from ~5 m depth into an assembly of physical, biological, and chemical sensors. In addition, sensors are mounted on the deck that measure wind and light-related variables. Sensors undergo different levels of calibration and validation which are discussed in more detail below.

Data collected by the FerryBox system are reported as raw data and Level 1: calibrated data in netCDF and are CF-compliant. Data are available typically within one week after acquisition (except for a few cases described in more detail below) and are provided and stored by NIVA. All data collected are treated with the same metadata standards – data collections and data files are accompanied by metadata that can be used independent of external assistance that include geographical coordinates, units, valid range, missing values, etc.). Quality flags are provided for all data that are subjected to the Copernicus Marine Environment Monitoring Service (CMEMS) criteria. When a pass/no pass quality flag is not available, a “no flag provided” flag is assigned. All measurement techniques employed by the FerryBox sensors have been described in peer-reviewed literature and examples of usage are also published (by either our group or other ocean observing groups).

Sea surface temperature and salinity: Measured using a Sea-Bird SBE-45 temperature/ salinity sensor. This sensor has been flight proven through many years of use by the oceanographic community. Temperature validated by periodic comparison with a portable traceable digital thermometer (Fig. 29 and 30). The portable thermometer is periodically checked against other traceable thermometers in the lab. Salinity samples are collected periodically and analyzed using a salinometer that is calibrated using salinity reference materials.

Chlorophyll a fluorescence: Measured using a TriOS microFlu chlorophyll a sensor. This measurement technique has been flight proven through several sensor designs by multiple sensor manufacturers and use by the oceanographic community. The measurements are validated periodically by collecting samples for lab-based fluorometric and spectrophotometric chlorophyll a analyses. Systematic drift due to biofouling is corrected using a regression-based approach.

Turbidity: Measured using an AML Oceanographic MicroX turbidity sensor. This measurement technique has been flight proven through several sensor designs by multiple sensor manufacturers and use by the oceanographic community. The measurements are validated periodically using organic colloidal turbidity standard solutions.

Oxygen: Measured using Aanderaa AADI-Optode 4835 sensor. This measurement technique has been flight proven through several sensor designs by multiple sensor manufacturers and use by the oceanographic community. The measurements are validated periodically by collecting samples for standardized lab-based oxygen titration measurements (Winkler titration).

pCO_2: Measured using a Franatech membrane equilibrator coupled to an infrared detector. This measurement technique has been used in lab-based measurements by multiple users in the oceanographic community, and the sensor design principles have been used by several sensor manufacturers. The infrared detector is a standard CO_2 measuring device. There are still some elements under development, including keeping flow and temperature more constant. The detector is calibrated periodically with certified reference gases, and the membrane is also checked using certified reference gases. Samples are periodically taken for measurements of total dissolved inorganic carbon and total alkalinity to constrain pCO_2 values. In-situ pH measurements are also used to validate measurements.

pH: Measured using a custom spectrophotometric sensor. The measurement technique uses pH-sensitive indicator dye that is evaluated for absorption at two wavelengths and pH is reported on the total scale. This technique has been flight proven through several sensor designs and in lab-based applications. Certified reference materials are used periodically to evaluate performance and drift.

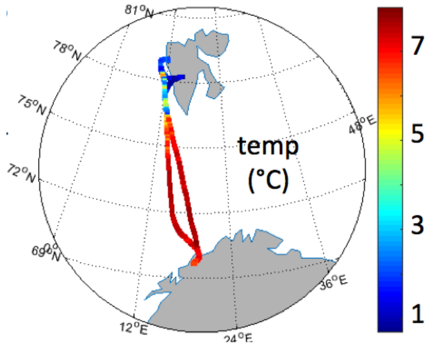


Figure 29. M/S Norbjørn with ferrybox system installed (left) and surface temperature data between Tromsø and Svalbard (right).

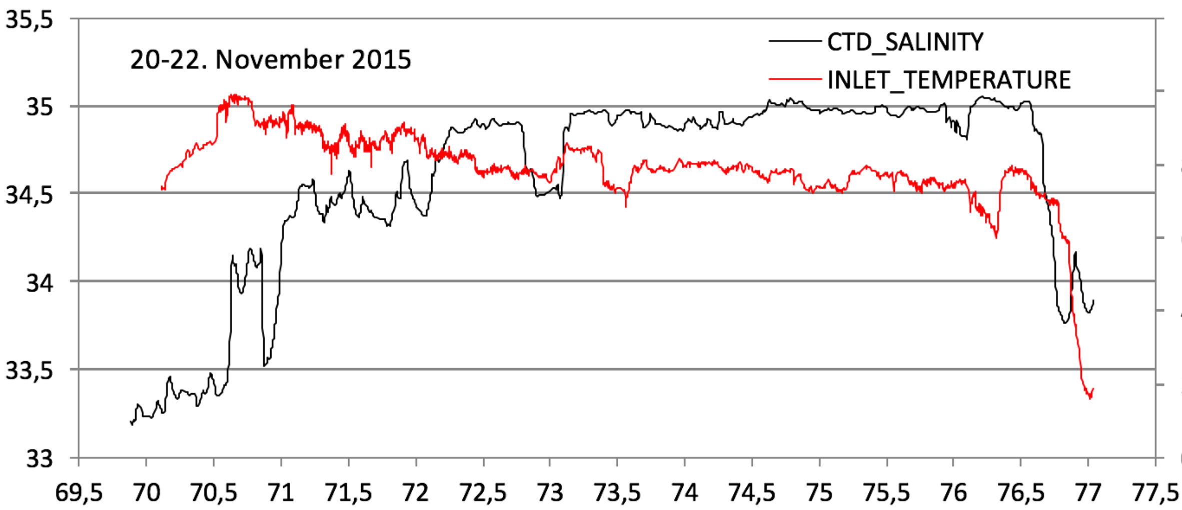


Figure 30. Detailed plot of CTD temperature and salinity data from the ferrybox line

2.11. UNIS

Contributor: Eva Falck

2.11.1. UNIS ocean observing system

Geographical area: 11 locations around Svalbard.

Time: August 2005 and onwards.

Observing platform: The UNIS ocean observing system comprises fixed moorings carrying oceanographic instruments e.g. current meters, CTD, pressure sensors. The first deployments started in 2005. The number of moorings varies from year to year. The area of data collection is shown in Fig 31.

Instruments and parameter(s) observed: Missing

General description and relevance: Missing

Data management: Data are stored in an institutional/departmental FTP repository. The data is updated irregularly, often a period after new data has been obtained.

Sustainability & Funding: The system is partially funded by UNIS and some moorings have been externally funded through projects such as UNDER-ICE and REOCIRC, both funded by the Research Council of Norway.

Data owners: UNIS (University Centre in Svalbard).

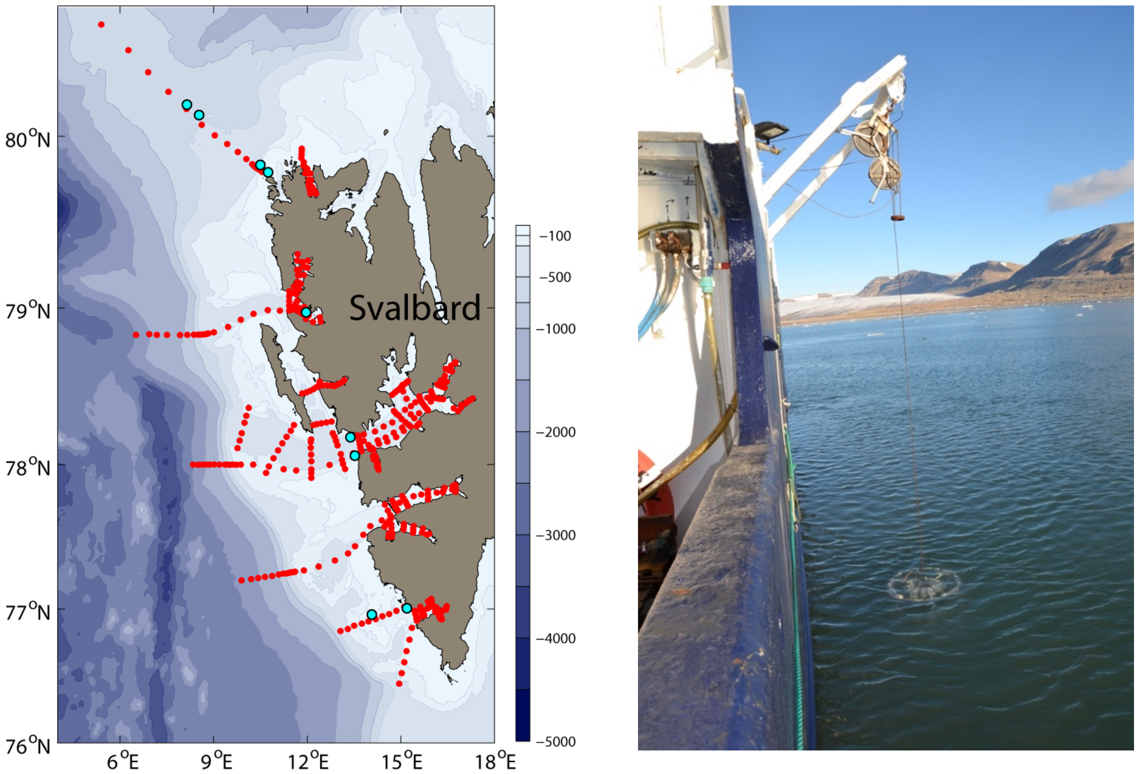


Figure 31. Left: Map of CDT sections obtained repeatedly by UNIS. Right: Photo of CTD station in a Svalbard fjord. Ref. Eva Falck.

2.12. Norut

Contributor: Rune Storvold

2.12.1. SIOS Dornier observing platform

Geographical area: Svalbard, Fram Strait

Time: August 2018 and onwards.

Observing platform: The SIOS Dornier observing system comprises of a permanently mounted instrument pod attached to one of the two Dornier DO228 aircraft flying logistics and support from Longyearbyen to Ny-Ålesund, Svea and Villum Station on Greenland. The Instruments consists of an aerial camera, hyperspectral imager and an X-band SAR-instrument.

Instruments and parameter(s) observed:

Aerial Camera

- Data collected: High resolution RGB imagery.
- Derived Products: Sea-ice concentration, Melt pond fraction

Hyperspectral imager

- Data collected: spectral radiance, 180 bands between 400 and 1000nm, 3.3 nm sampling spacing
- Derived Products: Ocean Color (chlorophyll-A)

X-band SAR

- Data collected: Raw co-polarized SAR data
- Derived Products: sea-ice concentration, ocean wave spectra, ocean surface winds

General description and relevance:

The Dornier platform performs about 20 flights across the Fram Strait each year for logistics to Villum Station. Weekly flights cover part of Kongsfjord, Isfjord and Van Mijenfjorden.

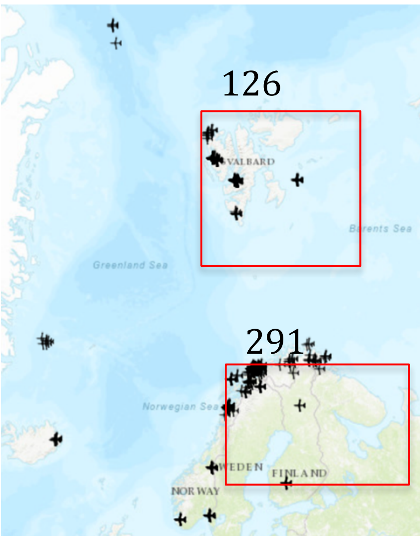


Figure 32. Left: Areas where NORUT has flown UAVs in recent years. A total of 463 flights have been completed. Right: photo of UAVs during a campaign in the Arctic.

Data management: Data are stored in an institutional repository. The data will be described and available for discovery though the SIOS portal. The data will be updated regularly, but in the starting phase it will take some time for cal/val, QC of products to be conducted and documented prior to release of data. (Fig. 32).

2.13. CNRS-OCEAN

2.13.1. EGO "Everyone's Gliding Observatories" platform as a tool to share Arctic glider data

The EGO initiative of several teams of oceanographers, interested in developing the use of gliders for ocean observations, helped to set up a strong glider community. The glider is a relatively new platform in oceanography, but one which has great potential thanks to its smart design. EGO was first composed of scientific teams from France, Germany, Italy, Norway, Spain, and the United Kingdom and EGO stood for "European Gliding Observatories" for a while but it is now more appropriate to call it "Everyone's Gliding Observatories", while colleagues from Australia, Canada, South Africa and USA, from academia or industry, have joined this open community. This idea of a glider group emerged in October 2005 and since then, collaborations have been developing. Experiments with international fleets of gliders have been carried out and EGO Workshops (including "Glider Schools") are organized every year or so to present and discuss both scientific and technological issues

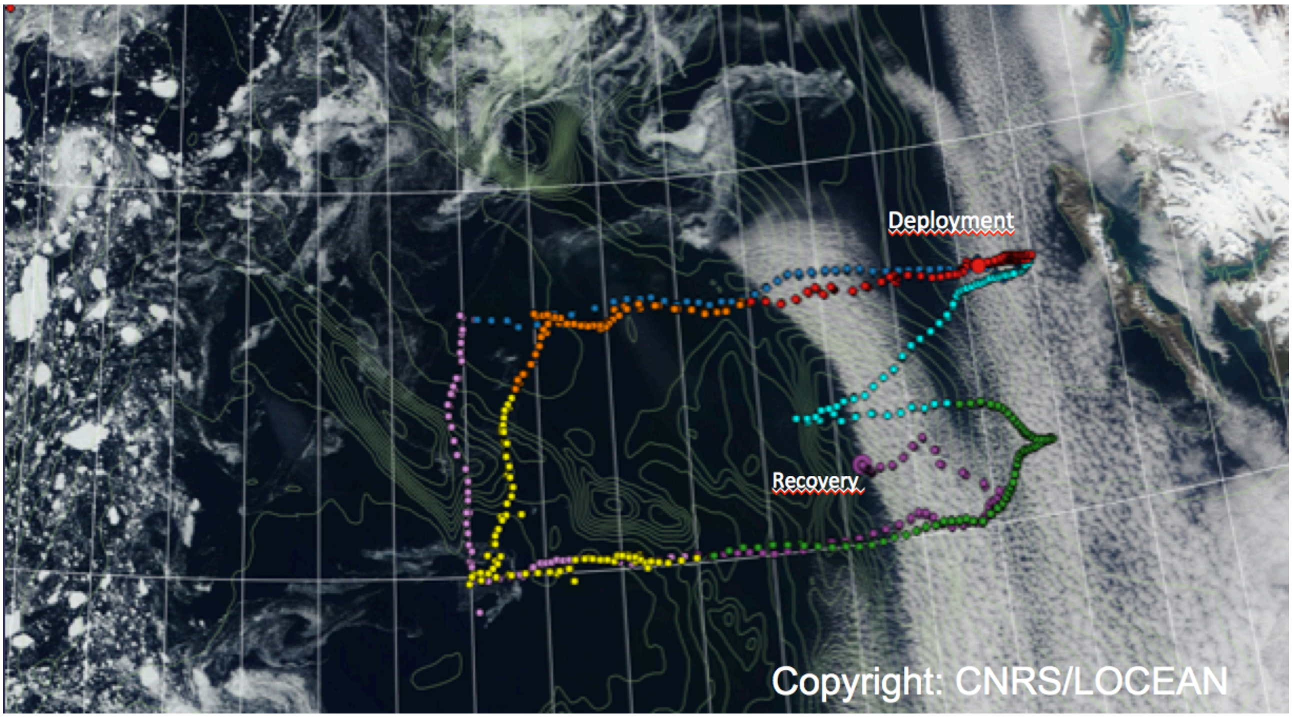


Figure 33. Trajectories of glider surveys conducted by CNRS/LOCEAN in the Fram Strait in 2017

CNRS is coordinating the EGO "Everyone's Gliding Observatories" initiative, (https://www.ego-network.org), designed to promote glider technology and its applications, and to facilitate networking within the glider community. The EGO site collects and disseminates information about the worldwide glider activity (deployments, observatories, instrument fleet), literature, technical notes and tutorials. EGO also provides resources related to gliders and management of glider data, in particular the development of software related to data visualization, uploading to repositories, quality check and processing, access from Global Data Assembly Center (GDAC), and recommendations for data dissemination, in real-time and delayed mode, to a wider community through global databases (like the Coriolis Data Center).

In the context of INTAROS, CNRS will promote the use of EGO in order to foster Arctic glider data collection and contribution to the relevant global data repository, to improve their quality, visibility and dissemination toward the international community, and to provide a real-time overview of the

Arctic glider observing activity. In the context of enhancing the distributed observing systems of the Arctic within INTAROS, glider deployments have been carried out in 2017 (Fig. 33) and will continue in 2018. Monitoring of the glider missions, real time transmission of the data and glider piloting can be achieved through the EGO system. Subsequent data processing and storage will also be performed with the use of EGO resources. EGO will also be a useful tool to map out past Arctic cruises.

References

EGO website (https://www.ego-network.org) and references therein

Carval T., Gourcuff C., Rannou J.-P., Buck Justin J.H. and B. Garau, 2017 : EGO gliders NetCDF format reference manual version 1.2. http://doi.org/10.13155/34980

Rannou J.-P., Gourcuff C. and T. Carval, 2016 : EGO gliders data processing chain, version 20160420_004a, SEANOE. http://doi.org/10.17882/45402

2.14. International Arctic Ocean Buoy Program

Contributor: L. H. Smedsrud/S. Sandven

Geographical area: The operational area of the Programme is the Arctic Ocean, including its marginal seas, except Exclusive Economic Zones where agreements of the Coastal States have not been obtained.

Time: 1991 to present (from 1979 to 1991 it was called the Arctic Ocean Buoy Program)

Observing platform: Buoys

Instruments and parameter(s) observed:

Sea level pressure, Surface air temperature, Sea ice motion, Snow depth, Sea ice thickness, Sea ice temperatures and Ocean temperatures and salinities.

General description and relevance: The **International Arctic Buoy Program** is headquartered at the Polar Science Center, Applied Physics Laboratory, University of Washington, in Seattle, Washington, United States. The program's objectives include to provide meteorological and oceanographic data in order to support operations and research for UNESCO's World Climate Research Programme and the World Weather Watch Programme of the United Nations' World Meteorological Organization. IABP participating countries include Canada, China, France, Germany, Japan, Norway, Russia, and the United States. Together, they share the costs of the program.

The IABP has deployed more than 700 buoys since it began operations in 1991, succeeding the Arctic Ocean Buoy Program (operational since 1979-01-19). Commonly, 25 to 40 buoys operate at any given time and provide real-time position, pressure, temperature, and interpolated ice velocity.

All buoys in the network should be equipped with transmitters to enable transmission of data in real-time using satellite telemetry such as Argos, and Iridium. Participants are required to provide appropriate metadata to Joint WMO/ Intergovernmental Oceanographic Commission (IOC) Technical Commission for Oceanography and Marine Meteorology (JCOMM) Observation Program Support (OPS). Deployment plans for new buoys are prepared every year, an example for 2017 is shown in Fig. 34, while a daily map of operating buoys is shown in Fig. 35. The organization's annual meeting provides discussion on instrumentation, forecasting, observations, and outlook.

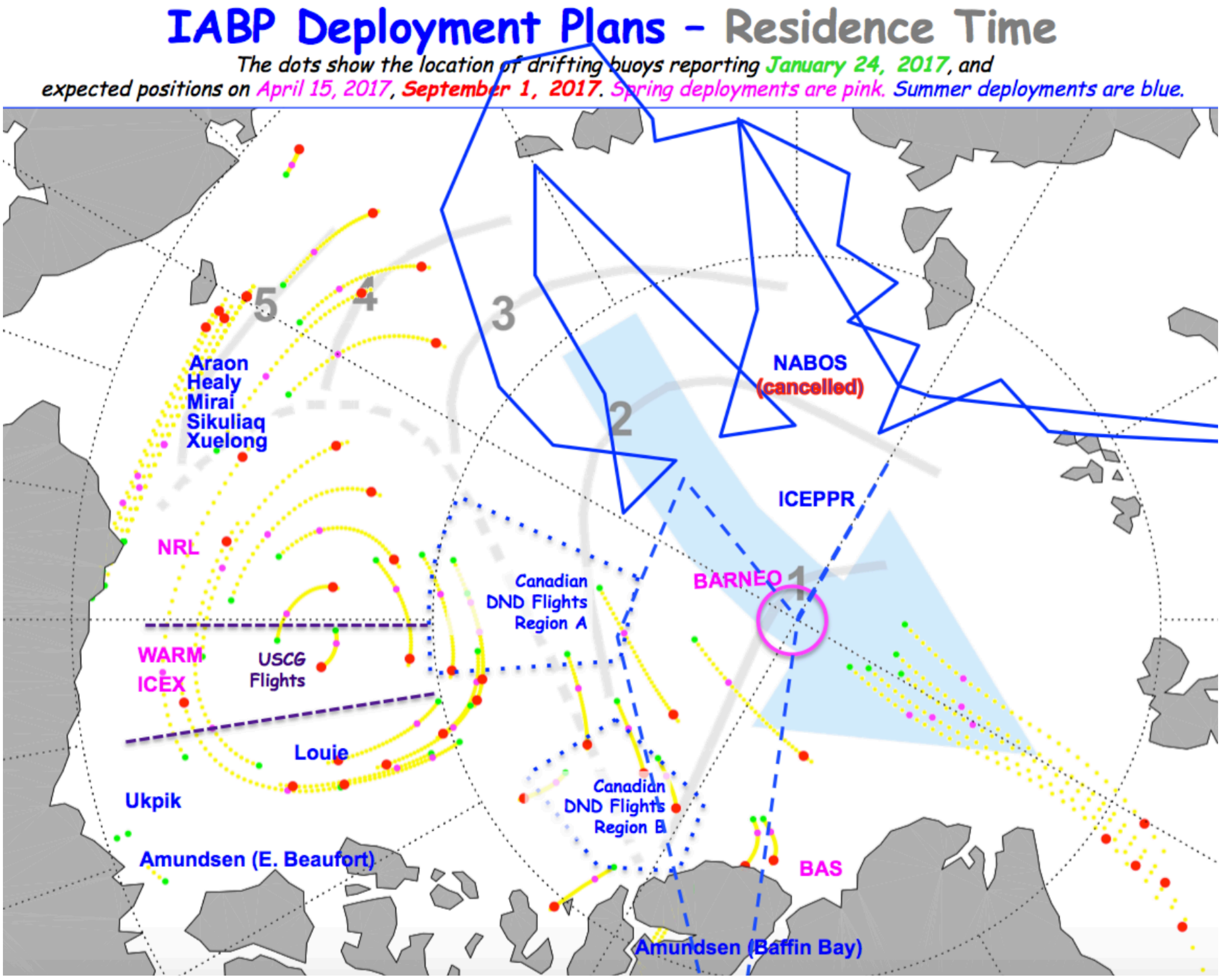


Figure 34. Map of the deployment plan for 2017

Data management: The data are open and freely available from several data repositories. The main site for data presentation and dissemination is http://iabp.apl.washington.edu/index.html. The data are also available at http://nsidc.org/data/g00791.

All data transmitted on the GTS are archived by the Integrated Science Data Management (ISDM, formerly Marine Environmental Data Services) of the Canadian Department of Fisheries and Oceans as the Responsible National Oceanographic Data Centre (RNODC) for Drifting Buoys of the JCOMM.

Sustainability & Funding: Funding of this program is from the participating institutions through research programs in Europe and North America.

Data owners: See operating principles for IABP at http://iabp.apl.washington.edu/overview_principles.html

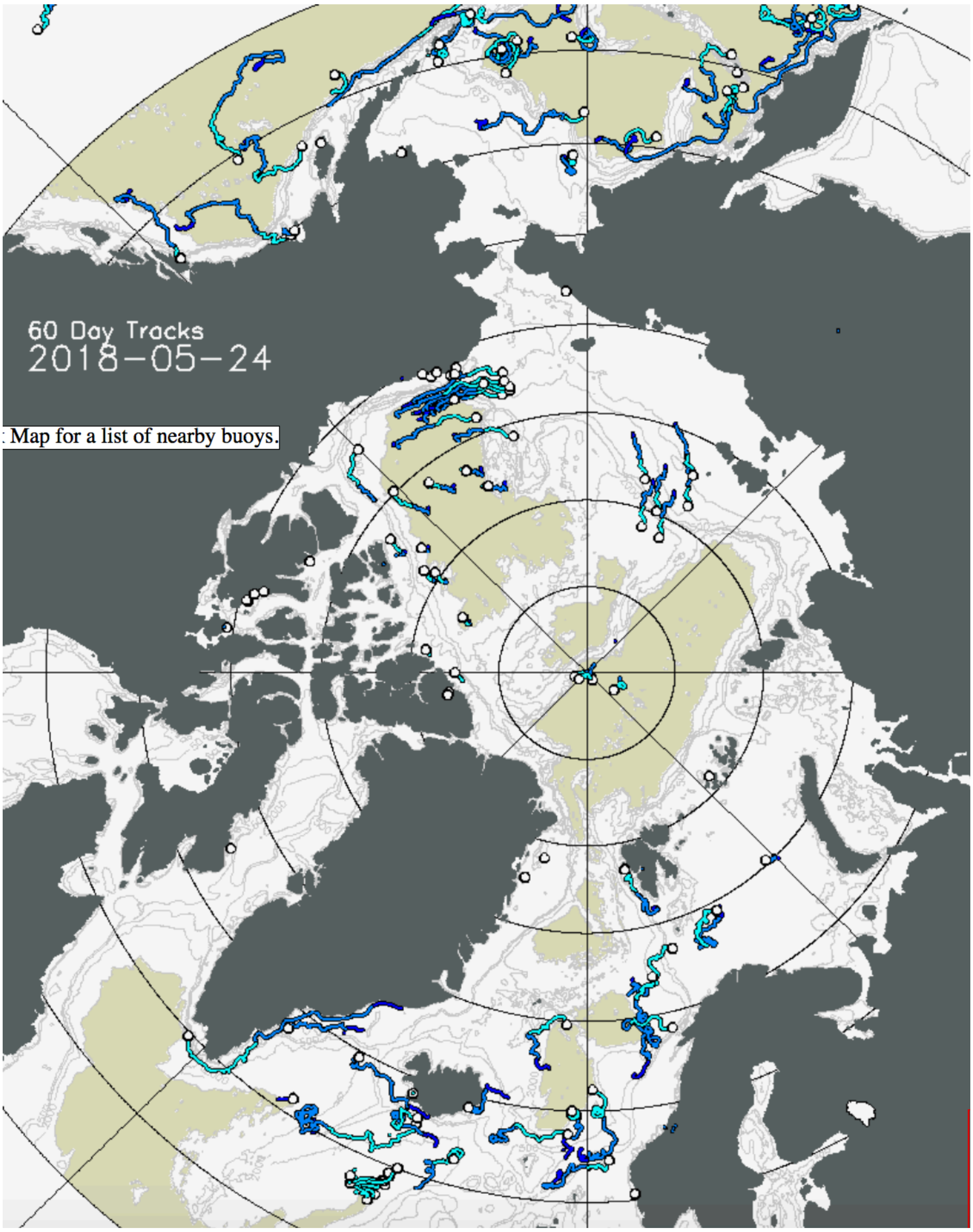


Figure 35. Daily map of operating buoys on 24 May 2018, with buoy trajectory for the last 60 days

3. Requirements

In this section the requirements needed as background for the assessment (Section 4) of the observation systems, in-situ data collections, and satellite products are discussed.

Requirements for the in-situ observing systems are stated for the spatial and temporal coverage of the systems and are discussed with respect to the scientific and/or monitoring purposes of the system. For instance, the requirement on spatial coverage of a network established to monitor a specific area (e.g. Greenland or Fram Strait) is defined based on the spatial extension and representativeness needed to the network for the fulfilment of its goal. As a matter of fact, each observing system has constraints due to technical, practical, economical, and political reasons, which affects the degree in which they can achieve their goals (this “gap” between goal and actual achievement is evaluated in Section 4). Depending on the individual cases, the requirements of the ice and ocean observing systems should be evaluated depending on the platform used, which is assessed in Table 3, Section 4.

3.1. In-situ ice-ocean observing systems

In this section we provide the criteria to evaluate the technological readiness for platforms, instruments; and the criteria used for the different data processing levels.

3.1.1. Platform, instrument and data management maturity

The ice and ocean in-situ observing systems are defined by the platform category, the sensors carried by the platforms, and the data management system connected to the observing system. In a sustainable observing system, the technical readiness level is important both with respect to the platform used, the sensors, as well as the operational level of the system. The Technical Readiness Level (TRL), as defined by the European Commission in the H2020 Workprogramme, is given in a scale from 1-9, as shown in Table 1.

Table 1. ***European Commission definition of technical readiness level.***

Technology Readiness Level	Description
TRL 1	basic principles observed
TRL 2	technology concept formulated
TRL 3	experimental proof of concept
TRL 4	technology validated in lab
TRL 5	technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	system prototype demonstration in operational environment
TRL 8	system complete and qualified
TRL 9	actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

3.1.2. Definition of Processing levels

Processing levels have been defined by organisations such the National Ecological Observatory Network (NEON) terminology: http://www.neonscience.org/data/data-processing. These levels are defined in Table 2 (left column) below . Note that space organisations such as NASA have defined data levels for satellite Earth Observation data slightly differently, as shown in Table 2 (right column). A data collection usually provides data at lowest processing levels, from the lowest level (raw data) to various higher level products. For in-situ data it is most important to provide level 1 and level 2 data, whereas level 3 data is most relevant for satellite data and/or reanalysis fields where models are used to for spatial and temporal interpolation.

Table 2. ***Definition of data levels.***

Data levels according to NEON	Data levels according to NASA
Level 0: raw data (Raw data are unprocessed measurements and observations from a single instrument, observation or field sampling techniques in native collection units, such as voltage)	**Level 0:** Reconstructed, unprocessed instrument/payload data at full resolution; any and all communications artefacts, e.g. synchronization frames, communications headers, duplicate data removed.
Level 1: calibrated data (Calibrated or quality-assured data are generally from a single instrument, observer or field sampling area. These data are transformed into standard scientific units, and are generally at native measurement resolution. Data quality control occurs, spatial and temporal coordinates are provided, and data can be temporally or spatially averaged (to reduce noise and increase accuracy)	**Level 1A:** Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters, e.g., platform ephemeris, computed and appended but not applied to the Level 0 data.
	Level 1B: Level 1A data that have been processed to sensor units (not all instruments will have a Level 1B equivalent). For some instruments, level 1B is the same as level 1A.
Level 2: Temporal interpolation (Corrects and/or fills in any gaps in time in the data that an individual sensor collects)	**Level 2:** Derived geophysical variables at the same resolution and location as the Level 1 source data
Level 3: Spatial interpolation (Connects gaps in space between sensors collecting the same type of data)	**Level 3:** Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
Level 4: More complex derived data products (Processing combinations include in-situ and remote sensing data, external data sets, and models).	**Level 4:** Model output or results from analyses of lower level data, e.g., variables derived from multiple measurements.

3.1.3. Data management

Regardless of platform type and readiness level, ocean observing systems need to strive for fulfilling the FAIR Guidelines for Data Management (Wilkinson et al., 2016). Broadly speaking, "being FAIR" entails:

- "making data findable, including provisions for metadata" (F)
- "making data openly accessible" (A)
- "making data interoperable" (I)
- "increase data re-use (through clarifying licenses)" (R)

Each of these aspects can be further elaborated in more detailed requirements, including both technical (e.g. machine-to-machine interfaces) and organisational (e.g. data policies and MOUs for data sharing between different providers and/or data infrastructures). An in-depth discussion of these requirements is beyond the scope of this report, but each of the general statements quoted above serves as high level requirements for ocean observing systems.

Ocean observing systems set up as part of national or international monitoring programs, typically have strong requirements to provide their data in real time to their designated users. Dedicated structures for data flow are often established for this purpose, with well documented metadata and data formats, standard interfaces to data servers and comprehensive descriptions of how data has been collected and processed before being released. Mechanisms for long-term storage and maintenance of the collected data are usually organized. However, this does not necessarily mean that the collected data are made openly or freely available, as some observation networks restrict data access to members of the network.

Ocean observing systems, primarily established for research purposes, will also have to establish a procedure to ensure long-term storage and curation of the data collected. Research-targeted systems will have less strict requirements for making their datasets available in near-real time, compared to systems established to serve e.g. climate services or operational oceanography. However, it is important that all research data are made available without undue delay or at least in a timely manner and supported by adequate documentation of both processing and quality control undertaken as part of the scientific studies in which the data have been applied.

Most national and international research projects today have a contractual obligation to make their data openly available. Unfortunately, the present situation of getting considerable credit for scientific publications and little or no credit for making data available, compels scientists to prioritise journal papers over data publishing. Despite this, there still is further need for research-targeted systems to make collected data openly available through mature data infrastructures, using standard formats for metadata and data, and with associated documentation to support re-use.

3.2. Requirements for in-situ ice-ocean data collection

Most requirements presented for in-situ ice ocean data collections are defined based on needs for the ice-ocean modelling community. The requirements are given by data characteristics such as uncertainty and spatio-temporal coverage and target levels (goal, breakthrough, and threshold). This is illustrated by the set of ocean requirements is found in EU's Copernicus In-situ Component Information System (CIS2)-portal, which is based on GOOS (Global Ocean Observing System) and Copernicus specifications for Essential Ocean Variables (EOVs) and can be obtained from EU's Copernicus In-situ Component Information System (CIS2)-portal (https://cis2.eea.europa.eu), which will be public accessible in autumn 2018.

The requirements of the variables presented in the OSCAR-database from WMO and Copernicus portal (see Table 3) are suited for meteorological, satellite remote sensing, ice ocean modelling and for gridded combined products. These products correspond to level 3-4. Ocean in-situ data are important component of the derived products. However, ocean in-situ observing systems provide data collection from Level 0 to 2, e.g. point measurements or sections in a variety of time windows. Level 3 and level 4 data requires spatial interpolation and use of modelling to produce reanalysis fields, which is not within the scope of this study.

Requirements defined by WMO and Copernicus are mainly addressing level 3 and level 4 data sets needed for the modelling and forecasting services under these organisations. The requirements from WMO and Copernicus are therefore not directly applicable for assessing ice-ocean in-situ observation system at level 1 and 2. The requirements for in-situ data collection are quite variable, depending on application areas for use of the data. Applications areas include ocean climate monitoring, ecosystem monitoring, operational services, model validation, data assimilation, environmental protection, geo-hazard monitoring, process studies and other research topics related to sea ice and ocean.

3.3. Requirements for gridded and satellite-based ocean variables

Requirements for satellite products in the Arctic (level 2 and level 3) are defined for a wide range of meteorological, oceanographical, sea ice and other thematic areas, as described in documents such as the POLARIS Gap and Impact Analysis Report, prepared for the European Space Agency in 2016 (https://www.arcticobserving.org/images/pdf/Board_meetings/2016_Fairbanks/16_Final-Gaps-and-Impact-Report---2016-04-22.pdf).

The requirements summarized in Table 3 are extracted from the CIS2 portal for the in-situ observing system for Copernicus. Table 3 presents data characteristics such as uncertainty and spatio-temporal coverage and target levels (goal, breakthrough, and threshold). The collection of requirements in the WMO OSCAR database (https://www.wmo-sat.info/oscar/requirements) is background for the table combined with requirements from the CIS2-portal, which is based on GOOS (Global Ocean Observing System) and Copernicus specifications for Essential Ocean Variables (EOVs).

Multiple sets of requirements for the same satellite product can be defined depending on application areas (climate, operational services, environmental protection, geo-hazard forecast, research development, etc.).

Table 3. *Requirements as presented by the CIS2-portal for the in-situ observing systems. The requirements are divided in three categories: Threshold, Breakthrough, and Goal. This table is based on Copernicus and GOOS specification to support their operational services.*

Name	Group	Conf. level	Uncertainty	Update Frequency	Timeliness	Horizontal resolution	Vertical resolution
Bathymetry	Ocean	Firm	10m 5m 1m			5 km 1 km 100 m	5 m 2 m 1 m
Chlorophyll	Ocean		0.2 mg/m3 0.1 mg/m3 0.01 mg/m3	5d 2d 1d	2d 1d 6h	60 km 10 km 5 km	10 m 5 m 1 m
Nutrients	Ocean	Firm	25% 10% 10%	90d 30d 7d	7d 3d 1d	100 km 10 km 1 km	100 m 10 m 1 m
Oxygen	Ocean	Firm	25% 10% 10%	90d 30d 7d	7d 3d 1d	100 km 50 km 10 k	100 m 10 m 1 m
pH	Ocean	Firm			7d 3d 1d		
River Discharge	Ocean	Firm		7d 1d 6h	7d 1d 6h		

Sea Ice Cover	Ocean	Firm	15% 10% 5%	3d 1d 1d	3d 1d 1d	0.1 km 0.1 km 0.1 km	
Sea state	Ocean	Firm	0.25 m 0.25 m 0.1 m	24h 3h 6min	6h 1h min	60 km 10 km 5 km	N/A N/A N/A
Sea surface height anomaly	Ocean	Firm	0.1 m 0.07 m 0.05 m	3d 1d 6h	3d 2d 1d	50 km 25 km 10 km	
Sea Surface Salinity	Ocean	Firm	0.1 psu 0.07 psu 0.05 psu	72d 24d 6d	3 d 2 d 1 d	25 km 10 km 5 km	
Sea surface Temperature	Ocean	Firm	0.5 K 0.2 K 0.1 K	3d 24h 6h	3h 2h 1h	25 km 10 km 5 km	
Subsurface currents	Ocean	Firm	50 cm/s 20 cm/s 10 cm/s	3d 1d 6h	3h 2h 1h	100 km 50 km 10 km	50 m 10 m 1 m
Subsurface salinity	Ocean	Firm	0.1 psu 0.07 psu 0.05 psu	12h 3h 1h	1d 6h 3h	30 km 5 km 1 km	100 m 10 m 1 m
Subsurface temperature	Ocean	Firm	1 K 0.5 K 0.1 K	24d 3d 1d	3d 1d 12h	50 km 10 km 2 km	50 m 10 m 1 m
Surface currents	Ocean	Firm	20 cm/s 10 cm/s 5 cm/s	3d 1d 2h	3d 1d 6h	20 km 5 km 1 km	

(1) "Conf level" is applied as in the OSCAR database. It refers to the confidence on which the given requirement is trusted (e.g., "firm" when the value is a well quantified goal in the pertinent community, "reasonable" when the value is quantified with robust arguments but it is not so widely applied as in the case of "firm", and "tentative" when the value is a first guess, based only on the experience of the person setting it).

4. Assessment of present observing capacities and gaps

In this chapter we present and briefly discuss the responses to the QA (observing systems), QB (data collections) and QC (remote sensing data/products). However, the first evaluation of platforms was not part of the Questionnaire, but the "choice" of platform has strong implications to the observing capacities.

4.1. Evaluation of the platform categories

In Table 4 we evaluate the different categories of platforms used in ice-ocean observing systems**.** Common for all platforms used in ocean observing systems are that they all capable to provide multidisciplinary usage, they have high technological level and they are robust for use in open ocean. The choice of platforms has consequences for the for the spatial coverage, timeliness, and robustness in ice.

Although, *fixed bottom anchored moorings and sea floor installations* are robust during operation, the ice cover introduce more complexity during the deployment and recovery process. The spatial coverage is limited in horizontal to the deployment sites, while the vertical resolution will depend on the number of instruments in the water column and if there are profiling instruments. Instruments in such platforms provide year-round observations at as high temporal resolution as is wanted, only limited by power and data storage. In general, these platforms have to be recovered to make data available. To secure data in real-time from underwater observing systems one need cables to shore. *Cabled systems* are however not implement in the ice-covered Arctic.

Moving and profiling platforms provide data in real-time or near real-time. Argo-floats are the main source of oceanographic data in open ocean, but they are not presently used in the Arctic (see http://www.argo.net). Argo-floats and gliders operations in ice covered regions are difficult, and they will need an underwater geo-positioning system installed during the operation both to navigate but also to provide meaningful data. Acoustic positioning of gliders has been used in the Arctic, and drifting RAFOS floats have been used in decades. (e.g. Mikhalevsky et al. 2015).

Ice tethered buoys are the only platforms proving year-round real-time data from the high Arctic, however these buoys are not robust to harsh sea ice dynamics as found in Marginal Ice Zones. Manned ice-camps are robust and deliver data in real time but are expensive and time-limited.

Tide gauges, are geographical fixed points along coastal regions of the Arctic. They are surface installation providing real time data, but they are not working in sea ice conditions.

Unmanned aerial vehicles (UAV) are currently under development for use in the Arctic.

Vessels are robust both in ice and in open ocean during normal wind and wave conditions, but field campaigns are mostly miss the winter season.

Table 4. ***Brief evaluation of the observing platforms used in ocean observing systems.***

Platform category	TRL 1-9 in ice	Robust-ness in ice	TRL 1-9 in ocean	Robust-ness in open ocean	Relevant Variables	Confidence level of measured variable	Delivery mode	Vertical coverage	Horizontal coverage
Fixed moorings	9	high	9	high	subsurface physical and biochemical variables	Firm	Delayed mode	Point measurements at selected depths or	Fixed geographical positions

								profiling instruments	
Sea floor network	Not tested	Not tested	9	high	subsurface physical and biochemical variables	Firm	Delayed mode	Point measurements at selected depths or profiling instruments	Fixed geographical positions
Cabled networks	?	?	9	high	subsurface physical and biochemical variables	Firm	Real time mode	Point measurements at selected depths or profiling instruments	Fixed geographical positions
Floats	5	low	9	high	subsurface physical and biochemical variables	Firm	Near real time	profiling instruments	Drifting
Gliders	5	low	9	high	surface and subsurface physical and biochemical variables	Firm	Real time	profiling instruments	Remote controlled
Sea Ice buoys	9	high	N/A	N/A	subsurface physical and biochemical variables	Firm	Real time	Point measurements at selected depths or profiling instruments	Drifting
Manned camps	9	high	N/A	low	subsurface physical and biochemical variables	Firm	Real time	Point measurements at selected depths or profiling instruments	Drifting
Repeated sections with ships	9	high	9	high	surface and subsurface physical and biochemical variables	Firm	Real time	Profiling instruments	Controlled
Repeated sections with aircrafts	9	medium	9	high	Surface observations		Real time	?	
Ship of opportunity-based network	9	high		high	subsurface physical and biochemical variables		Real time	Point measurements at selected depths	Controlled
Tide gauge network	N/A	N/A	9	N/A	Sea Surface Height Anomaly	Firm	Near real time	Point measurements	Fixed geographical positions

UAV	5	medium	5	medium	Surface observations	Medium	Real time		Remote controlled

4.2. In-situ Ocean and Ice Observations System

4.2.1. General information

The list of the assessed observation networks/systems, the coordinating body of the observing system, the platforms used, the addressed Arctic relevant variables (e.g. Essential Climate Variables (ECVs), Essential Ocean Variables (EOVs), Essential Biodiversity Variables, and others), their data repositories, and the coordinating agencies are given in Table 5.

It is not possible to assess all the existing observing systems and data collections in the Arctic, so we focus on those observing systems that are most relevant in the project. This can be done by comparing the observing systems assessed in INTAROS (Table 4) with the Global Climate Observing Systems (GCOS) and the Arctic observing systems assessed in the Polar View report from 2016 (POLARIS Gap and Impact Analysis Report).

Regarding assessment of **Sea Ice and Sea Surface Temperature**, we can refer to work done in the ERA-CLIM2 project, Deliverable D3.15 (http://www.era-clim2.eu/products).

Table 5. *Existing Ocean and sea ice in-situ observing systems assessed in INTAROS listed in alphabetical order.*

Observation System	Coordinated by	Platforms	Variables	Geographical Area
A-TWAIN	IMR / NPI	Moorings	Subsurface Temperature, salinity, current velocity, sea state	North of Svalbard and southern Nansen Basin
A-TWAIN Poland	IOPAN	Moorings	Subsurface Temperature, salinity, current velocity	North of Svalbard and southern Nansen Basin
AREX (Long-term large-scale monitoring program)	IOPAN	Repeated sections	Subsurface Temperature, salinity, current velocity, oxygen	Nordic Seas, Fram Strait, North of Svalbard
Argo Poland	IOPAN	Buoys	Acoustic travel times, Subsurface Temperature, salinity, current velocity	Nordic Seas, Fram Strait
Canada Basin Acoustic Propagation Experiment	SIO	Moorings	Acoustic travel times, passive acoustics, temperature, salinity, current	Beaufort Sea
Everyone's Glider Observatories (EGO)	CNRS LOCEAN	Gliders	Subsurface temperature and salinity, surface current, biogeochemical variables	Fram Strait
FRAM - (FRontiers in Arctic marine Monitoring)	AWI	Buoys, Moorings, Vessels	Numerous physical, biological and biogeo-chemical parameters in air, ice and ocean.	Fram Strait and high Arctic
Fram Strait Multipurpose Acoustic System	NERSC	Moorings	Acoustic travel times, passive acoustics, temperature, salinity, current	Fram Strait
Greenland Ecosystem Monitoring Programme	AU	Moorings, Vessels	Temperature, salinity, nutrients, chlorophyll a, PAR, turbidity, fluorescence, plankton species composition	2 stations on Greenland
IMR Barents Sea Opening mooring array	IMR	Moorings	Temperature and current velocity	5 moorings across the western Barents Sea.
IMR Barents Sea Winter Survey	IMR	Vessels	Temperature, salinity, nutrients, primary / secondary production, abundance, size, age, distribution of many fish stocks.	North-East Atlantic and high arctic
IMR fixed hydrographic sections	IMR	Vessels	Temperature, salinity, nutrients, Primary production, secondary production	Gimsøy-NW, Sem Islands N, Vardø N, Fugløya-Bear Island, Bear Island-W, Polhavet
IMR fixed hydrographic sections (near coast)	IMR	Vessels	Temperature, salinity, nutrients, Primary production, secondary production	Ingøy, Eggum, Skrova
IMR SI Arctic vessel mounted ADCP system	IMR	Vessels	Surface and subsurface current velocities	Ocean area around Svalbard
IMR-PINRO Ecosystem Survey	IMR	Vessels	Surface and subsurface current velocities	Barents Sea
International Arctic Buoy Programme	APL-UW, USA	Ice buoys	Ocean surface stress, Sea surface temperature, Surface currents, Sea-surface salinity, Sea-ice parameters	Arctic Ocean
IOC Tide Gauges in Greenland	DTU	Tide Gauges	Sea Surface Height Anomaly	4 stations on Greenland
IOPAN Long-term Monitoring in Svalbard Fjords	IOPAN	Vessels	Subsurface temperature, Subsurface salinity, Subsurface oxygen, Subsurface currents, Ocean turbulence	West Spitsbergen fjord Hornsund
NIVA Barents Sea Ferry Box	NIVA	Vessels	Temperature, salinity, chlorophyll a fluorescence, turbidity, dissolved oxygen, pH, pCO2,	Barents Sea opening
NorArgo	IMR / NorArgo	Buoys	Temperature, salinity, pressure and currents. Interior ocean oxygen concentration and fluorescence (chlorophyll-a).	Fram Strait
SIOS Airborne Infrastructure	Norut	Airborne Sensors	Surface currents, Sea state, Sea-ice parameters, Ocean colour	Svalbard
Station Mike: ICOS observing system	UiB and Uni Research	Mooring, buoy	Temperature, salinity, oxygen, chlorophyll and carbon parameters	Norwegian Sea
UNIS ocean observing System	UNIS	Moorings	Subsurface Temperature, salinity, current velocity, sea level, Oxygen	Svalbard

4.2.2. Spatial and temporal observation gaps

The spatial and temporal gaps of the observing system is highly dependent on the platforms. Table 4 show that the assessed ocean observing systems are based on different in-situ platforms, which either can be in fixed position (Fig. 35 left) or be floating/moving (Fig 35 right). Most of the assessed systems are based on moorings and repeated shipborne measurements which are robust and has a high TRL level, but they deliver data on an in delayed mode and on irregular basis, depending on weather conditions, season and research funding. In general, moving platforms are providing data with high spatial (along the track), but the data is aliased with time, which should be accounted for when analysing data. Geographically fixed installations (seabed fixed moorings and few terrestrial tide gauges) will provide a cleaner temporal variability in the observations, but with much less spatial coverage

Platforms such as buoys, gliders, floats and tide-gauges provide continuous data in real or near-real time. Floats cannot surface to send data or get geo-position from satellites in sea-ice covered regions and therefore Argo Floats are not present in the ice-covered Arctic. Ice tethered buoys are the counterpart of Argo Floats in this region, but vulnerable to the harsh environment in marginal ice-zones.

Vessels provide data during shorter campaigns and are therefore limited in time and space. Repeated campaigns along the same sections provides information on inter-annual variability of given season (mostly summer).

The maps in Fig. 36 show the spatial coverage of the assessed observing systems with fixed geographically locations.

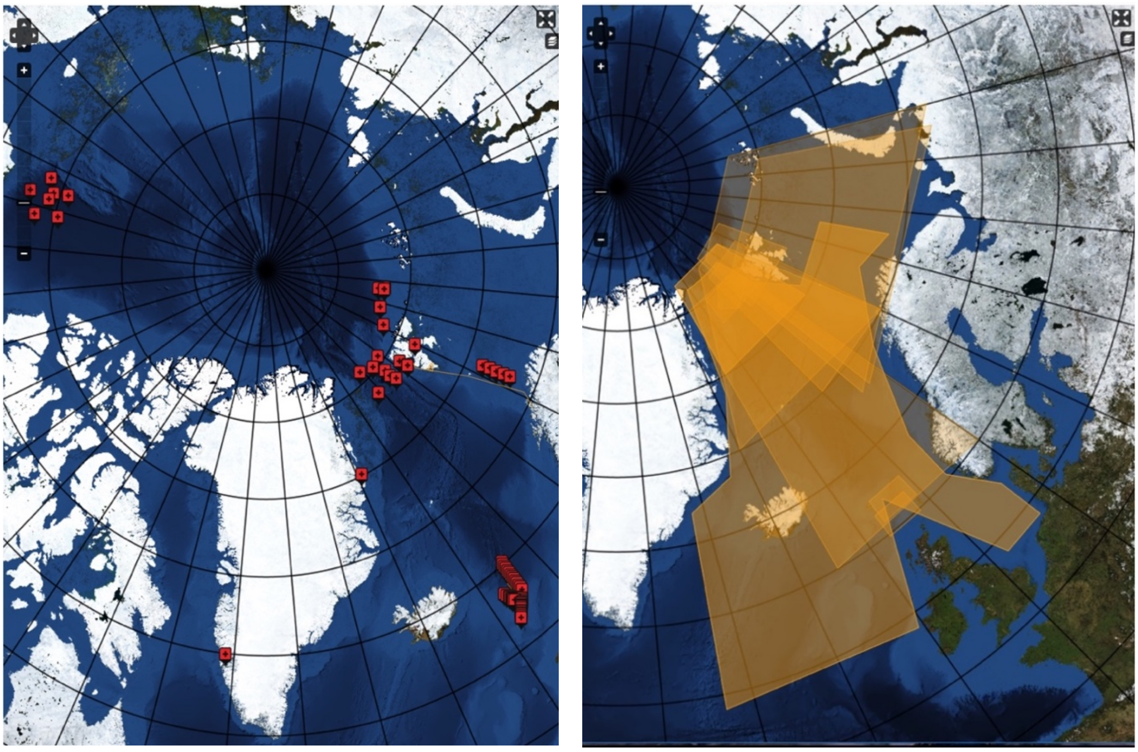


Figure 36. Left: a map of the stationary ocean observing systems. Right: map of general areas where observing systems use moving platforms (ships, buoys and gliders).

Most of these systems are limited in an area of the North Atlantic, around Greenland and Fram Strait. The map will be extended with more entries as the QA of the survey is now open for external responders. Also, for the areas investigated by moving and drifting observing systems, we address the observing systems mainly in the eastern Arctic. Furthermore, the map shows the coverage accumulated from 2004-2017 and is not representative for spatial coverage of individual years. The temporal coverage of the observing systems is presented in Table 6.

This assessment covers mostly the observations of INTAROS-partners, and therefore lacking systems from other institutes, in particular from non-EU institutes, which would improve the spatial coverage.

Table 6. ***Gantt-chart with temporal resolution and coverage of the observing systems.***

			Summer period		Winter period		all year	Irregular										
Observation System	**Position (stationary/moving)**	**Platform**	**until 2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
A-TWAIN (including A-TWAIN Poland)	Stationary	Moorings																
AREX (Long-term large-scale monitoring program)	Stationary	Repeated sections	1987 -															
Argo Poland	Moving	Buoys																
Svalbard fjords hydrography and ocean-glacier interactions	Stationary	Repeated sections	1999-															
Canada Basin Acoustic Propagation Experiment (CANAPE 2016)	Stationary	Moorings																
FRAM - Buoys	Moving	Buoys	1999-															
FRAM - Fram strait ocean mooring array	Stationary	Moorings	1997-															
FRAM - Gliders	Moving	Gliders	2007-															
FRAM - HAUSGARTEN	Stationary	Moorings	1999-															
FRAM - Vessels	Moving	Vessels	1999-															
Fram Strait Multipurpose Acoustic System	Stationary	Moorings																
Greenland EcoSystem Monitoring Program	Stationary and Moving	Moorings, Vessels	1994 -															
IMR Barents Sea Opening mooring array	Stationary	Moorings	Start August 1997															
IMR Barents Sea Winter Survey	Moving	Vessels	1976 - Januar and Februar															
IMR fixed hydrographic sections - Bear Island-W	Moving	Vessels	1969 -															
IMR fixed hydrographic sections - Eggum	Moving	Vessels	1936 -															
IMR fixed hydrographic sections - Fugløya-Bear Island	Moving	Vessels	1953 -															
IMR fixed hydrographic sections - Gimsøy-NW	Moving	Vessels	1957 -															
IMR fixed hydrographic sections - Ingøy	Moving	Vessels	1936 -															
IMR fixed hydrographic sections - Polhavet	Moving	Vessels																
IMR fixed hydrographic sections - Sem Islands	Moving	Vessels	1956 -															
IMR fixed hydrographic sections - Skrova	Moving	Vessels	1936 -															
IMR fixed hydrographic sections - Vardø-N	Moving	Vessels	1953 -															
IMR SI_Arctic vessel mounted ADCP system	Moving	Vessels												Start August 2014				
IMR-PINRO Ecosystem Survey	Moving	Vessels		August and September														
International Arctic Buoy Programme	Moving	Ice buoys array																
IOC Tide Gauges in Greenland	Stationary	Tide Gauges																
NIVA Barents Sea Ferry Box	Moving	Vessels																
NorArgo	Moving	Buoys										June 2012 -						
R/V Håkon Mosby	Moving	Vessels	2002 -															
SAVN (Faerose National History Museum)	Stationary	Community Based	1584 -															
UNIS ocean observing System	Stationary	Fixed Moorings																

The table reflects that a good portion of the observation systems are collecting data irregularly or during specific seasons.

The essential ocean variables, which are listed in Table 7, are defined by Copernicus and GOOS (http://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114). It shows that all of the physical variables belonging to the essential ocean variables are covered by the in-situ observing systems. In particular, the subsurface physical variables are measured by most of the observing systems. Oxygen, inorganic nutrients, the carbonate system, ocean colour and inorganic carbon concentration are measured by a few of the observing system, where the other biochemical variables are not measured by any of the observing systems in this report. Phyto-plankton and other biomass variables are measured by some of the vessel-based observing systems.

Table 7. ***Overview of observed variable for each observing system***

		A-TWAIN	A-TWAIN Poland	AREX (Long-term large-scale monitoring program)	Argo Poland	Canada Basin Acoustic Propagation Experiment (CANAPE 2016)	FRAM - (FRontiers in Arctic marine Monitoring)	Fram Strait Multipurpose Acoustic System	Greenland Ecosystem Monitoring Programme	IMR Barents Sea Opening mooring array	IMR Barents Sea Winter Survey	IMR fixed hydrographic sections	IMR fixed hydrographic stations (near coast)	IMR SI_Arctic vessel mounted ADCP system	IMR-PINRO Ecosystem Survey	International Arctic Buoy Programme	IOC Tide Gauges in Greenland	IOPAN Long-term Monitoring in Svalbard Fjords	NIVA Barents Sea Ferry Box	NorArgo	R/V Håkon Mosby	SAVN (Faeroese National History Museum)	SIOS Airborne Infrastructure	UNIS ocean observing System
Physical variables	Sea Surface Temperature (SST)								X	X	X	X	X		X	X				X				
	Subsurface Temperature	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X			X
	Sea Surface Salinity (SSS)								X	X	X	X	X		X	X				X				
	Subsurface Salinity	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X			X
	Surface Currents									X	X			X		X				X			X	
	Subsurface Currents	X	X	X	X	X	X	X		X	X			X		X		X		X				X
	Sea Surface Height(SSH)	X															X							X
	Sea State		X				X		X							X							X	
	Sea Ice		X				X		X							X							X	
	Ocean sound/ Acoustic Noise						X	X																
	Ocean Surface stress															X								
Biochemical variables	Oxygen	X	X		X		X					X	X		X			X	X	X			X	
	Inorganic macro nutrients						X				X	X	X		X					X				
	Carbonate system						X			X	X				X									
	Transient tracers																							
	Suspended particulates																							
	Nitrous oxide																							
	Carbon isotope (^{13}C)																							
	Dissolved organic carbon						X			X	X	X	X		X									
	Ocean colour						X												X	X			X	
Biology and Ecosystems	Phytoplankton biomass and diversity						X		X			X			X									
	Zooplankton biomass and diversity						X				X	X			X									
	Fish abundance and distribution										X				X							X		
	Marine birds, mammals abundance and distribution														X							X		
	Live coral cover														X									
	Microbes																							

4.2.3. Observing systems and potential environmental impact

Very few observing systems reported any environmental impact at all. One exception was that the *International Arctic Buoy Program* reported that many of the drifting buoys is not recovered and will therefore be deposited into the ocean. Fixed moorings are in general recovered, and ideally, only the steel anchor is left behind after recovery. However, sometimes the moorings are lost, and all the instruments, wire, cables remain in the ocean environment.

Manned camps do also produce vast and noise during human activities. Human activities can be use of helicopters, aircrafts, hovercrafts, and snow mobiles. After the manned camps are completed the equipment is brought back.

Acoustic multipurpose observing systems produce sound and goes routinely through an environmental assessment prior to deployment to ensure no impact on marine life. Other observing systems involving acoustic equipment such as Acoustic Doppler Current Profilers, acoustic modems, and upward looking sonars are not going through any environmental assessment prior to deployment. This is however not considered to be critical as the frequency is high and is relatively rapidly attenuated.

Sound from open ocean vessels are known to contribute to the ambient noise levels in the oceans. Icebreakers in heavy ice is known to produce significant amount of acoustic noise (e.g. Geyer et al, 2016), and it is therefore important to coordinate ice breaker activities and to choose routes with not to heavy ice. Ships in the Arctic may also pollute the environment with waste water and exhaust. Noise in the Arctic has been addressed in many forum, but so far no negative effects from the sources discussed here have been observed.

4.2.4. Maturity of the observing system

The maturity of the observations systems is defined by a set of criteria described below. In the survey a maturity level between 1 and 6 is selected, and the results are summarized in Table 8.

Scientific and expert support: The degree of scientific and technical expertise that underpins the measurement program.

1. None (No scientific or technical support is available)
2. Minimal scientific support required to sustain the program is available, sufficient to maintain the measurement program at present state, but not in case of major failure or breakdown of the observing system
3. Technical expertise is available to support operation of the observing system
4. As in (3) + at least two technical experts to secure the measurement program operation
5. *N/A*
6. As in (4) + research and development to ensure that the observing system is based on state of the art technology

Funding support: The long-term financial support that underpins the measurement program.

1. None (No dedicated funding support is evident for the measurement program)
2. Project based funding support available
3. As in (2) + expectation of follow on founding
4. As in (3) + not dependent upon a single investigator or funding line
5. Sustained infrastructure support available to finance continued operations for as far as can be envisaged given national and international funding vagaries
6. As in (5) + support for active research and development of instrumentation or applied analysis of the observations

Site representativeness (for terrestrial stations):

1. Unknown
2. *N/A*
3. The site only represents the immediate surrounding environment
4. The site is representative of a broader region around the immediate location
5. As in (4) + the site environment is likely to be unchanged for decades
6. As in (5) + the long-term site representativeness is guaranteed, e.g. due to protected area.

Data storage:

1. Data are not stored in any institutional repository, but in a personal repository.
2. Data are stored in an institutional/departmental repository
3. Data are stored in distributed repositories (institutional and not)
4. Data are stored in a National repository according to legal constraints on their location
5. Data are stored in National data repositories without legal constraints on their location
6. Data are stored in International data repositories

Data access: Level of open distribution of data, documentation of data, and any software to process the data from raw measurement to geophysical variables needed by the users. The highest scores in this category can only be attained for data provided free of charge without restrictions on use and reuse.

1. Unknown
2. Data is available request to trusted users or through supervision by originator
3. Data is available on automated request through originator
4. Data and documentation are available on supervised request through originator
5. Data and documentation are available on automated request through originator
6. As (5) + source data, code and metadata available upon request or automated without any restrictions

User feedback: Level of established mechanisms to receive, analyse and ingest user feedback.

1. None
2. Ad hoc feedback (which may be acted upon)
3. Programmatic feedback (systematic collection of user feedback related to the measurements and dissemination of lessons learnt)
4. As in (3) + consideration of published analyses
5. Established feedback mechanism and international data quality assessment results are considered
6. As in (5) + Established feedback mechanism and international data quality assessment results are considered in continuous data provisions

Updates to record: Level of systems in place to update data records when new observations or insights become available.

1. None (No update is made to the measurement series or data products after initial release)
2. Irregularly following accrual of a number of new measurements scientific exchange and progress or new insights
3. *N/A*
4. Regularly updated with new observations and utilizing input from established feedback mechanism
5. Regularly operationally by stable data provider as dictated by availability of new input data or new innovations
6. As in (5) + initial version of measurement series or data products shared in near real time.

Version control: Level of measure taken to trace back the different versions of algorithms, software, format, input and ancillary data, and documentation used to generate the data record under consideration.

1. None
2. Versioning by data collector
3. N/A
4. Version control institutionalized and procedure documented
5. Fully established version control considering all aspects
6. As in (5) + all versions retained and accessible upon request

Long term data preservation: Level of Long Term Data Preservation according to ESA-guidelines (http://earth.esa.int/gscb/ltdp/).

1. None
2. Local archive retained by measurement collector
3. *N/A*
4. Each version archived at an institutional level on at least two media
5. Data, raw data and metadata is archived at a recognized data repository, national archive, or international repository.
6. As in (5) + all versions of measurement series, metadata, software etc. retained, indexed and accessible upon request.

Table 8. *Maturity matrix for the observing system regarding sustainability and data management*

Observation System	Platform	Sustainability			Data Management						Data repository
		Scientific and expert support	Funding support	Site representativeness*	Data storage	Data access	User feedback	Updates to record	Version control	Long term data preservation	
A-TWAIN	Moorings	5	3	N/A	2	6	1	2	2	4	Norwegian Polar Data Centre
A-TWAIN Poland	Moorings	4	3	N/A	3	5	2	2	2	2	IOPAN database
AREX (Long-term large-scale monitoring program)	Repeated sections	4	4	N/A	6	5	2	3	2	3	IOPAN database
Argo Poland	Buoys	4	3	N/A	6	6	1	3	4	4	ARGO GDAC (Coriolis)
Canada Basin Acoustic Propagation Experiment (C	Moorings	3	2	N/A	2	2	2	2	2	3	Scripps Institution of Oceanography
FRAM - (FRontiers in Arctic marine Monitoring)	Buoys, Moorings, Vess	6	5	N/A	6	5	2	4	4	4	PANGAEA
Fram Strait Multipurpose Acoustic System	Moorings	3	2	N/A	2	2	1	2	2	3	NERSC (harvested by NMDC and NorDataNet
Greenland Ecosystem Monitoring Programme	Moorings, Vessels	5	6	5	2	4	2	2	2	3	GEM database
IMR Barents Sea Opening mooring array	Moorings	5	4	N/A	4	3	2	2	1	4	NMDC and ICES
IMR Barents Sea Winter Survey	Vessels	4	6	N/A	4	5	2	4	1	4	NMDC and ICES
IMR fixed hydrographic sections	Vessels	5	5	N/A	4	4	2	3	1	4	NMDC and ICES
IMR fixed hydrographic sections (near coast)	Vessels	4	5	N/A	2	3	2	3	1	3	NMDC and ICES
IMR SI_Arctic vessel mounted ADCP system	Vessels	4	3	N/A	4	3	2	3	1	4	NMDC and ICES
IMR-PINRO Ecosystem Survey	Vessels	5	6	N/A	2	6	2	3	1	4	NMDC and ICES
International Arctic Buoy Programme	Ice buoys array	4	4	N/A	2	3	1	4	1	1	
IOC Tide Gauges in Greenland	Tide Gauges	3	3	3	4	3	2	2	2	3	IOC and DTU
IOPAN Long-term Monitoring in Svalbard Fjords	Vessels	4	4	N/A	6	6	5	4	1	5	IOPAN database
NIVA Barents Sea Ferry Box	Vessels	6	4	N/A	1	4	2	2	2	3	NIVA database
NorArgo	Buoys	6	3	N/A	6	6	5	4		5	
R/V Håkon Mosby	Vessels	5	5	N/A	3	4	2	3	2	3	NMDC
SAVN (Faerose National History Museum)	Community Based	missing			missing						
SIOS Airborne Infrastructure	Airborn Sensors	3	4	N/A	2	2	2	2	2	3	
UNIS ocean observing System	Fixed Moorings	4	4	N/A	2	2	2	2	2	3	

*(for terrestrial stations only)

In general, is the scientific and expert support to the observing systems on a medium or high level. Repeated sections with vessels, including ferry boxes between Norway and Svalbard scores high on funding support, while the other observing systems scores medium or low. In terms of data management, does most observing systems provide free access to a data storage, but is lacking systematic support functions and information. The data management for moorings scores in general lower than other observing systems.

Table 8 shows that the application areas for the ice-ocean in-situ systems are primarily addressing climate and process-oriented research and partly supporting services. Six of the systems are used for climate services, and 2-3 of the systems provide information to the other categories. IMR-PINRO Ecosystem Survey is usable in most of the application areas.

4.2.5. Data usage

The observing systems have been assessed according to their usefulness in nine applications areas, as shown in Table 9 and in the pie chart (Fig. 37).

Table 9. ***Application areas supported by the different observing systems.***

Observing System	Climate research and Monitoring	Process oriented research	Research supporting operational services	Opera-tional services	Climate services	Public exploit ation	Commer-cial explo-itation-	Environ-mental assess-ment	Risk assess ment
A-TWAIN	X	X	X	X					
A-TWAIN Poland	X	X	X	X					
AREX (Long-term large-scale monitoring program)	X	X	X	X					
Argo Poland	X	X		X	X	X			
Canada Basin Acoustic Propagation Experiment	X	X	X						
Everyone’s Glider Observatories (EGO)	X	X	X					X	
FRAM - (FRontiers in Arctic marine Monitoring)	X	X							
Fram Strait Multipurpose Acoustic System	X	X	X						
Greenland Ecosystem Monitoring Programme	X								
IMR Barents Sea Opening mooring array	X	X	X						
IMR Barents Sea Winter Survey	X	X	X				X		
IMR fixed hydrographic sections	X	X	X				X		
IMR fixed hydrographic sections (near coast)	X	X	X						
IMR SI_Arctic vessel mounted ADCP system	X		X	X					
IMR-PINRO Ecosystem Survey	X	X	X		X		X	X	X
International Arctic Buoy Programme	X	X		X		X			
IOC Tide Gauges in Greenland	X			X	X				
IOPAN Long-term Monitoring in Svalbard Fjords	X	X	X						
NIVA Barents Sea Ferry Box	X	X	X		X	X			
NorArgo	X	X	X		X				
SIOS Airborne Infrastructure	X	X	X					X	

Station Mike: ICOS observing system	X	X	X		X			X	
UNIS ocean observing System	X	X	X						

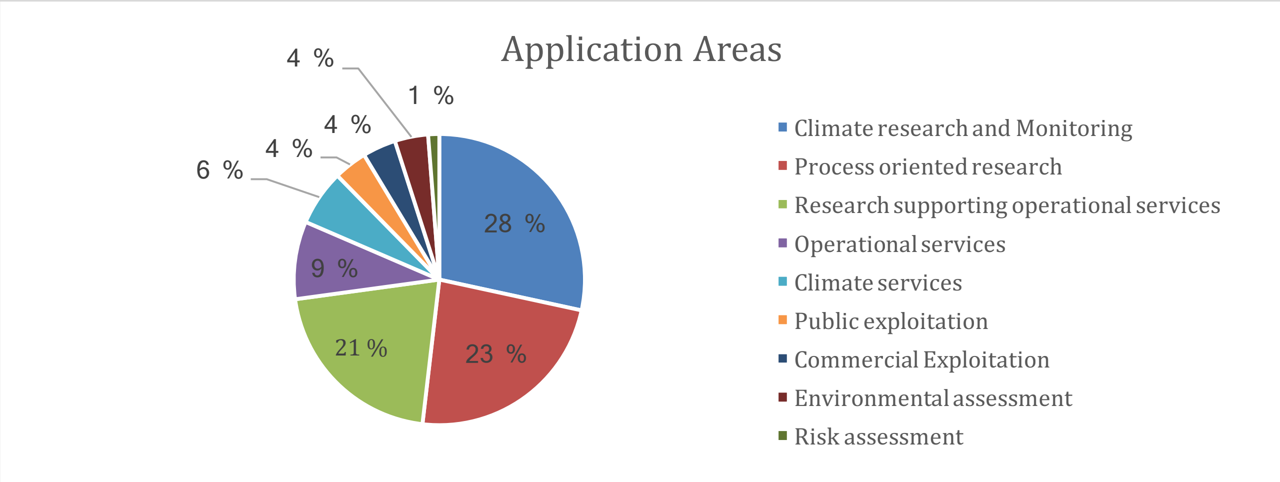


Figure 37. Distribution of the assessed observing systems among nine application areas. Several systems are registered in more than one application.

4.3. In-situ data collections

The various data collections belonging to an observing system have generally different characteristics in terms of traceability, uncertainty, resolution. Most of these characteristics depend on the applied instrumentation. The data assessment is performed by analysing the responses obtained through questionnaire B. The assessment includes presentation and brief analysis of the maturity matrices established for data collections. Special emphasis is put on the general information about data collections such as observed variables, applied instrumentation, to a certain degree the temporal/spatial coverage and information about the uncertainty, and metadata documentation.

4.3.1. General information

The key information on the assessed data collections is presented in Table 10. This information has been collected through Questionnaire B, section 1: General information about the data collection. A synthesis of the Technology readiness level (TRL) of the instruments used to generate the assessed data collection is provided here. The definition of the TRL levels are given in Table 1 in section 3. The main fining is that all instruments used has a readiness level 8-9, except for five biological/biogeochemical instruments which has go the response ‘not applicable’.

Table 10. ***List of specific ocean and sea ice data collections from Questionnaire B. The Technology Readiness Level of the instruments applied to measure/derive the assessed variables is marked.***

Data collection	Variables measured	Observing system data collections belongs to	Instruments used	TRL Level
A-TWAIN CTD hydrography September 2012 and September 2013	Subsurface temperature, Subsurface salinity	A-TWAIN	CTD SBE 911plus	TRL9
A-TWAIN mooring hydrography and current data Sep 2012 - Sep 2013	Subsurface temperature, Subsurface salinity, Subsurface currents, Sea surface temperature, Surface currents, Sea-surface salinity	A-TWAIN	RDI 300 kHz Sentinel ADCP, SBE37 microcatm RDI 300 kHz Sentinel ADCP	TRL9
A-TWAIN mooring hydrography and currents	Subsurface currents	A-TWAIN	RDI Workhorse ADCP, 150kHz	TRL9
A-TWAIN mooring hydrography and currents	Subsurface currents	A-TWAIN	RDI Workhorse ADCP, 300kHz	TRL9
A-TWAIN mooring hydrography and currents	Subsurface currents	A-TWAIN	Nortek Continental ADCP	TRL9
A-TWAIN mooring hydrography and currents	Subsurface temperature, Subsurface salinity	A-TWAIN	Seabird microcat SBE37	TRL9
A-TWAIN mooring hydrography and currents	Subsurface temperature, Subsurface salinity	A-TWAIN	Seabird Microcat SBE37, Seabird Seacat SBE16	TRL9
ArgoPoland	Subsurface temperature, Subsurface salinity, Subsurface currents, Sea surface temperature, Sea-surface salinity	ArgoPoland	ARVOR (NKE, France)	TRL9
AWI Polarstern VM ADCP measurements	Subsurface currents, Surface currents	FRAM	Vessel Mounted Acoustic Doppler Current Profiling (VM-ADCP) Teledyne RDI Ocean Surveyor, 153.6 kHz	TRL9
Benthic oxygen fluxes in the Arctic Fram Strait	Oxygen	FRAM	Oxygen optode, Aanderaa, type 3830-301 Oxygen microsensor, Clark type. Optical oxygen microsensor	TRL9
Biogenic particle flux at the FRAM observatory from mooring sediment traps	Suspended particulates	FRAM	Moored sediment traps	TRL9
Biogeochemical parameters from deep-sea sediments taken at the long-term observatory AWI-HAUSGARTEN	Benthic ecology	FRAM	Video guided Multicorer (for targeted and undisturbed sediment sampling)	TRL9
High resolution sea-bed photographs and footage from	Marine biodiversity, Epibenthic	FRAM	OFOS (Ocean Floor Observation System)	TRL9

repeated long term surveys for fauna investigations	megafauna abundance and distribution			
Inorganic nutrients measured on Fram-Strait water samples since 1997	Nutrients (Interior ocean concentrations of silicate, phosphate, nitrate)	FRAM	CTD/Rosette	TRL9
Ship borne CTD surveys of oxygen and chlorophyll	Oxygen (interior ocean oxygen concentration), Chlorophyll	FRAM	Seabird SBE 43 Oxygen Sensor (O2) WET Labs ECO AFL/FL Fluorometer (Chl) Dr. Haardt Instruments Fluorometer (Chl)	TRL9
Ship borne CTD surveys of temperature and salinity	Subsurface temperature, Subsurface salinity, Sea surface temperature, Sea-surface salinity	FRAM	Seabird SBE 911plus CTD (T, S)	TRL9
ACOBAR-2010-2012-acoustic traveltimes	Acoustic travel time	Fram Strait Multipurpose Acoustic System	Acoustic sources and receiver arrays	TRL9
ACOBAR-2010-2012-ambient-noise	Ambient noise	Fram Strait Multipurpose Acoustic System	Acoustic receivers	TRL9
ACOBAR:XBT measurements and derived values - Fram Strait-2010-2012	Subsurface temperature, pressure, sound speed	Fram Strait Multipurpose Acoustic System	T5 and T7 from Sippican	TRL9
DAMOCLES-2008-2009-acoustic-traveltime	Acoustic travel time	Fram Strait Multipurpose Acoustic System	Acoustic sources and receiver arrays	TRL8
DAMOCLES-2008-2009-ambient noise	Ambient noise	Fram Strait Multipurpose Acoustic System	Acoustic receivers	TRL8
DAMOCLES-2008-2009-Depth-Range-Averaged-Ocean-Temperature	Subsurface temperature	Fram Strait Multipurpose Acoustic System	Acoustic sources and receiver arrays	TRL8
ACOBAR-2010-2012-Depth-Range-Averaged-Ocean-Temperature	Subsurface temperature	Fram Strait Multipurpose Acoustic System	Acoustic sources and receiver arrays	TRL9
Greenland Ecosystem Monitoring Programme	Subsurface temperature, Subsurface salinity, Sea surface temperature, Sea-surface salinity, Oxygen	Greenland Ecosystem Monitoring Programme	Seabird 19+, 25	TRL9
Greenland Ecosystem Monitoring Programme - Nutrients	Nutrients (Interior ocean concentrations of silicate, phosphate, nitrate)	Greenland Ecosystem Monitoring Programme	Spectrophotometer (multiple different models)	N/A
Greenland Ecosystem Monitoring Programme - Plankton	Marine biodiversity	Greenland Ecosystem Monitoring Programme	Plankton nets	N/A

Greenland Ecosystem Monitoring Programme - Salinity	Subsurface salinity	Greenland Ecosystem Monitoring Programme	SeaBird 19+	TRL9
MarineBasis	Inorganic carbon	Greenland Ecosystem Monitoring Programme	Apollo Scitech DIC analyzer and total alkalinity titrator	TRL9
MarineBasis	Marine biodiversity	Greenland Ecosystem Monitoring Programme	Plankton nets	TRL9
MarineBasis	Nutrients (Interior ocean concentrations of silicate, phosphate, nitrate)	Greenland Ecosystem Monitoring Programme	Spectrophotometer	TRL8
MarineBasis	Primary production	Greenland Ecosystem Monitoring Programme	Multiple	N/A
MarineBasis	Sea-ice (sea ice concentration, sea-ice extent/edge, sea ice thickness, sea-ice drift, snow thickness, albedo and other related variables)	Greenland Ecosystem Monitoring Programme	Camera (multiple kinds)	TRL9
MarineBasis	Sea-ice (sea ice concentration, sea-ice extent/edge, sea ice thickness, sea-ice drift, snow thickness, albedo and other related variables)	Greenland Ecosystem Monitoring Programme	Ruler	TRL9
MarineBasis	Subsurface temperature	Greenland Ecosystem Monitoring Programme	Sea Bird 19+	TRL9
IMR Barents Sea Opening mooring array	Subsurface temperature, Subsurface salinity, Subsurface currents, Sea surface temperature, Surface currents, Sea-surface salinity	IMR Barents Sea Opening mooring array	Fixed mooring, CTD	TRL2
IMR Fixed hydrographic (near coastal) station network	Subsurface temperature, Subsurface salinity, Sea surface temperature, Sea-surface salinity	IMR Fixed hydrographic (near coastal) station network	CTD	TRL2
IMR fixed hydrographic sections	Subsurface temperature, Subsurface salinity, Sea surface temperature, Sea-surface salinity,	IMR fixed hydrographic sections	CTD	TRL3

	Nutrients (Interior ocean concentrations of silicate, phosphate, nitrate)			
IMR SI_Arctic vessel mounted ADCP system	Subsurface currents, Surface currents	IMR SI_Arctic vessel mounted ADCP system	Vessel-mounted Acoustic Doppler Current Profiler, VM-ADCP	TRL3
IMR-PINRO Ecosystem Survey Fish	Fish abundance and distribution, Marine biodiversity	IMR-PINRO Ecosystem Survey	Bottom trawl	TRL1
IMR-PINRO Ecosystem Survey Hydrography	Subsurface temperature, Subsurface salinity, Sea surface temperature, Sea-surface salinity	IMR-PINRO Ecosystem Survey	CTD	TRL3
IMR-PINRO Ecosystem Survey Nutrients	Nutrients (Interior ocean concentrations of silicate, phosphate, nitrate)	IMR-PINRO Ecosystem Survey	CTD rosette for water samples for later analysis in the lab	TRL2
WIFAR/UNDER-ICE acoustic recording in the Marginal Ice Zone-2012	Ambient noise	Integrated Acoustic Ice Station	Receiver arrays	TRL9
Regionally/seasonally downscaled data products of carbonate system chemistry, nutrients, and phytoplankton biomass (OCEAN)	Inorganic carbon, Nutrients (Interior ocean concentrations of silicate, phosphate, nitrate), Primary production	N/A	Various, dependent on dataset included in the reanalysis	N/A
NIVA FerryBox	Inorganic carbon	NIVA Barents Sea FerryBox	NIVA pH sensor (custom)	TRL9
NIVA FerryBox	Inorganic carbon	NIVA Barents Sea FerryBox	Franatech FerryBox pCO2	TRL8
NIVA FerryBox	Oxygen (interior ocean oxygen concentration)	NIVA Barents Sea FerryBox	Aanderaa AADI-Optode 4835	TRL9
NIVA FerryBox	Primary production	NIVA Barents Sea FerryBox	TriOS microFlu chlorophyll a fluorescence sensor	TRL9
NIVA FerryBox	Sea surface temperature	NIVA Barents Sea FerryBox	Sea-Bird SBE-45 temperature/salinity sensor	TRL9
NIVA FerryBox	Sea-surface salinity	NIVA Barents Sea FerryBox	Sea-Bird SBE-45 temperature/salinity sensor	TRL9
NIVA FerryBox	Suspended particulates	NIVA Barents Sea FerryBox	AML MicroX Turbidity sensor	TRL9
NorArgo	Subsurface temperature, Subsurface salinity, Subsurface	NorArgo	Argo float	TRL3

	currents, Sea surface temperature, Surface currents, Sea-surface salinity, Oxygen, Primary production			
EGO gliders (European Gliding obervatories)	Subsurface temperature, Subsurface salinity, Subsurface currents, Sea surface temperature, Sea-surface salinity, Suspended particulates, Ocean colour	OceanGliders (GOOS associated programme)	Gliders (all types)	TRL9
EGO gliders (European Gliding obervatories)	Subsurface temperature, Subsurface salinity, Subsurface currents, Sea surface temperature, Sea-surface salinity, Suspended particulates, Ocean colour	OceanGliders (GOOS associated programme)	Gliders (all types)	TRL9
Tide Gauges	Sea level (Regional sea level)	PSMSL (Permanent Service for Mean Sea Level)	Tide gauges	TRL9
CTD data collected with R/V Håkon Mosby 2002-2016 (a series of annual datasets)	Subsurface temperature, Subsurface salinity	R/V Håkon Mosby	CTD (manufacturer(s) and model(s) unknown)	TRL9
Digital terrain model (DTM) of the central Fram Strait	Bathymetry	RV Polarstern	SeaBeam system Hydrosweep DS-1 multibeam echosounder	TRL9
UNIS ocean observing system	Subsurface temperature, Subsurface salinity, Subsurface currents, Sea level (Regional sea level), Oxygen (interior ocean oxygen concentration)	UNIS ocean observing system	Seabird, SeaGuard	TRL9
Data Collections described in D2.2				
AREX hydrography	Subsurface temperature, Subsurface salinity, Subsurface currents, Sea surface	AREX	Seabird CTD 9/11+ system (double temperature sensors SBE3, double conductivity sensors SBE4, dissolved oxygen sensor SBE43, dissolved oxygen sensor RINCO, Seapoint Chlorophyll Fluorometer)	TRL9

	temperature, Surface currents, Sea-surface salinity, Oxygen (interior ocean oxygen concentration)			
Global Ocean Data Analysis Project version 2 (GLODAPv2)	All Subsurface physical and biochemical variables	Environmental Systems Science Data Infrastructure for a Virtual Ecosystem (ESS-DIVE)	Bottle samples, CTDs	TRL9
Physical Oceanography Mooring-Data of the AWI Fram Strait Mooring Array	Subsurface temperature, Subsurface salinity, Subsurface currents, Oxygen (interior ocean oxygen concentration)	FRAM	Various: e.g. SeaBird SBE 37-SM MicroCAT C-T Recorder (Temperature & Salinity) SeaBird SBE 37-SMP-ODO MicroCAT C-T-ODO (+ Oxygen Sensor) SeaBird SBE 56 Temperature Logger Teledyne RDI 300 kHz Workhorse ADCP (Acoustical Doppler Current Profiler) Teledyne RDI 75 kHz Long Ranger ADCP	TRL9
UDASH - Unified Database for Arctic andSubarctic Hydrography	Subsurface temperature, Subsurface salinity, Sea surface temperature, Sea-surface salinity	FRAM	Comprehensive & quality-controlled pan-arctic measuremets from various measurements & instruments	TRL9
UNDER-ICE-2014-2016-acoustic-travel time	Acoustic travel time	Fram Strait Multipurpose Acoustic System	Acoustic sources and receiver arrays	TRL9
UNDER-ICE-2014-2016-ambient noise	Ambient noise	Fram Strait Multipurpose Acoustic System	Acoustic receivers	TRL9
World Ocean Database Conductivity-Temperature-Depth Data (WOD-CTD)	Subsurface temperature, Subsurface salinity, Oxygen (interior ocean oxygen concentration), Chlorophyll	World Ocean Database	CTDs	TRL9
World Ocean Database Digital Bathythermograph Data (WOD-DBT)	Subsurface temperature, Sea surface temperature	World Ocean Database	DBT (type unknown)	TRL9
World Ocean Database Expendable Bathythermograph Data (WOD-XBT)	Subsurface temperature, Sea surface temperature	World Ocean Database	Various XBTs	TRL9
World Ocean Database Expendable Conductivity-Temperature-Depth Data (WOD-XCTD)	Subsurface temperature, Subsurface salinity, Sea surface temperature, Sea-surface salinity	World Ocean Database	XCTDs	TRL9
World Ocean Database Mechanical Bathythermograph Data (WOD-MBT)	Subsurface temperature, Sea surface temperature	World Ocean Database	Various MBTs	TRL9

World Ocean Database Ocean Station Data (WOD-OSD)	All Subsurface physical and biochemical variables	World Ocean Database	Bottle samples, low-resolution (expendable) CTDs, plankton nets	TRL9
World Ocean Database Salinity Temperature Depth Data (WOD-STD)	Subsurface temperature, Subsurface salinity, Sea surface temperature, Sea-surface salinity	World Ocean Database	Various STDs	TRL9

4.3.2. Maturity of the data collections

The maturity of the data collection is assessed by the level of data management and sustainability. Technology maturity readiness of the instruments used to generate the measured parameters of the assessed data collections is presented in Figures 38, 39 and 40. The assessment criteria follow the ISO standard 16290 consisting of 9 different categories of Technology Readiness Levels (TRL), which below are adjusted on a scale from 1 to 6:

TRL1: Basic principles observed.
TRL2: Technology concept formulated.
TRL3: Experimental proof of concept.
TRL4: Component and/or breadboard functional verification in laboratory environment.
TRL5: Component and/or breadboard critical function verification in relevant environment.
TRL6: Model demonstrating the critical functions of the element in a relevant environment.
TRL7: Model demonstrating the element performance for the operational environment.
TRL8: Actual system completed and accepted for flight ("flight qualified").
TRL9: Actual system "flight proven" through successful mission operations.

Table 11. *An overview of the maturities provided in Questionnaire B for the data collections. The data collections described in Deliverable 2.2 is shown at the end of the table.*

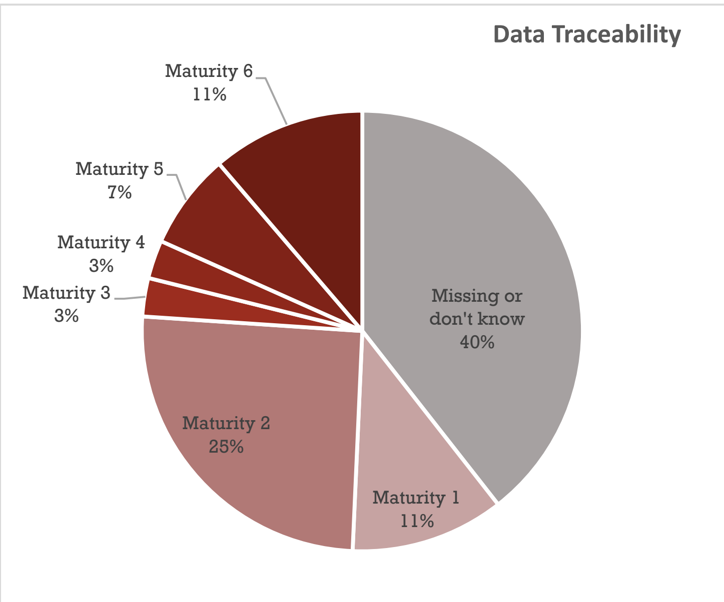
	Uncertainty characterization						Processing level	Metadata maturity				Documentation maturity		
Data Collection	Data traceability	Data comparability	Standards	Validation	Uncertainty quantification	Routine quality monitoring		Standards	Collection level metadata	File level metadata	Quality flags	Formal documentation on Scientific methodology	Formal validation report	Formal measurement series or product user guidance
A-TWAIN CTD hydrography September 2012 and September 2013	÷	÷	÷	÷	÷	÷	L1	4	3	4	Yes	2	÷	÷
A-TWAIN mooring hydrography and current data Sep 2012 - Sep 2013	÷	÷	÷	÷	÷	÷	L1	4	÷	4	Yes	÷	÷	÷
A-TWAIN mooring hydrography and currents	2	2	÷	÷	2	3	L1	1	2	4	No	1	2	2
A-TWAIN mooring hydrography and currents	2	2	÷	÷	2	3	L1	1	2	4	No	1	2	2
A-TWAIN mooring hydrography and currents	2	2	÷	÷	2	3	L1	1	2	4	No	1	2	2
A-TWAIN mooring hydrography and currents	÷	÷	÷	÷	÷	÷	÷	÷	÷	÷	Yes	÷	÷	÷
A-TWAIN mooring hydrography and currents	2	2	÷	÷	2	3	L1	1	2	4	No	1	2	2
ArgoPoland	5	4	÷	÷	2	4	L3	4	3	4	Yes	2	3	2
AWI Polarstern VM ADCP measurements	÷	÷	2	1	3	1	L0	5	2	3	No	2	1	2
Benthic oxygen fluxes in the Arctic Fram Strait	6	6	÷	÷	2	5	L1	÷	5	6	Yes	3	2	3
Biogenic particle flux at the FRAM observatory from mooring sediment traps	6	6	÷	÷	2	5	L1	5	5	6	Yes	3	6	2
Biogeochemical parameters from deep-sea sediments taken at the long-term observatory AWI-HAUSGARTEN	6	6	÷	÷	2	6	L1	÷	5	6	Yes	6	6	6
High resolution sea-bed photographs and footage from repeated long term surveys for fauna investigations	6	6	÷	÷	2	5	L0	5	5	6	No	3	6	2
Inorganic nutrients measured on Fram-Strait water samples since 1997	6	6	÷	÷	2	5	L1	5	5	6	Yes	2	2	2
Ship borne CTD surveys of oxygen and chlorophyll	÷	÷	3	2	2	4	÷	5	3	4	No	1	2	2
Ship borne CTD surveys of temperature and salinity	÷	÷	3	2	3	6	L1	5	3	4	No	3	4	6
ACOBAR-2010-2012-acoustic traveltimes	÷	÷	2	1	2	3	L1	1	2	4	Yes	3	2	3
ACOBAR-2010-2012-ambient-noise	÷	÷	2	1	2	1	L1	1	3	4	Yes	3	2	2
ACOBAR:XBT measurements and derived values - Fram Strait-2010-2012	÷	÷	÷	÷	6	1	L1	4	3	4	Yes	2	÷	÷
DAMOCLES-2008-2009-acoustic-traveltime	4	3	2	2	5	5	L1	1	3	4	Yes	2	2	2
DAMOCLES-2008-2009-ambient noise	1	1	2	1	2	1	L1	1	3	4	No	2	1	2
DAMOCLES-2008-2009-Depth-Range-Averaged-Ocean-Temperature	÷	÷	2	2	2	3	L4	1	3	4	Yes	3	2	2
ACOBAR-2010-2012-Depth-Range-Averaged-Ocean-Temperature	÷	÷	2	2	2	3	L4	1	3	4	Yes	3	2	2
Greenland Ecosystem Monitoring Programme	3	2	÷	÷	2	1	L1	1	2	1	No	1	2	2
Greenland Ecosystem Monitoring Programme - Nutrients	2	1	÷	÷	2	1	L1	3	2	3	No	1	1	2
Greenland Ecosystem Monitoring Programme - Plankton	1	1	1	1	1	1	L1	3	2	3	No	1	1	2
Greenland Ecosystem Monitoring Programme - Salinity	1	2	÷	÷	1	1	L1	1	2	3	No	1	1	2

MarineBasis	3	3	÷	÷	1	1	L1	3	2	3	No	1	1	1
MarineBasis	5	4	÷	÷	2	1	L1	3	2	3	No	1	1	1
MarineBasis	1	2	÷	÷	1	1	L1	3	2	3	No	1	1	2
MarineBasis	1	1	÷	÷	1	1	L1	3	2	3	No	1	1	1
MarineBasis	1	1	1	1	1	1	L1	3	2	3	No	1	1	1
MarineBasis	1	1	1	÷	1	1	L1	3	2	3	No	1	1	1
MarineBasis	1	1	1	÷	1	1	L1	3	2	3	No	1	1	2
IMR Barents Sea Opening mooring array	2	1	2	2	2	3	L1	1	2	3	No	2	2	2
IMR Fixed hydrographic (near coastal) station network	2	2	÷	÷	1	1	L1	1	2	4	No	4	1	2
IMR fixed hydrographic sections	2	2	÷	÷	2	3	L1	1	3	4	No	2	2	3
IMR SI_Arctic vessel mounted ADCP system	2	2	÷	÷	2	3	L2	÷	2	3	No	3	2	4
IMR-PINRO Ecosystem Survey Fish	2	2	1	1	2	1	L1	3	2	4	No	1	2	2
IMR-PINRO Ecosystem Survey Hydrography	2	2	3	÷	2	3	L1	4	3	4	No	2	2	3
IMR-PINRO Ecosystem Survey Nutrients	2	2	2	2	2	3	L1	1	2	4	No	2	2	3
WIFAR/UNDER-ICE acoustic recording in the Marginal Ice Zone-2012	÷	÷	2	1	1	1	L1	1	2	4	No	3	2	1
Regionally/seasonally downscaled data products of carbonate system chemistry, nutrients, and phytoplankton biomass (OCEAN)	÷	÷	÷	÷	÷	÷	L1	÷	÷	÷	Yes	2	1	÷
NIVA FerryBox	5	3	÷	÷	2	4	L1	4	3	4	Yes	3	2	6
NIVA FerryBox	5	3	÷	÷	2	4	L1	4	3	4	Yes	4	2	4
NIVA FerryBox	2	3	÷	÷	2	6	L1	4	3	4	Yes	4	2	6
NIVA FerryBox	5	3	÷	÷	2	6	L1	4	3	4	Yes	4	2	6
NIVA FerryBox	6	3	÷	÷	3	6	L1	4	3	4	Yes	4	2	÷
NIVA FerryBox	6	3	÷	÷	2	6	L1	4	3	4	Yes	4	2	6
NIVA FerryBox	6	3	÷	÷	2	6	L1	4	3	4	Yes	4	2	6
NorArgo	2	2	÷	÷	3	3	L1	1	3	4	No	3	2	3
EGO gliders (European Gliding obervatories)	2	4	÷	÷	2	5	L0	5	4	6	Yes	2	2	2
EGO gliders (European Gliding obervatories)	2	4	÷	÷	2	5	L0	5	4	6	Yes	2	2	2
Tide Gauges	2	2	1	1	1	5	L1	3	1	÷	No	1	2	2
CTD data collected with R/V Håkon Mosby 2002-2016 (a series of annual datasets)	÷	÷	÷	÷	÷	÷	L1	4	3	4	Yes	÷	÷	÷
Digital terrain model (DTM) of the central Fram Strait	÷	÷	÷	5	÷	5	L4	÷	5	6	Yes	3	6	6
UNIS ocean observing system	÷	÷	÷	÷	÷	÷	÷	÷	÷	÷	Yes	÷	÷	÷

Data Collections described in D2.2														
AREX hydrography	4	5	÷	÷	4	5	L4	÷	3	4	Yes	4	4	2
Global Ocean Data Analysis Project version 2 (GLODAPv2)	÷	÷	3	6	5	6	L1	6	5	5	Yes	6	4	6
Physical Oceanography Mooring-Data of the AWI Fram Strait Mooring Array	÷	÷	3	4	2	4	L1	5	3	4	No	2	4	2
UDASH - Unified Database for Arctic andSubarctic Hydrography	÷	÷	3	4	2	6	L4	÷	3	4	Yes	3	6	1
UNDER-ICE-2014-2016-acoustic-travel time	÷	÷	2	1	2	3	L1	1	3	4	Yes	1	2	÷
UNDER-ICE-2014-2016-ambient noise	÷	÷	2	2	2	3	L1	1	3	4	Yes	1	2	2
World Ocean Database Conductivity-Temperature-Depth Data (WOD-CTD)	÷	÷	1	1	2	1	L1	6	6	6	Yes	2	1	3
World Ocean Database Digital Bathythermograph Data (WOD-DBT)	÷	÷	1	1	2	4	L1	6	3	4	Yes	2	1	3
World Ocean Database Expendable Bathythermograph Data (WOD-XBT)	÷	÷	1	1	2	4	L1	6	6	4	Yes	2	1	3
World Ocean Database Expendable Conductivity-Temperature-Depth Data (WOD-XCTD)	÷	÷	1	1	2	4	L1	6	6	4	Yes	2	1	3
World Ocean Database Mechanical Bathythermograph Data (WOD-MBT)	÷	÷	1	1	2	4	L1	6	3	4	Yes	2	1	3
World Ocean Database Ocean Station Data (WOD-OSD)	÷	÷	1	1	2	1	L1	6	6	6	Yes	2	1	3
World Ocean Database Salinity Temperature Depth Data (WOD-STD)	÷	÷	1	1	2	4	L1	6	3	4	Yes	2	1	3

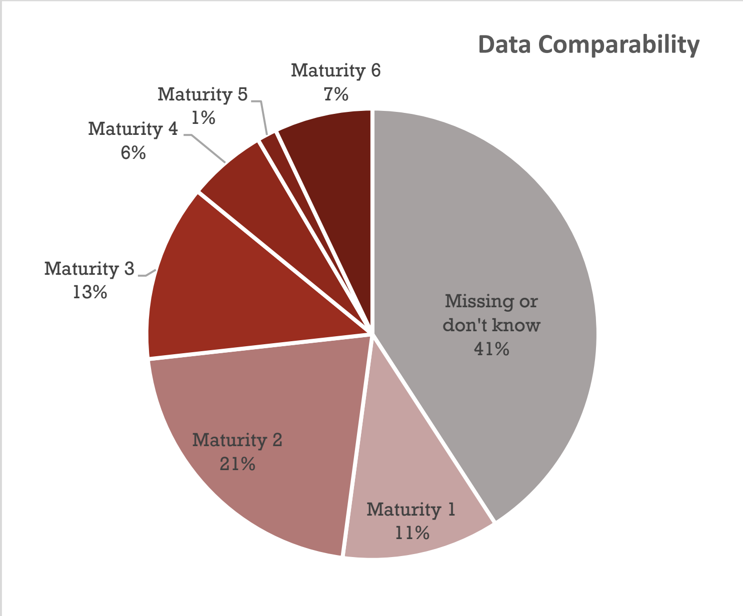
4.3.2.1. Uncertainty characterization

The uncertainty characterization of the data collections provides an overview of how well the uncertainty is described for data. In general, is the maturity for the different parameters low, which means only few of the data collections has a well-documented uncertainty characterization. 4 out of 5 data collections (79 %) provide limited or none information on quantification of the uncertainty.



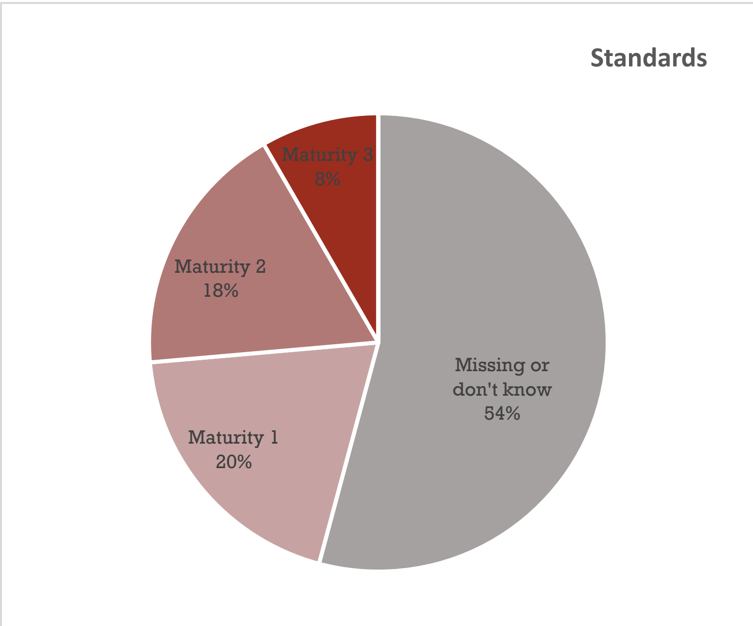
Data traceability is the property of the result of a measurement whereby it can be related to stated references, usually national or international standards such as SI units, through an unbroken chain of comparisons and processing procedures all having stated uncertainties. *(Not to be answered for derived data products)*

1. None
2. Comparison to independent stable measurement or local secondary standard undertaken irregularly
3. As in (2) + independent measurement / local secondary standard is itself regularly calibrated against a recognized primary standard
4. As in (3) + processing steps in the chain of traceability are documented but not yet fully quantified
5. As in (4) + traceability in the processing chain partly established
6. As in (5) + traceability in the processing chain fully established



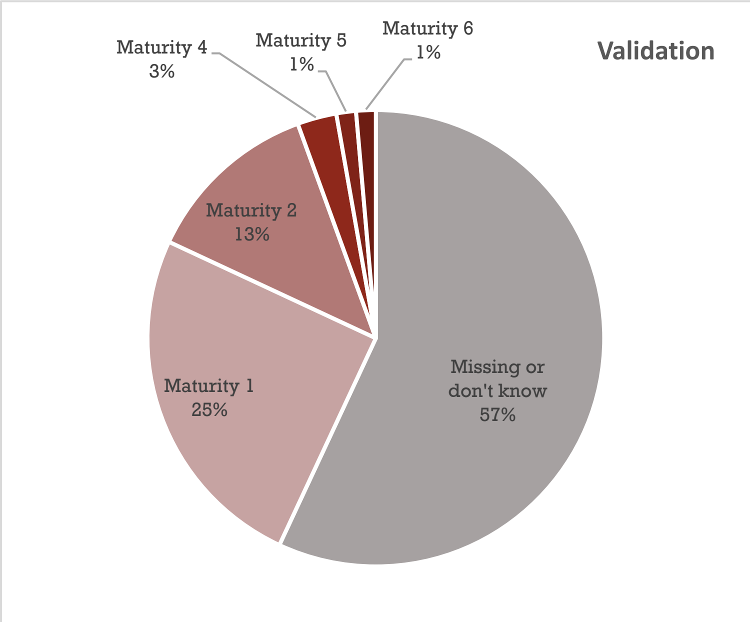
Data comparability evaluates the extent to which the data collection has been validated to provide realistic uncertainty estimates and stable operations through in-the-field comparisons. *(Not to be answered for derived data products)*

1. None
2. Validation using external comparator measurements done only periodically and these comparator measurements lack traceability
3. As in (2) + Validation is done sufficiently regularly to ascertain gross systematic drift effects
4. As in (3) + (Inter)comparison against corresponding measurements in large-scale instrument inter-comparison campaigns
5. As in (4) + compared regularly to at least one measurement that has traceability as in (5) or (6)
6. As in (5) + compared periodically to additional measurements including some with mature traceability



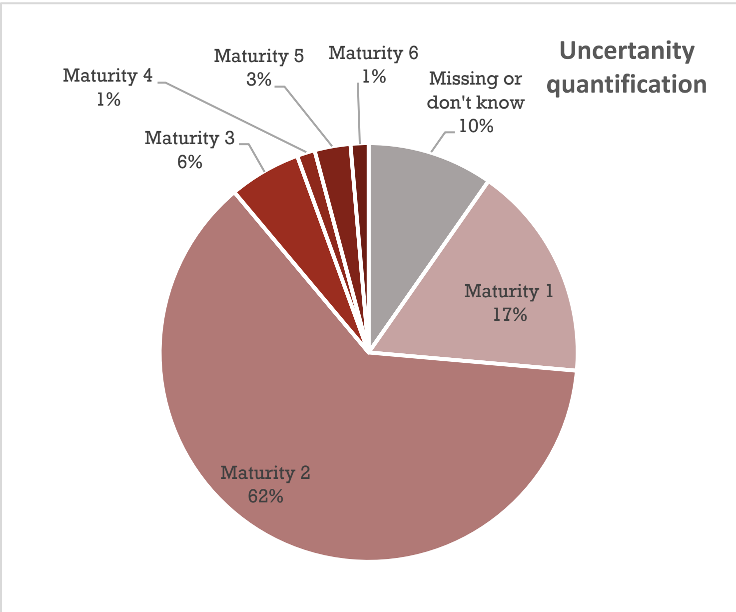
Standards is only applied to derived data products, e.g. for data collections that result from summarized individual measurements or are composed of integrated measurements (for instance, pan-Arctic climatological time series). To support a claim of traceability, the provider of a measurement result or value of a standard must document the measurement process or system used to establish the claim and provide a description of the chain of comparisons that were used to establish a connection to a particular stated reference. *(Only to be answered for derived data products)*

1. None
2. Standard uncertainty nomenclature is identified or defined
3. As in (2) + Standard uncertainty nomenclature is applied
4. As in (3) + Procedures to establish SI traceability are defined
5. As in (4) + SI traceability partly established.
6. As in (5) + SI traceability established



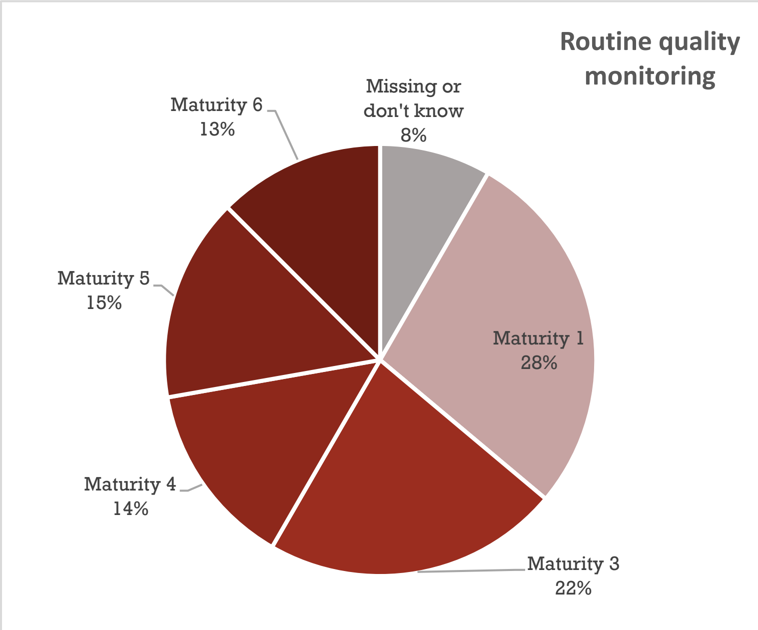
Validation is only to be answered for derived data products. It evaluates the extent to which the product has been validated to provide uncertainty estimates. *(Only to be answered for derived data products)*

1. None
2. Validation against external reference data done for limited locations and times
3. Validation using external reference data done for global and temporal representative locations and times
4. As in (3) + intercomparison against corresponding data records
5. As in (4) + data provider participated in one international data quality assessment
6. As in (4) + data provider participated in multiple international data assessments and incorporated feedbacks into the product development cycle



Uncertainty quantification evaluates the extent to which uncertainties have been fully quantified and their ease of use.

1. None
2. Limited information on uncertainty arising from systematic and random effects in the measurement
3. Comprehensive information on uncertainty arising from systematic and random effects in the measurement
4. As in (3) + quantitative estimates of uncertainty provided within the measurement products characterizing more or less uncertain data points
5. As in (4) + systematic effects removed and uncertainty estimates are partially traceable
6. As in (5) + comprehensive validation of the quantitative uncertainty estimates

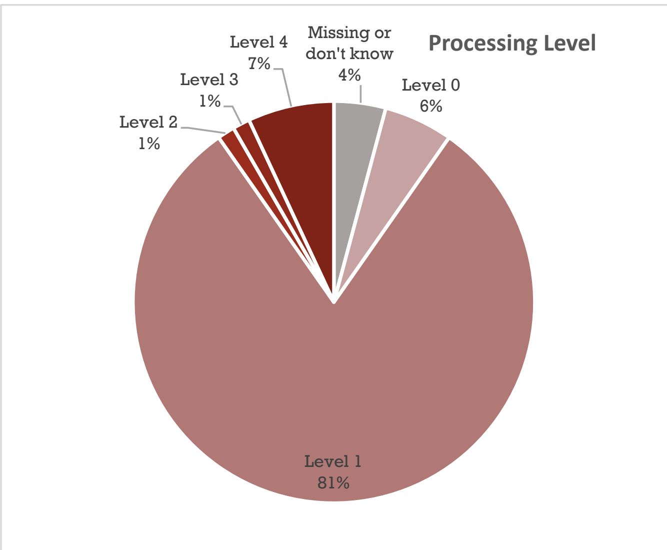


Routine quality monitoring is the monitoring of data quality while processing the data.

1. None
2. N/A
3. Methods for routine quality monitoring defined
4. As in (3) + Routine monitoring partially implemented
5. As in (4) + Monitoring fully implemented at all production levels
6. As in (5) + Routine monitoring in place with results fed back to other accessible information, e.g. metadata or documentation

4.3.2.2. Processing level

Almost all of the in-situ data collections in this report are of level 0 or 1, which means that data collections in general are at an early stage and more processing is needed in order to be used and accessible by external users.



Level 0: raw data (Raw data are unprocessed measurements and observations from a single instrument, observation or field sampling techniques in native collection units, such as voltage)

Level 1: calibrated data (Calibrated or quality-assured data are generally from a single instrument, observer or field sampling area. These data are transformed into standard scientific units, and are generally at native measurement resolution. Data quality control occurs, spatial and temporal coordinates are provided, and data can be temporally or spatially averaged (to reduce noise and increase accuracy)

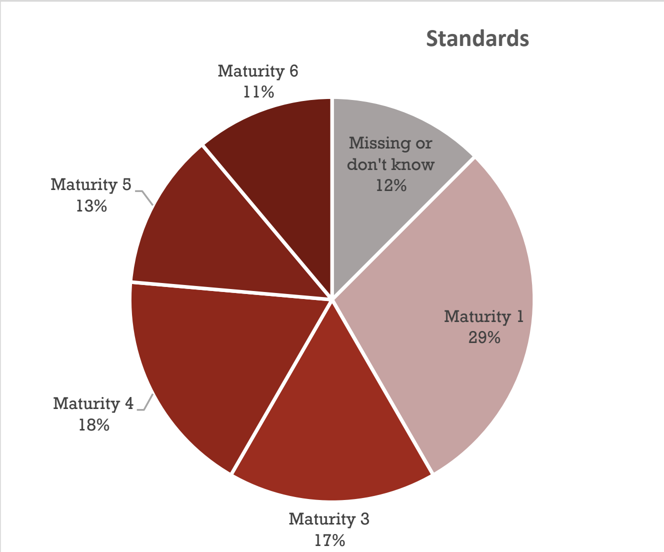
Level 2: Temporal interpolation (Corrects and/or fills in any gaps in time in the data

that an individual sensor collects).

Level 3: Spatial interpolation (Connects gaps in space between sensors collecting the same type of data)

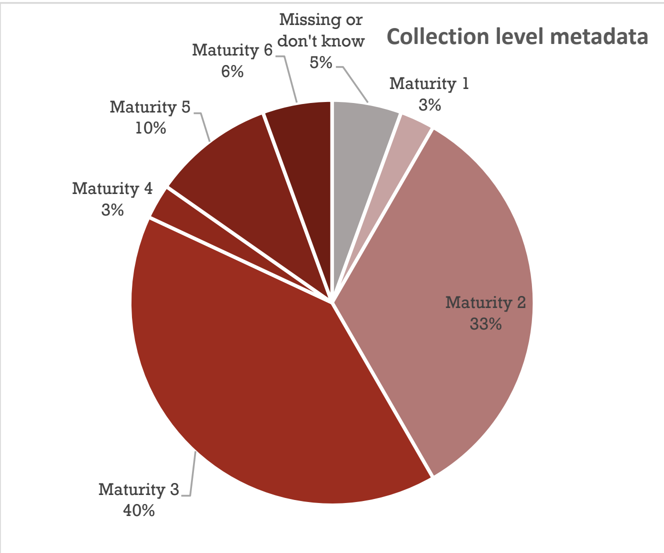
Level 4: More complex derived data products (Processing combinations include in situ and remote sensing data, external data sets, and models)

Most data collections include some level of metadata in the product, so it can be understood by an external user.



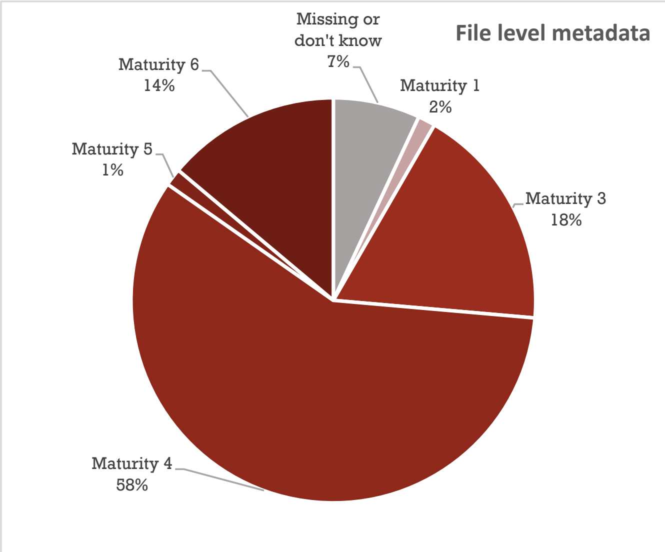
Standards: It is considered to be good practice to follow recognized metadata standards. Unless and until an ISO standard is developed and applied the assessors' judgement will be required as to the appropriateness of the standards being adhered to.

1. No standard considered
3. Metadata standards identified and/or defined and partially but not yet systematically applied
4. As in (3) + standards systematically applied at file level and collection level.
5. As in (4) + metadata standard compliance systematically checked by the data provider
6. As in (4) + extended metadata that could be useful but is not considered mandatory is also retained.



Collection level metadata includes attributes that apply across the whole of a measurement series, such as processing methods (e.g., same algorithm versions), general space and time extents, creator and custodian, references, processing history, etc.

1. None
2. Limited
3. Sufficient to use and understand the data independent of external assistance.
4. As in (3) + enhanced discovery metadata
5. As in (4) + complete discovery metadata meets appropriate (at the time of assessment) international standards
6. As in (5) + regularly updated

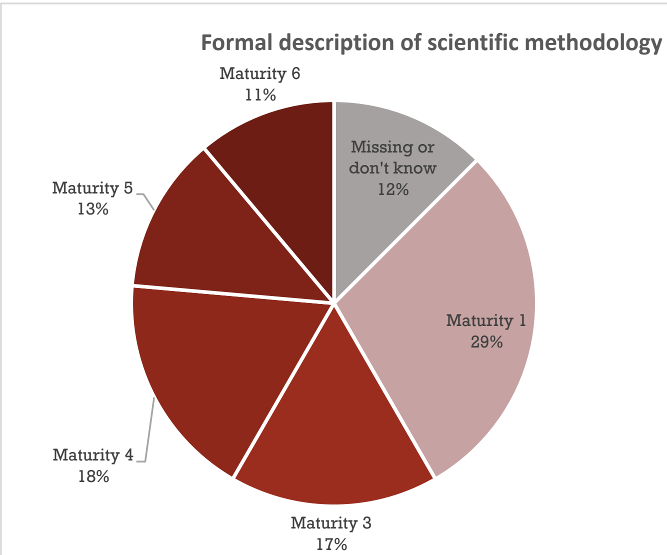


File level metadata includes such elements as time of observation, location, measurement units, measurement specific metadata such as ground check data, measurement batch number, ambient conditions at time of observation etc.

1. None
3. Limited
4. Sufficient to use and understand the data independent of external assistance.
5. As in (4) + Limited location (station, grid point, etc.) level metadata along with unique measurement set metadata (coordinate bounds) are provided.
6. As in (5) + Complete location (station, grid point, etc.) level and measurement specific metadata.

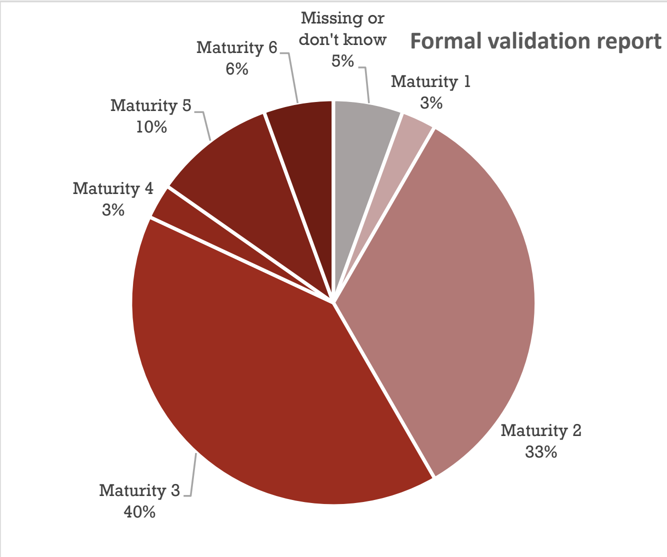
4.3.2.3. Documentation maturity

Most data collections provide some formal documentation of the data collections and have published description on methodology and has been compared against other methods in literature.



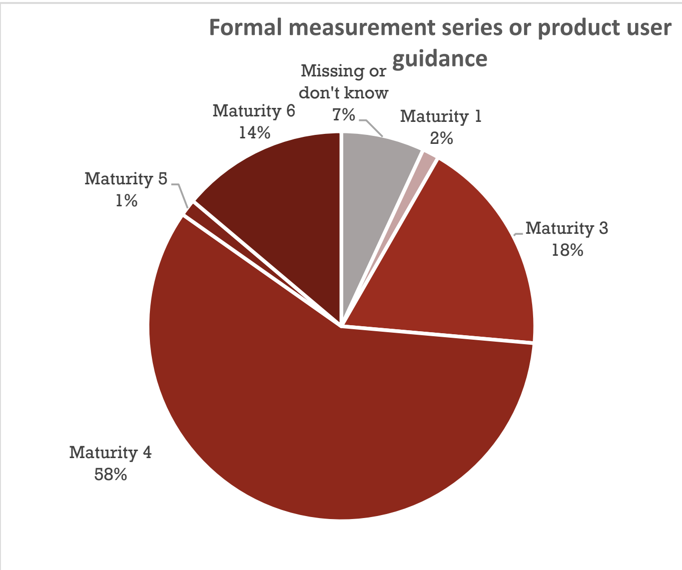
Formal description of scientific methodology refers to a description of the physical and methodological basis of the measurements, network status (if applicable), processing of the raw data and dissemination.

1. Limited scientific description of methodology available from data collector, instrument manufacturer, or PI
2. Comprehensive scientific description available from data collector, instrument manufacturer, or PI
3. As in (2) + Journal paper on measurement methodology published
4. As in (3) + Comprehensive scientific description available from Data Provider
5. As in (4) + Comprehensive scientific description maintained by Data Provider
6. As in (5) + Journal papers on measurement series/product updates published



Formal validation report contains details on the validation activities that have been done to assess the fidelity/reliability of the data collection.

1. None
2. Informal validation work undertaken
3. Instrument has participated in certified intercomparison campaign and results available in gray literature
4. Report on intercomparison to other instruments, etc.; Journal paper or product validation published
5. As in (4) + Sustained validation undertaken via redundant periodic measurements
6. As in (5) + Journal papers describing more comprehensive validation, e.g. error covariance, validation of quantitative uncertainty estimates published



Formal measurement series or product user guidance contains details necessary for measurement users to discover and use the data in an appropriate manner.

1. None
2. Sufficient information on the data collection available to allow user to ascertain minimum set of information required for appropriate use
3. Comprehensive documentation on how the measurement is made or the product derived available from data collector or instrument manufacturer or PI, including basic data characteristics description
4. As in (3) + including documentation of manufacturer independent characterization and validation
5. As in (4) + regularly updated by data provider with instrument / method of measurement/processing updates and/or new validation results
6. As in (5) + measurement description and examples of usage available in peer-reviewed literature

4.3.3. Sustainability and data usage of independent data collections

For those data collections that are not part of any observing system described in this report, is the sustainability and data management assessed independently. The respective maturity levels are shown in Table 12 (the same maturity level characterization applies here as for the observing systems).

Table 12. *Selected data collection not belonging to any observing system.*

	Scientific and expert support	Funding support		Data storage	Data access	User feedback	Updates to record	Version control	Long term data preservation
Digital terrain model (DTM) of the central Fram Strait	6	5		1	5	2	1	2	5
EGO gliders (European Glider obervatories)	3	4		1	5	3	4	4	5
Regionally/seasonally downscaled data products of carbonate system chemistry, nutrients, and phytoplankton biomass (OCEAN)	N/A	N/A		1	2	2	2	2	N/A
PSMSL Tide Gauges	2	1		1	2	2	2	1	1
UDASH - Unified Database for Arctic and Subarctic Hydrography	N/A	N/A		1	5	2	2	2	5
WIFAR/UNDER-ICE acoustic recording in the Marginal Ice Zone-2012	2	1		1	5	1	1	1	4

4.4. Selected satellite products

Satellite products are fundamental for obtaining a consistent spatial-temporal mapping of the Arctic Ocean and to monitor pan-arctic changes in the future. Satellite data retrieval is based on the measurement of electromagnetic radiation, reflected or emitted from the surface (land, water, ice). From this and depending on the wavelength of the electromagnetic spectrum used, optical to microwave systems has been designed. However, satellites products are limited to investigation of surface parameters with a given resolution and a given revisit time. This is complemented by in-situ observations, who are able to provide information from the interior of the ocean/ice/show at different spatial-temporal scales than satellite data.

INTAROS is not the first effort towards a comprehensive and easy to access centre for Arctic, or more generally polar data centre. Especially for satellite data there are several centres and projects giving overview of and access to observational data of considerable amount. That effort will not be duplicated here, but the users are referred to those centres for own exploration. The vast amount of data sets offered by those centres cannot be presented here in the same depth as the single data sets described in this deliverable.

- The Polar View report includes a list of all the available EO products for the Arctic (Appendix 1, Polar View, 2016). Although it provides a general assessment of the EO products, it contains only very limited information on the characteristics of each product (mainly content and data availability (i.e. temporal coverage)), while key information such as spatial and temporal resolution, coverage, timeliness, and uncertainty/validation are not provided (information on validation is provided only in few exceptional cases). A more thorough assessment of climate-related EO products has been conducted by the FP7 project CORE-CLIMAX (http://www.copernicus.eu/projects/core-climax).

- The data portal of Polar View (polarview.org) offers an interactive tool allowing to immediately see maps with sea ice concentration data, NIC sea ice charts, MODIS mosaics, and Sentinel-1 and Radarsat-2 imagery for selected periods.

For satellite data there are several data centres and data portals providing overview of and access to Earth Observation data products. The amount of Earth Observation data grows rapidly, especially because of the Sentinel programme under Copernicus, where data are freely available to all users.

- A major US data portal for Polar data is the **National Snow and Ice Data Center** (NSIDC) in Boulder, Colorado. The site http://nsidc.org/soac offers links to a large number of data collections in various cryospheric fields (sea ice, snow cover, glaciers, frozen ground, etc.). A search with the key word ‘sea ice’ yields 269 data sets from NSIDC and other US and international centres with the possibility to arrange them by relevance, area covered duration and last update. As an example, only the first data set of that list, Sea Ice Index, contains daily and monthly ice concentrations since 1978, plus monthly average sea ice extent, concentration, anomaly, and linear trend.

- In Europe the Franch data centre **CERSAT** (cersat.ifremer.fr) offers data and quicklooks of many satellite data products, such as daily sea ice concentration & displacement. CERSAT has participated in the survey an answered Questionnaire C. The datasets are updated and starts in 1992, so a 25-year dataset is available freely and at friendly format from various sensors (scatterometers, altimeters, radiometers). The web portal offers the possibility of dynamic view of sea ice extent and daily quicklooks.

Polar View (2016) has made a gap analysis of the information from EO missions in Polar Regions. The gaps in the different observation themes (defined as Sea ice, River and Lake ice, Ice Sheet, Glaciers, Snow, Icebergs, Permafrost, Ocean, Land, and Atmosphere) were identified with respect to the applicability of different groups of EO sensors to provide information on the different themes (see Fig 20 in Polar View, 2016). Based on the number of existing and future (planned) EO systems, the analysis revealed that all information themes are addressed by EO missions, although higher level of applicability are apparent for some themes (e.g. Land and Ocean) than for others (e.g. Atmosphere and River/Lake Ice). This brought to the final recommendation, that future mission planning should focus on making optimum use of existing, rather than development of new, sensor technology. Furthermore, the Polar View report identified the primary gaps in existing environmental information in meeting user needs on the basis of literature review and consultations with representatives and user organizations (Table 5 in Polar View, 2016). The assessed data characteristics were spatial and temporal resolution, timeliness (the amount of delay between the data collection and its accessibility for subsequent use), data continuity, and coverage. The key environmental information gaps were for Polar earth science: 1) Sea ice thickness 2) Ice sheet mass balance and 3) Snow cover

The two parameters considered of most concern across multiple themes were:

- Extent (sea ice, glacier, snow, iceberg, and permafrost)
- Surface structure/albedo (sea ice, ice sheet, glacier, snow, permafrost, and land).

4.4.1. General information on the assessed Satellite products

The INTAROS strategy is to link the selection of the assessed products (among the available products) to the demonstration studies done in WP6, and/or to the priority needs of some stakeholders (as ECMWF, ESA, or others). The Assessed ocean and sea ice satellite products are summarized in Table 13.

Table 13. ***Ocean and sea ice satellite products assessed in questionnaire CI.***

Satellite Products marked in light blue are developed as part of the INTAROS project and are described in deliverable 2.2 but are assessed together with the satellite products in deliverable 2.1.

Name of satellite product	Variables measured	Sensor(s) used	Satellite platform	Administrating bodies	Data repository
Arctic high resolution ice edge	Sea-ice edge	Synthetic Aperture Radar (SAR)	Radarsat2 Sentinel-1	NERSC	http://thredds.met.no/thredds/catalog/myocean/siw-tac/siw-nersc-sar-type-arc-v3/catalog.html
Arctic Ocean - Sea Ice Concentration Charts - Svalbard	Sea-ice concentration	Synthetic Aperture Radar (SAR), visual and infrared	Envisat, RADARSAT, Sentinel-1, MODIS and NOAA	Norwegian Meteorological Institute	http://marine.copernicus.eu/
Arctic Sealevel anomaly	Sea level (Regional)	Altimeter	ERS-1, ERS-2, EnviSat, SARAL, CryoSat-2, Sentinel 3A/3B	DTU	ftp://ftp.space.dtu.dk/pub/ARCTIC_SEALEVEL
ASI Sea ice concentration	Sea-ice concentration	AMSR-E/2	AQUA + GCOM-W	UB	https://www.seaice.uni-bremen.de
Global Ocean Sea Ice Concentration Time Series REPROCESSED	Sea-ice concentration	SMMR / SSM/I / SSMIS	Nimbus 7 / DMSP	Norwegian Meteorological Institute	http://marine.copernicus.eu/
Ifremer/CERSAT Arctic sea ice drift at large scale	Sea-ice drift	SSMI, QuikSCAT, ASCAT	DMSP, SeaWinds, MetOp	Ifremer	ftp://ftp.ifremer.fr/ifremer/cersat/products/gridded/psi-drift/data/
Ifremer/CERSAT Arctic sea ice drift at medium resolution scale	Sea-ice drift	AMSR-E, AMSR2	Aqua, GCOM	Ifremer	ftp://ftp.ifremer.fr/ifremer/cersat/products/gridded/psi-drift/data/arctic/amsr2-merged/

Ifremer/CERSAT Sea ice concentration	Sea-ice concentration	SSMI	DMSP	Ifremer	ftp://ftp.ifremer.fr/ifremer/cersat/products/gridded/psi-concentration/data/
Mean Dynamic Topography (MDT) and Mean Sea Surface (MSS)	Surface currents, Sea level (Regional)	Altimeter	ERS-1, ERS-2, EnviSat, CryoSat, Sentinel 3A/3B	DTU	ftp://ftp.space.dtu.dk/pub/DTU17
Multiyear sea ice concentration	Sea-ice concentration	AMSR-E/2 + ASCAT	AQUA + GCOM-W + METOP	UB	https://www.seaice.uni-bremen.de
OSI-205: OSI SAF High Latitudes L2 Sea and Sea Ice Surface Temperature	Sea and Sea Ice Surface Temperature	AVHRR	Metop	Norwegian Meteorological Institute	ftp://osisaf.met.no/archive/sst/l2p/avhrr_metop_a/
Sea Concentration from passive microwave data	Sea-ice concentration	Passive microwave	NIMBUS, DMSP	NERSC	arctic-roos.org
Thickness of thin sea ice	Sea-ice thickness	SMOS and SMAP radiometers	SMOS + SMAP	UB	https://www.seaice.uni-bremen.de

4.4.2. Spatial and temporal coverage and resolution

In this section, the answers from the questionnaire C, Section 3 on data spatial and temporal coverage and resolution are summarized.

The spatial coverage for satellite data products from passive microwave sensors is generally global, while high resolution data from SAR have more intense coverage in specific regions, such as sea ice areas. In the Arctic, all polar orbiting satellites has more frequent and dense spatial coverage than at mid and low latitudes. The spatial resolution for satellite data using passive microwave sensors varies between 10 km and 50 km. For SAR data the spatial resolution is typically 100 m.

The temporal coverage of passive microwave data is exceptionally long and regular, with daily data from 1978 to present, covering most of the Arctic and Antarctic sea ice. SAR data have been obtained quite regularly over the Arctic sea ice areas in the last 10 -15 years. With Sentinel-1, there is daily coverage of most sea ice areas, supporting the operational sea ice monitoring services.

Gaps in spatial and temporal coverage of satellite earth observation products are small compared to all other observing systems, in particular in-situ systems, which are to large extent point measurements. For further discussion of gaps and recommendations regarding satellite data products, we refer to the Polar View report from 2016.

The results from questionnaire C are summarized in Table 14 regarding spatial resolution and coverage, and in Table 15 regarding temporal coverage and resolution.

Table 14. ***Spatial resolution and coverage of selected satellite products***

Name of satellite product	Variable	Spatial Coverage	Spatial resolution	Required spatial resolution (**Threshold**, **Breakthrough**, **Goal**)
Arctic high-resolution ice edge	Sea-ice edge	Arctic	1 km	No requirements defined
Arctic Ocean - Sea Ice Concentration Charts - Svalbard	Sea-ice concentration	60N to 80N, -80 to 85E	10 km	100 km 50 km **25 km**
Arctic Sea-level anomaly	Sea level (Regional sea level)	60N to 82N, 0 to 360E	25 km	50km **25km** 10km
ASI Sea ice concentration	Sea-ice concentration	31N to 90N, 0 to 360E; -40S to -90S, 0 to 360E	6.25 km hemispherical, 3.125 km regional	100 km 50 km **25 km**
Global Ocean Sea Ice Concentration Time Series REPROCESSED	Sea-ice concentration	Global	10 km	100 km 50 km **25 km**
Ifremer/CERSAT Arctic sea ice drift at large scale	Sea-ice drift	31N to 90N, 0 to 360E	62.5 km	**25 km** 25 km 1 km
Ifremer/CERSAT Arctic sea ice drift at medium resolution scale	Sea-ice drift	31N to 90N, 0 to 360E	31.125 km	**25 km** 25 km 1 km
Ifremer/CERSAT Sea ice concentration	Sea-ice concentration	31N to 90N, 0 to 360E; -39.23S to -90S, 0 to 360E	12.5 km	100 km 50 km **25 km**
Mean Dynamic Topography (MDT) and Mean Sea Surface (MSS)	Surface currents, Sea level (Regional sea level)	60N to 88N, 0 to 360E	25 km	Surface Currents: 100 km **50 km** 10 km Sea level: 50 km **25 km** 10 km
Multiyear sea ice concentration	Sea-ice concentration	31N to 90N, 0 to 360E	12.5 km	100 km 50 km **25 km**
OSI-205: OSI SAF High Latitudes L2 Sea and Sea Ice Surface Temperature	Sea and Sea Ice Surface Temperature	50N to 90N, 0 to 360E; -50S to -90S, 0 to 360E	1.1km at nadir	25 km 10 km **5 km**

Sea Concentration from passive microwave data	Sea-ice concentration	60N to 90N, 0 to 360E	25 km	100 km 50 km **25 km**
Thickness of thin sea ice	Sea-ice thickness	31N to 90N, 0 to 360E; -40S to -90S, 0 to 360E	30 km	**25 km** 5 km 0.5 km

Table 15. ***Temporal coverage and resolution of selected satellite products***

Name of satellite product	**Variable**	**Temporal duration**	**Temporal resolution**	**Required Temporal Resolution**	**Data timeliness**	**Required Timeliness**
Arctic high-resolution ice edge	Sea-ice edge	July 2015 -	Daily		1 d	
Arctic Ocean - Sea Ice Concentration Charts - Svalbard	Sea-ice concentration	April 2012 -	Daily	3 days 1 day **1 day**	1 d	3 days 1 day **1 day**
Arctic Sea-level anomaly	Sea level (Regional sea level)	June 1991 - Dec 2017	Monthly, 3 days	**3 days** 1 day 6 h	90-360 days	**3 days** 2 days 1 day
ASI Sea ice concentration	Sea-ice concentration	July 2007 -	Daily	3 days 1 day **1 day**	1 day	3 days 1 day **1 day**
Global Ocean Sea Ice Concentration Time Series REPROCESSED	Sea-ice concentration	Oct 1978 -	Daily	3 days 1 day **1 day**	1 day	3 days 1 day **1 day**
Ifremer/CERSAT Arctic sea ice drift at large scale	Sea-ice drift	Jan 1992 - (Sep-May only)	3 days, 6 days, monthly	**24h** 24h 24h	30 days	**7 days** 4 days 3 days
Ifremer/CERSAT Arctic sea ice drift at medium resolution scale	Sea-ice drift	2002-2011 and 2012- (Oct -April only)	2, 3 and 6 day-lags	**24h** 24h 24h	7 days	**7 days** 4 days 3 days
Ifremer/CERSAT Sea ice concentration	Sea-ice concentration	Dec 1991 -	daily and monthly	3 days 1 day **1 day**	7 days	3 days 1 day **1 day**

Mean Dynamic Topography (MDT) and Mean Sea Surface (MSS)	Surface currents, Sea level (Regional sea level)	June 1991 - Dec 2017	Monthly, 3 days	**3 days** 1 day 6 h	90-360 days	**3 days** 2 days 1 day
Multiyear sea ice concentration	Sea-ice concentration	Jan 2009 -	Daily	3 days 1 day **1 day**	6h	3 days 1 day **1 day**
OSI-205: OSI SAF High Latitudes L2 Sea and Sea Ice Surface Temperature	Sea and Sea Ice Surface Temperature			3 days 24h 6h	1 day	**3h** 2h 1h
Sea Concentration from passive microwave data	Sea-ice concentration	Okt 1978 -	Daily	3 days 1 day **1 day**	2 days	3 days 1 day **1 day**
Thickness of thin sea ice	Sea-ice thickness	Dec 2010 -	Daily	6d 3d **24h**	6h	90d 30d **15d**

4.4.3. Gaps in uncertainty characterization

In this section, the answers from questionnaire C, Section 4 (Uncertainty characterization) are presented in Table 16 and 17. The maturity levels are the same as used for the in-situ data: Maturity Level 1, Maturity level 2, Maturity level 3, Maturity level 4, Maturity level 5, Maturity level 6). Missing answers are marked in grey (Missing). The maturities from questionnaire C, Section 5 (Metadata specification and documentation) and Section 2 (Data management) are also shown in Table 16.

In general, we see that only few of the satellite products in the arctic have applied standardized methods to validate the uncertainty of the measured variables. In fact, does only 2 out of 12 products provide a quantified uncertainty. Most of the satellite products are interpretations of the level-0/1 satellite data (where a measurement uncertainty is provided). Gridding and interpolation in time and space, makes it difficult to translate the uncertainty and will largely depend on the amount of quality checked measurements in the given area. This is particular the case for Arctic Ocean products since because of a varying sea-ice cover, which disturbs consistent measurements of the ocean surface.

Most data of satellite products are stored on a public server with free and unlimited access. However, in general is user guidance and documentation general on a low level.

Table 16. ***Uncertainty characterization matrix for selected satellite products***

	Uncertainty charact.				Metadata				Document-ation			Data management				
	Standards	Validation	Uncertainty quantification	Automated quality	Standards	Collection level metadata	File level metadata	Quality flags	Formal description of scientific methodology	Formal validation report	Formal product user	Data storage	Data access	User feedback	Updates to record	Version control
Arctic high resolution ice edge	1	1	1	1	2	3	3	1	3	1	1	6	1	1	1	2
Arctic Ocean - Sea Ice Concentration Charts - Svalbard	4	3	2	1	4	4	1	1	3	1	3	6	3	1	3	2
Arctic Sealevel anomaly	1	2	2	1	1	1	2	1	2	3	2	5	4	2	2	1
ASI Sea ice concentration	4	3	4	1	1	1	1	1	1	4	1	5	4	2	2	3
Global Ocean Sea Ice Concentration Time Series REPROCESSED	4	4	2	1	4	6	3	1	1	6	3	6	6	2	2	1
Ifremer/CERSAT Arctic sea ice drift at large scale	1	5	2	1	3	3	1	3	3	6	5	5	6	5	4	3
Ifremer/CERSAT Arctic sea ice drift at medium resolution scale	1	5	2	1	3	3	1	3	3	6	5	5	6	5	4	3
Ifremer/CERSAT Sea ice concentration	1	5	2	1	3	3	3	3	3	6	5	6	6	5	4	3
Mean Dynamic Topography (MDT) and Mean Sea Surface (MSS)	1	5	2	2	1	1	2	1	3	4	2	6	5	2	2	3
Multiyear sea ice concentration	1	5	2	1	1	2	1	1	3	1	1	6	5	2	2	2
OSI-205: OSI SAF High Latitudes L2 Sea and Sea Ice Surface Temperature	3	5	2	1	4	3	3	1	3	1	2	6	5	2	1	3
Sea Concentration from passive microwave data	3	5	2	1	1	3	2	1	2	3	1	6	5	2	4	1
Thickness of thin sea ice	3	5	2	1	1	3	2	3	3	4	1	6	2	2	2	3

Table 17. ***Uncertainty measurement requirements***

Name of satellite product	Variable	Uncertainty	Required Uncertainty
Arctic high-resolution ice edge	Sea-ice edge		
Arctic Ocean - Sea Ice Concentration Charts - Svalbard	Sea-ice concentration		15% 10% 5%
Arctic Sea-level anomaly	Sea level (Regional sea level)		0.1 m 0.07 m 0.05 m
ASI Sea ice concentration	Sea-ice concentration	5%-30%	**15%** 10% **5%**
Global Ocean Sea Ice Concentration Time Series REPROCESSED	Sea-ice concentration		15% 10% 5%
Ifremer/CERSAT Arctic sea ice drift at large scale	Sea-ice drift		5 km/day 3 km/day 1 km/day
Ifremer/CERSAT Arctic sea ice drift at medium resolution scale	Sea-ice drift		5 km/day 3 km/day 1 km/day
Ifremer/CERSAT Sea ice concentration	Sea-ice concentration	5%-30%	**15%** 10% **5%**
Mean Dynamic Topography (MDT) and Mean Sea Surface (MSS)	Surface currents, Sea level (Regional sea level)		0.1 m 0.07 m 0.05 m
Multiyear sea ice concentration	Sea-ice concentration		15% 10% 5%
OSI-205: OSI SAF High Latitudes L2 Sea and Sea Ice Surface Temperature	Sea and Sea Ice Surface Temperature		0.5 K 0.2 K 0.1 K
Sea Concentration from passive microwave data	Sea-ice concentration		15% 10% 5%
Thickness of thin sea ice	Sea-ice thickness		50 cm 30 cm 10 cm

5. Recommendations

5.1. In-situ Observing systems

5.1.1. The assessment: limitations and recommendations

The first assessment of in-situ observing systems includes only contributions from the INTAROS partners and consequently does not include all ice-ocean observing systems in the Arctic. Neither does it include the new installations in INTAROS WP3 ("Enhancement of multi-disciplinary *in situ* systems") and other projects where data collection is ongoing. The INTAROS advisory panel has recommended that it is essential to get a more complete picture of the ocean in-situ observing capacity by including observing systems outside the INTAROS project. As a follow-up of these recommendations, Questionnaire A is now open for external responders, and it has been broadcasted through SAON and the other projects in the EU Arctic Cluster. This will be followed up in the coming months. If the questionnaires are followed up by the scientific community it will be a useful tool for SAON and others to monitor how the observing capacity evolves and to provide recommendations how to fill gaps in the system.

To make the assessment useful it must be sustained during and after the INTAROS project period. It is therefore highly recommended to continue to engage the partners and external collaborators outside the project to update and filling out the Questionnaires A. In this way we can measure and monitor the impact of INTAROS and other projects on the development of the ice-ocean component of the integrated Arctic Observing System. This will be valuable information for scientists but also for Arctic programmes and funding agencies.

The Questionnaire B for the data collections is a tool for the iAOS data catalogue to provide an estimate of how mature the data collections are for the users in WP 6. The Questionnaire B has been filled out both for already existing data collections as well as data collections that has been improved within INTAROS. The assessment includes both kinds of data. We recommend that Questionnaire B is used to form a standard procedure for certification/indicator of the in-situ data collections.

Some large databases have not been described in this report, although they are important providers of sea ice and ocean data to the research community as well as to services and other users. It is recommended to address this issue in later reports.

5.1.2. Large scale Infrastructure and sustainability

Satellite observations are now under rapid development and play a major role in Arctic monitoring, while the ice-ocean in-situ observing systems are sparse and cannot fulfil many of the requirements to an Arctic observing system. The international community has previously articulated the need for enhanced under-ice observations. Most of the ocean in-situ observing systems is funded through research funding programs, around 70 % of observations are made through short term research programs. It is of high priority to develop funding schemes to implement and sustain research infrastructures to monitor changes in the Arctic environment on seasonal, annual, and decadal scales. In general, the ocean observing technologies does have a high readiness level, but implementation of the technologies in observing system is limited. Ice-ocean buoys drifting with the ice can provide multidisciplinary data in near real time, but very few institutions have long-term funding to deploy and replace the buoys. Bottom-anchored moorings are well-established multi-disciplinary platforms, but only a few with long-term funding are situated in the Arctic, e.g. Hausgarten and the Fram Strait array.

It is a major problem that in-situ observing systems lack sustainability. Especially, the ocean under the ice has no long-term funded and operational observing system. In order to make progress it is essential that appropriate funding mechanisms are installed. This will make it possible for ocean observatories in the Arctic to be operated outside the research programmes, for example through national, European and international coordinated ocean observing initiatives. This would be an important topic for the Pan Arctic Forum to be established within INTAROS in collaboration with SAON (WP1).

In-situ ocean observations are based on infrastructures, mainly supported by national agencies. To maintain the number of observation sites/platforms, it is important to take into account:

- Ageing of instruments/networks
- Changes in scientific goals and priorities
- Funding opportunities for in-situ observing systems
- Environmental impact on observing infrastructure (climate change, harsh environment)

5.1.3. Observing technologies and platforms

As observed in this report, platforms and instruments have a general high Technical Readiness Level, but they need to be renewed regularly to operate reliable in the harsh Arctic environment.

The ARGO program is the most important global ocean observing system, but it is not yet ready for operation in ice-covered regions. The profiling floats in the ARGO programme need to surface to transmit data, update their clocks, and positions via satellite. In ice-covered regions floats may not be able to surface for many months. During this time, the sensors will collect data, but the positions where the data are taken will be unknown and the clocks will not be accurate. Cheaper floats combined with installation of an underwater acoustic geo-positioning system can make a significant contribution to the observation of the Arctic ocean.

Similarly, we support the development of under-ice capability of gliders this includes better batteries for longer operations and robust and more flexible navigation system. The latter statement is the need for the gliders and floats to benefit from all known acoustic source signals with given position and transmission schedules. Today glider operations has to be assisted with specific acoustic network. Instead an acoustic network should be available for everyone at any time – analogous to the satellite based GPS system.

We recommend development of multi-disciplinary observatories using well proven and robust instrumentation mounted in sea floor installations, bottom anchored oceanographic moorings, and drifting ice-tethered platforms. To synoptically covering large areas, it is recommended to use acoustic tomography in combination with localized physical and biogeochemical measurements. Gliders and floats relies on UW-GPS and we recommend installation of multi-purpose acoustic network which can facilitate for acoustic thermometry, underwater GPS and monitoring of the ocean sound scape. The system will enable year-round observations of ocean heat content, ocean acidification, sea level measurements, sea ice thickness, vocalizing marine life, acoustic impact of human activities, and geophysical hazards (e.g. earthquakes, landslides, tsunamis). This would establish a multi-disciplinary observatory in the central Arctic.

5.1.4. Important gaps that limits the implementation of an observing system in the Arctic

5.1.4.1. Gaps in technology.

There is still a need to develop and adapt technologies and sensors to make biogeochemical and biological observations feasible. Several projects funded under "Oceans of tomorrow" focus on sensor development, many are still in testing phase (Biogeochemistry sensors, Bio-Argo (O_2, NO_3, Ph, Chl-a, Suspended material and downwelling irradiance).

5.1.4.2. Missing variables, and gaps in spatial and temporal coverage

There are many gaps in the data coverage in the Arctic, but the gaps in biogeochemical observations (oxygen, nutrients, Chl-a, Carbon/pH) are particularly important. Specifically, one can mention:

- Deep ocean observations are sparse, especially under the ice
- General lack of RT/NRT data in the Arctic
- Argo observations of temperature in the upper 10 m of ocean are needed

5.1.4.3. Gaps in data availability

In the Arctic there are limiting factors in accessing data in the same way as in other regions:

- Some data originators have strict data policies and are simply unable to share.
- Data are handled by military institutes and hence are not made available.
- R&D data where data originator wants to publish before sharing.
- In some institutes data are sold and hence they are not willing to share data that would compromise business.
- Some organizations and scientists express concerns about "incorrect interpretation of environmental data".

5.1.5. Specific recommendations by the partners

In addition to describing the general recommendations regarding the ice-ocean observing systems that have been assessed in this report, it is useful to high-light the specific recommendations given by statements the partners (Table 17). The statements are often similar to the general recommendations, in particular on the key challenges of funding and sustainability of the observing systems.

Table 18. ***List of specific recommendations by the partners***

Observing System / Data Collection	Partner	Recommendation
A-TWAIN	IMR & NPI	Sustained, (inter)national funding is required. Funding is now on project basis from the FRAM - High North Research Centre for Climate and the Environment, flagship "Sea Ice in the Arctic Ocean, Technology and Agreements".
A-TWAIN Poland	IOPAN	Close international collaboration and coordination is required. Project needs vessel-time for moorings deployment and

		recovery.
AREX (Long-term large-scale monitoring program)	IOPAN	Sustained funding is required, extension with biochemical measurements is recommended. Data handling and sharing protocols are needed to integrate with Copernicus/EMODnet.
Argo Poland	IOPAN	Deep ARGO and biogeochemical ARGO floats should be deployed. For all Arctic Argo projects, Arctic ARGO float should be developed (small, cheaper and/or 'smart', able to survive under the ice).
FRAM - (FRontiers in Arctic marine Monitoring) including HAUSGARTEN	AWI	HAUSGARTEN is the longest existing deep-sea observatory in the Arctic Ocean. However especially for moored instruments no near-realtime (NRT) data transfer is possible due to ice conditions. The observatory should be upgraded by a cabled connection to a Svalbard land station. This would allow NRT data transfer and perhaps energy supply also of newly developed and deployed FRAM instrumentation.
Fram Strait Multipurpose Acoustic System	NERSC	The acoustic multipurpose system need funding to be continued to be useful for climate monitoring, monitoring the Arctic environment and to be used as a UW-GPS system for gliders and floats. UW-GPS system is a prerequisite to expand the ARGO system into the ice-covered Arctic. In future, the system should be connected to the Fram Strait Freshwater Observatory and the FRAM infrastructure.
AWI Ship borne CTD surveys (RV Polarstern) (part of FRAM observing system)	AWI	Data processing and quality-checking standards should be defined and documented for oxygen and chlorophyll (fluorescence). For temperature and salinity, the established data processing and quality-checking standards should be documented for future personnel turnovers.
AWI Fram Strait Mooring Array (part of FRAM observing system)	AWI	Funding and personnel should be maintained (see above, FRAM observing system).
AWI VM ADCP measurements (RV Polarstern) (part of FRAM observing system)	AWI	Sustained personnel required (responsible person is about to retire soon). Data processing routines should be defined and better documented.
Greenland Ecosystem Monitoring Programme	AU	Sustained, international funding is required to standardize and coordinate across national efforts. The extensive logistical framework (ships, stations, programs) needs to be made available to a broader scientific community.
IMR Barents Sea Opening mooring array	IMR	More systematic updates (new measurements, including additional moorings) is recommended. The actual measurement program is funded sustainably by IMR. However, further

		development and use of the data for research is now funded on an ad hoc basis, this should be made more permanent.
IMR Barents Sea Winter Survey	IMR	The actual survey is funded sustainably by IMR. However, further development and use of the data for research is now funded on an ad hoc project basis, this should be made more permanent.
IMR fixed hydrographic sections	IMR	The temporal and spatial coverage of the main sections must be maintained.
IMR fixed hydrographic sections (near coast)	IMR	The temporal coverage must be maintained, frequency of observation not reduced.
IMR SI Arctic vessel mounted ADCP system	IMR	The observation network is part of the SI_Arctic /Arctic ecosystem survey and funded by SI_Arctic, which is a Strategic Institute program awarded to IMR by the Ministry of Fisheries through the Research Council of Norway for January 1 2014- December 31 2018 (5 years). The research cruise including the ADCP observation network should be continued after this date, but this requires additional sustainable funding.
IMR-PINRO Ecosystem Survey	IMR	This is for many purposes the most important survey in the Barents Sea. The survey is funded by IMR and PINRO, but there have been reductions in temporal and spatial coverage the last years from both institutes. It is important to maintain sustainable funding and keep a broad coverage.
Tide Gauge in Greenland	DTU	Tide Gauges in the arctic region is the only reliable source of in situ sea level measurements. Further installation of tide gauges in locations surrounding the arctic ocean is recommended.
IOPAN Long-term Monitoring in Svalbard Fjords	IOPAN	Project needs sustained funding. Extension with more biochemical measurements is recommended.
NIVA Barents Sea Ferry Box	NIVA	Sustained funding is required, robust data handling and sharing protocols needed to integrate with Copernicus/EMODnet
NorArgo	IMR & NorArgo	Argo Norway is now funded by an RCN infrastructure project coordinated by IMR with UiB, NERSC, met.no, Akvaplan NIVA, and Uni Research as partners. Sustainable funding beyond the end of this project is required.

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