INTAROS WP2: exploitation of existing Arctic observing systems

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Objectives and tasks

Objectives: Assess, exploit, and standardize the existing Arctic observing systems to enable established databases to deliver remote sensing and in situ data products to a multidisciplinary, integrated Arctic Observing System (iAOS).

- **Task 2.1 Assessment of existing Arctic Observing Systems and identification of essential gaps**
  Lead: MISU, Michael Tjernström
- **Task 2.2 Exploitation of existing data towards improved data products**
  Lead: GEUS, Andreas Ahlstrøm
- **Task 2.3 Compilation of data products from distributed databases and** observatories for integration in iAOS
  Lead: AWI, Ingo Schewe
- **Task 2.4 Synthesis and recommendations**
  Lead: MISU, Michael Tjernström

Main achievements: Task 2.1
Gap analysis and maturity assessment

1. **Definition of observing system** (which enabled a coherent and systematic approach)

2. **Definition of requirements** (Input to INTAROS Revised Requirement Report **D1.9**):
   a. Requirements on spatial coverage and temporal duration of the observing systems (not existing in WMO WIGOS because irrelevant for the gridded and integrated approach of WIGOS)
   b. Requirements for data collections provided at processing Level 0 to 2 (requirements from WMO and Copernicus are applicable to data al Level 3 or higher)
   c. Utilizing the maturity matrix approach developed in H2020 GAIA-CLIM CORE-CLIMAX projects, requirements (= best practice) for the following categories:
      - Sustainability
      - Metadata
      - Documentation
      - Uncertainty characterization
      - Public access, feedback, and update
      - Usage

Main achievements: Task 2.1
Gap analysis and maturity assessment

3. Survey

QUESTIONNAIRE A: Arctic existing *in situ* observing systems

- General info
- Sustainability
- Data management
- Data usage

QUESTIONNAIRE B: Arctic existing *in situ* data collections

- General info
- Uncertainty characterization
- Data coverage, resolution, timeliness, and format
- Metadata specifications, documentation
- Not to be answered, if the data belong to one of the listed observing systems:
  - Data management
  - Sustainability
  - Data usage

QUESTIONNAIRE C: Arctic satellite products

- General info
- Data coverage, resolution, timeliness, and format
- Uncertainty characterization
- Metadata specifications, documentation
- Data management
- Data usage

4. (Modest) model sensitivity studies

ATMOSPHERE: ECMWF model sensitivity to radiosounding observations

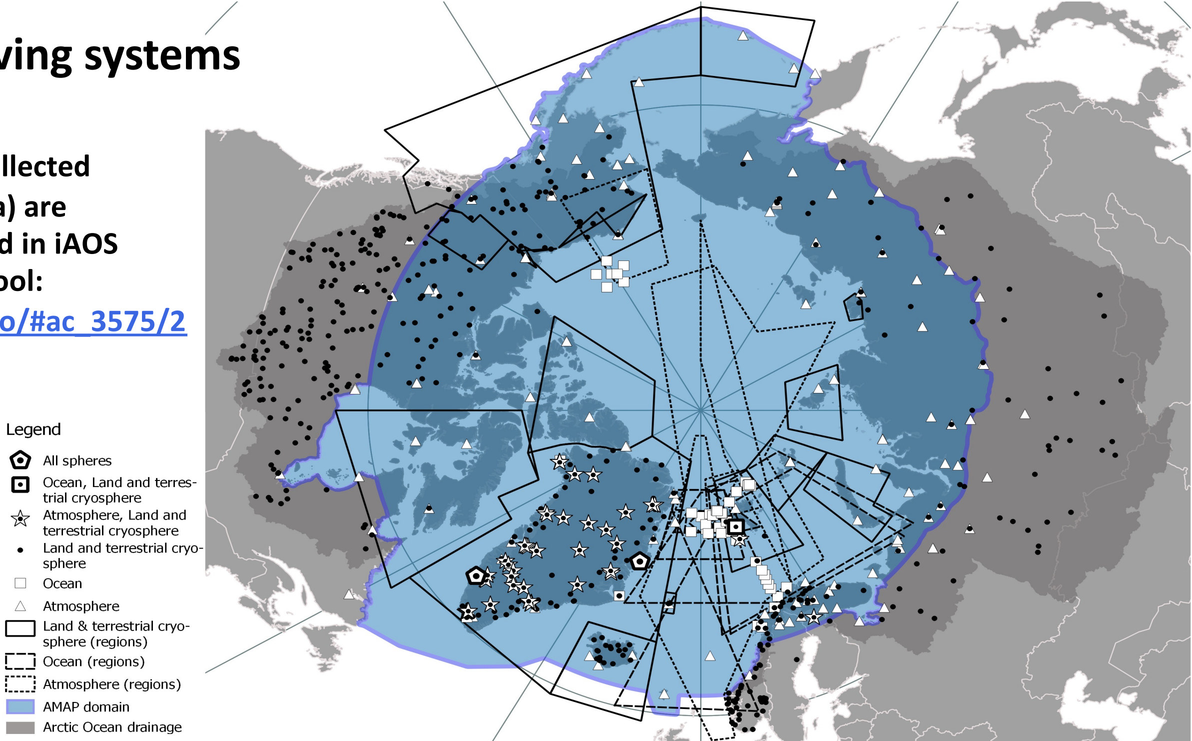
OCEAN MIT GCM sensitivity to SSH and salinity

LAND inverted modeling of 'field of view' for GHG tower network.

Main achievements: Task 2.1
Gap analysis and maturity assessment

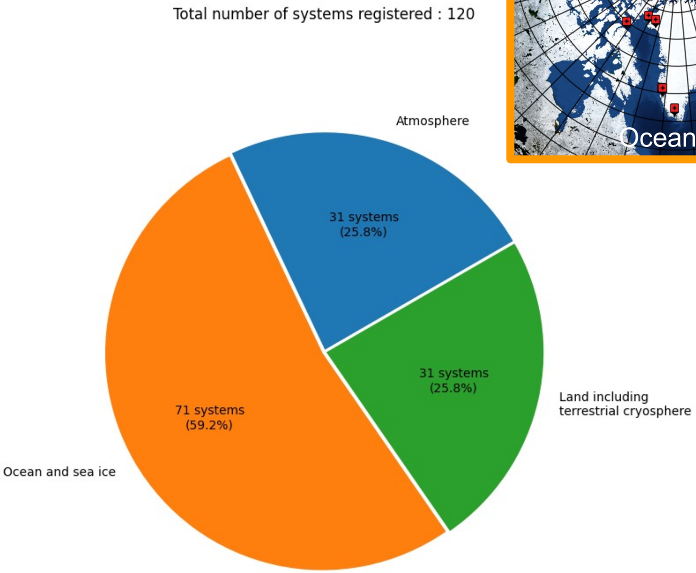
Assessed observing systems

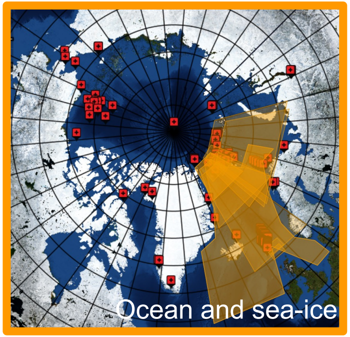
Questionnaire A and collected informations (metadata) are accessible and displayed in iAOS through the ARCMAP tool: https://arcmap.nersc.no/#ac_3575/2/90.0/0.0

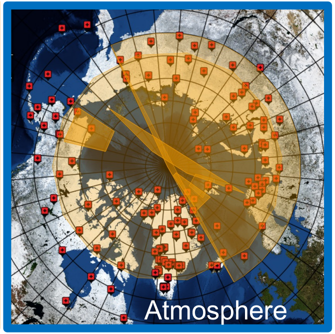


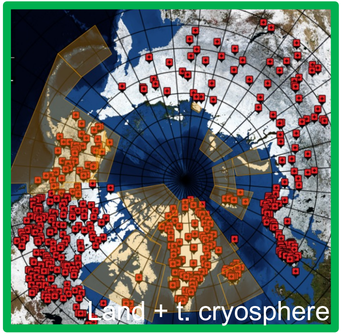
Main achievements: Task 2.1
Gap analysis and maturity assessment

Domain of the surveyed observing systems

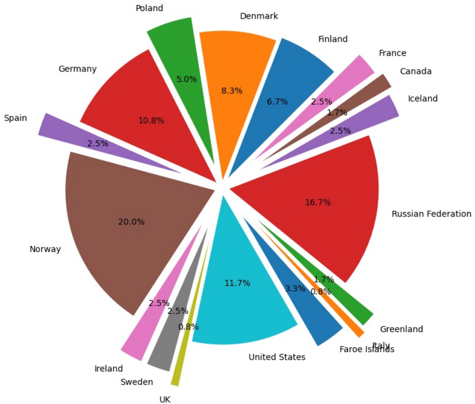








Countries of the respondents:



Main achievements: Task 2.1 Gap analysis and maturity assessment

5. Identified gaps of in situ observations:

Marine environment

a. **Atmosphere: In situ** observational gaps are in almost everything, especially in the vertical structure of atmosphere and of clouds; **satellite** retrievals, especially of clouds and profiling, are inadequate

b. **Ocean and sea ice**: Main gaps for **in situ** observations are in the vertical structure under ice, biogeochemical and biological observations, long-term moorings, sea-ice thickness and snow on the ice; **satellite** sea ice concentration data products have high uncertainty at low ice concentrations. Sea-ice related data products are required at higher resolution both for operational applications and assimilation into ocean and atmospheric circulation models.

Terrestrial environment

a. **Atmosphere**: For **in situ** observations there is need of increased data quality in some parts of the Arctic; long-term process observations of clouds and aerosols (e.g. in "super site") , especially in Russian Arctic where trace gas and trace-gas fluxes also have gaps

b. **Land and cryosphere**: For **in situ** observations: main gaps are in: scarcity of number/type of snow, glacier & ice sheet mass balance observations; availability of near-real-time observations; lack of uncertainty characterization of **satellite** products (importance of in situ data!). User feedback score is low in both in situ and satellite products

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Main achievements: Task 2.1
Gap analysis and maturity assessment

6. Assessment of information technology infrastructure (data repositories):

Gaps: most data repositories are not FAIR, and do not assign a DOI. FAIRness of data requires a close collaboration between the data providers/curators and the technology experts who maintain the data repositories. This is often lacking. Standards and tools for metadata and data are lacking.

Most advanced solutions are offered by International thematic portals, which provide access to a large volume of data and services and hold the most advances solutions for the efficient usability of the data:

EU RI: ACTRIS, ICOS, EuroARGO, and SIOS

WMO: GCW; Copernicus: INSTAC

Advantages: data are store in institutional repositories

Disadvantages:considerable resources are required to enable the data FAIRness

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Main achievements: Task 2.1
Gap analysis and maturity assessment

Deliverables:

- **D2.1** Report on present observing capacities and gaps: ocean and sea ice observing system (Resp. DTU)
- **D2.4** Report on present observing capacities and gaps: atmospheric observing system (Resp. MISU)
- **D2.7** Report on present observing capacities and gaps: terrestrial and cryospheric observing system (Resp. USFD)
- **D2.12** Observational gaps revealed by model sensitivity studies (Resp. UHAM)

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Main achievements: Task 2.2
Exploitation of existing data towards improved data products

7. **Improved data products** (processing, data management, data quality)
   NERSC: acoustic data; **AWI**: unified database for Arctic and Subarctic Hydrology; UiB and GEUS: Earthquake and Focal Mechanism Catalogue; **IOPAN**: AREX,, A-TWAIN, Argo floats, Hydrographic data; **AU**: Greenland Ecosystem Monitoring Programme; **FMI**: atmospheric black carbon; **IGPAN**: soil temperature

8. **New data products**
   - **UB**: new **total water vapour over ice and open water**, **thickness of thin sea ice**, and **sea ice concentration** products obtained exploiting existing satellite.
   - **IFREMER**: Arctic **sea ice displacement** from low (62.5) and medium (31.25km) resolution satellite data
   - **SHMI-hydrology**: The **Arctic-HYCOS dataset** was enhanced with regard to temporal and spatial coverage by combination of data from GRDC and NHS repositories, and with regard to station metadata.
   - **DTU glaciology and GEUS**: The new **Ice mass change of the Greenland ice sheet** product obtained combining in situ and satellite data have higher spatial resolution than previous products, enabling a better knowledge of ice mass change. Moreover, the new **ice velocity maps of the Greenland ice sheet** based on newly available Sentinel data will enable to remotely monitor Greenland ice dynamics at an unprecedented six-day temporal resolution.
   - **UPM**: new method to derive **ice discharge** data from combination of in-situ and satellite observations
   - **U Slaski**: new data on **front positions of tidewater glaciers** in Hornsund, Svalbard.
   - **FMI**: production of the **SMOS soil frost** satellite product; new **cloud products** from in-situ ceilometer data
   - **GFZ**: Increase temporal and geographic coverage of **turbulent and GHG fluxes** in the Arctic

Main achievements: Task 2.2

Exploitation of existing data towards improved data products

Deliverables:

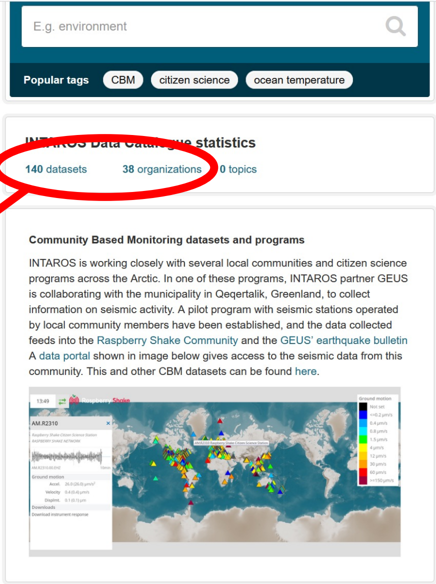
- **D2.2** Report on exploitation of existing data: ocean and sea ice (Resp. NERSC)
- **D2.5** Report on exploitation of existing data: atmospheric (Resp. FMI)
- **D2.8** Report on exploitation of existing data: terrestrial and cryospheric data (Resp. GEUS)

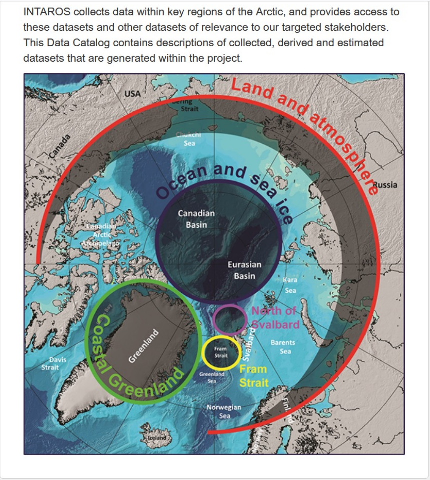
Main achievements: Task 2.3
Compilation of data products for integration in iAOS

8. **Compilation of data products** from distributed databases
9. **Harmonization of sparse data** following best practices and protocols

Available through:
- **open access databases**
- **INTAROS Data Catalogue**
  https://catalog-intaros.nersc.no/
  which is part of the iAOS portal

140 datasets
38 organizations





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Main achievements: Task 2.3

Tags from the INTAROS Data Catalogue:

CBM: 16; Citizen science: 12; Community-based monitoring: 7; Community-based observing: 5
Ocean temperature: 10; Acoustic thermometry: 3
Sound speed: 9;
Passive acoustics: 5; Active acoustics: 4;
Ambient sound: 4
Ocean salinity: 6
(ocean) pressure: 6
HAUSGARTEN: 4
UAK: 4
XBT: 4
CTD: 2
Environment: 9; Environmental changes: 3
Climate: 6; climate research: 4
Glaciology: 5
Cryosphere: 3
Sea ice: 7; sea-ice: 3
Natural hazards: 3

meteorology: 9; Atmosphere: 8; Arctic meteorology: 2; Meteorology: 2
AO2018: 7; AO18: 7; Arctic Ocean 2018: 6
ACAS: 6
Arctic (atmospheric) boundary layer: 5
Arctic surface fluxes: 2
Weather predictions: 3
Arctic clouds: 4
Svalbard: 9; Hornsund: 6; Hansbreen: 5
Greenland: 4; Greenland ice sheet: 2
High Arctic: 4
Alaska: 3
Faroe Islands: 2
Biology: 7; Biodiversity: 6
Birds: 3
Marine mammals: 3
Wildlife: 3

Main achievements: Task 2.3

<u>INTAROS Data Catalogue:</u> concreate steps toward data FAIRness.

Faindability**A**ccessibility**I**nteroperability**R**eusability

Findable

F1. (Meta)data are assigned a globally unique and persistent identifier
F2. Data are described with rich metadata (defined by R1 below)
F3. Metadata clearly and explicitly include the identifier of the data they describe
F4. (Meta)data are registered or indexed in a searchable resource

Interoperable

I1. (Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.
I2. (Meta)data use vocabularies that follow FAIR principles
I3. (Meta)data include qualified references to other (meta)data

Accessible

A1. (Meta)data are retrievable by their identifier using a standardised communications protocol
A1.1 The protocol is open, free, and universally implementable
A1.2 The protocol allows for an authentication and authorisation procedure, where necessary
A2. Metadata are accessible, even when the data are no longer available

Reusable

R1. Meta(data) are richly described with a plurality of accurate and relevant attributes
R1.1. (Meta)data are released with a clear and accessible data usage license
R1.2. (Meta)data are associated with detailed provenance
R1.3. (Meta)data meet domain-relevant community standards

Main achievements: Task 2.3
Compilation of data products for integration in iAOS

Deliverables:

- **D2.3** Catalogue of products and services based on ocean and sea ice data (Resp. AWI)
- **D2.6** Catalogue of products and services based on atmospheric data (Resp. SMHI) with later update concerning the atmospheric total water vapour data set
- **D2.9** Catalogue of products and services based on terrestrial and cryospheric data (Resp. GFZ)

Main achievements: Task 2.4
Synthesis and recommendations

Deliverables:

- **D2.10** Report on synthesis and recommendation from WP2 (Resp. MISU)
- **D2.11** Report on the maturity scores of existing observing systems in the Arctic (Resp. NUIM)

Expected impacts

- The **ARCMAP** tool, developed in an INTAROS spin-off project to enhance and automatize the WP2 questionnaires, provides unique and relevant metadata on observing systems, which can be shared with PolarObservingViewer, SIOS, and other relevant Arctic portals. ARCMAP is expected to grow and be more and more populated by the ongoing observing systems. It will serve SAON and anybody planning or assessing observations in the Arctic to quickly visualize various statistics on the observing systems and easily identify observational gaps in the Arctic.

- The **Arctic observing gap analysis** and the recommendations presented in the two synthesis reports D2.10 and D2.11 will provide a substantial input to the INTAROS and SAON roadmaps, and to the planning of future Arctic observations.

- The undertaken effort to **format and publish data and metadata in accessible repositories** has enhance the accessibility to a large number of data, including long-time series relevant for climate applications. Hence, a better exploitation of these data is expected. For some partners and institutions, this effort has caused the establishment of a state-of-art data repository compliant with FAIR principles, with benefits well beyond INTAROS.

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Expected impacts

Expected impacts from the exploitation of data in Task 2.2:

- **Impact on weather, hydrological, and sea-ice services:**
  - UB: new **total water vapour over ice and open water**, **thickness of thin sea ice**, and **sea ice concentration** products obtained exploiting existing satellite.
  - IFREMER: Arctic **sea ice displacement** from low (62.5) and medium (31.25km) resolution satellite data
  - SHMI-hydrology: The **Arctic-HYCOS dataset** was enhanced with regard to temporal and spatial coverage by combination of data from GRDC and NHS repositories, and with regard to station metadata.

- **Impact on climate modelling and policy makers:**
  - DTU glaciology and GEUS: The new **Ice mass change of the Greenland ice sheet** product obtained combining in situ and satellite data have higher spatial resolution than previous products, enabling a better knowledge of ice mass change. Moreover, the new **ice velocity maps of the Greenland ice sheet** based on newly available Sentinel data will enable to remotely monitor Greenland ice dynamics at an unprecedented six-day temporal resolution.
  - UPM: new method to derive **ice discharge** data from combination of in-situ and satellite observations
  - U Slaski: new data on **front positions of tidewater glaciers** in Hornsund, Svalbard.
  - FMI: production of the **SMOS soil frost** satellite product.

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Expected impacts

Expected impacts from the exploitation of data in Task 2.2:

- **Impact on modelling, process studies, climate monitoring.**
  - **GFZ**: Increase temporal and geographic coverage of **turbulent and GHG fluxes** in the Arctic
  - **FMI**: new **cloud products** from in-situ ceilometer measurements

Challenges

Assessment of observational gaps:

- Requirements for in situ observing systems were (and in big part still are) missing.
- There is not any defined metadata standard for observing systems. To make a consistent assessment across different disciplines, we needed to develop an internal “INTAROS” protocol.
- The assessment is naturally partial. For completeness, the survey should be extended also to those systems that are currently not included. However, this would require an international interest and commitment that is hard to stimulate without continuation of funding.

Harmonization of sparse data:

- Standard protocols for formatting data and metadata are still missing for many variables. This is a requirement for data interoperability and FAIRness.
- There is a knowledge and communication gap between the data providers/curators and the information technology experts who maintain the data repositories.

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WP2 Recommendations

- High sustainability is a proxy for high maturity scores in all assessed aspects. Sustained observing systems result from national, regional or global infrastructures often not specific to the Arctic ⇒

  Integrate Arctic observing in existing national/regional/global program rather than inventing new Arctic specific systems

- Scientific campaigns/expeditions provide the highest quality observations, but are deficient in almost all other aspects, especially on sustainability and data management ⇒

Revision of funding mechanisms:

- increase coordination/shared funding between operational and scientific driven observations
- involvement of private sector: more observations should be based on ships of opportunity
- a subset of ocean, sea-ice and atmosphere observations should always be made on all research expeditions, regardless of their scientific aim
- Dedicated funding should be ensured to the data management (from national or int. bodies)

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WP2 Recommendations

- **Arctic Ocean**: A lack of in-situ observing capacity across all disciplines. Almost nothing in the atmosphere; subsurface installations robust but few, and they deliver data in delayed mode ⇒

  For the atmosphere: a paradigm shift in system design is needed, where field experiments correspond to the reference system, satellites to baseline and reanalysis replaces the comprehensive level.

  For the ocean: increased number of autonomous observing platform and systems is needed, deployed on ice and under ice during field campaigns

- **Arctic land**: Quality is a larger problem than coverage ⇒

  Upgrade and complement existing stations, rather than expanding new networks; invest in new technology (to further automatize the measurements) at existing stations

- **Satellites**: provides the only data with sufficient spatial and temporal cover, but quality is sometimes lacking ⇒

  Invest in in situ Cal/Val multidisciplinary supersites and field campaigns to improve satellite retrievals, models and data assimilation

↓

Multidisciplinary in situ supersites/experiments, new technology!

WP2 Recommendations

- Better integration between in situ and satellite observations through:
  - Assessment of spatial representativeness of in situ observations,
  - deployment of large quantity of cheap, autonomous sensors over the critical gaps in spatial representativeness (e.g GNSS sensors for snow water equivalent, web-cams for snow extent, ice velocity, and coastal sea ice presence/drift).
- Better integration between European, American, Canadian, Chinese and Japanese observing programs and infrastructures, through:
  - Shared data portals
  - Shared use of research icebreakers (as in MOSAiC)

The floor is yours for comments!