# Copernicus needs for Arctic In Situ data

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## Abstract

The Copernicus Services and Space Component deliver a wide range of data and products with relevance for the Arctic region. Furthermore, important in situ data collection, rescue, and quality assurance activities are carried out as an inherent part of Copernicus production workflows. Thus, Copernicus is contributing significantly to the Integrated Observing System operating in the Arctic.

Access to data from sources other than satellites is indispensable for the generation and quality of Copernicus products, and for the Space Component to play its full role. Furthermore, as Copernicus is an operational programme, such data need to meet stringent requirements regarding timeliness, availability, and quality. The Copernicus In Situ Coordination activity led by the European Environment Agency (EEA) has launched a study with the purpose of clarifying to which extent the necessary in situ data from the Arctic region are available to the Copernicus programme. The study covers data already used by the Copernicus Services and the Space component; data that are freely available at various national and international data repositories but still not used by Copernicus; data with restricted availability due to institutional and/or national data policies; and data collected by research projects without a data management structure enabling a free data exchange.

It is mandatory for Copernicus to have access to a broad suite of in situ observations in sufficient quality and resolution in time and space. The wide range of products with relevance for the Arctic region delivered by the Copernicus Services and Space Component provides the necessary basis and justification for the identified in situ data gaps, specific requirements, and recommendations. The gap analysis has identified two groups of data gaps: i) observations needed but do not exist and ii) observations that exist but are not being used. The latter is mainly due to data not being freely available due to e.g. use restrictions and lack of institutional data management structure; or they do not fit Copernicus' needs due to i) untimely availability; ii) lack of sufficient metadata; or iii) Inadequate quality. In addition to these data gaps, two other important challenges related to observation technology and the sustainability of the observing systems have been identified. These results underline that there is a need for initiating dedicated actions to improve the availability and accessibility of critical in situ data to meet Copernicus' needs and to ensure proper cooperation and coordination between Copernicus and other key European and international initiatives aiming at sustaining an Arctic Observing System of Systems.

## Setting the scene[2]

The Copernicus programme is an EU Earth observation programme that delivers a vast resource of data and information from space, in situ and models on a full, free and open basis to underpin our understanding of a wide range of environmental issues – from the immediate impacts of natural or man-made crises to phenomena which operate over decades.

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[2] This section is primarily based on https://www.copernicus.eu/en/copernicus-services-information-and-sentinel-products-arctic-region

Access to data from sources other than satellites is indispensable for the generation and quality of Copernicus products, and for the space component to play its full role. Furthermore, as Copernicus is an operational programme, such data need to meet stringent requirements about availability and quality. There are big challenges in ensuring that the non-space data that Copernicus needs are available and can be used effectively in harmony with Copernicus' data policy.

The Arctic is a region very sensitive to environmental changes. There is a very close interrelation and delicate balance between atmosphere, terrestrial, cryosphere, sea ice and ocean, especially in relation to solar energy retainment, the radiation budget and the hydrological cycle. This has a great impact on physical, chemical and biological processes in the area.

Due to the hostile environment, there is a great lack of basic observations in the Arctic that can support scientific understanding of key processes. Most of the existing data are collected via time limited research projects. This lack of process knowledge results in significant errors in forecasting models – operational as well as climate.

Observations from a sustained and coordinated Arctic Observing System underpinned by a long-term observation strategy are therefore essential to Copernicus.

Specific requirements for in situ data and observing systems in the Arctic are strongly linked to Copernicus' product portfolio and its evolution. An overview of the wide range of products with relevance for the Arctic region delivered by the Copernicus Services and Space Component provides the necessary basis and justification for the in situ data gaps, specific requirements, and recommendations that will be presented subsequently.

**The Copernicus Marine Environment Monitoring Service (CMEMS),** provides a series of information products for the global ocean and European Regional Seas including the Arctic Ocean based on model forecast, satellite and in situ observations.

CMEMS' monitoring and forecasting products for the Arctic Ocean include traditional physical conditions such as temperature, salinity and currents from surface to the ocean floor supplemented with water level and surface wave conditions such as total wave integrated variables as well as their swell and wind-sea components. CMEMS monitoring and forecasting additionally include the evolution of basic biogeochemical variables such as nutrients (nitrate, phosphate and silicate), phytoplankton and zooplankton biomass, oxygen, chlorophyll and primary productivity. These products are naturally complemented in the Arctic Ocean by a large set of ice related quantities such as sea ice coverage, edge, thickness, drift and icebergs distribution. Arctic sea ice extent has been identified as a key variable used to track the vital health signs of the ocean and implemented as an Ocean Monitoring Indicators product.

An integrated part of CMEMS is the In Situ Thematic Assembly Centre (INSTAC), which ensures a consistent and reliable access to a range of in situ data for the purpose of service production and validation.

**The Copernicus Atmosphere Monitoring Service (CAMS),** provides information products about atmospheric composition and solar radiation. Several products are of interest for the Arctic region; among these, one can especially highlight:

- Emissions by fires at high latitudes (Canada, Siberia) and transport of the corresponding plumes of gases and aerosol affecting atmospheric composition in the Arctic region. A new (experimental) deposition flux product is available for test. The impact of substantial fire events like in August 2017 on radiation and weather anomalies is also under investigation.
- Monitoring and forecasting of the ozone layer, including Arctic “mini-holes” events.
- Emissions of greenhouse gases, reactive gases and aerosol from shipping estimated by bottom-up calculations (from actual ship characteristic and tracks).
- Net fluxes of CO2, CH4 and N2O (monthly means) from inverse modelling.

All these products are available from the catalogue of products on the CAMS website.

**The Copernicus Climate Change service (C3S),** delivers routinely monthly maps of sea ice in both the Arctic and Antarctic areas.

The products presented in the monthly summaries of sea-ice are based on data from ECMWF's ERA5 reanalysis of observations from 1979 to the present. ERA5 does not analyse sea-ice observations directly. Instead, it incorporates analyses of fractional sea-ice cover (or concentration) produced elsewhere. The analyses used for dates from September 2007 onwards has been made of the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) product, which in turn uses a global sea-ice analysis produced by the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI-SAF). The ERA5 sea-ice field does not include ice shelves. These shelves comprise ice that originates from and is anchored to the land. The maps of average sea-ice cover for a particular month include a climatological ice edge for that month. This ice edge is defined by the location of the 15% value in the average cover for 1981-2010.

ERA5 forms the basis for the new climate bulletins. C3S is also procuring a prototype high-resolution regional reanalysis over the Arctic as well as a specific action on the production of Earth Observation based sea-ice ECVs. Finally, one of the Economic Sectoral activity addressed by C3S -Shipping - addresses the impact of climate change on ship routing issues.

**The Copernicus Land Monitoring Service (CLMS),** provides key information on the state of vegetation, including crops and forest. The monitoring of snow cover, lake ice, inland water volume and quality is also part of the land service portfolio. Land cover maps produced by the Service at high and very high resolution are essential information for land planning, and for supporting sustainable use of natural resources and preserving biodiversity and natural habitats.

The **Copernicus Space Component’s** six operational Sentinel missions are delivering data on a 24/7 basis. Three of them consisting in two satellites flying in tandem are already in orbit:

- Sentinel-1 provides all-weather, day and night radar imagery for land and ocean services. The twin satellites Sentinel-1A and Sentinel-1B were respectively launched on 3 April 2014 and on 25 April 2016. At this point in time, Sentinel-1 is the primary source of data for information on the Arctic providing information for services related to monitoring of Arctic sea-ice extent or routine sea-ice mapping.
- Sentinel-2 provides high-resolution optical imagery for land services. It provides for example, imagery of vegetation, soil and water cover, inland waterways and coastal areas. Sentinel-2

also delivers information for emergency services. The twin satellites Sentinel-2A and Sentinel-2B were respectively launched on 22 June 2015 and on 7 March 2017.

- Sentinel-3 provides high-accuracy optical, radar and altimetry data for marine and land services. It measures variables such as sea-surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. The twin satellites Sentinel-3A and Sentinel-3B were respectively launched on 16 February 2016 and on 25 April 2018. The Sentinel-3 mission will for example allow increasing the predictability of characteristics such as sea state, ice formation, ocean circulation and the impact of physical conditions on ocean biogeochemistry which are all relevant for Arctic area.

In addition, Sentinel-5P has also been launched in 2017, contributing to Polar/Arctic observation. The main objective of the Sentinel-5P mission is to perform atmospheric measurements, with high spatial-temporal resolution, relating to air quality, climate forcing, ozone and UV radiation.

In the future, and in the context of the evolution of Copernicus, preliminary studies and activities have started to develop a dedicated mission to address in particular the objectives raised in the EU Arctic Policy. The top priority concept of mission, the Copernicus Imaging Microwave Radiometer mission could be launched at the horizon 2026-2027. With this concept, the two poles will be systematically covered on every orbit and the mission will offer a Sub-daily coverage (~5-6 hours) of the Arctic area. A second mission, observing the topography of the Arctic environment and relying on the heritage of the Cryosat-2 mission, is also in the preliminary phases of development by ESA.

These activities are developed in the context of broader discussions on the evolution of Copernicus, which include other missions and initiatives of relevance to the Arctic. Notably an initiative on developing an anthropogenic CO2 emission monitoring and verification support capacity, with its own dedicated space component.

## Survey on availability of In Situ data for Copernicus purposes

Monitoring of the Arctic region relies heavily on satellite observations supplemented by ground based observing networks. Additionally, the enormous potential of data from the Sentinels cannot be realised without access to accurate ground truth observations, which are required for mandatory calibration and validation activities.

The Copernicus In Situ Coordination activity led by the European Environment Agency (EEA) initiated late 2018 a project with the aim of clarifying to which extent the necessary in situ data (near real-time as well as delayed) are available to:

- Maximize the exploration of present and future Copernicus Sentinels;
- Produce and validate products from the Copernicus Services – in particular CMEMS, C3S, and CAMS.

The objective of the project was to provide an analysis of:

- Requirements for meteorological, ocean incl. sea ice and cryosphere in situ data in the Arctic region by Copernicus Services and Space Component;
- Existence and availability of the requested data incl. identification of condition for accessing restricted data (payment, use restrictions etc.);
- Identified gaps.

The project was implemented during the first half of 2019 with input from ESA, EUMETSAT, ECMWF and Mercator Ocean International resulting in a comprehensive report, Buch et al, 2019. The report is available on https://insitu.copernicus.eu/

## Main Results

The Copernicus Services and Space Component requirements for in situ data in the Arctic Region has been collected and analysed. The analysis shows that it is mandatory for Copernicus to have timely access to a broad suite of in situ observations of sufficient quality and resolution in time and space. The Copernicus community has clearly articulated which variables are essential for their production line as well as their requirement for timely delivery and quality, while the resolution in time and space is still open for further clarification. The latter issue is being addressed in the Copernicus In Situ Coordination Information System ($CIS^2$) established as part of the Copernicus In Situ Component led by the EEA.

The project group has collected a thorough, although not complete, overview of existing in situ data from the Arctic, i.e.:

- Data already used by the Copernicus Services and Space component;
- Data freely available at various national and international data repositories but still not used in the Copernicus production line;
- Data with restricted availability due to institutional and/or national data policies;
- Data collected in research projects without a data management structure enabling a free data exchange.

The gap analysis has identified two groups of data gaps:

1. Observations needed but do not exist - this kind of gap can be roughly identified by comparing the requirements and spatiotemporal distribution of the observations;
2. Observations that exist but are not being used because:
    - Data are not freely available due for example. data policy, lack of institutional data management structure, delayed release from research projects, need for revenue generation, technological confidentiality and even political issues;
    - They do not fit Copernicus purposes due to
        a. Untimely availability - most of the applications have strong time constrains, e.g. near real time forecast and validation need observations in near real time; interim reanalysis needs observations in interim scale, i.e., 1-12 months before production time;
        b. lack of sufficient metadata;
        c. Inadequate quality - observations for Copernicus must fulfil certain quality standards.

In addition to the data gaps, two important challenges have been identified:

- Technology gaps. The harsh and remote environment puts special demands on the instrumentation for in situ observations as well as data communication in near real-time, and the existing technology and infrastructure is extremely costly. The gap in technology has up to now put limitations on the monitoring of the Arctic, so there is a need to find innovative

cost-effective technological solution for Arctic observations securing continuous near real time data flow from this harsh environment including during wintertime;

- Sustainability gaps. The sustainability of observation is highlighted as very important to maintain areal coverage and long time series. The sustainability problem has recently been investigated and documented by the Copernicus In Situ Coordination Component (Buch et al, 2019) showing severe sustainability problems for European in situ observations in general - particularly for atmospheric composition and ocean observations. The present analysis shows that the sustainability issue is more pronounced in the Arctic for all thematic domains, since many in situ observations rely on time limited research funds.

## General conclusions

The analysis leads to the following general conclusions:

- Environmental in situ data from the Arctic are managed by national data centres, international data centres, funding agencies and individual research project, both in countries with Arctic coastline and countries with an Arctic interest;
- National observations programmes generally meet national priorities and lack international coordination;
- The purpose of using in situ observations in Copernicus ranges from calibrating and validating satellite sensors, algorithms and numerical models, to assimilation by operational and reanalysis models. In addition, for the climate service, consistent and long-term observations are needed to identify the trend and long-term variability of the climate;
- In situ observations are very sparse in the central Arctic;
- Due to lack of good communication facilities, many data are delivered in delayed mode and are therefore inappropriate for near real time productions in particular. Other data e.g. research data are made publicly available too late to be available even for interim re-analysis purposes i.e. there is a need for internationally agreed standards for timely delivery delayed mode data taking into account scientists right to publish;
- The Arctic environment put high demands on robust technology and there is a clear need to pursue innovative technology development;
- Several services express that the limited amount of data is a bigger problem than the quality of data, although poor data quality in itself is problematic;
- Insufficient data management structures at data producer level constitute a big problem which negatively affects:
    - Formats of data and metadata;
    - Accessibility;
    - Timely delivery;
    - Quality documentation.
- Access to Russian data are extremely limited and calls for a dedicated action to free more critical observations in cooperation with Russian authorities;
- The given heterogeneity of the data sources implies that:
    - Automated data quality control is difficult and poor quality can consequently significantly impact verification results;
    - It is important that data are collected at sites which are representative of their wider area rather than their immediate surrounding.

## Next steps

The analysis has underlined the need for initiating dedicated actions to improve the availability and accessibility of critical in situ data to meet Copernicus' needs. It is however important to ensure proper coordination with other key European and international initiatives, e.g.:

- The Sustaining Arctic Observing Networks (SAON) is a joint initiative of the Arctic Council and the International Arctic Science Committee that aims to strengthen multinational engagement in pan-Arctic observing. SAON has recently approved a strategy and implementation plan covering the 2018-28 period;
- WMO, IOC and GEO all have a strong focus on the Arctic region due to the fact that climate changes are happening faster and is more pronounced in this region;
- EU has funded several H2020 projects with a focus on the Arctic region. These projects have been collecting, and continue to collect a lot of valuable information towards design of a fit-for-purpose observation system e.g. user requirements for products and services, operation of some observation system although limited in time, etc. The EU has established an Arctic Cluster for internal coordination between these projects. It would especially be important to establish links to the INTAROS project which has a major goal to establish a roadmap towards a sustained Integrated Arctic Observations System;
- Relevant national authorities since the implementation of a future sustained Integrated Arctic Observing System will rely heavily on national funding. In this respect it will also be important to investigate ways to cooperate with national data providers and involve indigenous people in the implementation.

As a practical way forward, Copernicus is considering the feasibility of the following short-term actions that need to be implemented in a coordinated and collaborative manner:

- Establish formal links to intergovernmental bodies such as SAON, WMO, IOC and GEO to ensure that Copernicus requirements for a sustained and integrated observing system are articulated and taken into account;
- Liaise with Horizon Europe to promote that
    - Arctic relevant observing technology and data communication development is included in future research calls – focus could be on multipurpose and autonomous observing platforms;
    - Research projects are requested to secure free exchange of data along the FAIR principle using existing European data management infrastructures.
- Continue to setup and leverage international cooperation arrangements between the EU and non-EU countries with an Arctic interest, e.g. Canada (e.g. the Canadian Arctic Weather Science Project, CAWS[3]), South Korea, Japan, and the USA;
- Continue to define and document Copernicus specific requirements to an Arctic in situ observing system – attention should especially be on:
    - Resolution in space and time;
    - Data quality improvement;
    - Metadata improvements.
- Pursue innovative cost-effective technological solutions for Arctic observations securing continuous near real time data flow from this harsh environment also during wintertime;
- Initiate data rescue activities composed of but not limited to the following components:

[3] https://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-19-0291.1?mobileUi=0&

- Continuous support of projects like the C3S inventory effort, enhanced data collection, homogenization and mining;
- Maintain and further develop centralised data portals for the individual thematic domains;
- Start a task force focussing on unlocking existing data not currently available to Copernicus. The effort could include support to organisations without a proper data management structure, and support for implementation of proper data quality control procedures;
- Improve access to Russian data sources for all thematic areas in cooperation with relevant Russian authorities.

The Copernicus Services and Space Component deliver a wide range of data and products with relevance for the Arctic region. Furthermore, important in situ data rescue, collection, and quality assurance activities are carried out as an inherent part of Copernicus production workflows. Thus, Copernicus is contributing significantly to the integrated observing system operating in the Arctic. However, it is evident that gaps related to e.g. the monitoring capacity and sustainability of observing networks do exist and need to be addressed. Copernicus' requirements for an Arctic Sustained Observing Network overlap with those of other scientific and in particular operational users. Copernicus acknowledge that it is of the outmost importance that future gap filling activities as well as new initiatives are implemented in a coordinated and holistic manner to avoid duplication of work, facilitate cost-efficient and sustainable solutions, and leverage synergy effects. Consequently, Copernicus aims at cooperating with European and international networks and organisations and other interested parties to develop and implement a roadmap for a future Sustained Arctic Observing System.

## References

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