
KEPLER
Key Environmental Monitoring For Polar Latitudes And European Readiness
Co-funded by the Horizon 2020 programme of the European union
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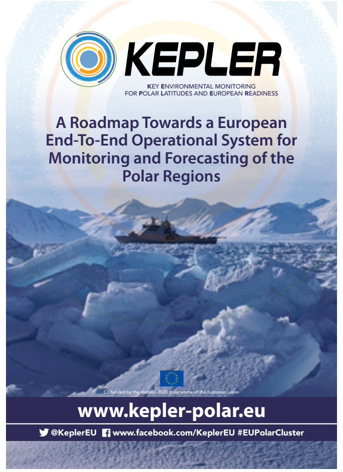
Overview Of Project

KEPLER (**K**ey **E**nvironmental monitoring for **P**olar **L**atitudes and **E**uropean **R**eadiness) is a multi-partner initiative that brings together knowledge and experience from the operational European Ice Services, Copernicus[1] information providers and other experts to prepare a strategic vision. This vision, which we call a roadmap, will allow Copernicus to deliver an improved European capacity for monitoring and forecasting the Polar Regions.



The KEPLER roadmap is for operational integration of all relevant European capacities for monitoring and forecasting the state of the Polar Regions. It combines existing capabilities from within the Copernicus services, as well as those from outside expertise. Importantly, the needs of end-users and stakeholders living and working with 'Downstream Services' has been central to the evaluation.

This approach supports the evolution of Copernicus into a monitoring programme that is both relevant, and one that delivers the necessary information to tackle the issues facing European actors in the Polar Regions. For example, climate change monitoring and prediction, waste/pollution management, the safe and efficient navigation in ice-infested waters, and in avoidance of environmental hazards on land. This also enables Copernicus services to continue to provide the information that is needed to help the move towards a low carbon economy.

Key findings from the KEPLER project

- we have identified existing, long-held, user requirements that have not been appropriately addressed;
- there is scope for future improvement to intensify user uptake;
- These improvements could be delivered with new satellite Earth Observing capabilities, such as the Copernicus Expansion Missions, coming online in the later half of the decade.
- There is a requirement for greater inclusion and support for in situ monitoring efforts, including Citizen Science initiatives.
- This would provide a greater sense of 'ownership' of Copernicus by European citizens.
- Greater focus must also be placed on utilising the many resources, both inside and outside of Copernicus, to provide stronger oversight and quality assurance of data products and information.
- By doing so, Copernicus will ensure that these products are relevant and fit-for-purpose, informing decisions both today and in the future.
- This will promote the accelerated uptake of new research and technological developments coming out of Horizon Europe.
- KEPLER identified that terminologies within Copernicus differ from internationally accepted practice, which can cause confusion and impede users from effectively communicating their requirements.

The Roadmap addresses the above mentioned challenges, moving us towards a comprehensive European end-to-end operational system, by improving design aspects such as the set of required observations, and the potential inclusion of prior information to better constrain sparsely observed areas/variables. It suggests strategies to close gaps in our current forecasting capabilities, and ways to develop and sustain the observing system.

[1] European Union's Earth Observation Programme looking at our planet and its environment for the benefit of Europe's citizens. https://www.copernicus.eu/en

Andy Smith, British Antarctic Survey

User And Stakeholder Needs

Evaluation of downstream user and stakeholder needs within maritime sector and terrestrial community-based users has been central to KEPLER's objectives. Stakeholders include representation of intermediate users, such as the research community who provide climate and weather forecasting products. Current and historical user needs were assessed on how their requirements have evolved over the years with the changing climate and user competencies.

A range of environmental parameters for different marine, land-based, and climate and weather forecasting domains were determined. These specifications concentrated on the required spatial and temporal scales, driven by user and stakeholder activities. General recommendations from marine and land-based end-users focused on requests for technological developments, within the capability of current satellites, for provision of improved products.

These include:

- products with higher spatial and temporal resolution, i.e. better than 300 meters and with daily updates;
- improved information quality, so that products represent actual environmental conditions;
- low latency with availability in near-real time (less than 3 hours).

These developments will result in improved monitoring, both for tactical guidance and climatological planning. There were also requests for information to be:

- disseminated through more accessible mechanisms;
- presented in familiar and standard data formats.

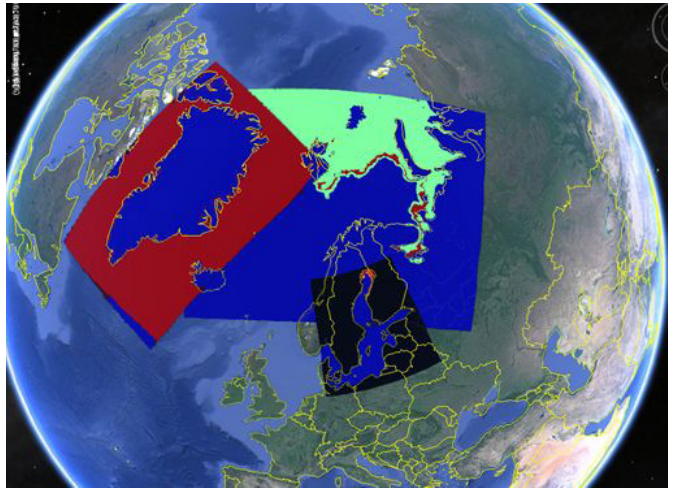
It must be remembered that communications capabilities in some high-latitude regions continue to be extremely limited (have low bandwidth). Therefore the data volume of Earth Observation (EO) products must be kept small in order to enable delivery to these locations both efficiently and within budget.

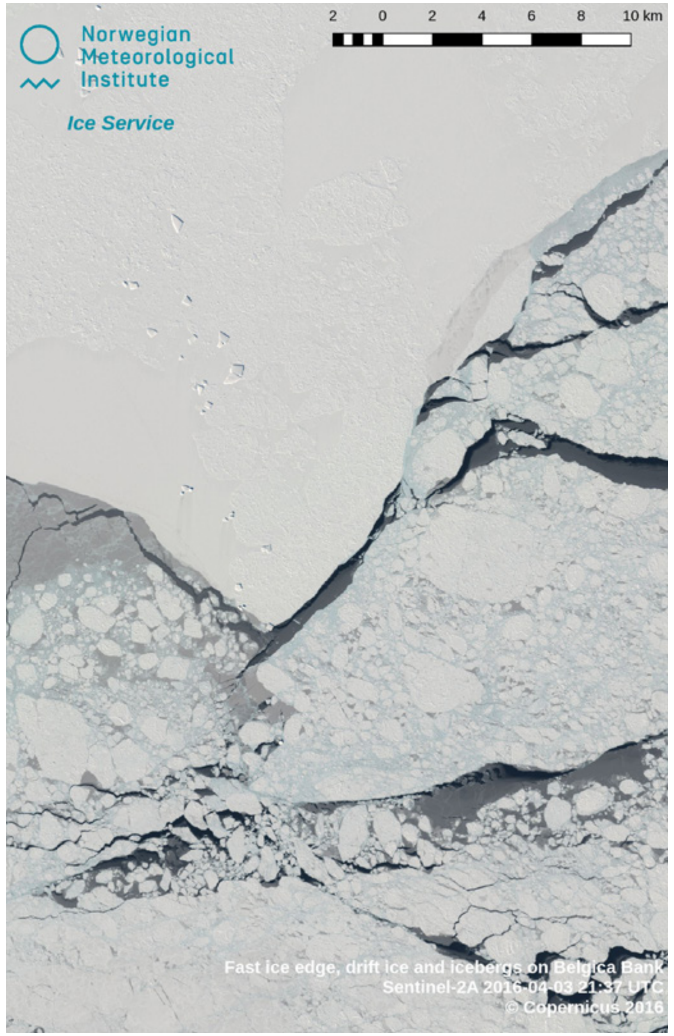
A clear outcome of the user needs assessment was recognising that there is confusion around terminology between data developers and information providers working for Copernicus, and end-users and stakeholders, including the international regulatory agencies providing information for the marine and land-based environments. The following terms have different meanings to different sectors:

- high-resolution;
- near-real time;
- operational;
- short/long term.

A consistent approach is needed as the ambiguous terminology greatly affects the uptake of Copernicus products from downstream services and end-users. This restricts development of value-added products. We therefore recommend that descriptions for products developed for Copernicus are explicit and accurate about their intended use, and continuous quality assurance metrics are used to ensure transparency as to the limitations of the product for both geographical area and time of year. It is absolutely crucial for operational information services that the data and information ingested into their value-added products are clearly documented, in order for users to make informed decisions. Copernicus services should reflect these requirements in order to increase user uptake.

Identification Of Research And Capacity Gaps





A major component of KEPLER was to identify the current obstacles, or gaps, that limit the Polar Regions monitoring and forecasting capabilities of the Copernicus services.

To achieve this, KEPLER provided an assessment of how the in situ observations community can better contribute to Copernicus monitoring. We also investigated the role citizen science can play in the expansion of Copernicus' in situ monitoring priorities. This resulted in recommendations to increase the use of in situ observations in Copernicus product development and quality assurance, and improve communications with the wider Polar research community.

The maturity of the different types of new and novel observing platforms and sensors, and their practicality for Polar Regions deployment were evaluated in consultation with their developers. Although these show promising results, they have yet to be made available at a cost-effective level that would enable widespread deployment. Copernicus should continue to monitor these developments, to be ready to take advantage of them when such a level is reached.

Even though the Copernicus Space Component is the keystone to successful polar monitoring, developments are needed to improve the system. KEPLER prepared a comprehensive review of the current status of remotely sensed parameters acquired over Polar Regions, and compared them with the products provided by the Copernicus services. This allowed further identification of current data gaps, and evaluation of the feasible synergies between parameters from different satellite missions (in particular the Copernicus expansion) that will enhance the information content in relation to the end-users requirements.

KEPLER reviewed the parameters which could be estimated with the future EU HPCM polar missions (CIMR, CRISTAL, ROSE-L). Table below shows, with color codes, which parameters could be acquired by each of the polar HPCM satellites. This analysis emphasises that all three missions are needed to cover the high priority environmental parameters identified by the Polar Expert Group (PEGIII).

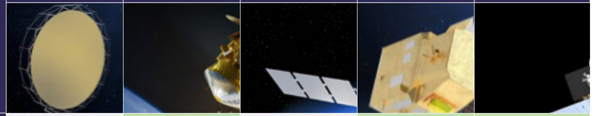
1. Floating ice	2. Glaciers and ice caps	3. Ice sheets	4. Snow on land
Sea ice type ●●	Surface velocity ●	Grounding lines ●	Snow water equival. ●●
Iceberg detection ●●	Extent ●	Surface velocity ●	Extent/ Fraction ●
Ice extent, fraction and concentration ●●	Mass balance ●	Extent/ Calving front ●	
Sea ice (iceberg) drift ●●		Surface melt extern ●	
Sea ice thickness ●●		Mass change ●	
Surface temperature ●			
Snow depth ●●			

- CIMR
- CRISTAL
- ROSEL

- **Recommendation for Copernicus:** the three polar HPCM missions are needed to cover the identified high priority environmental parameters

We employ the quantitative network design (QND) approach to assess the impact of these scenarios. It is ideally suited to assist the formulation of mission requirements, or the development of earth observation products.

- For the sea ice-ocean observations, our targets are 1-week to 4-week forecasts of sea-ice and of snow volumes, for selected regions along the Northern Sea Route and the Northwest Passage, as well as for the entire Arctic.
- For the atmospheric CO_2 observations, our target quantities are the land-based fossil fuel emissions in the first week of June from several Arctic countries, namely Canada, Denmark, Finland, Iceland, Norway, and Sweden.



Sensors	PMR (e.g. CIMR)	RA (e.g. CRISTAL)	IR (e.g.LSTM)	Optical (e.g. CHIME)	SAR (e.g. ROSE-L)
PMR (e.g. CIMR)		lake ice thickness		**Soil moisture downscaling**	Snow Water Equivalent **Soil moisture**
RA (e.g. CRISTAL)	SIT[1], **ice type**, snow depth			Phytoplankton groups	
IR (e.g.LSTM)	**SIT, ice surface temperature, sea surface temp**	**SIT**, **ice type**			
Optical (e.g. CHIME)	**SIC**, **ice type**	**ice type** MPF		**Phytoplankton groups, phytoplankton dynamics**	snow extent snow wetness **snow avalanche** lake ice extent
SAR (e.g. ROSE-L)	SIC, **SIDrift**	sea ice deformation evolution **iceberg properties**, snow depths on sea ice	**ice type**	**SIC**, **ice type**	

A detailed review was performed on the marine parameters that are presently assimilated, and any major limitations were identified. The potential for assimilation of new, relevant variables was assessed, and an analysis was introduced on how to evolve data assimilation, through inclusion of lower level satellite data.

KEPLER also evaluated several observational scenarios in terms of their performance in a data assimilation system, with an emphasis on the Copernicus Sentinel satellites, with particular focus on the HPCMs. One group of scenarios consisted of observations of the Arctic sea ice-ocean system, while another consisted of observations of atmospheric CO_2.

Polar Regions Information From Copernicus Services

KEPLER provided recommendations for improving the ability of Copernicus to describe the changing Polar Regions, taking into account the availability of additional complementary data from space including the Copernicus expansion missions (previously HPCM[2]) CIMR,[3] CRISTAL[4] and ROSE-L.[5]

To formulate these recommendations, an assessment was conducted of the two main Copernicus services for the Polar Regions, both Land and Marine: CMEMS (Copernicus Marine Environment Monitoring Service), and CLMS (Copernicus Land Monitoring Service).

Where possible, the findings were supplemented with other relevant sources, as well as with other Copernicus services such as the Climate and the Emergency Services.

KEPLER created two assessments, which included a comprehensive description of existing and already planned observations, and forecast and reanalysis model products, including the sources of data disseminated in catalogues. These assessments on the overview of the Copernicus services provided fed into the KEPLER Roadmap, described overleaf. Data policy, and commitments on the access and monitoring of product quality supporting the product portfolio are also covered by the Copernicus services. An inventory of the products offered by the different Copernicus services has revealed a few inconsistencies, and we have recommended the inclusion of missing variables.

Copernicus services are user-driven, with feedback being monitored by questionnaires or regular surveys. Based on an analysis of these surveys, a gap analysis was produced. This was combined with an assessment of the Copernicus expansion missions' observations capabilities against Copernicus services commitments. The result provided a foundation for further enhancing the existing services. It must be stressed that the possibility of having the 3 expansion missions in synergy will provide tremendous opportunities for Copernicus services, in their core and continuity commitments with important improved capabilities. It is likely that this synergy will reinforce links between intermediate users and Copernicus services in meeting the end user requirements.

[2] High Priority Candidate Missions
[3] Copernicus Imaging Microwave Radiometer
[4] Copernicus Polar Ice and Snow Topography Altimeter
[5] Copernicus L-band Synthetic Aperture Radar

Improved Sea-Ice Mapping And Forecasting

KEPLER brought together experts from diverse institutions, to provide recommendations on how to improve existing European capacities for production of ice charts, sea-ice climate data records and sea-ice forecasts to the timescale of days to seasons ahead. These recommendations were based on a detailed gap analysis between documented user needs on the one hand, and currently available sea-ice information products on the other.

The experts noted that users often report that the available sea-ice information has insufficient spatial resolution and is sometimes outdated. Sustained funding is important, therefore, in order to develop and make available sea-ice information with increased spatial resolution and timeliness.

Findings suggest that current services lack many physical parameters or features of sea ice that are reported as important by users. The experts therefore recommend research and development on reliability of any estimates of uncertainty of observations, and forecasts of these parameters can be added to the Copernicus product portfolio: this is a promising avenue along which to improve user uptake of sea-ice information products, and this is crucial for users in order to anticipate if the product will have a positive impact on making successful operational decisions.

The above recommended improvements are only possible with the continued availability of established types of sea-ice satellite observations, as well as the addition of new types. Therefore, KEPLER emphasizes that the continuity and evolution of satellite missions such as the Copernicus expansion missions are the foundation of any evolution of sea-ice products in the Copernicus services portfolio.

In light of the complex and interdependent landscape of service providers and users for sea ice information, it is essential that a sustained dialogue and collaboration between data producers, intermediate users, and end users is fostered. KEPLER recommends the co-development of products as the best way forward in order to ensure fit-for-purpose sea-ice information for Europe.

A Roadmap Towards A European End-To-End Operational System For Monitoring And Forecasting Of The Polar Regions

Through these outputs from the rest of KEPLER, we have been able to develop a roadmap that lays the foundation for the **operational integration of all relevant European capacities** for monitoring and forecasting the state of the Polar Regions - with a focus on land and marine capabilities. The end-user and stakeholder requirements, analyses of the current (and future) Copernicus system, obstacles of research and capacity gaps, and sea-ice mapping and forecast capabilities are **synthesized** by this roadmap to **ensure all components** of the system are covered.

With the uptake of our recommendations as described in full in our Roadmap report (www.kepler-polar.eu/roadmap), KEPLER is confident that the Copernicus monitoring system for Earth will deliver the necessary information to tackle the issues facing European actors in the Polar Regions. This includes in-situ and satellite components, data handling capabilities, forecast and reanalysis modelling systems, and dissemination procedures.

Copernicus support will meet the varied needs of climate change monitoring and prediction, waste/pollution management, and safe and efficient navigation in ice infested waters, and facilitate the shift towards a low carbon economy.

The KEPLER Roadmap towards a European end-to-end operational system addresses the design aspects and recommends strategies to close gaps in our current capabilities, along with ways to evolve and sustain the observing system.

The information flow incorporating the Copernicus services is conceptualized in this pyramid diagram, which consists of several layers. The user needs are located at the right of the pyramid, reflecting the requirement that the services should be strongly user-driven throughout.

For more detail, please see the full Roadmap report at **www.kepler-polar.eu/roadmap**

Within the KEPLER final roadmap we provide three exemplary user stories to demonstrate the needs of user-driven services, but also to point out the actions that have to be taken to establish these services. The user stories developed in KEPLER are:

(i) 'EO based decision making for cost-efficient and safe maritime navigation',

(ii) 'EO based decision making for reindeer herders', and

(iii) 'EO based marine emergency response'.

A schematic diagram illustrating the information flow within an end-to-end system. KEPLER has developed suggestions and recommendations for the layers that make up this schematic. Boxes with dark blue backgrounds are covered by Copernicus today. Boxes with half dark blue backgrounds are covered partially by Copernicus.

Coloured arrows symbolise the interactions of the different layers in and around Copernicus that are working well (green), could be improved (amber), or not running well (red) according to KEPLER's findings.

QC=Quality Control.

In the third layer are the Copernicus services that KEPLER is addressing are located, including:

- Copernicus Land Monitoring Service (CLMS);
- Copernicus Marine Environment Monitoring Service (CMEMS);
- Copernicus Climate Change Service (C3S).

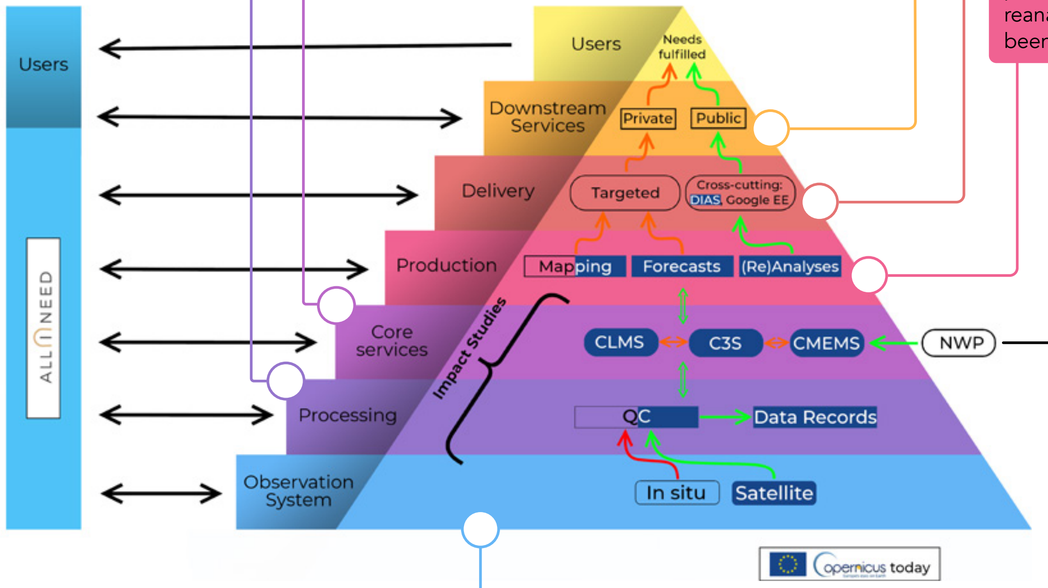
Here, the data from the processing layer are used by models and data assimilation systems to generate reanalyses and forecasts, and these provide output products either directly to the end-users, or indirectly via Downstream services. Impact assessment studies link all layers from 'Observation System' to 'Production' as they assist in the design of the observing system to improve forecast capabilities (marked by a brace). The power of impact assessment studies is demonstrated in KEPLER by a specific method with a focus on Copernicus High Priority Candidate Mission (HPCM).

Above the delivery layer are 'Downstream Services,' designed for the specific needs of users, making access to data and information easier or generating specific user-driven services.

A 'Delivery' layer, the fifth, is divided into targeted and cross-cutting product delivery. The former is not part of Copernicus, but a cross-cutting data delivery service known as Data and Information Access Services (DIAS). Ideally, all information of the different layers should be available through one data centre which would be an extension of the DIASes.

The second layer is the data assembling layer where the raw data are processed. It includes the quality controlling and generation of (gridded) data sets used by the Copernicus services for monitoring and forecasting.
This also includes the generation of climatological records.

A 'Production' (fourth) layer is included because recommendations and suggestions concerning products for sea-ice mapping, reanalysis and forecasts have also been made by KEPLER.



On the right of the pyramid diagram a box denoted NWP (Numerical Weather Prediction) is added symbolizing the need for atmospheric forecasts by the Copernicus Services. While the atmospheric reanalyses are distributed by C3S, short-term forecasts are not part of Copernicus.

The bottom layer of the pyramid represents the acquisition of observations including satellite, air, ocean, ice and land-based measurements. Boxes shaded in dark blue are performed by the Copernicus services, with in-situ observations not currently being directly compiled by Copernicus.

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