KEPLER Deliverable Report

Report on Deliverable D4.1

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Context of deliverable within Work Package

This report analyses the Marine environment monitoring service (CMEMS) with respect to the maritime sector needs and suggests how to develop them in 5 to 10 years' time. The user needs were collected in WP1.1. and were analysed together with current CMEMS services and foreseen future challenges. Recommendations for CMEMS and Copernicus in general are provided at the end of the report.

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CMEMS and sea ice mapping

The Copernicus Marine environment monitoring service (CMEMS) has currently 27 sea ice products in the portfolio. The sea ice products are mainly produced by the national ice services, metocean institutes and remote sensing units.

Traditionally the CMEMS sea ice products were used in numerical modelling, but there has been increasing interest from the maritime sector on integrating some of these products into their production chains.

In this study the CMEMS Arctic marine services development and harmonisation recommendations are provided by the ice services that are mandated to produce routine products for maritime safety. The maritime user needs from KEPLER WP1.1 were correlated with what the ice services are currently able to reliably provide and analysed against the CMEMS current portfolio's gaps. The CMEMS on-line catalogue is updated continuously. Information in this report is taken on May 26th, 2020.

This document reports the three analyses: User needs gap analysis, Geographical gap analysis and Future challenges. Based on these analyses, the recommendations on how to develop CMEMS in the coming 5-10 years are provided in the last chapter.

The national sea ice services have dual roles related to CMEMS: they are both major product providers and users. The ice services have a long history of sea ice mapping and customer service. The first priority of ice services is to provide routine sea ice information to support activities related to health and safety and environmental hazards. These areas are specified according to the meteorological (METAREAS) and navigational areas (NAVAREAS) designated by the WMO (WMO-574), which also contains further information about the ice services of the world. As there is currently no reliable way of automating sea ice parameter retrieval from Synthetic Aperture Radar (SAR), even in synergy with other satellite sensors, the current state of ice chart (map) production requires a manual interpretation from ice analysts with all available and relevant satellite data and ground truth information. The satellites used primarily consist of SAR and optical satellite sensors.

The ice charts for navigation follow guidelines established by the WMO terminology and criteria for the regulatory authority on ice provision (JCOMM-TR-080, SPA_ETSI_ENC_01, WMO-No.259 and WMO-No.558) and are produced in accordance with the Manual of Standard Procedures for Observing and Reporting Ice Conditions (MANICE), the authoritative guide produced by the Canadian

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Ice Service (Environment Canada, 2005; Orson, 2007). The mandate for most ice services is the UN SOLAS Convention, Chapter V, Regulation 5, adopted by the national governments.

User requirement gap analysis

The user requirements gap analysis is based on the user requirements studied in the Kepler Report on Deliverable D1.1, with the exception of those regarding the Antarctic. The summary Table 1 has been derived from the common desired parameters of EC and ESA project reports (D1.1, pg. 27, Table 7). These are analyzed using a "traffic lights" approach (Table 2), based on questionnaires in Norwegian Ice Service Survey for Arctic Shipping Forum (2018), AECO - Polar Tourism (2017) and International Ice Charting Working Group (IICWG, 2019).

As questionnaires referred to in D1.1 have some differences in defining the resolution categories and demands, the four categories in Table 1 are a holistic take on the results. While over 50% of users in the IICWG survey demand 50m resolution, in the ASF/AECO surveys over 50% are still satisfied with 1 km resolution, but would prefer better. The "moderate" category at 500m is still satisfying for a significant take of users.

Categories for update frequency and timeliness have been derived analogically from user needs in D1.1. Daily updates are acceptable for over 50% of the users, while 25% still demand updates twice or more often per day. Only about 20% are satisfied with weekly delivery.

Timeliness describes the delay from observation to product delivery. Categories in Table 2 have been set according to minimally accepted levels. Less than 25% of users accept a 48-hour delay. Considering product timeliness the measurement method should be taken into account, e.g. the ice drift estimated from two SAR images can be acquired even within two hours from the latter image, but represents the mean drift between the two images.

Table 1: Common desired parameters from EC and ESA project reports.

	CMEMS			
	Resolution	Update frequency	Timeliness	Product ID
Ice Concentration (Baltic)	1km	daily		011_004
Ice Concentration (Arctic)	1km	daily		011_002
Ice Type	10km	daily		011_001
Ice Edge (Baltic)	1km	daily		011_004
Ice Edge (Arctic)	1km	daily		011_002
Ice Thickness (Baltic)	500m	daily		011_004

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Ice Thickness (Arctic)	25km	weekly		011_014
Ice Drift (Baltic)	800m	depends on SAR data		011_004
Ice Drift (Global)	10km	depends on SAR data		011_006
Deformation (Baltic)	1km	daily		011_004
Snow on Sea ice	12.5 km	daily	Forecast	002_001_a
Icebergs	10 km	Weekly		011_007
Ice surface temperature	5km	daily		011_008
Detailed Ice Charts				
Waves at ice edge	10km	daily	Forecast	011_001

Table 2: Color coding based on IICWG, ASF and AECO Polar Tourism Survey: Dark red: not met at all/missing product, Very poor: satisfies less than 25% of the users, Poor less than 50%, Moderate at least 50% and Good 75%.

User satisfaction	Resolution	Update frequency	Timeliness
No service	-	-	-
Very poor	1 - 10km	weekly	48h
Poor	500m - 1km	two days	24h
Moderate	50 - 500m	daily	12h
Good	0 - 50m	sub-daily	7h

In general, mariners want more timely information at higher resolutions. Many products are based on SAR data with resolution 50-100 m, and in available vector format ice charts the resolution is already close to this. NetCDF in CMEMS has a fixed coarser grid at 500-1000m or more.

WMO has a standard ice chart archive and transfer format called SIGRID-3, which is already in place and produced in all major ice services (JCOMM, 2014). It is based on a widely-used open vector shapefile format, which is familiar to mariners and ice services and has qualities attractive to several user groups. The format is also readable by all common Geographical Information System (GIS) software.

Electronic Navigation Charts (ENC) and Electronic Chart Display and Information Systems (ECDIS) are becoming widely available on ships navigating in icy waters and it is necessary to provide ice data in a format that can be used in these systems, preferably in SIGRID-3 file format. The SIGRID-3 file format can be directly converted to the International Hydrographic Organization (IHO) and Joint

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Technical Commission for Oceanography and Marine Meteorology (JCOMM) standard format, S411, suitable for ENC and ECDIS, required by the maritime user community (survey feedback from ASF 2018 and AECO).

In contrast to raster formats where ice characteristics are represented on a grid, vector formats represent features (such as areas of ice outlined on a chart) as a series of vertices that define the outline of the feature in space. The vector file preserves all of the information in the original chart, and charts can be re-projected or re-scaled without loss of information. It is also possible to convert a vector product to a raster if necessary.

CMEMS is recommended to offer an option for a SIGRID-3 Shapefile format in its services for transferring and archiving ice information.

While ice services use Copernicus raw data products (i.e. Sentinels and others at Level 1) there is currently very little uptake of CMEMS products (i.e. Level 2 or above) in ice services. Ice services require high precision sea ice information in areas at the ice edge, marginal ice zone, coastal zones and in the pack ice that may be susceptible to dynamic changes due to prevailing environmental forcings, particularly during the melt and summer seasons. All sea ice data products currently continue to require a great deal of quality control to be suitable for use in routine operational products, thus it is more reliable to process data in-house prior to integrating them into ice charts.

Users have requested information on the product's uncertainties for strategic and tactical planning and also for operational navigation purposes. Currently some products include uncertainty information as a parameter in the products (for example SEAICE_ARC_SEAICE_L3_NRT_OBSERVATIONS_011_014, relative error), some include it in Quality Information Document (for example ARCTIC_ANALYSIS_FORECAST_PHYS_002_001_a) and some lack the information (for example SEAICE_BAL_SEAICE_L4_NRT_OBSERVATIONS_011_004). If qualification metrics are based on validation from ice charts for products in Copernicus and CMEMS, products that are developed to be integrated into ice charts should be based on in situ measurements or alternative ground-truth sources (i.e. optical), also explained in further detail in KEPLER WP3. It is recommended that products should include levels of certainty taking into consideration inherent seasonal and regional characteristics and limitations in order to be more useful for maritime users.

As many users are navigating through sea ice they would benefit from timely information of specific phenomena, such as leads and polynyas, sea-ice ridges, compression, etc. that can be used as critical background information for the choice of routing and adjustments. Ice services aim to include more WMO ice standard parameters in ice charts, such as the stage of development, on a more frequent basis, while minimizing the amount of manual time required by ice analysts.

Additionally, users assert the need for products useful for navigation in iceberg zones. The current iceberg products from CMEMS are more appropriate to climatology and thus are not appropriate for

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developing value-added products in the case of situational awareness, or risk assessments for mariners avoiding areas with icebergs. The production for CMEMS is automated which ensures timeliness, but filtering methodology, update frequency and product format for the entire North Atlantic need to be addressed. Secondly, the current Sentinel-1 C-band processing is only working for icebergs in ice-free areas, i.e. without any sea ice around. Icebergs in sea ice is a major hazard for ships going into the sea ice. A future L-band SAR mission (ROSE-L) may help to address the issue of identifying and reporting icebergs in sea ice on a routine basis. (ESA 2018, IICWG 2019)

Ice chart analysis is based on manual interpretation, so increasing frequency is possible with more personnel resources, but is already challenged with update frequency and timeliness. Temporal frequency is also subject to the availability of remotely sensed data. For the most commonly used sensor type, satellite-based SAR, the typical revisit time is twice a day based on their orbit at higher latitudes (70-80N). At lower latitudes (50-60N) the orbit characteristics make the update frequency more sparse, on average about 1 satellite pass per day, but may vary from 0 to 2 passes due to the nature of the Sentinel-1 constellation. The update frequency for mid-latitudes is therefore a challenge using the Sentinel-1 only and is currently supplemented with non-Copernicus Third Party Missions (TPMs). The current twin satellite constellation would need additional satellites to address the issue.

Satellite altimeter and radiometer measurements of sea ice thickness are more important for other uses than navigation, as their spatial resolution and update frequency are much coarser than navigational demands. Higher surface resolution instruments are also needed to address the needs of ice surface temperature measurements.

Currently, there is no method for measuring snow over sea ice. Also, space-borne methods to estimate or measure instantaneous ice drift should be investigated.

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Geographical gap analysis

Introduction

There are currently 27 sea ice products in the Copernicus marine services product portfolio. Of these, 15 are near-real-time products which are updated on a daily or twice weekly basis and can thus, at least in theory, be used by ships in day-to-day operations in or near sea ice. The remaining 12 are reanalysis or reprocessing products that are either updated less frequently or cover historical dates. These products could be useful for statistical or planning purposes.

In this chapter, the spatial aspects of the CMEMS sea ice products have been investigated in order to identify coverage gaps. For full information on the products, please refer to the CMEMS product catalogue.

Near real-time products

For the purpose of this study, the near-real-time products are divided into three groups based on type. Automatically processed satellite data is the most common type, with seven available products. Four products contain model data, and three products consist of ice charts produced by manually analyzed satellite and/or in-situ observations. In the CMEMS catalogue, however, there is no special category for ice chart products as they are included in the satellite definition. The products are listed in table 3. The products' geographical coverages, as defined in the CMEMS web portal product info (geographical coverage), are shown in Map 1, 3 and 4 below.

Table 3: Near real-time sea ice products in the Copernicus marine services product portfolio.

Product ID	Product description	Type
010_001	Global ocean SST & Sea Ice analysis (high res)	Satellite
010_014	Global ocean SST & Sea Ice analysis (low res)	Satellite
011_001	Arctic & Antarctic sea ice OSISAF	Satellite
011_006	Global ocean high res SAR sea ice drift	Satellite
011_007	Arctic ocean SAR sea iceberg concentration	Satellite
011_008	Arctic ocean sea and ice surface temperature	Satellite
011_011	Baltic sea SAR ice thickness and drift	Satellite
011_012	Antarctic ocean sea ice edge from SAR	Satellite

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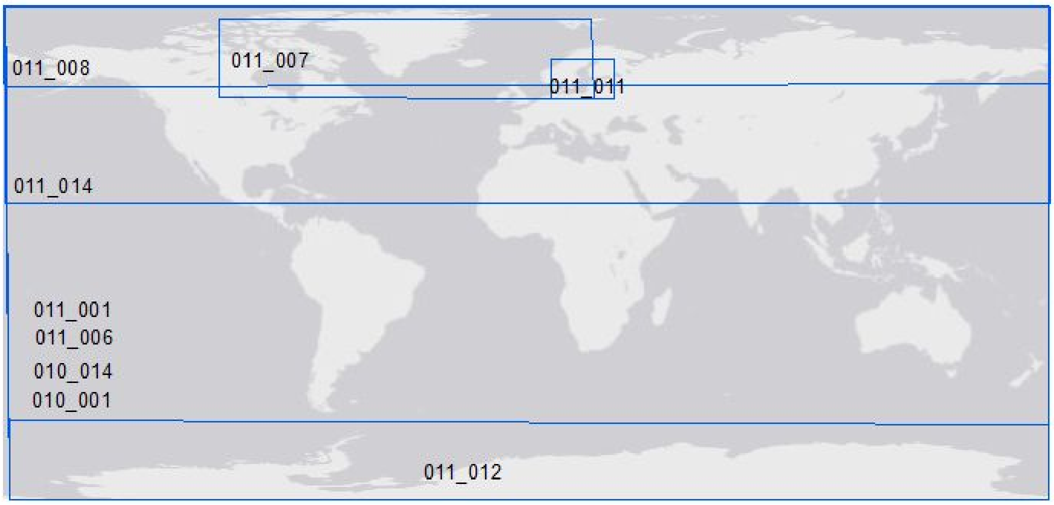
011_014	Sea ice thickness derived from merging Cryosat-2 and SMOS ice thickness	Satellite
001_015	Global ocean analysis and forecast	Model
001_024	Global ocean analysis and forecast	Model
002_001_A	Arctic ocean physics analysis and forecast	Model
003_006	Baltic sea physics analysis and forecast	Model
011_002	Arctic Ocean sea ice concentration charts - Svalbard and Greenland	Analysis chart
011_004	Baltic sea ice concentration and thickness	Analysis chart

Satellite-based products

Of the 7 products identified as based on satellites, 4 have global coverage, 2 are focused on the western Arctic, 1 on the Antarctic and 1 of the Baltic Sea.

It is noted that some of these products' actual footprint is smaller than geographical coverage given in product info, as it is limited by satellite data availability which varies from day by day. Thus, full coverage is not always guaranteed. To exemplify this, the geographical coverage of product 011_006 is shown in map 1 and the footprint on 2020-01-31 is shown in map 2.



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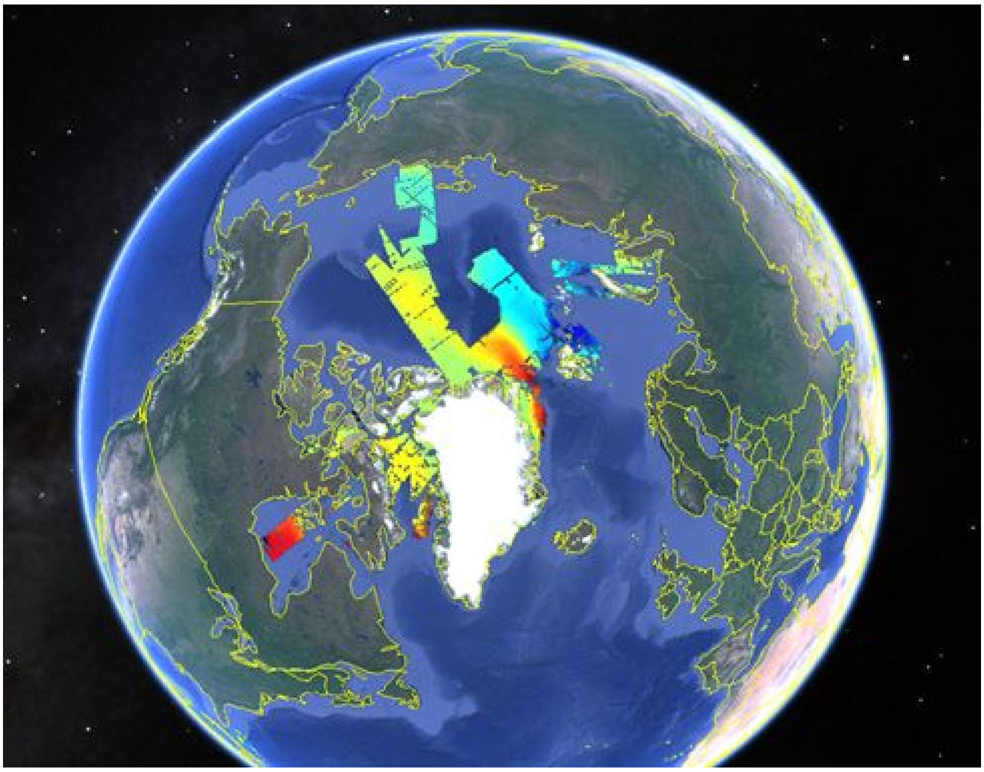
Map 1: The automatically processed satellite products geographical coverages given in the Copernicus marine services product portfolio.



Map 2: The actual footprint of the automatically processed satellite product 011_006 in the Arctic on 2020-01-31 in the Copernicus marine services product portfolio.

Currently, there are areas that are not covered by SAR satellites sufficiently for making and providing vital information and services for the mariners: At the North Pole region (88-90N) there exists a gap, so-called "North Pole Hole" which the current SAR instruments do not cover well. Secondly, in many sub-Arctic latitudes (50-70N including South Greenland) the coverage and update frequency of SAR satellite observations is not sufficient.

Model-based products

The model-based products give full coverage in their footprint. There are two global products, one for the Arctic and one for the Baltic Sea shown in map 3.

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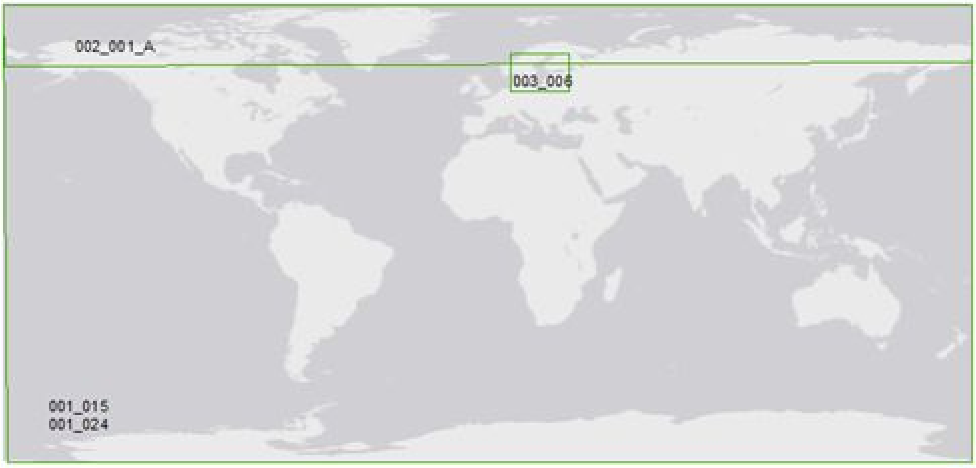

Map 3: The model-based product's geographical coverages given in the Copernicus marine services product portfolio.

Ice chart products

Of the existing charts available in the Copernicus marine services product portfolio, provided by the ice services in Denmark, Norway and Sweden/Finland, there is no coverage on the eastern parts of the Arctic or the Antarctic. In map 4 below, the geographical covers are outlined, while the charts actual extents are shown in map 5. Note that 011_002 consists of three different products, one covering Svalbard and two covering Greenland (or parts of Greenland). The actual footprints of these products differ from the geographical coverages given in CMEMS web portal product info. It is recommended to create a clear spatial overview of actual product data availability

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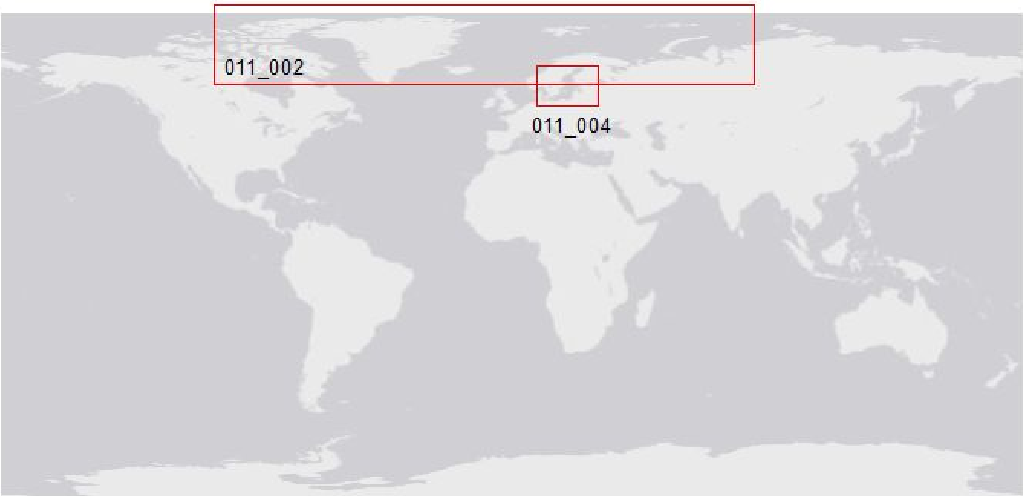
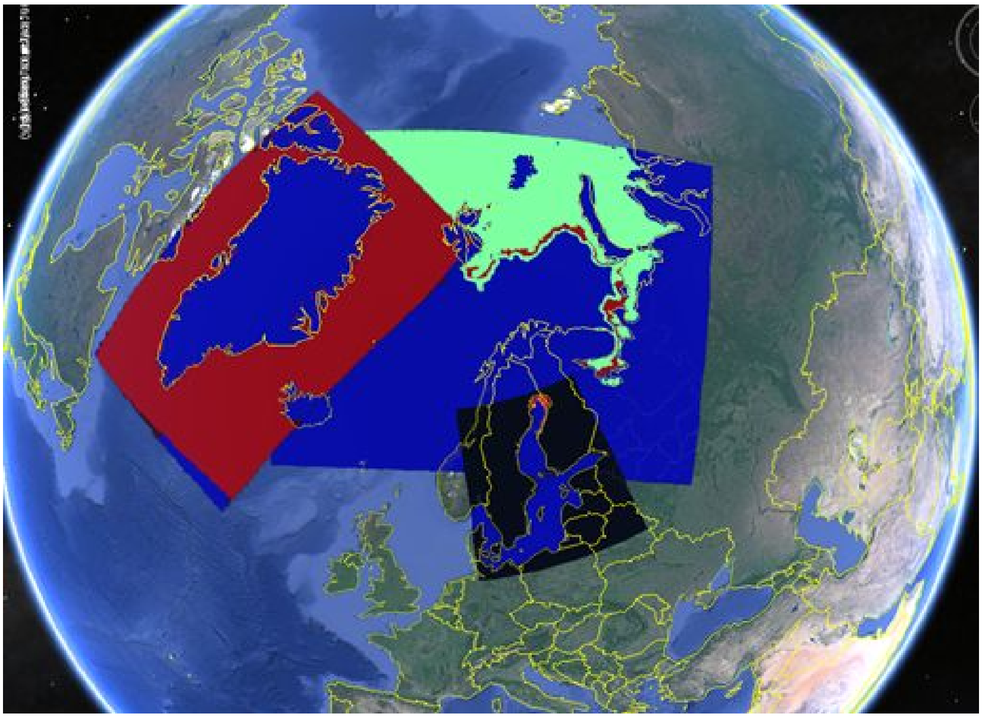


Map 4: The ice charts products geographical coverages given in the Copernicus marine services product portfolio.



Map 5: The actual extent of the ice charts available in the Copernicus marine services product portfolio.

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Reprocessed and reanalysis products

In the CMEMS product catalogue, 12 products are defined as reanalysis or reprocessed (Table 4). Reanalysis products are model-based while reprocessed means they are based on satellite and/or in-situ observations. There are three typical spatial extents; Global, Arctic and Baltic sea. There are no specific reanalysis or reprocessed products for the Antarctic, though this area is included in the global products.

Table 4: Reprocessed and reanalysis sea ice products in the Copernicus marine services product portfolio.

Product ID	Product description	Type
001_031	Global ocean physics reanalysis (high res)	Model (reanalysis)
001_026	Global ocean ensemble physics reanalysis	Model (reanalysis)
001_030	Global ocean physics reanalysis (low res)	Model (reanalysis)
002_003	Arctic ocean physics reanalysis	Model (reanalysis)
003_011	Baltic sea physics reanalysis	Model (reanalysis)
010_011	Global ocean sea surface temperature and sea ice	Reprocessed
010_016	Baltic sea surface temperature	Reprocessed
010_024	Reprocessed seas surface temperature analysis	Reprocessed
011_009	Global ocean sea ice concentration	Reprocessed
011_010	Arctic Ocean sea ice drift	Reprocessed
011_013	Arctic Ocean sea ice thickness	Reprocessed
015_002	Global observed ocean physics	Reprocessed

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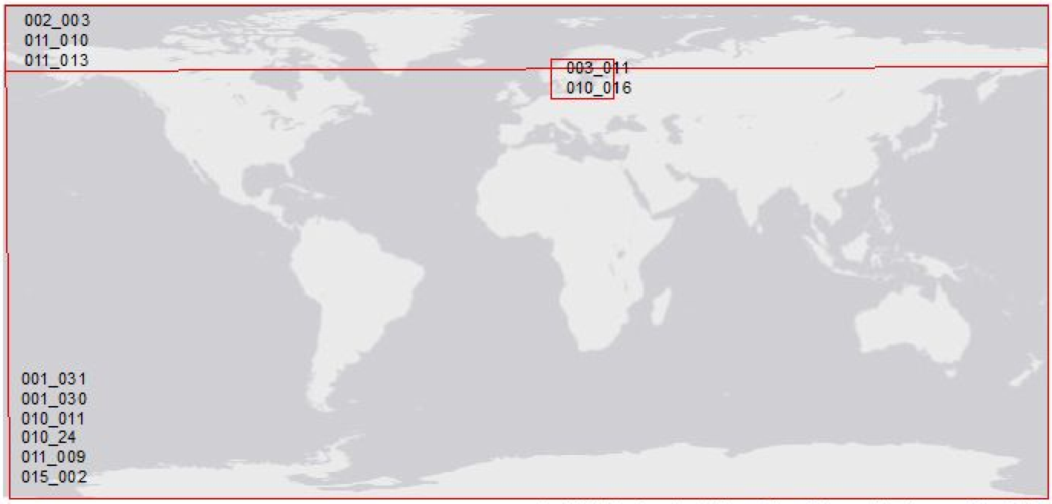

Map 6: The products geographical coverages of reprocessed and reanalysis products in the Copernicus marine services product portfolio.

Metadata Information

A current challenge from an operational perspective in the CMEMS catalogue of products is that the mapping information (reference of the projection) is not included in the metadata for every product. This should be an integral part of the standard documentation for implementing and delivering each product, updated for each product upgrade. Any changes in product development and format can have significant implications for down-stream service providers being able to provide routine information for users if the input data is not produced in a standard format that can easily be ingested into their internal systems.

Operational ice services, as the recognized authority for ice information provision by the WMO, have a responsibility to provide routine information under specific guidelines and require a rigid network of systems in place to ensure they are able to deliver products in a timely manner while maintaining the product quality. Other downstream services or third-party services are not required to follow the same WMO standards for information, yet can be used as complementary products to support ice services and may be able to provide additional tailored ice information for customers. For this reason, a product used for operational purposes must be able to indicate a suitable level of reliability and consistency in order to be fully integrated into the production chain. In general, both intermediate and end-users, are mainly concerned with producing or accessing the most updated information on a timely basis. In the case of operational ice services there is little flexibility to troubleshoot issues related to IT systems and metadata, especially when it may not be intuitive to understand. If a product demonstrates it is challenging to implement, it will not be considered useful. This has been noted in the ice services as they have received several questions from

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intermediate and end-users who have been confused by inaccurate metadata. It demonstrates how fundamental issues should be addressed with products during the initial development, otherwise there are implications further down the production chain.

There should be improved quality control of the metadata related to map projection information. Errors related to geo-localisation can lead to safety risks for navigation. The metadata format should be consistent across all products for easier accessibility and assimilation into operational products, for example ensuring that the georeferencing information adheres to the widely used NetCDF CF metadata conventions, and that information contained within the product catalogue entry, documentation, and file metadata is consistent. A brief review of documentation for preparing new products found a number of gaps, and although standards for parameter metadata and availability of documentation are part of the process, components like geospatial metadata, and documentation or catalogue consistency with the product are not. This, and a review of the product portfolio raised questions as to whether there were further issues that could be improved upon. Procedures for product acceptance and delivery should also be adequate and consistent between the CMEMS MFC and TAC. Some CF compliance errors are inherited from older products, while some newer products are upcoming evolutions of the CF standards. These changes should be addressed with some urgency given that a large proportion of the CMEMS portfolio for the Arctic Ocean was found to be affected (see Table 4 below).

Table 4: Review of CMEMS portfolio with product CF metadata compliance and geo-referencing information in the NETCDF metadata (CF Compliance checkers at:http://cfconventions.org/compliance-checker.html). Rows highlighted in green are products that have sufficient quality.

Product	***Type***	*CF Compliant?*	*Georef. Error*
ARCTIC_ANALYSIS_FORECAST_PHYS_002_001_A	MODEL	N	Y
ARCTIC_ANALYSISFORECAST_PHY_TIDE_002_015	MODEL	N	Y
ARCTIC_ANALYSIS_FORECAST_WAV_002_014	MODEL	N	Y
ARCTIC_ANALYSIS_FORECAST_BIO_002_004	MODEL	N	Y
ARCTIC_REANALYSIS_PHYS_002_003	MODEL	N	Y
ARCTIC_REANALYSIS_BIO_002_005	MODEL	N	Y
SEALEVEL_GLO_PHY_L4_NRT_OBSERVATIONS_008_046	OBSERVATIO N	1.6	N
SEALEVEL_GLO_PHY_L4_REP_OBSERVATIONS_008_047	OBSERVATIO N	N	Y
OCEANCOLOUR_ARC_CHL_L4_NRT_OBSERVATIONS_009_087	OBSERVATIO N		Y
OCEANCOLOUR_ARC_OPTICS_L4_NRT_OBSERVATIONS_009_08 9	OBSERVATIO N	N	Y
SEAICE_ARC_SEAICE_L4_NRT_OBSERVATIONS_011_002	OBSERVATIO	N	Y

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	N		
SEAICE_ARC_SEAICE_L4_NRT_OBSERVATIONS_011_007	OBSERVATION	1.6	N
SEAICE_ARC_SEAICE_L4_NRT_OBSERVATIONS_011_008	OBSERVATION	N	Y
SEAICE_ARC_SEAICE_L3_REP_OBSERVATIONS_011_010 The catalogue takes users to one version of the product, with issues, and ftp-access takes users to another, correct version.	OBSERVATION	Y and N	Y and N
SEAICE_ARC_SEAICE_L3_NRT_OBSERVATIONS_011_014	OBSERVATION	N	N
SEAICE_ARC_SEAICE_L3_REP_OBSERVATIONS_011_013	OBSERVATION	1.6	N
WIND_GLO_WIND_L3_NRT_OBSERVATIONS_012_002	OBSERVATION	N	Y
WIND_GLO_WIND_L4_REP_OBSERVATIONS_012_003	OBSERVATION	N	Y
WAVE_GLO_WAV_L4_SWH_NRT_OBSERVATIONS_014_003	OBSERVATION	N	Y
WAVE_GLO_WAV_L3_SWH_NRT_OBSERVATIONS_014_001	OBSERVATION	1.6	Y
WAVE_GLO_WAV_L3_SPC_NRT_OBSERVATIONS_014_002	OBSERVATION	1.6	N

High activity areas

There is full coverage of model-based products in the Arctic and the Baltic Sea. The outlined footprints of satellite products, i.e. global coverage, western Arctic and the Baltic Sea, are not always guaranteed as the actual coverage is limited by satellite data availability which varies from day to day. The outlined footprints of available ice charts (Denmark, Norway, Sweden/Finland) does not coincide with the actual coverage, which includes the following noted user activity areas according to current knowledge of the ice services, strengthened and visualized by Map 7:

- Greenland
- Iceland
- Coastal areas in Northern Norway
- Baltic Sea
- Barents Sea
- Svalbard Islands
- Kola Peninsula
- Kara Sea - main part

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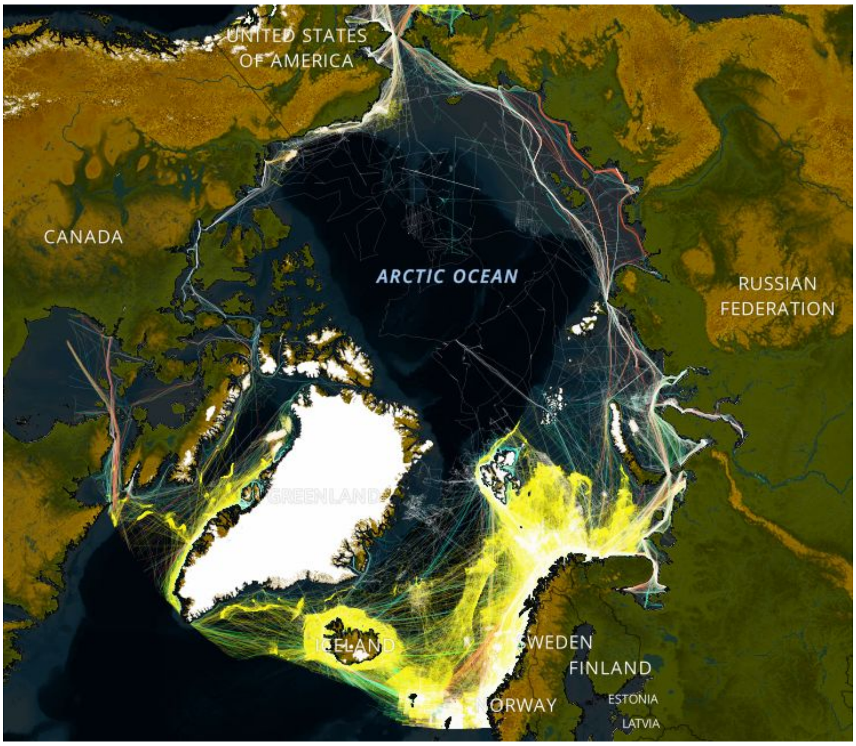
- Yamalsky district

High activity areas lacking coverage in the actual extent of the ice charts in the Copernicus marine services portfolio:

- Beaufort Sea
- Bering Strait
- Northern Sea Route
- Northwest Passage

Improved ice chart coverage is needed in the eastern Arctic.



Map 7. Ship traffic lines in the Arctic in 2012 (north of 60°N). The ship traffic observations are made through the satellite-based Automatic Identification System (AIS), which provides the identification of the spatial location of a vessel at a given time. Ship tracks denote the estimated routes undertaken by ships. Data-source: Automatic System (AIS) data, provided by The Norwegian Coastal Administration /www.havbase.no (2013) and further processed by DNV and WWF. [*http://wwfarcticmaps.org/DIQAB7*](http://wwfarcticmaps.org/DIQAB7)

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Pan-Arctic service

The marine community is primarily requesting local and regional ice information, but as ships navigate large areas and across borders, an understanding of the larger area is necessary. The possibility of developing a service that would provide a pan-Arctic ice chart has been discussed widely among the ice services over the years. This would benefit the new shipping routes possibly emerging with the declining ice cover, as discussed further in the Future challenges chapter. Currently, users can download ice information from CMEMS or from different ice services, but it is not convenient when moving across the area of responsibilities; users have to download different products possibly from different producers and confusion can occur in the overlapping or potential gap areas.

A solution would be to implement a system into CMEMS that facilitates an automated collection and merging of ice information into a single product. In CMEMS, the Arctic ice charts would be merged to provide a pan-Arctic Ice chart, while maintaining the operational quality to support navigation.

This is already being done in the western Arctic by the Danish Meteorological Institute (DMI) and the Canadian Ice Service (CIS). Automatic algorithms merge the routine ice analyses into a single combined chart. Map 8 shows an example of DMI and CIS daily joint SIGRID-3 products. Blue lines indicate individual regional ice analysis boundaries. Newest ice analysis is always on top. The example is from 02 April 2020, automatically extracted and created from the SIGRID-3 from the two ice services. The output is scalable and the resolution meets shipping requirements.

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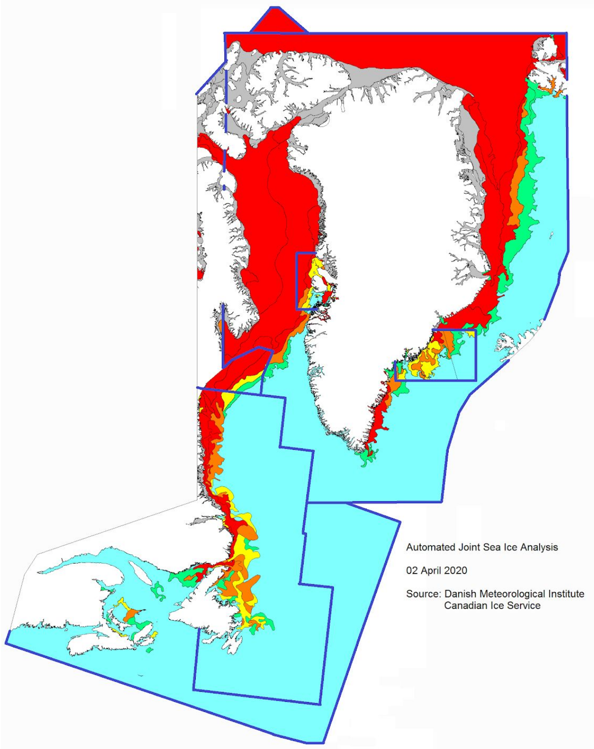

Map 8: Expanded geographical coverage of routine ice analyses from Danish Meteorological Institute DMI and Canadian Ice Service CIS by automated merging.

It would be beneficial for operations and science to develop a similar hemispheric product using output from all relevant ice centers, thereby also covering the current geographical gaps in the eastern Arctic. It is technically possible to expand this type of product and include SIGRID-3 files from other ice services into a Pan-Arctic Ice Chart. Copernicus Services is recommended to be the focal point to integrate and expand this idea to a pan-Arctic scale in future production.

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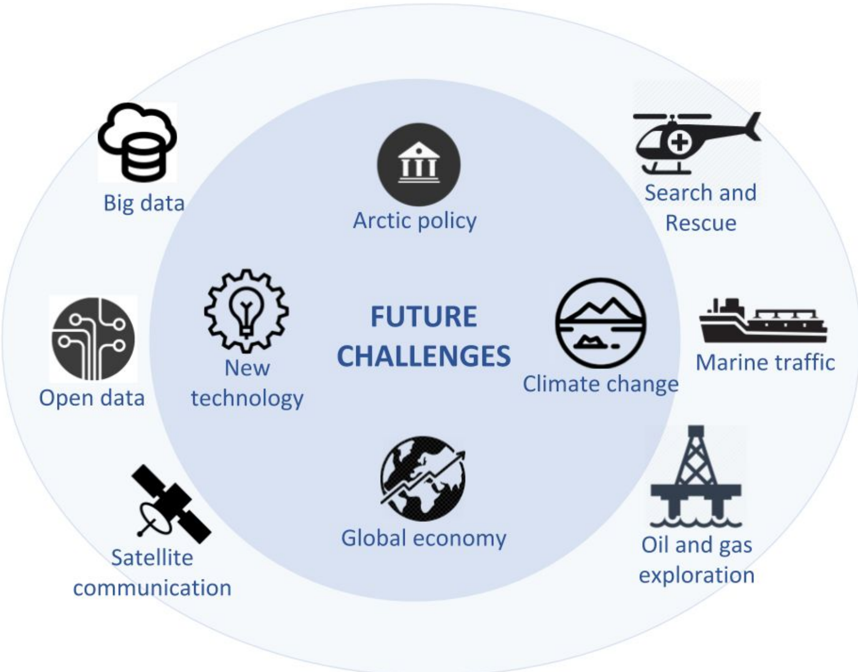
Future challenges

Future challenges concerning sea ice mapping for maritime purposes consists of many different issues and angles. Many of them could be interlinked and summarized as part of two branches, which are climate changes and technological developments.

The activity in the Arctic is heavily dependent on the global economy; activities are increased in an economic boom and cut down in a recession. Currently, there does not exist a common Arctic policy covering for example usage of Arctic natural resources or environmental issues. If such is implemented, it will have an effect on the services needed. The global economy and Arctic policy are matters that do not depend on CMEMS and thus are not covered here in detail.



Climate Change

In a changing climate many aspects of Arctic navigation and service provisions will be different and what the future holds is unclear. Sea ice in the Arctic is expected to become less stable as more dynamic first-year ice is predicted to replace the current fraction of compact second/multiyear ice (Jeffries et al., 2013). Thinner drift ice is generally more vulnerable to environmental conditions because it is susceptible to ocean and wind forcings, which can lead to the further dismantling of the drift ice on a more frequent basis. The retreat of sea ice, caused by climate changes, and opening of

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areas once ice-covered all year-round leads to changing framing conditions for shipping in ice-covered waters:

- longer time windows for operations
- thinner but more dynamic sea ice regime
- significant year-to-year ice cover variability continues
- significant challenges for safety continues (ridging, ice compression, icing, darkness, snow, etc.)
- Arctic destinations will be more exposed to ocean impact (waves, wind, precipitation, rapid changes)
- no or minor changes in iceberg environment in the North Atlantic Ocean (i.e. continued large variability between seasons and from year to year makes it hard to define iceberg climatology. Bergy waters always pose risk to ships navigating these waters).

Potentially new areas of prime interest will emerge, such as the central Arctic Ocean with the trans-Arctic shipping route (Smith et al., 2013) and the ice-free Barents Sea with unexplored resources (Henderson et al. 2014; The Norwegian Polar Institute, 2015). With more ice-strengthened ships being built following requirements from the Polar Code, an increase of traffic through areas in the Arctic will be likely (IMO, 2017). These factors are also anticipated to create more expeditious paths through areas not previously used year-round, and that are considered commercially viable (Jones et al. 2019). Maritime traffic will increase, including autonomous vehicles, and gaps in the Arctic infrastructure data provision and resources will become more of a challenge to meeting economic, environmental, health and safety requirements (Melia et al., 2016; Stevenson et al., 2019). This will lead to new user requirements and demands on the services providing sea ice information.

Information providers will need to understand how to produce relevant data for end-users in these situations, as well as, have the ability to assimilate valuable information for end products. This will put higher demands also on search and rescue (SaR) preparedness which will require improved coordination between information providers and all users where data can be easily accessed or delivered and understood. The primary purpose of ice information to ships is incidence avoidance. This implies a reliable and updated product. In the case of SaR operations the authority will always check up on the latest and next update, before contacting the ice center for special products and advice on the ice situation.

An expected increase in irregular environmental conditions will create a greater demand for information provision on multiple spatial and temporal scales, simultaneously, within different phases within maritime activities. This makes it crucial that a system is in a place where information providers are in regular communication with users and products and services are being adjusted to

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accommodate fundamental requirements to support safe navigation through ice-encumbered waters.

The available product catalogue should never be allowed to stagnate but rather be updated continuously based on user needs. Increased demands will include higher spatial resolution and more detailed information content and coverage i.e. greater range of sea ice (and iceberg) parameters, new and larger areas covered, pan-Arctic products, or combinations of different areas in the same product. New demands will also be put on timeliness and temporal resolution with frequent or continuous updates based on available observations and satellite data at the hands of the users in near real-time, preferably instantly.

Technological development

With the current speed of development and evolution within the technological sector future technology improvements might not only be beneficial for sea ice mapping purposes but also a major challenge. There will be more demands placed on technology in the form of requests for new data formats and platforms, including scalability, and distribution methods. As ship traffic to specific destinations in the Arctic and Arctic shipping transits are expected to increase over the coming decade, marine community requirements are expected to increase. The larger user base is expected to be more diverse in terms of vessel ice class, vessel type, navigator experience, geographical coverage. This is already observed in certain Arctic regions covered by the ice services.

The main source of information to current ice services comes from satellites. With new satellites and new types of sensors, these products can be reshaped and enhanced even though new analysis methods might need to be developed (ESA 2018; IICWG, 2019). This will again impose pressure on the ice services for more focused products and services to ships in ice-covered waters. This is not just related to the current ice situation, but to ice statistics and forecasts for strategic and tactical decision making.

Clear visualization and measurement of the data quality and uncertainties will be necessary and valuable to the users. Improvements to current products will require an increase to high resolution (on the meter scale) satellite coverage in multiple frequencies (i.e. C, L and X band) and a combination of sensors. More ground-truth for validation on input data will also be necessary, which is overall believed to increase extensively within the near future for available technologies. A big challenge will be to deal with the amount of incoming data as well as new platforms for open data, crowdsourcing and big data, technologies that open up for new thinking, innovation and competition.

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Resources in the Ice Services

Ice analysts are experts in sea ice mapping in their operational area because they understand how to interpret and combine different sensors based on regional and seasonal nuances as they maintain continuity by following the changing conditions on a routine basis. When working with environmental conditions there will always be outliers that general automation has not demonstrated the ability to always detect. If full automation is considered in the future one of the main challenges will be maintaining expert and local knowledge in ice mapping services along with a gradual implementation of an automated methodology.

The current state of available satellites could potentially allow for a semi-automation within ice services but will require a significant level of manual quality control due to geophysical caveats in how satellites detect sea ice, particularly during the melt and summer season. The amount of quality control needed exceeds the benefits of automation. There will be a need to implement more automation in the future to effectively be able to utilize the large volumes of data and resources that will be available. Ice charts are the main sources of tactical information for mariners and the ice chart data archive is widely used as a source of ground-truth data and product validation. Thus, ice services need to be able to maintain the standard of quality in their routine products, with end-users, and within the ice chart data archive.

The ice services operate mainly on relatively stable government budgets, which also provides continuity in operations. On the other side this is also a significant limitation for expansion, even in times with global warming, technology advances and more ships/requirements. This is not new for the ice services and the challenges are to some extent addressed via international collaboration, sharing of knowledge, experience and products.

The co-operation between the research community and the operational services is not always synchronized and could in the future be enhanced in terms of using the same data format specifications and standards. CMEMS is supporting this goal through its activity, which encourages researchers to and increases the interlinkage of data and products. This way the science programs would be able to take full advantage of the extensive ice service knowledge and the ice services would fully benefit from the scientific achievements, ideally via a coordinated effort from the beginning.

Big data, open data and satellite communications

In recent years large volumes of SAR data for routine mapping of sea ice and icebergs have become available for the ice services. The volumes are expected to increase dramatically in the years to come as more satellites and sensors are introduced, and new technology allows the resolution and coverage of SAR data to improve. All ice services around the Globe find the increasing access to SAR data for ice-charting very positive, but also challenging as ice analysts and IT infrastructure including

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communication satellites are pressed to the limit. However, certain ice-covered waters, like subarctic latitudes and the North Pole, will continue to lack sufficient SAR coverage for full support of shipping (Lancheros et al. 2018; PSTG 2016)

Open data is defined as data that can be openly accessed, used and shared. A growing number of public and private sector organisations have open data policies that outline how they intend to openly publish data. The European Ice Services are committed to open data policy, but also depend to a large extent on open data; it is considered valuable for the routine production of operational ice information. The open data policy is expected to become more universal in the future which will subsequently allow ice services and users to have access to greater volumes of multiple data sources.

A potential challenge for all users may be that an increase in data provision will introduce challenges with non-standardized data formats and the development of multiple data portals. The user should understand that quality control and product quality can vary depending on the CMEMS downstream service providers.

Currently, the communication link to the users at sea is limiting the service quality they can receive. Data communication at the sea is currently satellite communication, which is slow compared to the terrestrial network, and in the high arctic, above 80 degrees north, reaches a few hundred kilobytes per second, at best. Through improved satellite communications systems, e.g. with new geostationary equatorial orbit and low Earth orbit satellites being launched and network convergence, users can acquire multiple products at higher resolutions (Jones et al., 2019).

Search and Rescue (SaR)

Dynamic ice conditions may introduce more unpredictability in a situation so it is important that the correct resources and information are easily and readily available. Future activity in the Arctic and less stable ice conditions will increase the possibility of an accident where health and safety or environmental hazards will be of great concern. Improvements with SaR coordination is going to be paramount, particularly in areas that are not heavily regulated. There are challenges with obtaining the correct data or information during an incident due to issues with satellite communications, big data, and resources in the ice services mentioned in this document. However, new challenges will develop with accurately and efficiently being able to evaluate risk assessment for a situation if the protocol for information provision is not clear. Current challenges with proper coordination for information support may be addressed by ongoing exercises and collaborations. However, changes in the potential infrastructure of ice information providers in the future can lead to complications during an event. It is mandatory that SaR is updated on relevant operational sea ice mapping service practices so they can continue coordination exercises in the case of an event.

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One of the primary roles of ice services is incident avoidance. In the case of a SaR, users require easy access to updated standard products that are specific to operations, relevant supporting information and there should be a specialist available that can provide advice. Time is critical in cold waters and targeted support is crucial. Low spatial resolutions, coarser than 1 kilometer, are only of interest at the planning stages for the SaR community because it is deemed too imprecise for almost all active operations. An example based on navigation and tactical use, a coarser resolution than 1 km spatial resolution cannot detect features that are important for maritime operations such as ice concentration at the marginal ice zone (MIZ), coastal zones, pressure ridges, ice concentrations, ice drift, leads and polynyas. Therefore, it may be a challenge for product developers to translate the results of the current focus on low-resolution sensors into sustainable, marketable products and services for end-users. However, these products could potentially assist with long-term planning and probability analysis for ships or infrastructure to plan activities in a given area if the end-users have an understanding of how to work with the data and format.

The Copernicus Emergency Satellite Tasking Service (REACT) is coordinating rush ordering and delivery. Certain eligible Copernicus Services (mainly Emergency and Security) are authorized to place such orders. This does currently not include the ice services, however Rescue Coordination Centers often use available ice and satellite information to plan and execute rescue missions. It would be beneficial for all parties to have a more well-defined role in REACT for the ice services when they are supporting Search and Rescue missions.

Recommendations

The recommendations for CMEMS are listed in no particular order.

Recommendations - User needs

1. Harmonizing the different Arctic ice charts and the Baltic Sea ice chart parameters according to the WMO standards is recommended and ice services should be supported with the necessary data products to enable seamless transition without disrupting existing services.

2. Different Arctic ice charts and the Baltic Sea ice chart parameters should be merged into a combined ice chart product. It should cover the navigational needs for ice edge, extent, concentration, age, type (stage of development) and thickness. This product can also include an analysis field of polynyas and leads.

3. CMEMS is recommended to offer an option for a SIGRID-3 Shapefile format in its services for transferring and archiving ice information. SIGRID-3 file format is already in place and produced in all major ice services, and at in-situ data providers including Ice Watch. It is

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scalable, supported by all GIS software and also enables the data transfer into the Electronic Navigation Chart (ENC) compatible file format.

4. For several products, spatial resolution can already be increased within limitations of SAR data (10-100m) and manual ice analysis spatial resolution. Through the use of vector Shapefiles, resolution in the focus areas can be retained without excess bandwidth use.

5. Products should include levels of certainty taking into consideration inherent seasonal and regional characteristics and limitations in order to be more useful for maritime users. If qualification metrics are based on validation from ice charts, products that are developed to be integrated into ice charts need to be validated based on in situ measurements or alternative ground-truth sources. Please see WP3 for further detail.

6. Iceberg products that can display individual icebergs with higher resolution need to be developed, and introduced to CMEMS. Ideally with all false targets filtered out. Satellite update frequency in certain regions needs to be analyzed and eventually combined with Copernicus Contributing Missions. SAR satellite surface detection hit rate/confidence needs to be parameterized.

7. Development of new methods to provide information of pre-dominant ice type, snow over sea ice, ice drift at higher timeliness and surface temperature at higher resolution.

8. Improve service timeliness, aim towards frequent or continuous updates based on available observations and satellite data at the hands of the users in near real-time, preferably instantly. The demand for real-time services is expected to strengthen in the future.

Recommendations - Geographical gap analysis

9. Create a clear spatial overview of actual product data availability as it may differ from the maximum product footprint described in the product metadata significantly.

10. There should be improved quality control of all product documentation and metadata, and the products should adhere to standard guidelines, such as NetCDF CF metadata conventions. The metadata format should be standardized and consistent across all products for easier accessibility and assimilation into operational products. These changes should be addressed systematically over the long-term.

11. Include mapping information (reference of the projection) in the metadata for every product. This should be an integral part of the standard documentation for implementing and delivering each product and updated for each product upgrade.

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12. Invest in more high spatial resolution (on the meter scale) sea ice products needed for navigation and for the assimilation into high-resolution forecast models. Maintain current resolution products (coarser than 1 kilometer) including the ice charts, as they are of great use for tactical planning and the archives used as extensive ground-truth datasets.

13. Provide resources to fill the geographical gaps of ice chart coverage over the eastern parts of the Arctic and the Antarctic, thereby including the lacking high user activity areas at the Beaufort Sea, Bering Strait, Northern Sea Route and Northwest Passage and providing an independent European capacity.

14. Establish a common platform that integrates information from combined ice chart products (recommendation #2) and merges regional ice charts from relevant ice services to a pan-Arctic chart.

Recommendations - Future challenges

15. Encourage and establish a framework that facilitates dialogue and discussions with information providers, operational ice service providers, third-party services and users. This can also assist in coordinating: user needs, mariner training requirements, science priorities and product development for optimization of the product portfolio and support the development of more relevant products to be used by operational maritime users. The available product catalogue should be continued to be frequently updated based on user needs.

16. As the ice cover changes due to climate change, include new focus areas, such as the central Arctic Ocean (trans-Arctic route) and areas that are no longer ice-covered all year round.

17. Introduce new multisensor products for risk assessment. Develop a system that can provide overlapping information for users to choose from, for decision making in near real-time activities.

18. Establish better flexibility to integrate new data formats, platforms for open data, crowdsourcing, big data and new distribution methods.

19. Explore new ways of displaying sea ice information (IMO Polaris maps, short term trends and deviations from typical ice conditions).

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Recommendations for Copernicus in general

20. Ensure continuous availability of Sentinel satellite data by ensuring that maintenance on data access hubs is carried out incrementally, and not simultaneously, thus avoiding significant downtime during European working hours.

21. The ice services are recommended to have a clearer and more well-defined role in Copernicus REACT for their direct support of Search and Rescue missions at ice-covered seas.

Recommendations concerning satellite missions

To obtain high-quality daily sea ice and iceberg products, it is recommended:

22. More satellite data is required than what the Sentinel-1 constellation is able to provide at subarctic latitudes (50-70°N) and at the North Pole region (88-90°N).

23. High spatial resolution (on the meter scale) satellite coverage in multiple frequencies (i.e. C, L and X band) in different combinations is needed. The proposed ROSE-L mission is anticipated to respond to these requirements, but also to identify icebergs in sea ice. In support, more ground-truth data is needed.

24. Maintain continuity of existing frequencies and acquisition types, like altimeters and passive microwaves to preserve the climatological time series.

25. Keep in mind that a stable and long-term SAR satellite acquisition scenario has the highest priority for operational navigational needs. Improved routine monitoring and increase of images and data over specific areas are secondary.

The above-mentioned advice are the ones resulting from KEPLER T1.1, 1.4 and 4.1. There are other very important requirements for future satellite missions regarding sea-ice mapping, but this report focuses specifically on the operational needs of the maritime community. For more information, see examples from https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_High_Priority_Candidates.

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WMO-574 Sea-Ice Information Services in the World document can be found at:
https://www.jcomm.info/index.php?option=com_oe&task=viewDocumentRecord&docID=9607

Related Publications and Dissemination Output

Previous KEPLER deliverables;

D1.1 Stakeholder Needs: Maritime Sector Needs
D1.4 Overall Assessment of Stakeholder Needs

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