KEPLER Deliverable Report

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Context of the deliverable within Work Package

This report represents downstream user needs from the maritime sector, community-based users, upstream and intermediate users, including research, serving the climate and weather forecasting community. Downstream is here defined as the European citizen or business concern, intermediate and upstream as services acquiring and processing data into information products for the downstream. This can include intermediate users, such as researchers developing new products, and upstream which are the operational centres acquiring, collating and processing data, such as through forecast models, into information products.

This document will synthesize feedback from all subtasks in work package 1 focusing exclusively on stakeholder and end-user needs. Work package 1 was separated into 3 subtasks by these three categories of stakeholder and end-user. The report evaluates specific parameters required by these groups, focusing on the general scales (spatial and temporal) based on their activities.

The European Ice Services (EIS) were responsible for leading subtask 1 in Part (2). As operational ice services, they act as a conduit between stakeholder and end-user needs for this community, and with research and development groups who develop value-added products to support this sector of users. Ice services directly interact with users and have an intrinsic knowledge of different scales users work and how they use sea ice information and their challenges (i.e. bandwidth, data format, information systems, and data needs). Additionally, these services evaluate derived products and forecasts that are normally developed from research institutes to determine what is appropriate for operational users. This work package collated previous and current feedback collected from stakeholders and end-users who operate in ice-encumbered areas and provide a concise and comprehensive summary of relevant user requirements expressed over approximately the last 15 years. This subtask investigated commonalities between user needs, scales, recommendations to determine how they have evolved and investigated what has already been done so far to address these needs from the operational services, space agencies, and the research community. Feedback from stakeholders and end-users from the marine sector was grouped in subsections summarizing pertinent 1) EC and ESA reports from 2004 - 2018, 2) workshops focusing on user needs for this community and 3) Internal and unpublished surveys conducted by the ice services from 2017 - 2019.

In collaboration with Snowchange and NORCE (Norway Research Centre), subtask 2 in Part (3) will represent stakeholder needs for community-based observations and addresses specific feedback related to what the local community and indigenous people would like to have for the future. It focuses on the remote sensing needs of the local and Indigenous communities of NW Russia, Sweden, Finland, and Norway. The approach includes a discussion of cryospheric hazards, traditional weather observation and prediction materials from the Sámi communities. In order to review the stakeholder needs and community-based observations from the project, we have had to operate under very tight timeframes. Given that soliciting feedback from communities requires the need for more personal discourse and is often resource-intensive. Thus, this section attempts to capture during winter 2019 on the intersecting topics of stakeholder needs and community-based observations. Our emphasis has been to highlight living voices and current information and challenges, as opposed to a full academic study of the needs – indeed the time, space and resources available have only allowed reporting from the field, and not a full scientific study on the topic.

Tasks 1 and 2 of Work Package 1 "Stakeholder Needs" aims to explore the needs of end-users of products that build on polar environmental observations. In contrast, Task 3 "Climate and Weather Forecasting Needs" in Part (4) explores the needs of intermediate users that transform and assimilate polar observations into routine and forecast products. This task thus aims to ensure that the satellite data, derived products and services needed for accurate and reliable predictions of weather and climate are identified. To this end, the users of Polar observations for environmental forecasting and climate research, including users of Essential Climate Variable (ECV) datasets, are engaged to document their requirements and suggestions for improvements. This section happened to coincide in timing with the most important conference setting the agenda for the Ocean Observing community in the coming decade namely OceanObs19, held in September 2019 in Hawai'i. We have found it appropriate to summarize the main recommendations from the peer-reviewed conference papers that concern the Arctic in this deliverable report, as it represents the status of the research community needs.

The recommendations from subtasks 1.1 - 1.3 from KEPLER work package 1 will be provided to subsequent KEPLER work packages 2-5 which will evaluate these needs regarding the current state of Copernicus services, research and satellite capabilities and develop an end-to-end roadmap based on this feedback from the operational maritime community. The following work packages will also present the possibilities with addressing some of the user needs through Copernicus and provide additional recommendations if necessary.

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Part 1. Introduction

This report will provide a comprehensive summary of marine sector needs, community-based and societal needs, and needs for weather and climate forecasting in the Antarctic, Arctic and the Baltic that have been compiled from multiple European Commission (EC) and European Space Agency (ESA) projects, internal and unpublished surveys, and stakeholder and end-user workshops. There have been parallel efforts to understand user needs in this community for the last 15 years, and this report will take advantage of the work done to assess general requirements and recommendations from previous reports, relevant workshops and surveys specific to stakeholder needs and combine them with updated information on stakeholder and end-user needs.

Background

The European Union (EU) Framework Program 6 and 7 (FP6 and FP7, respectively) ran from 2002-2013 and focused on various projects focusing on addressing the needs of society by connecting research and applied sciences. The FP7 (2007-2013) specifically incorporated research with industry partners (from private and public sectors) and policymakers to facilitate formal collaborations and identify user needs from stakeholders and end-users working in the Polar and Subpolar regions, particularly those operating in cryospheric conditions. During FP7, and the first years of H2020, the first pilot services of Copernicus, or the Global Monitoring for Environment and Security (GMES), as it then was, were set up as research projects. These went operational in 2015, however, the services are still to some extent immature with regards to serving the needs of end-users. Hence the LC-SPACE-02-EO-2018 call that KEPLER addresses have the requirement "*to advance a coordinated preparation of a mature European capacity*" and to identify "*further research and development to be undertaken to reach sufficiently mature capacities for an operational integration*".

The onset of the Sentinel satellite missions in 2014 increased the Synthetic Aperture Radar (SAR) coverage, thus improved Earth Observation (EO) capabilities for operational monitoring. This created new opportunities for product developers and information providers (government and commercial) to improve the development of value-added weather and sea ice products and forecasts for the public sector. Additionally, stakeholders and end-users had access to more high spatial resolution imagery, normally reserved for government and private use, due to the considerable expense for one image. This helped to open a new era of an increased potential for economic activity for operators and information providers, as well as the onset of challenges with "Big Data."

Therefore, the new requirements, changing environmental conditions in the Polar and Subpolar regions combined with the evolution of technology and EO computing power, has defined a userscape where the flow of data between stakeholders, end-users and intermediate users are not always successive and data needs vary depending on the type of user, the activity and the phase in which the activity is being performed (early planning stage vs. late phase).

Definition of Users

A number of organizations, authorities and projects are already working in the field of marine transportation, weather and climate forecasting with the aim to continuously improve safety at sea with various roles and responsibilities. The descriptions of the stakeholders include their views of essential features and functions of the service. The views from the end-users and stakeholders are essential factors in these user-cases and scenarios is of great importance when the design of functioning integrated services is being outlined (Appendix B - *User Stories*)

Stakeholders and end-user definitions are often used interchangeably because both groups have common interests and may work in many roles depending on the required activity (Figure 1). For example, stakeholders can be end-users. However, they will be separated accordingly in this project and simply defined as the following:

- ***Stakeholder:*** A person or a group interested in a product or service which may be used to develop value-added products or services to end-users. Those who can influence how services look and thus have requirements for the services. These can be international organizations such as IMO or WMO. If there are satellite data needs, then organizations such as ESA have to be taken into account. But stakeholders can also be a service provider, national or international if their requirements are reflecting the services.
- ***Intermediate users:*** Product developers and information providers that generate value-added products to end-users. Intermediate users normally work in research, commercial and governmental institutes, but often private and commercial operators include internal personnel. Intermediate users develop products for, but not limited to, research, operations, planning and logistics purposes.
    - *Information Providers*
    - *Data developers*
- ***End-users:*** A person or group that uses a product or service for decision making or research, which may be used to generate a product or service for a next end-user
    - *Involved user* - A user representative party to whose needs the service is to be developed, and who will actively validate that service
    - *Customer* - A user that pays for the service or product
    - *Beneficiary:* - A user or a group who benefits from the use of the service or product

In Figure 1 various user types are presented as well as the user categories and other stakeholders they represent. Different categories may overlap. The main categories are marked with a **bold** cross, while Figure 1 is representing the general data flow between the different categories and userscape.

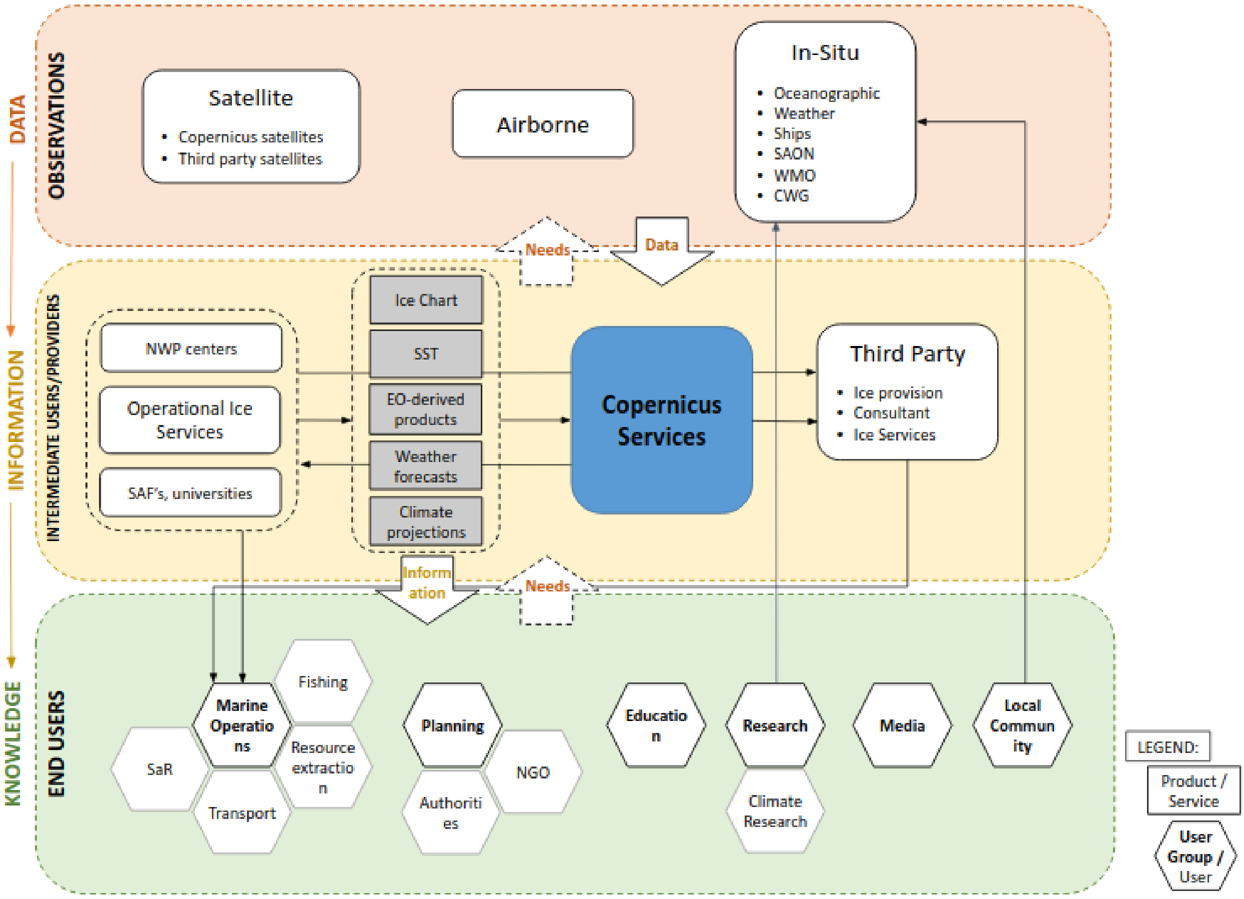

Figure 1: Illustration describing the userscape and data flow between the different categories.

Previous Studies on User Feedback

From the EU FP7 and the current Horizon2020 projects, identifying user needs has been the forefront of the EC and ESA interest, particularly with new EO missions. Previous and current EC and ESA projects have clearly identified data, satellite gaps and needs for the marine community together with weather and forecasting based on surveys and workshops more than the past 15 years [deliverable 1.1 - Maritime sector needs]. For this reason, it is necessary to acknowledge the current state of user fatigue from participating in multiple surveys, meetings, workshops and other dialogue over the course of this time. This has been expressed by the stakeholder and end-user community over the last few years, particularly within ongoing projects (EU-Polarnet, Salienseas, and KEPLER) when trying to inquire about user needs. The stakeholder and end-user community also stated that they were unclear about the long-term goals of these projects, how their feedback has been communicated to the EC, ESA and research community to improve products and an overall plan for dissemination to the general public.

The emphasis of this report will summarize the main recommendations and parameters for all users from previous and current feedback. This will help to identify recommendations to guide the KEPLER project to produce a relevant end-to-end roadmap on how we can forge closer links to the data and information provision community to the user community. The following sections will provide further details on each of these resources and summarized to provide guidance on user needs and gaps in knowledge for subsequent work packages in KEPLER.

Definition of Operational

The concept of "operational" varies between WMO and Copernicus documents. The following describes how the term is regarded between the two organizations:

WMO's concept of "operational": The term "operational" according to the WMO consists of a set of standards and regulations that all official ice services (including those recognized by the International Hydrographic Organization [IHO]) comply with in order to provide reliable routine service for end-users. As the WMO is the international regulatory body for environmental information service provision, these standards require multiple levels of the international agreement upon what type of information marine services should be providing based on areas of responsibility, data format, expert competency and product maintenance (i.e. WMO 49, section 1.2.1 and (WMO-No. 558), Volume I]. In order to ensure the standards are adhered to by the official recognized information providers, the components that make an operational system according to WMO conform to the general requirements and advisory boards for meteorological and hydrological services documented in WMO documents WMO 558, 471, 49, as well as the JCOMM ETSI group.

It is important to note that the WMO requirements for meteorological and hydrological services and information are specific to the needs of the end-users that perform in weather-sensitive marine activities such as communities and activities near the coasts, recreational boating activities, SaR, resource extraction, and governmental services that often travel in areas of dynamic environmental conditions (WMO 471, section 2.2). Operational services for weather and ice regulatory agencies are described in the WMO National Requirements 558 where the p*rovision of metocean information and expert advice on the use and interpretation of historical data and related products should be arranged in accordance with national practices* and need to be routine and reliable. This means that information products provided by official services should be (WMO 471, section 2.2.2):

- Standardized data format amongst all recognized agencies in order for all end-users
- Routine products need to be easily interpreted by all users who have maritime activities in specific monitoring area
- The quality of the data should be developed to support the spatial and temporal scales required by the end-users with periodic evaluations to update as necessary

- A fundamental requirement for an operational product is that it continues to be routine and reliable despite the data available at any given time and is overseen with the expertise of the ice analyst or forecaster

The quality assurance provided by ice analysts in routine products is considered to be a source of ground truth because they have a level of expertise consistent with ice service training protocols. This is described in the Ice Analyst competency document, developed through the IICWG Task team "ICE ANALYST/FORECASTER COMPETENCIES" and was approved in September 2019. This is expected to be officiated through the WMO ETSI group 2020

Copernicus's concept of "operational": Copernicus services (CMEMS & CLMS) are core services and have open and free data policy. These are integrated services with website access for users and dedicated service for user support. Products are made available on a 24/7/365 basis while the service desk is operated during office hours 5/7. Performance targets also are defined, managed and measured in CMEMS (see D2.2 KEPLER). Concerning the management of the products, the CMEMS has to ensure reliable access to the products and information at any time for external users. Performance targets of download capacities and visualization capabilities are defined and measured. Commitments in the access to the web portal, the unique entry point and on the Service Desk element also have their own performance targets. See http://marine.copernicus.eu/services-portfolio/service-commitments-and-licence/ for a complete description of all the measured elements.

A-frame summarises the commitments of the Copernicus Marine Service imposed by the European Union. The service is driven by 9 rules under which any decision must comply. Only rules relevant for stakeholders are listed here, the complete list is given in (Copernicus Marine Service Portfolio 2017, CMEMS, D. Obaton and A. Delamarche):

- The CMEMS is a European Core Service (Rule 2) - This rule explains that 'one of the main preoccupations of the CMEMS is to target intermediate users'.
- The CMEMS has an open and free data policy (Rule 3)
- The CMEMS is an integrated service (Rule 5) with a unique point of access for users (website, Service Desk).
- The CMEMS is an operational service (Rule 6) - The CMEMS is reliable. It is checked and reviewed against service commitments. The CMEMS ensures the quality of products (scientific verification and validation) and results are made available for users. Products are available on a 24/7 basis while Service Desk and producers are operated during office hours 5/7, excluding public holidays.
- The CMEMS is a User-Oriented Service (Rule 7) - User requests are managed (training and questionnaires) and users feedback and their satisfaction are measured and monitored.

Key performance indicators, timeliness and availability of real-time products, are also measured and monitored for each product in Copernicus. If the timeliness is delayed by less than 2 minutes of the target delivery time, the product is still considered on time. The availability (viewing and downloading) is measured and refreshed in real-time (every 15 min).

Part 2. Maritime Sector Needs

Marine users consisted of those working in marine safety including search-and-rescue, vessel operators, local fishing communities, planning and logistics, ice/marine services, weather services, and those working in the private sector. A number of projects, authorities, and organizations are already working in the field of marine transportation with the goal to continuously improve safety at sea with various roles and responsibilities. Their full support is a key issue for the KEPLER project, and a key objective is to ensure that there is a clear, concise and achievable road map for the Copernicus program to develop industry and societal-driven value-added technologies, products and other services that are relevant to their requirements. This will also enhance the European capacity in EO for the monitoring of the Polar Regions, and its sustainable development, to the benefit of the society. With the first Sentinel-satellites being operational for several years now, it is important that in the next phase, Copernicus 2.0 starting in 2021, services utilizing these are developed further to maturity to meet the requirements of the Polar Regions.

In the Polar Regions, the recognized international authorities for sea ice and iceberg information to support maritime safety and advise in a regulatory capacity are roles defined by the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC) Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM). These reside in the various national ice services which, in some instances, are backed by further international groups including International Maritime Organization (IMO) and conventions such as the International Convention for the Safety of Life at Sea (SOLAS). Most ice services have operated continuously since the 1960s, although some have histories back to the 1910s. They are, therefore, in the operational context, mature services. In KEPLER, the European Ice Services (EIS) (consisting of national ice services from Norway, Sweden, Finland, and Denmark) are in direct contact with end-users, marine and industry operators in the Arctic and Baltic who rely on varying levels of ice provision services and products to safely and efficiently operate in ice-encumbered areas. The EIS collated stakeholder and end-user responses from the following previous EC and ESA projects.

The Arctic environment has been showing an increase in changes with trends in weather and sea ice interannual variability and is projected to open up new routes in areas that were once ice-covered year around. The increasing number of commercial opportunities in these regions and further sea ice instability will require a need for more accurate and comprehensive environmental monitoring information to help provide guidance to end-users as they're navigating areas that may become more unpredictable. In 2017 the IMO adopted an international set of requirements for ships travelling in sea ice encumbered areas [21 & 22]. As a result, ship operators are required to have a certain competence in using various environmental data, depending on the activity, and it is mandatory that a ships' design is suitable to travel in specified ice conditions, based on the ship's class.

It is critical to understand the following: how all users apply different types of data; the temporal and spatial scales they work; identify when they're required; overall preferred data (i.e. geophysical parameters) in order to develop appropriate products. The peak time for activities in the Arctic, the Baltic and Antarctic vary greatly depending on the type of industry, location of ice-covered areas surrounding coastal zones inhabited by communities, and interests in exploration and tourism.

Regional differences in activity-specific for marine operations in the Arctic can be separated into the following sections:

1. *European Arctic:* Southeast coast of Greenland to Cape Chelyuskin
2. *Canadian Arctic:* Canadian Archipelago, including the Northwest Passage and West Greenland
3. *Alaska:* Coast of Alaska, including the Aleutian Archipelago and the Bering Strait
4. *Russian Arctic:* the Chukchi Sea to the Eastern Barents Sea, including Northern Sea Route

It is important to bear in mind that the responses compiled in this report are specific to the respondents. Perspectives among operational users vary due to the nature of different activities that are often performed during different times within the season, require several types of information at multiple spatial and temporal scales, depending on the phase within the activity [39]. Each of these sources of information detailed in this report (i.e. reports, surveys, and workshop outcomes) are collective responses from stakeholders and end-users based on targeted inquiries, thematic workshops and projects that seek out specific information depending on the aim of the information requested. Therefore, there is a bias introduced in the summary which is limited to the respondents who were willing to provide feedback, their understanding of the questions being asked and specific companies who represented operational marine industries (i.e. shipping, fishing, planning, etc.).

Additionally, stakeholders and end-users can work in several different industries or economic sectors simultaneously, thus their information needs will vary depending upon their requisite roles. The majority of this section will focus on feedback for ice information needs from the European Arctic and Baltic. Ice information needs for these areas differ from those in the Antarctic for the following reasons:

- The Antarctic is more remote and although visitor numbers are increasing, these are a magnitude less than those for the Arctic.
- It has less infrastructure, that is more sparsely situated except for the region around the Antarctic Peninsula.

For these reasons, the Antarctic is seen as a lower priority for satellite coverage. As its coastline lies mostly at higher latitudes than the Arctic it is, therefore, a much larger area that is less easy to cover on consecutive orbits.

The European Arctic sees the greatest activity with vessel traffic during the Spring and Summer seasons when the sea ice is retreating and ice tends to be more dynamic. It makes it easier for non-ice reinforced vessels to travel along the marginal ice zone and ice edges because the ice can be dispersed and many ships are able to travel to areas (i.e. fjords and narrow channels) that are normally inaccessible during the freeze-up and winter seasons. Polar tourism is a prominent industry during this time due to the increased interest from the general public on climate change. Wildlife is also most active along the ice edges boundaries between stable and unstable ice conditions, thus an increase in the number of passenger vessels that will travel in ice-encumbered areas should be anticipated. Additionally, energy resource extraction and planning has been active in the Barents Sea and north-east Greenland coast in recent years, with a strong focus on reducing operational risks and safeguarding the environment. This has increased the requirements for metocean and ice information products that exceed those currently routinely available (Knol et al, 2018).

Marine activity in the European Arctic is in contrast with that of the Baltic. Traveling through sea ice in the Baltic has been strictly regulated by national authorities for many decades, due to the smaller regional area, critical winter navigation responsibilities and the need for international cooperation between many states. Environmental protection measures have been in place since 1974 under the auspices of HELCOM (Baltic Marine Environment Protection Commission, also known as the Helsinki Commission). While ice conditions are forecasted to become gradually less severe, the enclosed nature of the sea can lead to high interannual variability. The Baltic is characterized by a more seasonal and smaller ice area compared to the Arctic but monitored by established ice services in Sweden and Finland. The produced ice charts are of comparatively good quality, but due to wind and currents, the ice conditions may change rapidly and the drift ice can quickly become compacted against the coasts and against the fast-ice edge. One of the main challenges in the Baltic sea is maintaining transportation routes of ice open to vessels as there are a large number of port calls to the Baltic region during the winter. This secures a demand for assistance from icebreakers depending on the vessel's power and size. The detailed sea-ice information is currently based on synthetic aperture radar (SAR) imaging in order to maintain and improve the safety of Baltic sea transportation. There is a requirement from the maritime sector for more detailed ice charts or other products based on SAR data, especially in the areas of deformed ice. Ice thickness data is being obtained either from in situ observations from along the routes of the vessels or from a small number of coastal stations.

In the Antarctic, the operational activity is mainly due to polar tourism along the western part of the Antarctic Peninsula, Amundsen and Bellingshausen Seas, it is, however, beginning to move eastward through Antarctic Sound and to the Weddell Sea and south, towards the Ross Sea. Other areas for small volume, but significant traffic, are the eastern side of the Weddell Sea and the western side of the Ross Sea, into the McMurdo Sound. These two areas have a concentration of national research stations that necessitate annual resupply. User needs have been outlined by the Council of Managers of National Antarctic Program (COMNAP) in a White Paper [40] and satellite needs paper

[30]. Further out, in the areas of the ice edge around the Antarctic, there are fisheries activities that occasionally require vessels to venture into hazardous areas. PMW sea ice concentration products are used for navigation, not because of user preference, but of the lack of anything else. Users have indicated that they would prefer improved SAR coverage, and the Argentinian SAOCOM mission is seeking to address this issue [Argentine Navy, pers. comm.].

Stakeholder and End-user Needs from the Maritime Sector

The European Union (EU) Framework Program 6 and 7 (FP6 and FP7), respectively ran from 2002-2013 and focused on various projects with the aim of addressing the needs of society by connecting research and applied sciences. The FP7 (2007-2013) specifically incorporated research with industry partners from (public and private sectors) and policymakers to facilitate formal collaborations and to identify user needs from stakeholders and end-users working in the Polar and Subpolar regions, particularly from those who operate in cryospheric conditions.

The onset of Sentinel satellite missions in 2014 increased with the Synthetic Aperture Radar (SAR) coverage, thus improved EO capabilities for operational monitoring. This created new opportunities for product developers and information providers (government and commercial) to improve the development of value-added weather and sea ice products and forecasts for the public sector. Stakeholders and end-users had access to more high spatial resolution imagery, which was normally reserved for government and private use, due to the considerable expense for a single image. This helped to open a new era of an increased potential for economic activity for operators and information providers, as well as the onset of challenges with “Big Data”.

In 2017 the International Maritime Organization (IMO) adopted an international set of requirements for ships traveling in sea ice encumbered areas [21 & 22]. As a result, ship operators are required to have a certain competence in using various environmental data, depending on their activities and it’s mandatory that a ship’s design is suitable to travel in specified ice conditions based on the ship’s Polar Class (PC).

Sections in the KEPLER deliverable 1.1 - Maritime sector needs (in part 3) were separated by the relevant EC/ESA reports, workshops, and outcomes from surveys conducted by the European Ice Services in order to provide a comprehensive review of schemes that have been funded to better understand user-needs for the operational maritime community. Additionally, a thorough section illustrating current information provision for end-users can be found in this report in Part 7. Appendix B: User Stories. Most end-users worked in tactical marine activities and a smaller percentage worked with short and long-term planning and logistics. Another smaller sector was represented by research working with sea ice provision for operations. This sector can be simultaneously end-users, stakeholders and intermediate users and will be more focused in Part 4 *Intermediate User Needs for Climate and Weather forecasting*.

Due to the dynamic sea ice conditions, particularly during the Spring and Summer, the spatial resolution of sea-ice information is of particular concern. The effects of regional weather systems impact how the ice changes, especially when it's less compact and more unstable. The current state of information provision cannot always provide details on sea ice features such as ice type and deformation on the scale that would improve support for the operational marine community; unless it is administered by private or commercial services that need to be prepared in advance.

From the D1.1 report, some common themes on the spatial resolution were combined in a summary table to show the level of interest in spatial scales for different parameters based on whether these were for tactical or planning purposes (Table 1). The level of interest is overwhelming for high-resolution products for tactical purposes, where high resolution is understood to be on the sub-kilometer scale (Figure 2).

Spatial resolutions on the kilometer scale are of interest at the planning stages for most users, and a larger portion in the research community. End-users deemed these too coarse for navigation and tactical use due to the inability to detect features important for maritime operations such as ice concentration at the edge, at marginal ice zone and coastal zones, ice concentration, leads, and polynyas (See Part 2: ICEMON, ESA POLARIS, and CPEG reports). In addition, a number of intermediate users noted that this was an impediment to the development of regional forecast products applicable to end-user demands (see Part 4). Fifteen years of reports and assessments from EC and ESA have been reviewed to understand why there is a gap in communication of user requirements and stakeholder needs for satellite-based products.

This section summarizes the outcomes from EC and ESA projects specifically focused on evaluating stakeholder and user-needs from early reports (i.e ICEMON) to current ongoing projects (EU-PolarNet). From this, we highlight commonalities between user responses in order to present a correlation of user needs from different sectors and how they have either evolved or stayed the same over time given the improvements of new technologies and satellite sensors. Many projects were active simultaneously and collaborated with one another in order to assess needs by relying on the same surveyor mechanisms to obtain user feedback, however, targeted different user groups. (i.e. ACCESS, SIDARUS and NorthernView). Some challenges in evaluating all user reports to the same standard were that results from each project may have been weighed differently due to the project criteria. Additionally, while some projects expressed the use of existing data, others may have only included information on desired parameters. However, there are prevailing user-needs that have been found and not yet been addressed or resolved with the current state of satellite coverage. The following sections will review previous reports in chronological order and provide a brief synopsis according to the targeted user group, existing and desired parameters and main recommendations from each project and are illustrated in Tables 2 & 3.

Table 1. List of reports. Summary of user requirements surveys and reports, key parameters assessed, and their conclusions on spatial resolution according to tactical and planning timescales.

		% of users
	No interest	
░	Low interest	> 0% < 12.5%
▓	Medium interest	> 12.5% < 25%
█	High interest	>25%

Tactical ⟷ Planning

		SPATIAL SCALES BY USER	High Resolution					Low Resolution
	Name	User Type	0 - 10 m	10 - 50 m	50 - 300 m	300 - 1000 m	1 - 10 km	10+ km
Surveys	IICWG	Navigators	█	█	░	░	░	░
	NIS	Shipping, Icebreakers, Logistics/Planning and Polar Tourism	░	░	▒	█	▒	░
Report	ACCESS	Shipping	█	█	█	█	█	▓
		Oil and Gas	█	█	█	█	░	░
		Research	█	█	█	█	▓	▓
		Other	█	█	█	█		
	SIDARUS	Marine Safety	█	█	█	█	▓	░
		Marine and Coastal Envir.	█	█	█	▓	▓	▓
		Climate and Forecs	░	░	░	░	░	█
Workshop	Copernicus Maritime Survellance (EMSA) - Baltic	Marine safety, security, and marine environment monitoring	▒	▒	█			
	Copernicus Maritime Survellance (EMSA) - Arctic	Marine safety, security, and marine environment monitoring	█	█	█			
		SPATIAL SCALES BY PARAMETER						
		Parameter	0 - 10 m	10 - 50 m	50 - 300 m	300 - 1000 m	1 - 10 km	10+ km
Report	CPEG	Thin Sea Ice (Research)					█	░
		Thin Sea Ice (Navigation)	█	█				
		Sea Ice Type (Research)					█	
		Sea Ice Type (Navigation)	█	█				
		Iceberg Detection (Research)					█	
		Iceberg Detection (Navigation)	█	█				
		Iceberg Drift (Research)					█	
		Snow depth/Density (Research)					█	
		Snow depth/Density (Navigation)		█				
	ESA Polaris	Ice thickness	█	█	█	▓	░	░
		Stage of Development	█	█	█	▓	░	░
		Extent	█	█	█	▓	░	░
		Structure/Age	█	█	█	▓	░	░
		Topography	█	█	█	▓	░	░
		Motion	█	█	█	▓	░	░
		Iceberg	█	█	█	▓	░	░
		Snow on sea ice	█	█	█	▓	░	░
		Drift		▓	█	█	█	░
		Sea ice deformation	█	█	█	▓	░	

Operation ice services focus → ← Current CMEMS focus

It is important to note that the mandate of those working in operations is the provision of ice information for monitoring safety and navigation in their area of responsibility according to the WMO meteorological areas (Metarea) and navigational area (Navarea) guidelines [21 & 22]. Therefore, the results from user-needs are normally published in the form of project, internal and international reports, surveys and user consultation included in white papers or in-house documents within the ice services. List of reviewed reports can be found in Table 1. There were some common parameters and recommendations from all the reports that users identified (Tables 2 and 3).

The majority of desired or requested improvements with sea ice parameters were focused on sea ice thickness, ice drift information and snow on sea ice at a sub-kilometer scale. Snow on sea ice greatly affects monitoring by satellites, and also it affects the icebreaking performance of ships hulls. The reports reflected feedback from both the Arctic and the Baltic which we would expect to have different operational specifications for sea ice information and this is also evident from the ISABELIA project report.

Feedback from these reports was consistent with the requirements stated in the first CPEG report. The second CPEG report concentrated on attainable goals with the recommendation of High-Priority Copernicus Missions CIMR, CRISTAL and ROSE-L, however, **the summary recommended goals that were described to be at a lower level than users and product developers catering to those end-users, required for navigation and tactical support.** Detailed feedback on further needs from the mariner community can be found in a recent survey can be found in the subchapter: *Internal Survey Feedback: IICWG Survey 2019*

General recommendations from users have focused requests for technological developments within the scope of satellite capabilities to provide improved products such as higher spatial and temporal resolution products, as NRT data assimilation, usage of more SAR information in routine products to present sea ice features more accurately for tactical guidance and requests for the provision of better accessibility and understanding of sea ice products. (Table 2).

Finally, recommendations were consistent from all reports that route- and voyage planning were important. Additionally, the availability of improved sea-ice forecasts from high-resolution data would give valuable support to maritime operations. Feedback from sea ice forecast needs from surveys is covered in the *Internal Survey Feedback* of this section. Based on dialogue with users, direct experiences from ice services, and feedback contained in all sections in Part (4) of this report, it is still rare for sea ice forecasts to be used for tactical support of operational maritime activities.

Table 2. Common desired parameters from EC and ESA project reports (grey) and Surveys (white). **IC** = Ice Concentration, **IT** = Ice Type, **IE** = Ice Edge, **IEX** = Ice Extent, **L/OW** = Lead and Polynyas, **IA** = Ice Age, **SIT** = Ice Thickness, **ID** = Ice Drift, **D** = Deformation, **F/MYI** = Discrimination between FYI and MYI, **IT/RA** = Ice Thickness with Radar Altimetry, **DIC** = Detailed Ice Charts, **W**= Waves at ice edge, **SN** = Snow on Sea ice, **FR** = Sea Ice Freeboard, and **IB** = Icebergs.

	Desired Parameters															
	IC	**IT**	**IE**	**IEX**	**L/OW**	**IA**	**SIT**	**ID**	**D**	**F/MYI**	**IT/RA**	**DIC**	**W**	**SN**	**FR**	**IB**
ACCESS	🟥	🟥	🟥	🟥	🟥		🟥	🟥	🟥	🟥	🟥	🟥		🟥		🟥
SIDARUS	🟥	🟥	🟥	🟥	🟥		🟥	🟥	🟥	🟥	🟥	🟥		🟥		🟥
ICEMON	🟥	🟥	🟥	🟥	🟥		🟥	🟥	🟥	🟥				🟥		
ESA Polaris				🟥		🟥	🟥	🟥						🟥		🟥
PEG	🟥	🟥					🟥	🟥						🟥	🟥	
ISABELIA						🟥	🟥	🟥	🟥			🟥	🟥			
EU-PolarNet				🟥		🟥	🟥	🟥						🟥		🟥
SWARP	🟥	🟥					🟥	🟥		🟥		🟥	🟥			
FMI	🟥						🟥		🟥			🟥				
IICWG							🟥	🟥	🟥					🟥		🟥

Table 3. Common agreement on main recommendations from EC and ESA project reports (grey) and Surveys (white). **MS =** Multiple Sensors/Complementary data, **AF** = Affordable data, **ACS** = Automatic Classification (SAR), **IS** = In situ observations, **NRT/DA** = NRT Data Assimilation, **DA/S** = Data Assimilation from SAR, **HRSF** = High-resolution Sea ice forecasts from SAR, **DSAR** = More details from SAR (i.e mode flexibility, increased coverage and higher resolution of sea ice features, **I/SD** = Iceberg size and drift, **L** = Improved latency on products, **DA** = Data that is easily understood and available, **SF** = Familiar data formats and standards, **DT** = Better dissemination, tools and training of different data products for non-specialists, and **RA**= Risk Analysis.

Main Recommendation														
	MS	AF	ACS	IS	NRT/DA	DA/S	HRSF	DSAR	I/SD	L	DA	SF	DT	RA
ACCESS			🟥	🟥	🟥	🟥	🟥		🟥					
SIDARUS			🟥	🟥	🟥	🟥	🟥		🟥					
ICEMON	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥						
ESA Polaris	🟥		🟥	🟥			🟥		🟥	🟥	🟥	🟥	🟥	
PEG				🟥										
EMSA	🟥							🟥		🟥				
IICWG	🟥		🟥	🟥			🟥						🟥	
ISABELIA			🟥					🟥						
EU-PolarNet	🟥				🟥	🟥	🟥			🟥	🟥	🟥	🟥	
SWARP	🟥		🟥	🟥	🟥			🟥		🟥		🟥		
FMI								🟥			🟥	🟥	🟥	
IICWG	🟥													🟥

A general comment of this section regarding the EC and ESA reports is that there were not only overlapping feedback from user requirements and main recommendations, most of the reports referred to one another to show how feedback had already been collected from users at different stages over the last 15 years. It is evident that surveys and repeated projects focusing on user needs for marine operators has resulted in end-user fatigue in providing additional feedback. The questionnaires in the surveys are slightly varied but there are more similarities in the overall outcomes rather than differing opinions. These reports are well-known to some who are familiar with these projects, however, finding archive copies have been difficult because these are project-based reports and there is no standard archiving of documents that are clearly distributed widely to the research and operations community. It is still unclear how information from these individual reports are communicated to policymakers, researchers, funding agencies who can influence the development of sea ice information, especially when these groups do not very often interact with end-users.

Summary of Stakeholder and User Workshop Assessments:

A number of workshops targeting end-users and stakeholders have been held in the past few years. These include the Arctic Sea Ice Prediction Stakeholders Workshop (ASIPSW) and SALIENSEAS workshops, both in January 2018, and a workshop with EMSA on 20/12/2016. Further to this, a number of assessments have been performed by ice services and projects.

List of targeted workshops:

- IICWG ASRSC Report XII (October 2011)
- Arctic Frontiers 2018: Stakeholder Sea Ice Forecast Workshop and SALIENSEAS Stakeholder Advisory Group Workshop
- Copernicus Maritime Surveillance Service (EMSA, 2018)

Key findings of the ASIPSW and SALIENSEAS workshops

- Need for more co-production of decision-making systems to educate both sides on potential new products and services, and tailor solutions to industry needs.
- Create an iterative process to product development that allows for synergies and a better understanding of respective skills, limitations, and promotion for better tools.
- Establish a common language between stakeholders and ice information providers.
- Encourage industry to employ and engage with more sea ice scientists
- Create better visualization tools, taking into account low bandwidth limitations.
- Better communication by forecasters of the assumptions, limitations and expectations.
- Build-in understandable confidence and uncertainty estimates into forecasts. Accuracy is a key requirement.

- Link to complementary programs and initiatives focusing on the links between industry needs and forecasts.

In contrast, the SALIENSEAS workshop made more specific recommendations for the types and level of information required, including:

- Winds along the ice edge, katabatic and storm events
- Polar Low forecasts
- Annotated satellite images, in preference to ice charts, for experienced navigators.
- WMO Egg Codes to portray inhomogeneity of the ice and comply with the Polar Code.
- Many users were unaware of the range of metocean services available.
- More automated compilation and filtering of a large number of available services, with the use of common format standards.
- Need for a dedicated sea ice analyst to distil and interpret information.

To some extent, the SALIENSEAS conclusions reflect the communication issues between end-users and ice forecast providers stated in the ASIPSW. Both workshops highlighted the lack of awareness of ice information product availability, due to poor interaction and communication with data developers and end-users. Additionally, these groups do not speak the same language regarding the use of similar terms. This confusing situation seems to be exacerbated by multiple types of information providers including national ice services, Copernicus services, and commercial providers, all competing for the same end-user base.

Many of the points raised by SALIENSEAS are already a fixture of ice information provision. Annotated satellite images can provide more information, but only if the user is sufficiently experienced to interpret them. Additionally, the use of many products is currently not feasible at higher latitudes due to satellite communications bandwidth limitations. This, and the use of sea ice analysts to distil the data and information into knowledge resulted in the need for the current network of national ice services to adhere to standard recognized formats. These include SIGRID-3 for ice chart interchange and S-411 for ENC's, based on the Egg Code terminology, to reduce data volume and communications overheads.

Key findings of the EMSA Workshop

Though EMSA primarily focuses on sub-Arctic and mid-latitude areas, there is a strong overlap with monitoring operations for sea ice-encumbered waters and areas in the subpolar regions regarding spatial and temporal resolution satellite needs, as well as the data access and infrastructure (i.e. data format, accessibility, provision of understandable and relevant information for specific users, etc.) that are common to all operators working in the maritime domain. Additionally, the breakout sessions during this workshop covered ice monitoring needs related to Copernicus services but did not provide any specific information on desired or required parameters. The following summarizes the feedback from the workshop related to maritime requirements in KEPLER WP1.

As EMSA is focused on maritime safety, feature detection is one of the primary concerns. One of the main suggestions was to improve delivery time for both SAR and optical acquisitions and to increase the number of featured products for activity and feature detection. This includes ships and icebergs and the tools to discern between the two. Regarding the differences between the two Copernicus services, CMEMS and CMS (see the Overview section of this report), EMSA expressed that the use of CMS for ice monitoring is limited to support to the safety of navigation in ice conditions where it is most helpful to support safe passage through areas that include dynamic ice conditions and to detect ice sheets and icebergs in NRT.

Regarding the future implementation and EO capabilities, users requested improvements with services for data acquisition and latency. The integration of new satellite constellations, preferably with SAR and optical, was considered important for all sectors. Furthermore, with improvements in satellite latency, users wanted more integration with AIS and the development of synergies with Remotely Piloted Aircraft Systems (RPAS) operations, Frontex Maritime Aerial Surveillance (MAS) and the availability of RPAS possibly through Copernicus.

Regarding technological requirements, it was noted that user experience and understanding with different types of data varied and some fundamental recommendations on improvements to Copernicus are described in Part 7 - *Discussion and Recommendations*

Key findings of Internal Surveys

Internal surveys are occasionally conducted by ice services in order to update and improve their products for end-users evolving maritime user requirements and needs and to maintain with WMO requirements. The following section summarizes surveys that were administered by the national ice services (NIS, DMI, FMI, and SMHI) over the last three years, as well as during the EC projects; SPICES [ref] and KEPLER. There were many different organizations represented, covering a range of different user types which will be described in this report.

List of internal surveys:

- Norwegian Ice Service Survey for Arctic Shipping Forum (2018) / AECO - Polar Tourism (2017)
- FMI Ice Map as a Product, Observation and the Concept Survey (2017)
- FMI Survey on Services and Products (2018)
- SMHI Survey (2019)
- IICWG Survey (2019)

As the Arctic region is characterized by a year-round ice cover in some areas and partly very rough ice conditions including ice pressures and heavy multi-year floes, particularly around the Northern and Eastern part of Greenland and within the pack ice above Svalbard and the Barents Sea.

Regarding user needs for ice information, in the Arctic, it can be more limited compared to the Baltic Sea due to lack of frequent in situ observation sites and stations, and additional high-resolution satellite coverage considered to be "operational" (i.e. commercial satellites are normally used to augment areas of missing high-resolution satellite coverage from the ESA Sentinel 1 mission). However, Table 1 and Figure 3 reflect the collective need for spatial and temporal resolutions for the Arctic and Baltic operators and show that they coincide with requirements to have more frequent coverage (i.e. As often as possible and daily) with the minimum spatial resolution at <1km, depending on the phase (early or late) in the activity. Overall, new and improved products for the maritime sector were consistently requested in order to provide high-resolution ice products based on SAR, as well as information on ice thickness and ice type at the sub-kilometer scale.

The organizations that responded from the Arctic Shipping Forum (ASF) survey in 2018 and AECO multiple-choice surveys were combined and categorized by their primary interest in the Arctic Sea, into different user sectors (Fig. 5, Appendix C). Sectors such as logistics (air) and polar tourism are known to use ice charts but tend to be smaller-scale operations where they utilize publicly available data and do not necessarily have the resources or time to interact with the data or information provider.

For ships operating in the Arctic Sea, the communication bandwidth can be limited at high latitudes (over 80N) or when ships are traveling in the interior of fjords or mountainous regions. The NIS survey feedback from ASF 2018 and AECO presents the data format and delivery preferences from users and provides information on how sea ice products will be more user-friendly in the future. The internal feedback clearly shows the difference in how the user sector uses the data in terms of their operations.

Survey results suggest:

- Users depend on receiving easily accessible sea ice information as JPEG/PNG/PDF or a format that is clear and easy to understand for the operator (Fig. 9 D1.1 - Maritime user needs), also consistent with preferred data formats desired (Fig. 10 D1.1 - Maritime user needs).
- Due to potential poor satellite coverage and bandwidth challenges. It is crucial for the information provider to compress and limit the amount of data before transferring out to the ships. From NIS experience with users, preferably at an approximate file size between 1-1000 Kb, depending on the ship's capability.
- The preference for GeoTIFF, Shapefiles, and NetCDF are primarily useful for information providers (eg. in Earth Observation) and can be government and logistics and planning. These sectors can be end-users and intermediate users, and they are often stationary and located with unlimited internet access at all times. For this reason, it makes it easier to work with additional data formats and they are adept at working with other electronic data

formats containing sea ice information that may be too large to access from ships or platforms in remote areas or not easy to understand for practical users (Appendix C).

The AECO survey for polar tourism included additional questions related to NIS ice information provision products and how user-friendly they found the accessibility and data formats to be compared to one another. The following outcomes from the surveys suggest:

- Ice charts are considered to be more user-friendly for accessibility and with the data format, with PolarView being secondary, compared to EU Copernicus services. From this suggests there may be a large gap between the expectations and in communications from the end-users and information providers from downstream services, such as the Copernicus Services, on how the sea ice information should be delivered.

Feedback from the NIS survey assessed how sea ice forecasts were useful, the level of user-friendly data formats. The results were based on a scale from 1-5, where 1= very easy and 5 = very difficult. The cumulative average for each data format is summarized in Figures 11 & 12 (Appendix C - *Internal Survey Results*). Sea ice forecasts for passenger vessels there's an overall need from the operational marine community to have reliable, understandable and easily accessible sea ice forecasts available at multiple time-scales. They assist with strategic and route planning (short-term and sub-seasonal), as well as being valuable for long-term planning or logistics (seasonal).

Sea ice forecasts typically assimilate passive microwave derived sea ice concentration and, if more advanced, sea ice thickness estimates, both at low resolutions of 5 or more kilometers. While this is felt to be inadequate by some developers, there are few attempts to push for datasets that are more complicated to derive due to the time and resources used in setting up and running these models. Drifting sea ice poses a challenge for sea ice forecasts to accurately assimilate certain parameters such as sea ice type, thickness, and concentration, particularly during the late spring and summer seasons due to snowmelt. It is especially difficult to convey sea ice in forecasts at the MIZ (Marginal Ice Zone) and along with the coastal areas where due to the merging of satellite products from multiple time points and with varying sensor frequency footprints, there is often smearing of the ice edge and any features of potential interest [See Appendix C - *Internal Survey Results*].

Summary of Stakeholder and End-user Surveys

From the questionnaires, the users were asked what type of sources of sea ice information, parameters and data format they use on a daily basis. The overall feedback shows a majority of respondents use daily ice charts as a primary source for retrieving sea ice information for tactical and strategic route-planning in the Arctic Ocean. For users who are new to the Arctic area, daily ice charts provide a basic guide to understand and help to find the best routes through the sea ice. Personal experience is most used together with the ice charts, but these are often users working in industries such as shipping, icebreakers and few operators in polar tourism. The use of raw satellite data in conjunction with ice charts is mostly used by intermediate users or by more experienced data users, such as in the research community, in order to provide value-added products to the end-users. This user sector tends to be more stationary, with unlimited internet access at all times.

The participants were asked about the level of detail they required in ice information products (eg. update frequency) for tactical and operational settings. Most of the respondents answered daily or as often as possible (NRT). However, the definition of NRT sea ice data among the user sectors is vague. For example, in an operational setting the understanding of NRT can vary from 30 minutes to a few hours, whereas for those who work with forecasting can range from one to a couple of days to a week, depending on the use of the product, particularly for those that are designed for long-term planning and a climatological perspective over time. From an operational perspective, end-users can work on various spatial and temporal resolutions at one time or whether or not they are in the early planning phase (40). It is critical to understand the spatial and temporal scales that need to be considered when developing products useful for end-users because many users have often needed that overlap at any given time or it could be one user that works on multiple scales at one time.

Discussion of End-user needs for the Maritime Sector

Sections in this Part (2) were separated by the relevant EC/ESA reports, workshops, outcomes and surveys conducted by national ice services (Appendix C) in order to provide a comprehensive review of schemes that have been funded to better understand user-needs for the operational marine community. In this section, most end-users worked in tactical marine activities and a smaller percentage with short and long-term planning and logistics. Another smaller sector was represented by research working with sea ice provision for operations. This sector can be simultaneously end-users, stakeholders and intermediate users and will be more focused on the KEPLER work package 1, subtask, 1.3. As stated in the summaries, operational end-users consistently agreed on what was required regarding sea ice parameters, high spatial and temporal scales in which they operated, a preference for the use of more SAR data, the general need for data to be delivered in a standard and understandable format, and the desire for reliable sea ice forecasts at appropriate resolutions for tactical activities (between approximately 2-3 days).

Another component was identifying the types of sea ice information that could be beneficial for long-term planning and probability estimates (i.e. for Arctic logistics, resource extraction and regulatory information for ship-building requirements and the Polar Code). The mechanisms to obtain user-feedback varied which greatly impacted the results. This is due to differences in the project, workshop, or survey aim, how the questions/surveys were structured and the distribution and expertise of respondents. From results collated in this report, the EC and ESA reports were long-term projects (i.e. 2+ years) motivated to provide guidance on future activities, and product and development needs for the general public. Workshops were 1-3 day activities that were targeted to answer specific questions towards a distinct group, and surveys were set-up due to internal interests and needs from applied institutes in order to assess their operations. An underrated and expected challenge is that it is also difficult to get most-end users to provide feedback on surveys and participate in meetings or workshops if it takes them away from their normal activities, especially if there is no additional incentive, such as financial or a direct result in product improvements or data exchange. Therefore, the same end-users may be targeted to provide feedback over multiple projects and activities.

Another challenge is related to how information on user-needs is disseminated. Extensive survey and questionnaire results for user feedback are normally situated in national or internationally funded project reports that are not always easy to find or available after the life of the project. Though operational and applied research interact with end-users and conduct internal studies of user needs, it is not common practice to publish this information, especially in peer-reviewed articles. Additionally, the research community, understandably, does not include statistics on user-needs in their publications. With these distinctions in mind, it may be difficult to find commonalities between various activities. As a consequence, in recent years end-users have expressed a great deal of frustration that they've spent the time providing constructive feedback (i.e. through surveys, workshops, meetings, etc.) and they are not clear about how this information is being used to improve services for their activities. From the amount of time and effort that has been spent on understanding and identifying requirements for the operational marine community, it is clear that this sector is considered to be high-priority for the EC, ESA, operations, and research. It is also evident that user needs have not changed too much because the same requests are still being reiterated from current feedback in the last 15 years. However, we have more comprehensive feedback from the maritime users due to how the respondents were surveyed and that there is a long archive of user needs due to the importance of this community within Polar activities which can be found in Appendix B.

The first mandate for ice services is to constantly update their products with the latest satellite information available in order to provide the most accurate routine products. Operational services have the flexibility to modify their products while maintaining compliance with the WMO standards defined by a consensus of all the ice services in the world [21 & 22]. Since the launch of the ESA Sentinel's beginning in 2014, the information provided to the marine operational community has greatly improved due to the increase of higher spatial and temporal resolution from different sensors, as well as third-party services that develop value-added products for users. However, end-users continue to require essential sea ice information (i.e. sea ice type, deformation and ridging information, presence of ice at the edge and coastal zones and detection of leads) for operations in sea ice encumbered areas, as well as more accurate sea ice forecasts on shorter time scales. From an interest in the research and ice information provision community to resolve these issues, it is clearly not due to a lack of trying. Refer to WP4: Sea ice mapping and forecasting on how information providers can improve automation of operational routine information.

Part 3. Community-based Observing and Societal Needs

The Community-Based Observing and Societal Needs section focusing on the Indigenous and local community priorities assessed information from Northern Sweden, Norway, Finland, and Russia with main focus on Indigenous knowledge and livelihoods, search and rescue issues and Russian context. The assessment included regional interviews with knowledge holders, workshops and a concluding Conference report, literature, and media review and visits to remote Indigenous camps.

Areas of Interest for Community-based Observing and Societal Needs Sector

In order to review the stakeholder needs and community-based observations from the project, we have had to operate under very tight timeframes. This part attempts to capture the voices of winter 2019 on the intersecting topics of stakeholder needs and community-based observations. Our emphasis has been to highlight living voices and current information as opposed to a full academic study of the needs – indeed the time, space and resources available have only allowed reporting from the field, and not a full scientific study on the topic.

The following methods have been included in the work:

- The work began with literature analysis and archival work in all regions to establish the scope of the discussions and framework for the KEPLER project.
- Regional coordinators then proceeded to interview Indigenous stakeholders anonymously[1]. We used semi-structured interviews with key stakeholders from the Snowchange community network.
- Additional information was gathered from phone and field interviews, discussions with search and rescue operators, and recent media associated with the topic.
- Existing maps and satellite and other remote sensing data were reviewed and have been included as an example of the needs and extent of services, especially in NW Russia.
- One young professional fisherman worked as a co-author to test and put into practice satellite-based technologies for winter seining on a boreal test lake by keeping a research diary as a member of a fishing team.
- An online survey amongst Sámi coastal fishermen in Norway for scouting of needs, priorities, and wishes.
- Field visits to remote reindeer corralling areas and wilderness areas were undertaken to test the availability of remote sensing services and to meet Sámi practitioners in the field.
- A geographical analysis of the balance of available services, risks and needs from the viewpoint of the Indigenous communities and other stakeholders in the European peripheries.

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[1] interviewees had the choice to include their names if desired, consent forms were collected

- An Indigenous knowledge workshop was organized in Inari, Finland to review and discuss all findings.

As a method of satellite, remote sensing services using the Sentinel-satellites can become very useful for indigenous people in similar ways as satellite-based ice charting today is useful for fishing and navigation in Arctic environments. In this section, we give examples of a few services that can be implemented in regions where reindeer herding and other nature-based economy demands good knowledge on the extent and quality of snow and other key environmental variables such as ice on rivers and lakes and avalanche activity to name some examples.

Stakeholder and End-user Needs: Resources for Feedback

Snow Monitoring and Avalanche activity monitoring

The user needs for snow monitoring services were partly covered in the FP7 CRYOLAND project and published in a user requirement report (Malnes et al., 2016). This user report analyzed the need for satellite-derived snow products for hydrological and climatic studies. Since the CryoLand project (2013-2016), the CCI Snow project is currently developing snow monitoring services on a global scale, but with a minor focus on Arctic regions due to difficulties that arise with monitoring snow during the polar night period. CCI Snow furthermore provides products with typically 1km resolution, covering large areas. This coarse resolution is of less interest to community-based users that require higher resolution (the hillslope scale is about 100m).

Remote sensing of snow avalanches (also called avalanches) is a young and evolving scientific field where major development was made possible with the operational availability of Sentinel-1 radar satellite data from autumn 2014. Eckerstorfer et al., (2016) gave an overview over avalanche remote sensing using optical, lidar and radar sensors on terrestrial, airborne and spaceborne platforms. Depending on the desired spatio-temporal monitoring resolution different sensor-platform combinations make sense. For example, constant monitoring of avalanche activity on a single slope with very high spatial resolution requires the use of a terrestrial lidar (e.g. Deems, et al., 2015). For quantifying an extreme avalanche cycle over a small region, very high resolution optical satellite imagery (e.g. Spot 6) would be the sensor-platform combination of choice (e.g. Bühler et al., 2019). Finally, for continuous monitoring of avalanche activity over large areas, the Sentinel-1 constellation provides a steady dataflow over all snow-covered mountain areas worldwide (with the exception of the Transantarctic Mountains). The ESA AvaMap project (2018-2019) demonstrated the potential of using Sentinel-1 for monitoring avalanche activity during an entire winter in Europe (the Alps and Iceland), Afghanistan and North America. The key for consistent monitoring is the temporal resolution of Sentinel-1 data, which is highly satisfying in Europe, especially at high latitudes where daily coverage is achieved. North America, on the other hand, suffered from 12 days of repeat cycles, which introduced large uncertainty in avalanche monitoring. The daily coverage of Sentinel-1 data at European high latitudes led to an operational avalanche monitoring service using Sentinel-1 data for the Norwegian Avalanche Warning Service. In the Satskred project, a near-real-time automatic avalanche monitoring system for Norway was designed and tested. Equally, for all areas monitored by Sentinel-1 medium (can bury a car) to very large avalanches are detectable with a probability of detection close to 90 %.

The ESA feasibility study ‘Improved Alpine Avalanche Forecast Service’ analyzed the need for remote sensing of avalanche activity amongst local and regional avalanche forecasting services in Europe. The main requirements for operational use of remote sensing data for avalanche monitoring were an hourly temporal resolution, about 10 m spatial resolution, and highly reliable data flow. If these requirements were fulfilled, avalanche warning services would show a high willingness to pay for remote sensing products. The feasibility study concluded in 2014 that no available remote sensing product could fulfill these requirements. This is still true in 2019, however, as outlined further above, sensor-platform combinations can be tailored to fit the need for each user.

Wet snow monitoring using SAR is currently not being prioritized in Copernicus services or CCI Snow. Nagler et al. (2015) showed that wet snow maps can provide very high accuracy when compared with S2 or LS8 data.

Snow water equivalent and/or snow depth will always be a highly prioritized parameter for any user. Current monitoring services use (CCISnow/Copernicus Land Service) use passive microwave sensors with coarse resolution sensors that in many ways are irrelevant for users in mountainous and coastal regions. In a brand new study by Lievens et al. (2019) there are some promising results on using Sentinel-1 cross- and co-pol ratio to retrieve snow depth at 1 km scale. These results need further studies. The general view is that there is a need for an appropriate new sensor to retrieve SWE at scales from 10m-1000m, and L-band SAR interferometry or multiple-frequency SAR backscatter seems to be the best options (Rott et al., 2010..)

Satellite Communications Services and GPS

Satellite services and user access have been partly connected with the proliferation of cellular services associated with GPS-enabled smartphones becoming available to “ordinary people” as well as authorities and specialists. Yet, maintaining traditional knowledge is essential on the local scales. This has included the “Russian GPS”, or GLONASS with services located in the Russian Federation, CIS countries and Brazil. Our research has completed several pilot scouting missions as a part of the project. First, the use of satellite service -based navigation tools as a part of an ice fishery on a boreal lake and its relationship with traditional knowledge was explored. GPS and associated sonar tools provided improvements in navigational safety and fish location information especially in rough conditions of blizzards, darkness, and mist.

Traditional harvest sites could be marked with ease on the devices. Challenges included customary ownership of these sites, data protection including the digital maps of the sites, and too much reliance on the technologies in below -30 degrees celsius contexts where batteries may have low capacity and satellite services are not available. Second, we spoke with the Sámi traditional

knowledge holders in NW Russia on the questions of traditional weather prediction and uses of cell and satellite services. Whilst the satellite services and forecasting are improving, the weather forecasting data comes in such large blocks that the Sámi felt the regional variation is not taken into account.
Therefore "reading nature" and her signs, especially in the tundra and high Arctic conditions, is required to maintain skills and ways of navigation using traditional knowledge. The Sámi felt that people should only partly trust the satellite and cell services and maintain a healthy scepticism. This includes, for example, the deep and historical connection to place names and seasonal life cycles the Sámi have across the region.

Third, the uses of RenGIS and other satellite-based tools have provided a more complete view of Swedish Sámi land use and needs, but this has been slow to translate into changes in practice and governance of multiple other competing land uses. Fourthly the use of satellite and radio services on the coastal Sámi fishery is daily. Traditional navigational knowledge of the coast is reflected for example in Sámi language maritime place names and landmark systems. According to a practitioner survey the use of satellite radio and improved emergency tools are needed in the coastal small-scale fisheries.

A preliminary view of the satellite receiving stations in Sodankylä, Finland and in Kiruna, Sweden shows they are providing services to global clients, but concerns have been raised regarding the geopolitical interests and intentions of some of the nations, especially China. Additionally, in recent months Russia has aggressively disrupted and jammed GPS services as a part of the global international tensions. China is constructing a "Polar Silk Road" initiative to explore the uses of the Northern Sea Route and investigating data services and other mechanisms to enter into the Arctic as a major player this century. Chinese delegations have visited satellite receiving stations and are already working with Sweden to secure said services. Some stakeholders in Sweden question the validity and aims of the Chinese data streams and services and whether they constitute threats or challenges to the hosting countries. Whilst the Arctic hosts these receiving stations the satellite services and remote sensing capabilities are not necessarily available or affordable to the communities next to these stations. International facilitation is needed to avoid dangers associated with the GPS jamming events, given the great reliance of, for example, aviation routes on these services in Kirkenes, Ivalo, and other close-by airports.

Satellite Monitoring of Land-based Features

Uses of remote sensing services such as satellite data analysis provide a more up to date situational view locally of natural resources used in the northern taiga or boreal. They have provided mechanisms to analyze the cumulative environmental impacts of forestry, mining, infrastructure and so on in new ways if the openness of the data is guaranteed. This is of high value to those communities who may have equity issues or even a land and water conflict with outside parties.

Equally so the uses of publicly available remote sensing services can provide important data on ice and snow cover to improve safety and trip planning, at least in Finland, Norway, and Sweden. The issue was also highlighted by the coastal Sámi fishermen in Norway. This highlights the potential usefulness of easy-to-use end products that synthesize Arctic research and data into user-friendly interfaces with open access. Also, the future application of drones could be one method used to increase the coverage, scale and ecosystem-based assessment of change (D3.2 in WP3).

There is no continuous permafrost in the European North, but the melt events of the *palsa* mires in the Sámi home area are in need of rigorous monitoring. Overall issues such as changes in avalanche frequency and numbers, heat spells of 30 C and more in the summertime, droughts and other major regional events were identified as worth monitoring.

Emergency Services

By listening to peripheral voices from the search and rescue services of Finland regarding emergencies in the national parks as well as the wilderness villages of Kola Peninsula communications access is not available or remains very low in these regions. Deaths have followed when the services have not delivered on location or temporal scales.

Cellular Technologies and Communication Infrastructure

The proliferation of cellular services, on par with the so-called snow machine revolution of the 1960s in the region, has improved and expanded the availability of personal access and communications possibilities in the European North. However, the mission has been only partly accomplished. The infrastructure to establish such services in the wilderness remains a challenge as these areas are the least populated in the region and the incentive to provide services remains low.

Summary

Following the recent OECD discoveries, the Sámi and other minorities in the European North and NW Russia should be positioned as special access stakeholders for remote sensing services. This may mean culturally appropriate interfaces in Sámi languages, tailored services for reindeer herding communities and subsidies, for example, to allow satellite phones to be purchased for those remote communities who are otherwise removed from the technological mainstream. Overall, there is a great need for affordable, higher bandwidth communications, which is a synergy with maritime user needs. The following remote sensing instruments that would enhance monitoring for safety and hazards

We recommend the following to be implemented in this context:

1. End-user services should be easily available, also in Indigenous languages, such as the Saami, on hand-held portals and devices.
2. The coverage and affordability of services should cover all areas of the Indigenous home areas, especially in the context of emergency services.
3. Portals that portray real-time scalable land use and ice changes should be easily available, also in Indigenous languages, such as the Saami, on hand-held portals and devices.
4. Advancement of technological solutions should be mindful of the "slow culture" of Indigenous communities and traditions. Data is not openly accessible always and intellectual property rights, Indigenous sacred engagement with their landscapes and places, harvest locations and other cultural aspects should be followed.
5. All stakeholders are to be made aware of the Ottawa Principles of Indigenous Knowledge, available at http://www.saamicouncil.net/fileadmin/user_upload/Documents/Eara_dokumeanttat/Ottawa_IK_Principles.pdf

We should recognize the global trend that favours the speedy development of and further reliance on technologies this century. Traditional knowledge, life skills, and wilderness economies lose out in this particular process if steps are not taken to provide feasible alternatives. These steps might include protected territories and contexts and mechanisms that foster the use and revitalization of traditional land uses, languages, place names, economies and ways of life as determined by the communities, families, and individuals themselves.

The European North still contains semi-nomadic and seasonal lifeways unique in the world as well as Indigenous societies which have maintained a very close relationship with nature. The dominant narrative of Arctic monitoring and research rests on remote sensing and its applicability. To a certain extent, we should perhaps resist this dominant narrative and challenge its implications for local cultures and other navigational, weather and subsistence systems that are more endemic and suitable in the local contexts. Technology is always and only a tool, not a substance. We should also be aware of the context of increased technological solutions that are embedded in geopolitical ambitions in the Arctic as a transport and natural resources periphery, as opposed to a thriving homeland and home of the Indigenous people.

Part 4. Intermediate User Needs for Climate and Weather Forecasting

To explore the polar observational needs of the weather, sea ice, and climate prediction communities, KEPLER Task 1.3 developed a survey composed of eight questions that were distributed to (i) a number of identified key experts and expert groups through personal request and (ii) the broader community through relevant email lists. Outcomes of the questionnaire, distributed in May 2019, are the main basis of Task 1.3. deliverable report and the related content of this WP1 (Task 1.4) synthesis report. The questionnaire includes first a section that provides background on KEPLER and the rationale of the questionnaire, in order to minimize the potential for misunderstandings and thus to maximize the relevance of the answers.

In the Task 1.3 delivery report we provide (0) a high-level summary of the results, (i) the background text introducing the questionnaire, (ii) the questions asked, (iii) the list of experts and expert groups we have asked to fill the questionnaire, including information on who responded, (iv) a summary of KEPLER-relevant aspects of the IICWG-DA Workshop in Bremen, (v) a synthesis of the outcomes of the questionnaire, and (vi) complementary information obtained from a collection of review papers published for the OceanObs'19 conference (see key statements). In this section of the present WP1 (Task 1.4) synthesis report we provide only the most important results; additional details can be found in the Task 1.3 report.

Survey results

In total, we have received 26 responses to our survey. 10 responses came from Ice/Marine Services (including private sector), 6 from Weather Services, 1 from a Forecast Research group, 7 from Satellite Production Research/Service groups, and 2 from groups associated with Copernicus Services. Given the qualitative design of our questionnaire, the following synthesis for each of these groups is likewise qualitative.

The responses from **Ice/Marine Services** (including the private sector) reflect a need for more frequent SAR imagery, in particular in the Southern Hemisphere, but also Sub-Arctic. They expect increasing downstream-user needs regarding latency and resolution and call for better technology to overcome high-latitude bandwidth limitations. Some ice services ask for better (single-point) access to in-situ observations (e.g. ice drifter data). They are moving towards a semi-automated analysis of SAR data and integration of short-term forecasts and are in need of better and more detailed ice type and thickness data, in particular in coastal areas.

Specific points raised by Ice/Marine Services:

1. There is a high demand in very accurate, highly frequent and spatially resolved information about sea ice and iceberg conditions given high resolution satellite Synthetic Aperture Radar (SAR) and optical imaging. *Please see #2 of this section.*
2. Main demands of users are for routine daily products to be available (including weekend ice charts), and for sea ice type information to support Polar Code requirements.
    a. Currently, ice services do not use derived data or automated products as part of their service due to the insufficient accuracy in the ice edge and coastal zones, critical for navigation, and lack validation for seasonal robustness.
    b. The types of satellite monitoring systems, namely a combination of full or compact polarimetric C-band and L-band SAR, are unavailable routinely but have shown this may support a semi-automation for routine products.
3. More information is requested from the Southern Hemisphere and Sub-Arctic and Canadian side (including iceberg detection). Detection of icebergs smaller than 100m would be also desired. There is a high demand for very detailed sea-ice thickness information (especially in coastal areas).
4. Development and exploitation of new technologies for data compression and communication would enable to optimize (decrease) the latency when working with highly resolved observational information (a call for better technology to overcome high-lat bandwidth limitations). There is an urgent need in advanced methods for (semi-)automatic product generation.
5. To provide accurate short-term forecasts of ice conditions suitable for navigation and iceberg drift (with little latency), exploiting high resolution ocean – sea-ice - wave models with data assimilation is (and will be) required. Satellite observations at matching spatial resolutions will be required.
    a. Forecast models are typically assimilated using PMW derived sea-ice products which are not of adequate quality for operational sea-ice monitoring for navigation purposes.
    b. The current state of forecasts have climatological value and can provide information on the probability to assist with long-term planning.
6. *In-situ* sea ice and atmospheric observations/observing system should necessarily complement satellite data. Analyses of already available observations (satellite and in situ) would enable observational uncertainties specification required to make the best use of observations in data assimilation systems.

Weather Services are in need of better observations (and forecasts) for wind and swell waves on coastal areas where global models do not behave well. They call for making more of the existing routine (research) observations available for NRT applications. They would like to obtain more lower-troposphere observations, especially over sea ice, a denser network of polar surface observations (e.g. from buoys), and better wind profile observations. Regarding the latter, there are high expectations toward the ESA Earth Explorer mission Aeolus and follow-ups. For NWP Centers, the CIMR Copernicus mission could prove very beneficial for the ocean and sea-ice information.

Specific points raised by Weather Services:

1. High-quality NRT operational satellite data (Copernicus-Sentinel-based wind retrieval, SIT and SIC, SID retrieval, snow data, SST) are needed. With respect to wind retrieval for operational use, there is a demand to reduce latency (below ~1h). These products (not all) are assimilated to provide optimal initial and boundary conditions for the numerical weather forecast or/and for sea ice short-term and seasonal prediction.
2. Data assimilation systems and methods should be further exploited and explored in order to use different satellite data products (including the option to use Level 1 or Level 2 products) and *in-situ* Polar information for optimizing the ocean – sea ice and atmospheric states, improving forecast, and for designing observational networks. (Example: Level 1 brightness temperature data assimilation). The polar lower troposphere is mentioned as an area needing improvement (of observation, of assimilation, etc).
3. There is a need to investigate the benefits of using a fully coupled atmosphere-ocean - sea ice - wave modeling systems (including data assimilation). For data assimilation, a proper specification of observational information uncertainties is crucial and would still allow using the information of relatively low quality (with lower weights, accordingly).
4. *In-situ* meteorological observations, as expected, are of very high demand, since the conventional polar observation network is still quite sparse (especially over the sea-ice and ocean). The observed information on the wind profile, swell waves, temperature, moisture, as well as surface fluxes, is vital for NWP model evaluation, uncertainties specification and for process understanding that would lead to improved (newly-introduced if necessarily) model parameterizations.

Satellite Production Research/Service groups require more accurate radar altimetry and more and better *In-Situ* observations for algorithm development and Calibration and Validation (CalVal). They stress the importance of the continuity of observations from certain sensor types, e.g. from the Copernicus candidate mission CRISTAL ("whole product lines can depend on one instrument”*) for continuous ice (and snow) thickness measurement, moreover, also covering latitudes beyond 81.5, even more, vital for mapping the shrinking sea ice. Similarly, they express a need for continuity and higher resolution of Passive Microwave data, stating that “services will be very much degraded if none of CIMR or AMSR3 fly”*. For both CRISTAL and CIMR, the launch should be expedited so that missions overlap with current satellites (SMOS, Cryosat-2 and AMSR-E) used operationally for SIT and SIC retrieval is obtained.

They call for open and timely access to reanalysis and Earth Observation data. Also trained algorithms would benefit from better technology to overcome bandwidth limitations. Additional needs related to the readiness of satellite observations for automatic product generation and to improve NWP forecasts with higher resolution in time and space (e.g., for the application of weather filters).

Specific points raised by Satellite Production Research/Service groups:

1. Satellite observations are needed with improved quality, resolution and cloud screening for polar regions (including optical, SAR and PMR): *"For global snow monitoring, we need similar instruments to SSM/I and SSMI/S, preferably with higher spatial resolution. Sentinel-3 data might take over for AVHRR, preferably with improved capability for cloud screening." "SLSTR/OLCI seem not to have been developed for polar applications as already provided cloud mask is unusable in this region and the spectral contents from the sensors are not including enough information to do appropriate cloud screening. MODIS is much better, but not perfect."* *
2. The need for mission continuity is stressed in numerous questionnaire responses; specific examples mention CRISTAL, CIMR, and AMSR3.
3. Getting observations fast and automatically is important. The development of new approaches in data compression, communication, and online processing is called for.
4. The complementary combination of data from different sensors is regarded as an opportunity, e.g., combining SAR and microwave radiometry information for snow cover monitoring (see #2 in this section).
5. A need to develop appropriate observation operators to assimilate directly level-2 (or even level-1) products, e.g. related to sea-ice parameters, is identified.
6. A virtuous loop is identified in which improved satellite products can lead to more accurate weather and marine forecasts, itself leading to better satellite products (when forecast data is used for weather filtering of satellite products).
7. An artificial barrier between NWP (EUMETSAT) satellites & Copernicus satellites is being criticized, noting that e.g. CIMR serves both.
8. A lack of in-situ observations is a challenge for CalVal.

Finally, the **Forecast Research** group points out that advances can be made on many fronts. Using satellite-based sea-ice concentration, thickness, drift, snow on the ice, as well as ocean temperature and salinity (including in-situ) observations for data assimilation, progress could arise from reduced latency and higher resolution of these observation types. In this context also the long-standing request for explicit uncertainty specification, ideally including cross-covariances, remains. It is stated that, ultimately, data assimilation could exploit level-2 (or even level-1) observations better than higher-level products. However, to that end, appropriate observation operators need to be developed first. Similarly, independent rather than merged products are preferred (although the latter might be easier to use, depending on the details of the data assimilation system).

Specific points raised by the Forecast Research group:

1. Detailed information on the observational data uncertainties (including error covariances) is identified as a remaining need.
2. *In-Situ* observations (e.g., river runoff) and a strategy for fully utilizing the existing Arctic Observing network (GCW, IASOA, IABP, CALM, IPA, INTERACT, DBO, PAG, The Arctic Rivers Observatory), which implies improved cooperation between institutes and programs, including communication and data sharing.
3. Generally, satellite-based high-resolution information on SIC, SIT, Drift, snow on the ice, ocean T&S obtained with reduced latency for data assimilation.
4. Fast access to level-2(1) products for assimilation (work is required to define consistent observation operators, but allows to utilize more accurate observational information).
    a. It is preferable to assimilate simultaneously independent observation/retrievals rather than using merged data products.

The respondents associated with **Copernicus Services** (C3S, CLMS) highlight needs specific to their respective domains. Services associated with NWP and (atmospheric) reanalyses call for better observations of the lower troposphere, especially over sea ice, better exploitation of existing observations (e.g., improved surface-emissivity modeling), wind-profile observations (Aeolus and follow-on missions), and denser surface observations (e.g., drifting buoys). The CIMR mission is highlighted once more like a promising future source of enhanced ocean/sea-ice observations. Note that ice-thickness satellite products related to C3S have been covered under *Satellite Production Research/Service* above and that the needs related to Copernicus Services, in general, will be addressed in more detail in WP2 of KEPLER.

Overall (across groups), more resources are requested for further developments (addressing the resolution and quality of the information) with respect to the following:

1. **Satellite observations (missions, sensors and products, quality of the retrievals)**. There is an urgent need for observations that allow estimating accurately sea-ice lead fractions, ice-flow-size distributions, snow depth, the surface energy budget, and other parameters ("Surface fluxes are important"). Continuity of the current satellite observing system (microwave instruments, SAR, optical) should be secured. Optimal utilization of existing and future data should be ensured.
2. **Synergistic use of information from different sensors (sources)**. All groups agree that a synergistic use of sensors, ranging from SAR to Passive Microwave, is a good way to improve the quality and availability of information. However, there is a disagreement between groups as to which sensors provide the optimal solution for accuracy and reliability, depending on the application area.
3. **Data compression and communication methods.** With the current speed of development and evolution within the technological sector, future improvements might not only be beneficial for sea ice purposes but also a major challenge. There will be more demands

placed on the technology in the form of requests for new data formats and platforms, including scalability, and distribution methods. The user base is expected to be larger and more diverse in terms of vessel ice class, vessel type, navigator experience, and geographical coverage. This is already observed in certain Arctic regions covered by the ice services. 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 new thinking, innovation and competition.

4. ***In-Situ* observations (more recent, and exploitation of historical) on the coupled sea-ice – ocean-atmosphere system's state.** The exploitation of existing historical observing systems and information should be ensured to enable process understanding and climate studies as well as for designing and evaluating numerical model configurations (also with data assimilation).
5. **Uncertainties specification.** To enable a precise evaluation of numerical models and the best use of data assimilation it is crucial to dedicate some additional funding to study observational error statistics. This should cover instrumental and algorithm uncertainties specification as well as representation error estimates.
6. **Modeling and data (also Level 2/1) assimilation.** For short-term forecasting applications, there is a very high demand in exploiting highly-resolved atmosphere and ocean-sea-ice models (2 km and less than 1 km, respectively). The Earth System Model approach based upon coupled sea-ice–ocean (including waves)–atmosphere–land model simulations, including data assimilation in most if not all components, is foreseen.
    a. Stated again (see #4 of the section above "Specific points raised by the Forecast Research group") Data assimilation systems should be further developed in a sense of using (a synergy of) multiple observational information and **consider the possibility to use Level 2/1 data as well as independent rather than merged data products.**

Finally, the survey responses reveal huge differences in what is regarded as "near-real-time" (1 hour up to 7 days) and what is regarded as "high resolution" (10m up to 10 km). Typically, ice services and their downstream users regard the lower end of these ranges as "high resolution and near-real-time", whereas the groups involved in automatic satellite products and model-based forecasting regard the medium-to-upper end as valid. This discrepancy is not a new discovery but highlights that this gap still exists.

During discussions at the IICWG-DA workshop, it was concluded that this gap between what model-based forecast systems can deliver and what end-users "want" will remain for the foreseeable future, but also that it can be closed gradually from both sides. This can be achieved by increasing resolution and reducing the latency of forecast products (and the underlying observational products) on the one hand, but also by optimizing input data and the way forecast products are used, such that they become useful also with resolutions previously considered too coarse.

**Taken from survey responses*

Complementary information from the OceanObs’19 review papers

Key messages related to polar observational needs have been expressed in a large number of review papers issued for the OceanObs’19 conference, 16-20 September 2019. This conference was “a community-driven conference that brings people from all over the planet together to communicate the decadal progress of ocean observing networks and to chart innovative solutions to society’s growing needs for ocean information in the coming decade.” The review papers, listed below under “References”, have been published within a dedicated Research Topic in *Frontiers in Marine Science* and are an excellent opportunity to complement the outcomes of our KEPLER 1.3 questionnaire. The collection of 130 articles can be found here:

https://www.frontiersin.org/research-topics/8224/oceanobs19-an-ocean-of-opportunity#articles

Appendix C3 provides a list of key statements with respect to polar observational needs from the OceanObs’19 review papers. Overall, the statements corroborate the outcomes of the KEPLER questionnaire by the meteorological services, research and development and data developers. For example, the urgent need to ensure the continuity of altimetry and high-resolution passive microwave data alike is pointed out, as is the development of new observation technologies. Strongly increased resolution is another need raised unanimously (in particular km-scale remotely sensed snow and ice property data), as is a need to reduce the data void in the pole-hole region(s). While there is agreement that ice (and snow) thickness observations are a critical area where advances are needed and in reach (e.g., with CRISTAL), some details, e.g., whether merged (and high-level) or separate (and lower-level, e.g., freeboard) products are the best way forward when it comes to data assimilation are open questions.

Summary

Task 1.3 of KEPLER aims to explore the polar observational needs of the weather, sea ice, and climate prediction communities. To this end, we have developed a questionnaire for which we have received 26 answers: 10 responses came from Ice/Marine Services (including private sector), 6 from Weather Services, 1 from a Forecast Research group, 7 from Satellite Production Research/Service groups, and 2 from groups associated with Copernicus Services (Table X). Intermediate results have been presented and discussed at the 9th IICWG-DA Workshop in June 2019 in Bremen, Germany. Moreover, we have compiled additional information on polar observational needs from a collection of review papers published for the OceanObs’19 conference.

Overall, key polar observational needs and issues raised include the following overarching points:

- The importance of the **continuity of satellite observations** from certain sensor types is stressed, particularly synthetic aperture radar, multi-frequency microwave radiometry, and radar altimetry in high-latitude orbits.
    - Continuous time-series of European satellite-based estimates of both sea ice concentration and sea ice thickness are of utmost importance for both operational users and climate research.
- In addition to continuity, there are high expectations toward **improved (and new) sensor technology, parameters and expected outcome** of sensors and products, regarding both well-established as well as more recent and experimental product types. For example:
    - The improved capabilities of CIMR and CRISTAL , compared to previous sensors will help to better address intermediate user needs w.r.t. resolution and accuracy of sea-ice concentration and thickness data.
    - The inclusion of L-band and hybrid/compact polarimetry SAR for operational sea ice mapping will allow for suitable automation for operational ice services over what is capable with the ESA Sentinel-1 SAR in C-band only.
    - Significant advances are also expected from the future availability of observations that provide information on, e.g., wind profiles, snow on sea ice, and surface energy fluxes, and observations with reduced “polar hole”.
- **Making more of the existing** routine (research) **observations** available for NRT applications should have high priority. Aspects include more research on observational impacts, development of appropriate observation operators, and intensification of calibration/validation with appropriate in-situ data.
- There is still a clear **gap between what model-based forecast systems can deliver and what polar (marine) end-users need**, in particular in terms of resolution. Continuous investments into the development of high-resolution forecast systems, observations, and appropriate data assimilation techniques are required to generate more user-relevant services.
- **The use of the terms “near-real-time” and “high-resolution” continues to be inconsistent between end-users/service providers and some product developers.** This highlights that this gap still exists between how products and services are being disseminated to provide support for all users.

Note that the questionnaire responses and hence this report do not cover the requirements of ECV users to the extent originally planned, and were addressed separately in WP4 (D4.2). Similarly, the requirements of CMEMS are treated separately in WP2. The knowledge gaps and future capabilities of EO missions, including the six HPCMs, are reviewed in WP3 (D3.3).

Part 5. Determining Scales and Resolution for Different Users

General recommendations from end-users were focused on requests for technological developments within the scope of satellite capabilities to provide improved products such as those with "higher spatial and temporal resolution", products suitable for NRT data assimilation, inclusion of more SAR information in routine products to present a better representation of features for improved monitoring, tactical guidance and requests for the provision of better accessibility and understanding of products. However, the terms NRT and resolution for spatial and temporal vary according to the user. For example, a 5 km spatial resolution for synoptic weather or climate forecasting is considered to be high (Part 4), whereas end-user activities that are more precise and based on specific locations, will require information according to the scale of the area, normally at the multiple meter scale (subtask 1.1 and 1.2). This section tries to define the commonalities between the different user sectors.

Low resolution, i.e. spatial resolutions coarser than 1 kilometer, are deemed too coarse for many active operations (e.g. Search and rescue, maritime operations, etc.) but can support activities related to planning and providing a good overview of sea ice information. An example based on navigation and tactical use shows that a resolution lower than 1km spatial resolution cannot detect features important for maritime operations such as ice concentration at the edge, marginal ice zone and coastal zones, pressure ridges, ice concentration, leads, ice drift, and polynyas. Therefore, it is a challenge for product developers to translate the results of the current focus of low-resolution sensors into sustainable, marketable products and services for end-users while they are actively carrying out an operation. However, they will require information to understand how the environment is changing on a synoptic scale. This information can also be helpful for users to calculate probability analysis for ships or infrastructure to plan activities in a given area, if the end-user has an understanding of how to work with the data and format.

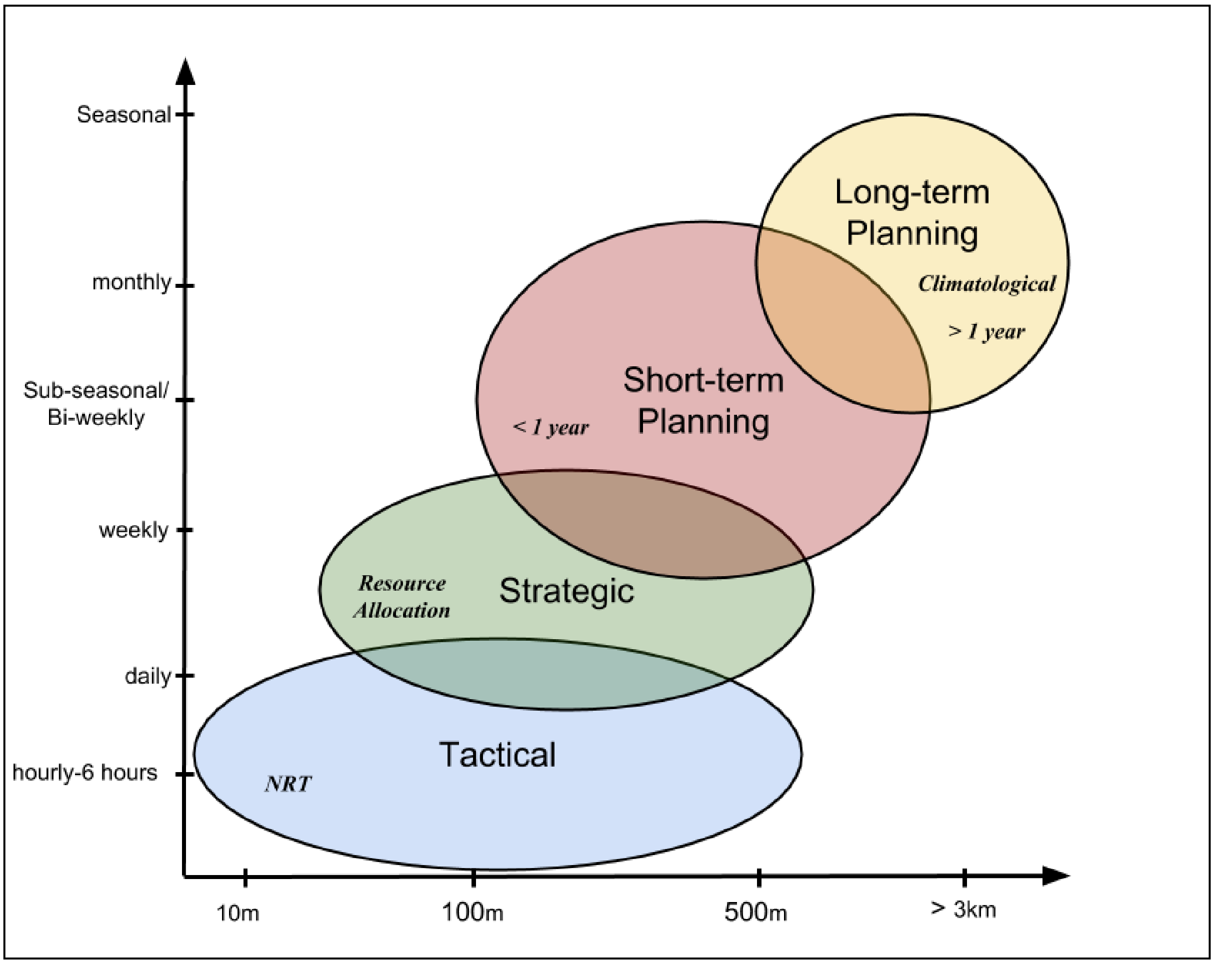


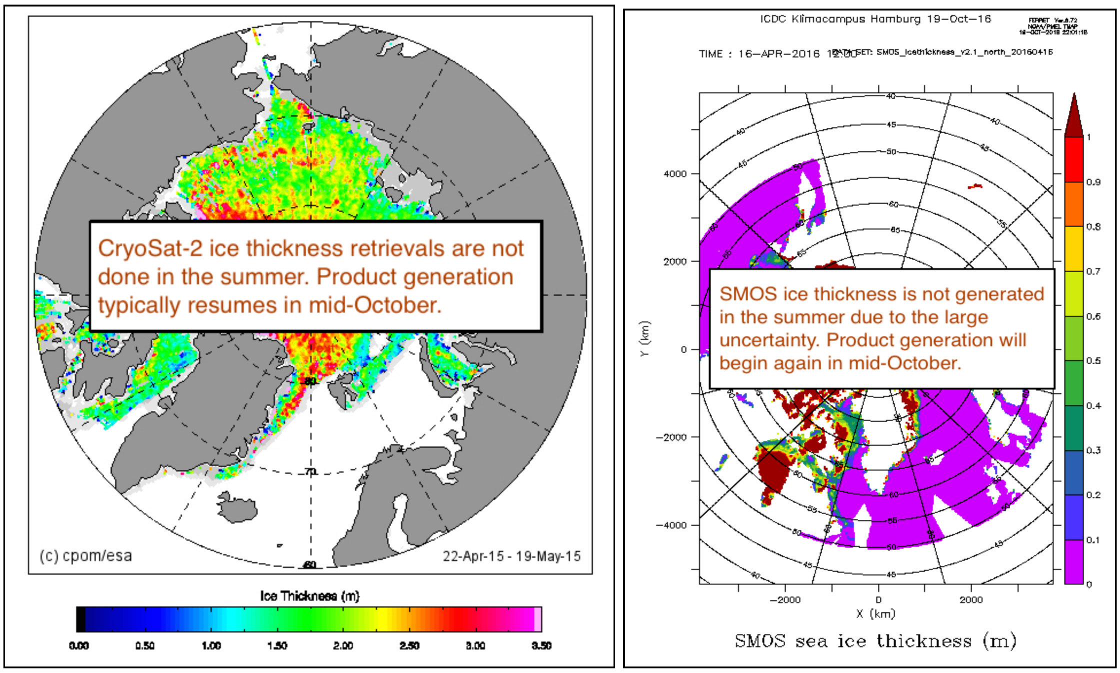
Figure 2: Scale diagram showing the different situations and spatial resolution from the maritime and land user sector. The users can require different sets of data based on their activity.

For geophysical models, the acceptance of high- or low- resolution is generally relative to available computing resources. Sea ice models can however be classified between "continuum" models (for example CICE (Hunke et al 2002), LIM (Vancoppenolle et al. 2009), neXtSIM (Rampal et al. 2016) that consider the statistics of ice: the probability of finding ice, the frequency distribution of ice thickness present in a grid cell/mesh) and "discrete element" models that resolve the interactions between individual floes (Rabatel et al. 2015, Herman et al. 2019). Continuum models can be used at resolutions up to the size of individual floes (tens to hundreds of meters) but discrete element models should rather be used to simulate a theater of operations in ice.

When preparing satellite products for use in models (like in data assimilations or a validation), the researchers do not have a strict definition of scales when referring to satellite products or sensors. It is very often meant as a relative measure (e.g. a high-resolution sensor qualifies as "high" with a coarser similar - often older sensor). It is clear that the Japanese Advance Microwave Scanning Radiometer (AMSR2)'s resolution is coarse compared to OLCI (Sentinel-3), MSI (Sentinel-2), or the SAR on board Sentinel-1, but it is nevertheless much higher resolution than the capabilities offered by the heritage Special Sensor Microwave Imager/Sounder (SSMIS). By the same token, a product derived from the candidate CIMR will be high-resolution (with respect to those derived from SSMIS). Similarly, the Advanced Very High Resolution Radiometer (AVHRR) was “very high resolution” at that time although only 1 km at best. CIMR will also be “high-resolution” because it will be approaching the limits of what is feasible for this particular type of instrument (microwave radiometers) with today's technology. When discussing "needs" with modelling users, the researchers either refer to specific scales (e.g. the grid spacing of the model) or use "high"/"low" resolution when there is a common understanding of what it means for the user and the data provider. Often, the concept of high spatial resolution is linked to what the application/usage is: a 5 km observation is high-resolution when the target model has a 5 km resolution.

Concerning the temporal scales, the same inconsistency is observed. Depending on the communities, the concept of “near-real-time” covers all from a few tens of minutes (e.g. < 15 min) to a couple of days. In the forecast community, the concept of a “cut-off time” is important as it defines how fast an observation must be made available to the forecast system in order to be used in the forecast cycle (observations that do not meet this cut-off are not used to initialize the forecast). We also noted that the concept of “latency” (delay between acquisition and availability) is not necessarily well understood by all communities. There can for example be a long delay between the availability at the end of a ground segment, and the availability at the user’s location (especially if in remote areas or on a ship).

The implications of these gaps in terminology are that they introduce ambiguity for end-users if the intended purpose of value-added products is not clearly stated or disseminated. As previously stated in the summary from feedback 1.3, this gap can be closed gradually from both sides. Until this is resolved, descriptions for products developed for Copernicus are recommended to be explicit about their intended use, and transparent about their limitations. This is to clarify what is for intermediate users, i.e. operational use, and in order to avoid any disreputable circumstances. An example can be found at the WMO Global Cryosphere Watch (GCW) where the product outlooks include disclaimers that clarify when the nominal production is interrupted, e.g. during the summer melt season (Figure 3).



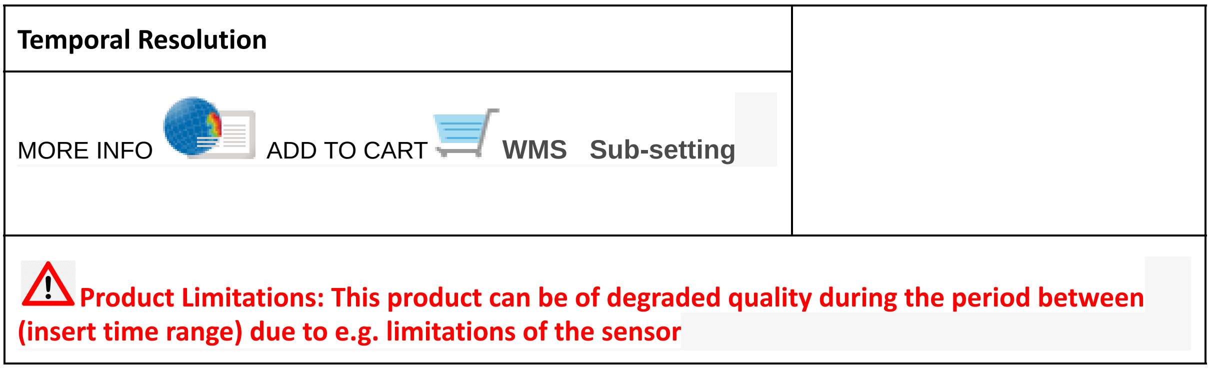
CryoSat-2 ice thickness retrievals are not done in the summer. Product generation typically resumes in mid-October.

SMOS ice thickness is not generated in the summer due to the large uncertainty. Product generation will begin again in mid-October.

Figure 3. WMO Global Cryosphere Watch Outlook. Retrieved August 18, 2020 (*https://globalcryospherewatch.org/state_of_cryo/seaice/*).

It is absolutely crucial to understand the production line of operational services and products developed for Copernicus services should reflect that in order to increase user uptake. If there are fundamental limitations, especially during a period of the year, that could prevent the product to be incorporated into a daily production pipeline or to be used on a routine basis by end-users, this should be clearly indicated for each product, e.g. on the front page of Copernicus services (Figure 4). This follows a similar example found at the EUMETSAT OSI SAF page (http://osisaf.met.no/p/ice/index.html#lrdrift), hosted by MET, though this information is not linked to the front main EUMETSAT OSI SAF product page (http://www.osi-saf.org/).

Product Identifier		
Product identifier		
Observation/Model	**Assimilation**	**Coverage**
Variables		**Product Outlook**
Horizontal Resolution (number of vertical levels)		
Temporal Coverage		



Temporal Resolution

MORE INFO ADD TO CART **WMS Sub-setting**

⚠ Product Limitations: This product can be of degraded quality during the period between (insert time range) due to e.g. limitations of the sensor

Figure 4. Example of Copernicus service product information layout to include additional information on product limitation

Limitations for products should be well described to ensure the product can be relevant for users for certain parts of the year. **A recommendation to include some or the following criteria in products that will potentially be used for operational purposes:**

1) Overall product limitation
2) Intended use
3) Potential risks, if intended use is misunderstood
4) Related products
5) Planned improvements

From an intermediate user perspective (e.g. information provider for navigational support), it is difficult to build a stable production pipeline due to these limitations. Users will need to know when they should supplement a particular product and require an alternative pipeline, during this time to maintain the quality of production.

Part 6. Discussion and Recommendations for KEPLER Work Packages

Feedback from stakeholders and end-users will be grouped in subsections summarizing in part 2) EC and ESA reports from 2004 - 2019, 3) workshops focusing on user needs for community-based and indigenous people and 4) Intermediate user and climate forecasting needs. The recommendations from these three subtasks from KEPLER work package 1 will be provided to subsequent KEPLER work packages 2-5 which will evaluate these needs regarding the current state of Copernicus services, research and satellite capabilities and develop an end-to-end roadmap based on this feedback. The following work packages will also present the possibilities with addressing some of the user needs through Copernicus and provide additional recommendations if necessary.

Information from the stakeholders will flow into the intermediate orbit, consisting of a layer of three scientific analysis activities (WP2-WP4) that synthesizes the results and recommendations from this report into a roadmap towards an end-to-end operational system (WP5) for monitoring and forecasting of the state of the Polar Regions.

Recommendations for WP2 - Polar Regions provision in Copernicus Services

Concerning maritime users: our work in KEPLER confirms that the requirements from this community are very stable in time. Throughout the last 10-15 years, they were polled, mariners operating in polar regions have indeed consistently asked for frequent (several times a day), and sub-km (even meter scale) information about the marine environment they are operating in. This information is not available to them at present.

Regarding projects and workshops that continue to request information user-needs, this begs the question as to why there is so much overlap and repetition; and why a single user feedback survey has not been considered sufficient. The lack of evolution in these requirements poses several questions that data producers and -in our case- particularly KEPLER, the European Commission, and Copernicus Program should reflect upon.

Why, despite the ramp-up of the satellite space component relevant for sea-ice monitoring (incl. Sentinel-1), are the maritime users not faced with automated products and services they will rely upon in their operations?

Does it stem from a difficulty to relay the requirements and transform them into new elements of the space components and / or services? Is it due to data producers not paying enough attention or not having the knowledge needed to prepare their products for maritime users? Are communication technologies the bottleneck between the processing centers and the maritime users? Where is the gap between research results and viable operational solutions?

The routine ice service operations are currently funded by the national government, and not Copernicus. There are no ice products at CMEMS which are relevant for the ice service and the maritime community due to scale, parameter and format issues which are addressed earlier (see Appendix B - *User stories*). Recognizing that maritime users are one of the key downstream users of the Copernicus services, the points above should be interesting to discuss in all WPs, in preparation of the road-map for a future end-to-end operational service in the polar regions.

Recommendations for WP3 - Identification of research and capacity gaps

- Making more of the existing routine (research) observations available for NRT applications should have high priority. Aspects include more research on observational impacts, development of appropriate observation operators, and intensification of calibration/validation with appropriate *in-situ* data.
- When working with environmental conditions there will always be outliers that general automatisation has not demonstrated the ability to always detect. If a full automatisation is

considered in the future, one of the main challenges will be maintaining expert and local knowledge in ice mapping services along with gradual implementation of an automated methodology.

- This work package should also assess whether or not the current state of satellite provision is adequate for data developers to provide products that could be useful for end-users. If so, it is recommended to provide validation reports or examples that support this evidence. If not, what future missions could provide sensors that would support product development to be used by end-users.
- To identify if the gap can be reduced between what model-based forecast systems can deliver and what polar (marine) end-users need, in particular in terms of resolution, continuous investments into the development of high-resolution forecast systems, observations, and appropriate data assimilation techniques are required.
- The uses of publicly available remote sensing services can provide important data on ice and snow cover to improve safety and trip planning, at least in Finland, Norway, and Sweden. The issue was also highlighted by the coastal Sámi fishermen in Norway. This highlights the potential usefulness of easy-to-use end products that synthesize Arctic research and data into user-friendly interfaces with open access.
- The future application of drones could be one method used to increase the coverage, scale and ecosystem-based assessment of change.

Recommendations for WP4 - Improved sea-ice mapping and forecasting

Geographical gap analysis of the CMEMS and it's producers capabilities are included in the D4.1 KEPLER. Gaps should be reported in order to improve CMEMS in future (See Appendix B - *User Stories*).

Regarding sea ice forecasts, both ASIPSW and SALIENSEAS workshops concurred that short-term forecast products had been influential in all sectors and were most valuable in the early planning phase. Sub-seasonal products are currently useful to provide a broad overview of knowing when to discontinue services for marine operators. However, sea ice forecasts are not necessarily relied upon for operations. They could be more valuable with strategic planning if they included less ambiguity regarding uncertainty estimates, particularly for trajectory forecasts that can provide useful information to plan alternative courses of action, similar to the weather forecasts.

However, end-users continue to require essential improvements for sea ice information (i.e. sea ice features, type, deformation and information on ridging, presence of ice at the edge and coastal zones and detection of leads) for safe navigation and operations in sea ice encumbered areas, as well as more accurate sea ice forecasts on shorter time scales. From an interest in the research and ice information provision community to resolve these issues, it is clearly not due to a lack of trying. More details will be included in the gap analysis in D4.1 KEPLER.

Recommendations for WP5 - End-to-end roadmap

Size and bandwidth of EO products should be considered in order to enable delivery in remote locations (Polar Regions) for those users who would like to access the full product; more developed reports (i.e. EMSA provides for oil spills, could be considered for other products if there were sufficient demand).

The reliability of services (i.e. availability and priority) was stated as particularly important. This included the need for assurance that planned image acquisitions will have the highest priority (from national and commercial agencies), and that improved routine monitoring and increase of images over specific areas could assist to prioritize surveillance areas and increase updates on feature detection and positions of objects in the water.

Typically commercial operators such as Polarview and KSAT fill the gap between information (free and commercial) and the user needs. This means customized service and products, such as a local site ice chart. They are often limited in staff but are capable of fast and flexible service. That is something many ice services lack based on feedback from the European Ice Services (EIS). But EIS can also be commercial service providers, producing and offering commercial products. Usually, they produce routine free of charge services and can include more information for customized commercial services. In this role, the commercial operators are the last user in the production chain before the customer.

CMEMS contracts are based on open competition but have requirements for guaranteed delivery and consistency that require all providers and product developers to be in agreement on understanding the data quality.

Overall (non-WP specific recommendation for Copernicus in the Polar Regions

- High latitude communications do exist in remote polar regions, but continues to be extremely limited. Users required to have a stable internet connection to access data for operating in remote land or sea areas may find it difficult to acquire critical information of situational awareness.

- Continuity and improved capabilities of satellite observations from certain sensor types are crucial. Continuous time-series of European satellite-based estimates of both sea ice concentration and sea ice thickness are of utmost importance for both operational users and climate research.

- A recurring recommendation from users is the need for the development of data that is easily understood and available in familiar and standard data formats. This includes being able to easily access the information from multiple sources without having to encounter bandwidth intensive formats and issues.

- Standard format usually includes ENC's, ice charts in various standard graphics formats, GIF, PDF and JPEG2000 for raw satellite data when used.

- Additionally, the increase of sea ice information provision should also include better dissemination, tools and training of different data products for non-specialists. Issues with end-users understanding of multiple products have been a critical challenge of user uptake with new products. For most marine users it can also be difficult to access large data files due to communication limitations in Polar Regions.

- Clearly, the use of definitions to describe sea ice information products by providers and developers are not necessarily consistent with what end-users recognize (Appendix C - *Internal survey results*). As shown in Figure 9 and 10, intended use (i.e. "operational"), spatial and temporal terms are also used differently across the satellite providers, information providers and data developers. From end-user feedback, this poses a fundamental challenge in disseminating the benefits of currently available products if providers and users are not communicating using the same language.

- SAR and optical, and in combination with other sources of information (i.e. intelligence, transponder data, AIS).
    - Rapid tasking time and quasi near real-time delivery time and wide area coverage
    - Video-streaming could potentially add value, whether from satellite or RPAS

- Data integration:
    - Link with onboard AIS receiving capabilities and access to vessel positioning information (i.e. Satellite AIS) in combination with EO data was deemed crucial
    - EO data shall also be used as complementary to existing data sources (e.g. AIS or LRIT) and integrated into Automatic Behaviour Monitoring algorithms.
    - Image data for strategic intelligence: There may also be a benefit in analyzing cumulative historical satellite data for pattern analysis, with a view to developing better strategic intelligence.

Part 7. Appendix

A - Acronyms

ACCESS: Arctic Climate Change, Economy and Society

AECO: Association of Expedition Cruise Operators

AF: Arctic Frontiers

AIS: Automatic Identification System

ALOS: Advanced Land Observing Satellite

AMSR-2: Advanced Microwave Scanning Radiometer 2

ARCUS: Arctic Research Consortium of the U.S.

ARTES: ESA Advanced Research in Telecommunications

ASF: Arctic Shipping Forum

ASIPSW: Arctic Sea Ice Prediction Stakeholders Workshop

AVHRR: Advanced Very High Resolution Radiometer

BAS: British Antarctic Survey

BCCR: Bjerknes Centre for Climate Research

BSH: German Federal Maritime and Hydrographic Agency

CEOS: Committee on Earth Observation Satellites

CIMR: Copernicus Imaging Microwave Radiometer

CliC: Climate and Cryosphere Project

CMEMS: Copernicus Marine Environmental Monitoring Service

CMS: Copernicus Maritime Surveillance Service

COMNAP : Council of Managers of National Antarctic Program

CPEG: JRC Technical Report for User Requirements for a Copernicus Polar Mission

CRISTAL: Copernicus Polar Ice and Snow Topography Altimeter

C3S: Copernicus Climate Change Service

D: Deliverable

EC: European Commission

ECV: Essential Climate Variable

EIS: European Ice Services

EMSA: European Maritime Safety Agency

ENC: Electronic Navigational chart

EO: Earth Observation

ERA – NET: European Research Area Network

ESA: European Space Agency

ETSI: Expert Team on Sea Ice

FMI: Finnish Meteorological Institute

FYI: First year ice

GEOSS: Group on Earth Observations and its Global Earth Observation System of Systems

GIS: Greenland Ice Services

GMES: Global Monitoring for Environment and Security

HPCM: High-Priority Copernicus Mission

ICEMAR: Copernicus pilot program ice service for maritime operations

ICEMON: Sea ice monitoring for marine operation safety, climate research, environmental management and resource exploitation in Polar Regions

IICWG: International Ice Charting Working Group

IGOS: The Integrated Global Observing Strategy

IHO: International Hydrographic Organization

IMO: International Maritime Organization

INTAROS: Integrated Arctic observation system

INTERACT: International Network for Terrestrial Research and Monitoring in the Arctic

ISABELIA: Improvement of Maritime Safety in the Baltic Sea through Enhanced Situational Awareness

JRC: Joint Research Commission

JCOMM: Joint Commission on Marine Meteorology

KEPLER: Key Environmental Monitoring for Polar Latitudes and European Readiness

KSAT: Kongsberg Satellite Service

MET: Norwegian Meteorological Institute

Metarea: Meteorological area

MIZ: Marginal Ice Zone

MYI: Multi-year ice

Navarea: Navigational area

Navtex: Navigational telex

NIS: Norwegian Ice Service

NORCE: Norway Research Centre

NRT: Near real-time

PEG: Polar Expert Group

PC: Polar Class

PMW: Passive Microwave

PSTG: Polar Space Task Group

ROSE-L: L-band Synthetic Aperture Radar

SALIENSEAS: Saliency of climate services for marine mobility Sectors in European Arctic Seas

SaR: Search and Rescue

SAR: Synthetic Aperture Radar

SCAR: Scientific Committee for Antarctic Research

SIDARUS: Sea ice downstream services for Arctic and Antarctic Users and Stakeholders

SIPN: Sea Ice Prediction Network

SMHI: Swedish Meteorological and Hydrological Institute

SMOS: Soil Moisture and Ocean Salinity, ESA Earth Explorer mission

SPICES: Space-borne observations for detecting and forecasting sea ice cover extremes

SWARP: Ships and Waves Reaching Polar regions

TPM: Third-Party Mission

UCL: University College London

VNIR: Visible Near Infrared

WMO: World Meteorological Organization

WP: Work Package

WRCP: World Research Climate Project

B - User stories (from the maritime community)

Concerning the maritime users, the KEPLER work (see Part 2, and Survey highlights) confirms the requirements from this community have been the same throughout the last 15 years. Mariners operating in polar regions have indeed consistently asked for frequent (several times a day), and sub-km (even meter scale) information about the marine environment they are operating in. This information is not available to them at present.

Ice services and products to ships navigating ice-covered waters must be simple, accurate, timely, reliable and relevant for journey planning and the captain's decision making at sea. The vast majority of ships have specific requirements and bandwidth limitations. This means that only ice products with known contents, confidence and update frequency will be used onboard. Consequently, any production line must address this aspect for services to ships. Typically it is a matter of providing the right focused information, directly or indirectly, rather than as much information as possible.

The ice products to ships are not intended to tell the captain what he sees out of the windows but intended to provide situational awareness and forecast changes below the vessels horizon along the route to the destination.

The actual requirements are typically regional or local and vary depending on the season, region, vessel ice capability and weather. It is not feasible to serve all ships individually so the ice service would be interested in accessing a well-defined standardized portfolio of satellite data, ice data, forecast products into standard ice products directly serving navigational requirements. It is here that current CMEMS products are of very limited use. A detailed gap analysis will be run and evaluated in work package 4 of KEPLER.

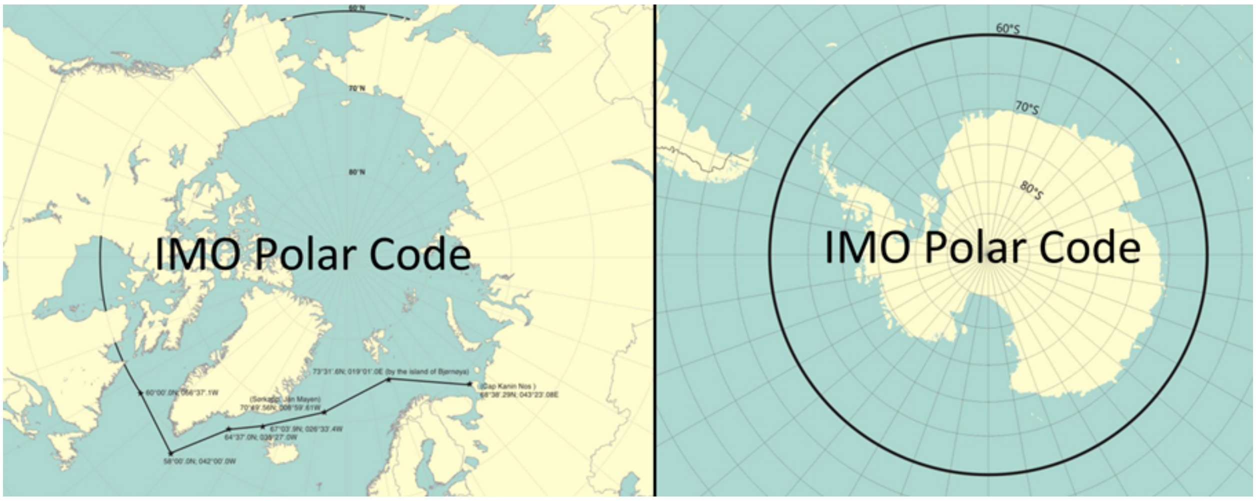
Below are a few examples addressing the gaps and actual needs.

The Polar Code, implemented by the International Maritime Organization in 2017, is a global regulation for ships navigating Polar Waters, for enhanced safety and environmental protection.

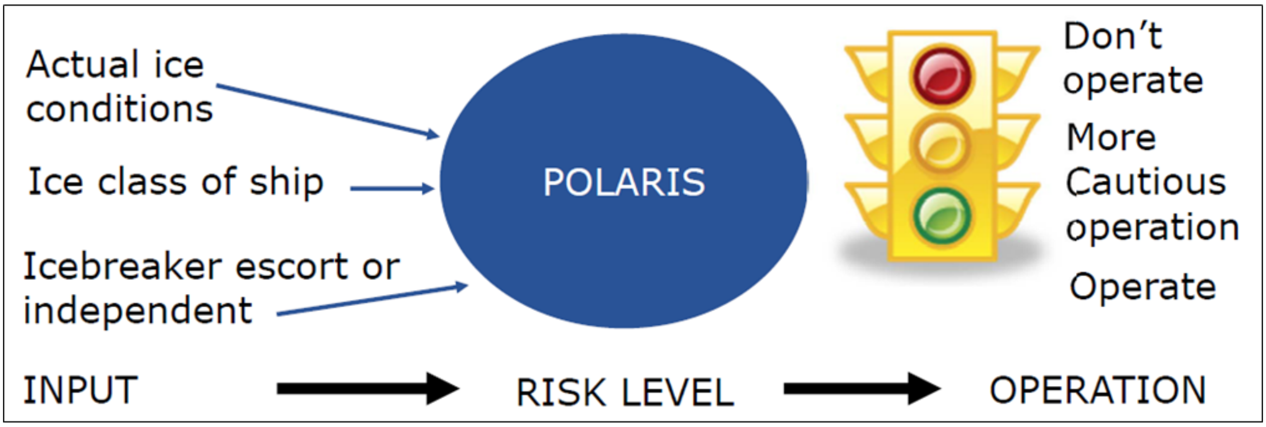
An example, extracted from IMO Polar Code, chapter 11:
11.2 … the voyage plan shall take into account the potential hazards of the intended voyage.
11.3 … the master shall consider a route through polar waters, taking into account the following:
    .3 current information on the extent and type of ice and icebergs in the vicinity of the intended route;
    .4 statistical information on ice and temperatures from former years;

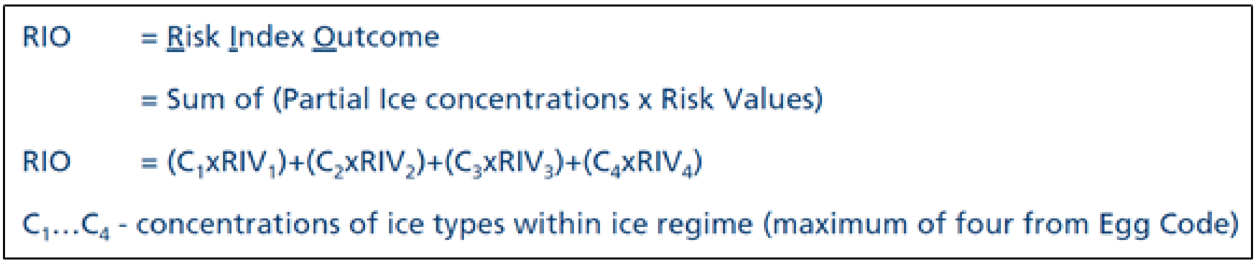
Polar Code does not state the quality, frequency and contents of relevant ice products, including how to find/receive them; only that the vessel should be capable of receiving ice information. But on the other side ice information to ships should be “fit for purpose”.

It should also be noted that the Polar Code does not cover all ice-covered waters, like the Baltic or the Labrador Sea where ice at sea is a significant hazard or obstacle



A risk assessment tool “POLARIS” for operations in/near ice was developed with the Polar Code, combining, sea ice concentration, stage of development and vessel ice class, illustrated below

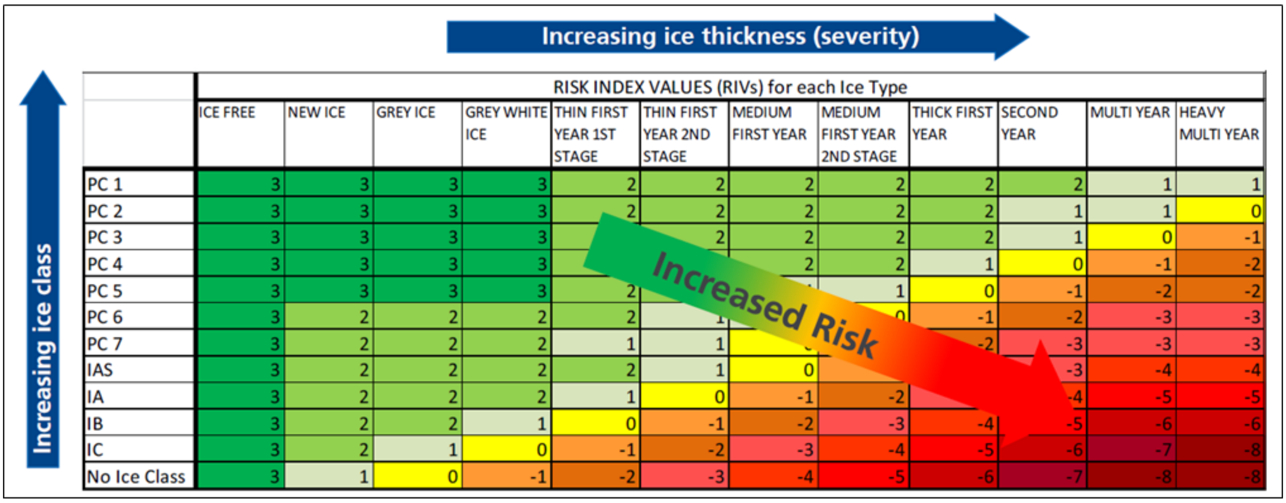



RIO = Risk Index Outcome

= Sum of (Partial Ice concentrations x Risk Values)

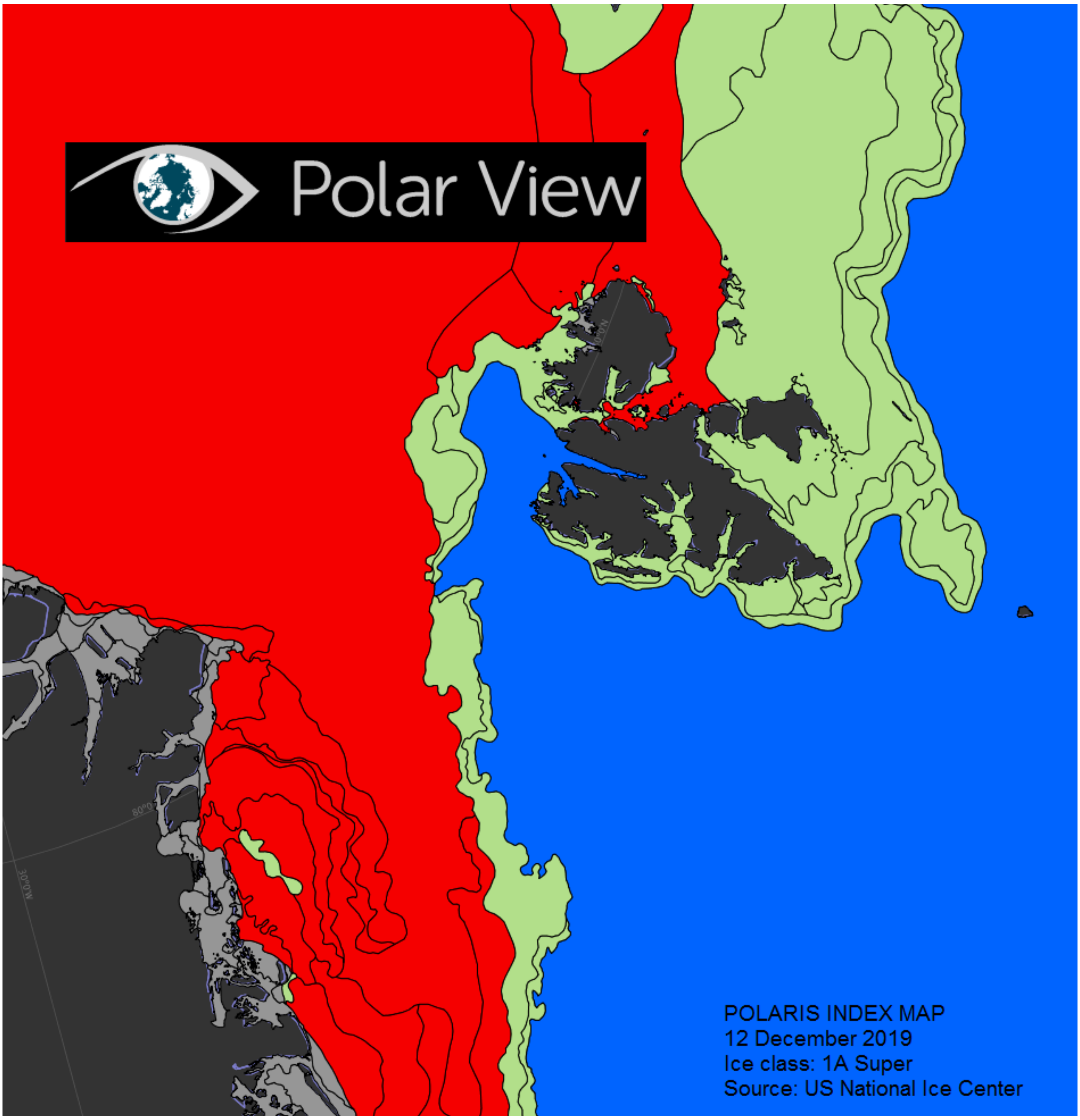
RIO = $(C_1xRIV_1)+(C_2xRIV_2)+(C_3xRIV_3)+(C_4xRIV_4)$

$C_1 \ldots C_4$ - concentrations of ice types within ice regime (maximum of four from Egg Code)



	RISK INDEX VALUES (RIVs) for each Ice Type											
	ICE FREE	NEW ICE	GREY ICE	GREY WHITE ICE	THIN FIRST YEAR 1ST STAGE	THIN FIRST YEAR 2ND STAGE	MEDIUM FIRST YEAR	MEDIUM FIRST YEAR 2ND STAGE	THICK FIRST YEAR	SECOND YEAR	MULTI YEAR	HEAVY MULTI YEAR
PC 1	3	3	3	3	2	2	2	2	2	2	1	1
PC 2	3	3	3	3	2	2	2	2	2	1	1	0
PC 3	3	3	3	3	[illegible]	2	2	2	2	1	0	-1
PC 4	3	3	3	3	[illegible]	[illegible]	2	2	1	0	-1	-2
PC 5	3	3	3	3	2	[illegible]	[illegible]	1	0	-1	-2	-2
PC 6	3	2	2	2	2	1	[illegible]	0	-1	-2	-3	-3
PC 7	3	2	2	2	1	1	[illegible]	[illegible]	-2	-3	-3	-3
IAS	3	2	2	2	2	1	0	[illegible]	[illegible]	-3	-4	-4
IA	3	2	2	2	1	0	-1	-2	[illegible]	-4	-5	-5
IB	3	2	2	1	0	-1	-2	-3	-4	-5	-6	-6
IC	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8
No Ice Class	3	1	0	-1	-2	-3	-4	-5	-6	-7	-8	-8

The ice information is based on standard output from the ice services using WMO Sea Ice Nomenclature, however resource intensive to generate with necessary accuracy, which is not available today from any automated source. Below is an example of POLARIS risk index map.

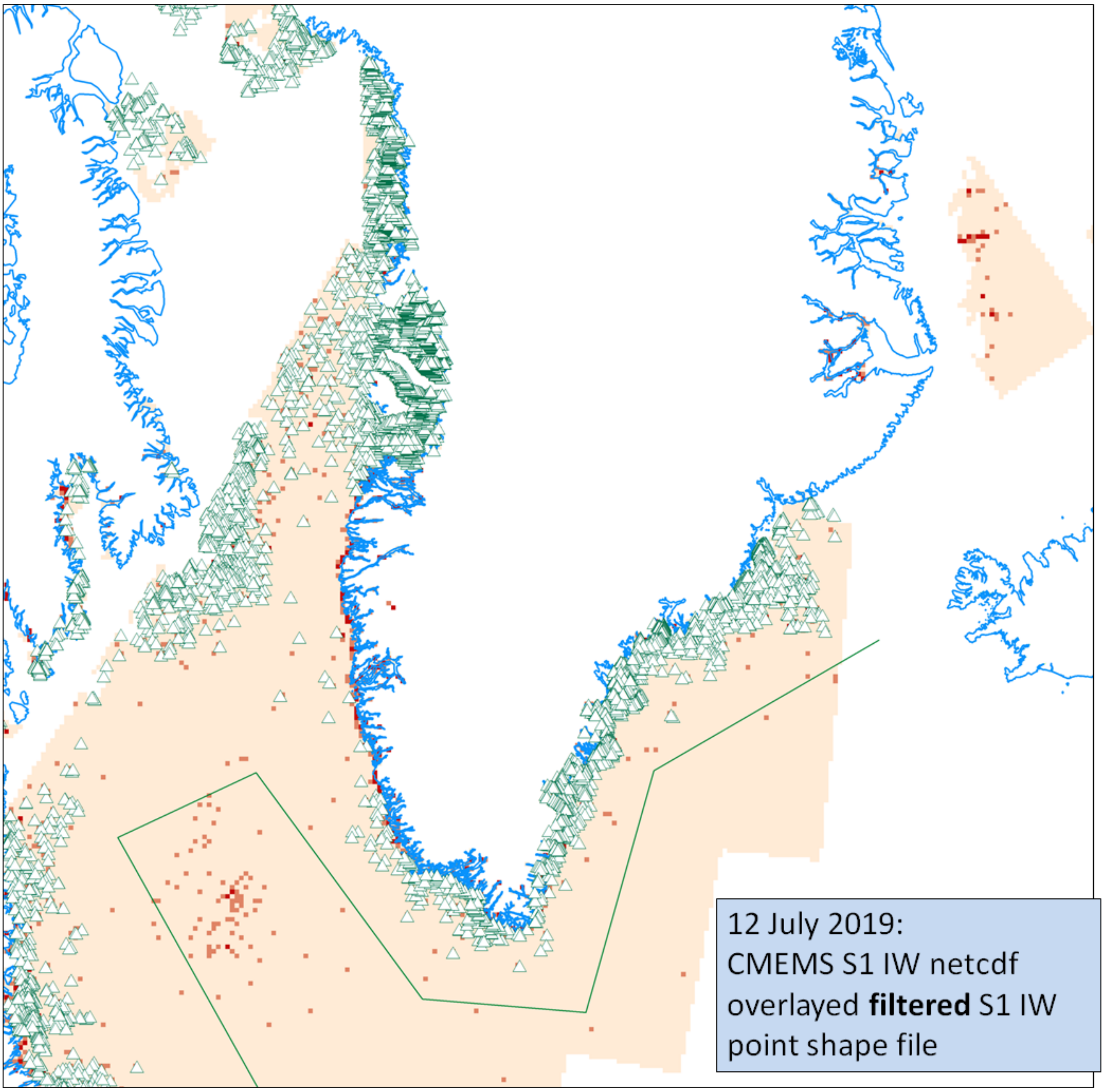


POLARIS INDEX MAP
12 December 2019
Ice class: 1A Super
Source: US National Ice Center

Also outside the sea ice edge major hazards for ships occur, like icebergs, bergy bits and growlers.

Small icebergs, bergy bits and growlers calved from a large iceberg in the open sea.

Accurate and focused iceberg products for the North Atlantic Ocean are not provided to/by CMEMS today. For intermediate use at the ice services, a format change is needed, implementation of editable scalable format, as well as filtering of ships. The current CMEMS setup for icebergs is focused modelling only and is based on Sentinel 1, which at subpolar latitudes or in areas with many ships not provide the necessary resolution and update frequency. Addition of Copernicus Contributing Mission satellites or Sentinel 1 Next Generation satellites addressing this need may be considered.



12 July 2019:
CMEMS S1 IW netcdf
overlayed **filtered** S1 IW
point shape file

Example on current CMEMS iceberg product overlayed a quality checked iceberg layer files, based on Sentinel 1, which provides input to the publication of an “iceberg limit” to shipping in North Atlantic.

Table 4: User stories and mariner needs that came out of IICWG survey 2019

Mariner task	**Mariner ice product needs - qualitative**	**Mariner ice product needs - quantitative**	**Background Satellite data available**	**Ice service situational awareness products available**	**CMEMS situational awareness products available**	**Ice service forecast products available**	**CMEMS forecast products available**
Route planning, risk assessment	regional ice information	Regional or large scale maps, statistics	YES	YES	PARTLY	NOT RELEVANT	NOT RELEVANT
Navigation in ice-covered waters	regional/local ice information	Acceptable minimum resolution of parameter = 50 m or better	YES	YES	NO	NO	NO
Decisions based on updated ice product	Timeliness	6 hours or better	OK	PARTLY	NO	NO	NO
Navigating dynamic ice areas requires frequent timely updates	Update frequency	Daily, certain regions twice daily	SAR COVERAGE MARGINALLY AVAILABLE IN SUB-POLAR AREAS	PARTLY	PARTLY	NO	NO
Decision making, navigation in ice	regional/local ice information	Bergy water, sea ice edge, ice thickness, floe size	YES	PARTLY	NO	NO	NO
Navigation in ice	regional/local ice information	Icebergs in sea ice, melting stage, pressure ridges, snow, compression	NOT AVAILABLE	NOT AVAILABLE	NOT AVAILABLE	NOT AVAILABLE	NOT AVAILABLE
Route planning, navigation in ice	Ice forecast serving operations in near shore or in sea ice	Icebergs, sea ice fields, Most important time scale 0-24 hours	---	PARTLY	NOT AVAILABLE	NOT AVAILABLE	NOT AVAILABLE
Route planning to stay clear of any ice	Ice forecast serving operations outside sea ice	Icebergs, sea ice edge, most important time	---	PARTLY	PARTLY	NOT AVAILABLE	NOT AVAILABLE

		scale 0-48 hours, ice drift					
Ice products available on the bridge of ship	Channels for accessing ice products	Internet, email, bulletins, telephone	---	YES	NO	NO	NO
Addressing limited bandwidth (south of 75°-78°N)	Ice products formats handled	Graphical, scalable, max 2-4 Mbytes	---	YES	NO	NO	NO

C - Supplements

Other deliverables in Stakeholder Needs WP1:

D1.1 Maritime sector needs (KEPLER)

D1.2 Community-based observing and societal needs (KEPLER)

D1.3 Report on weather and forecasting needs (KEPLER)

Internal survey results:

Internal surveys are often conducted when working with end-users in order for services to update and improve their products for evolving user needs. The range of sea ice information users covering the European Arctic, from Greenland to Russia, interact with all the national ice services for the Arctic and the Baltic (NIS, GIS, FMI, SMHI, and the German Federal Maritime and Hydrographic Agency [BHS]). The following sections in part 2 summarize surveys that were administered by national ice services over the last three years, as well as during the EC projects, SPICES [36] and KEPLER. There were many different organisations represented, covering a range of different user types which will be described in each section.

List of internal surveys:

- Norwegian Ice Service Survey for Arctic Shipping Forum (2018) / AECO - Polar Tourism (2017)
- FMI Ice Map as a Product, Observation and the Concept Survey (2017)
- FMI Survey on Services and Products (2018)
- SMHI Survey (2019)
- IICWG Survey (2019)

NIS survey for Arctic Shipping Forum (2018) /AECO - Polar Tourism

The user organisations that responded from the Arctic Shipping Forum (ASF) 2018 and AECO multiple choice survey were combined and categorised by their primary interest in the Arctic Sea, into different user sectors. The main user sectors were those involved in the following:

- Polar tourism with (18)
- Logistics (6)
- Shipping (5)
- Information providers (Intermediate users - EO)
- Military, and governmental regulations were under-represented with just one respondent in each of these categories(%)

Sectors such as logistics (air) and polar tourism are known to use ice charts but tend to be smaller scale operations where they utilise publicly available data and do not necessarily have the resources or time to interact with the data or information provider.

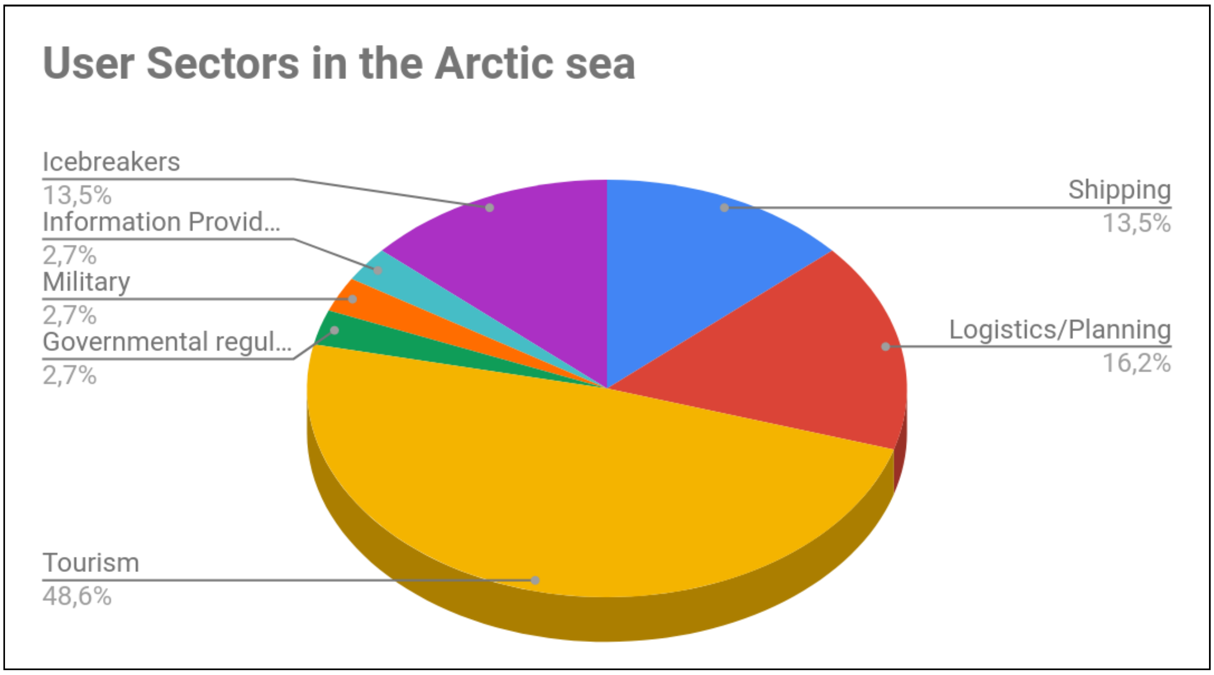


Figure 5: Pie chart showing the maritime user sectors in the Arctic Sea. In total 37 participants from Arctic Shipping Forum 2018 and AECO - Polar tourism who answered with free text and comments.

Respondents were asked about the types of general information users prefer on a daily basis (Figure 6). Daily ice charts were the primary source of information followed by personal experience by the user. This is expected because most operators who frequently travel through ice-encumbered areas, such as those working in polar tourism or shipping industries, require certifications and competencies that qualify them to operate in these environments. This does not necessarily apply to all those operating in the Arctic. The Polar Code [21 & 22] requires all navigators operating through sea-ice to have key competencies of understanding sea ice properties and how to access standard information, but the proficiency in operators who have intrinsic knowledge of understanding ice behavior in specific regions, varies depending on the industry.

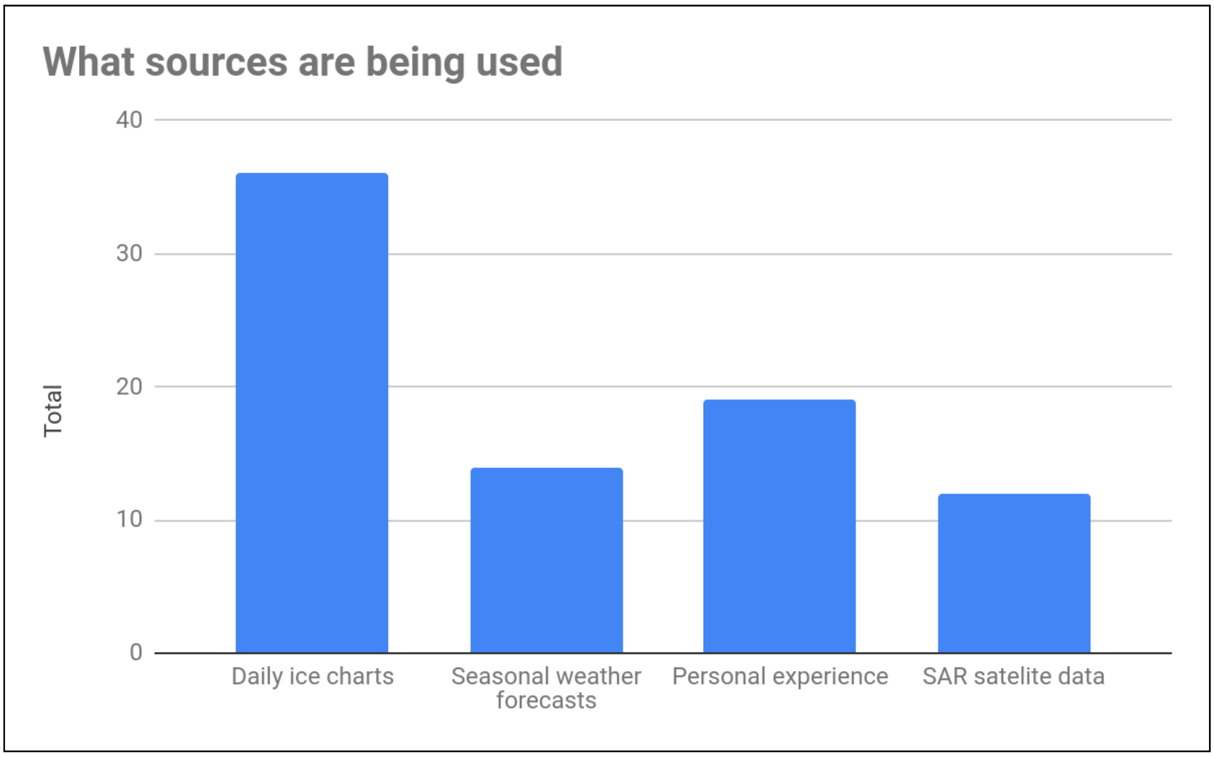


Figure 6: Diagram showing what sea ice information sources are being used on a daily basis, many of the respondents tend to use combinations of these sources.

As the Arctic region is characterized by a year-round ice cover in some areas and partly very rough ice conditions including ice pressures and heavy multi-year floes, particularly around the Northern and Eastern part of Greenland and within the pack ice above Svalbard and the Barents Sea. Due to an environment that can impose safety and environmental risks, ice mapping of the Arctic Sea is highly dependent on remote sensing on the meter scale, for operations as the primary source of information. Regarding user needs for ice information, in the Arctic it can be more limited compared to the Baltic Sea due to lack of frequent in situ observation sites and stations, and additional high resolution satellite coverage considered to be “operational” (i.e. commercial satellites are normally used to augment areas of missing high resolution satellite coverage from the ESA Sentinel 1 mission). However, figure 7 and figure 8 reflect the collective need for spatial and temporal resolutions for the Arctic and Baltic operators and show that they coincide with requirements to have more frequent coverage (i.e. As often as possible and daily) with the minimum spatial resolution at <1km, depending on the phase in the activity. Overall, new and improved products for the maritime sector were consistently requested in order to provide high resolution ice products based on SAR as well as information on ice thickness and ice type.

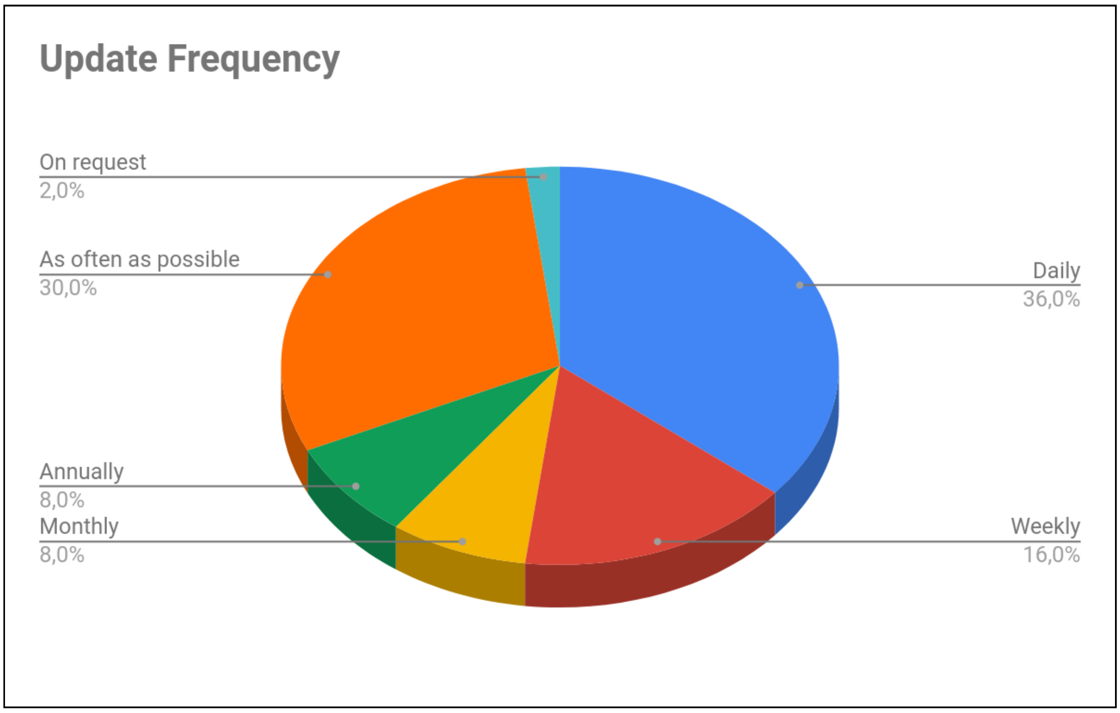


Figure 7: Pie chart showing the update frequency for tactical and operational ice forecasts

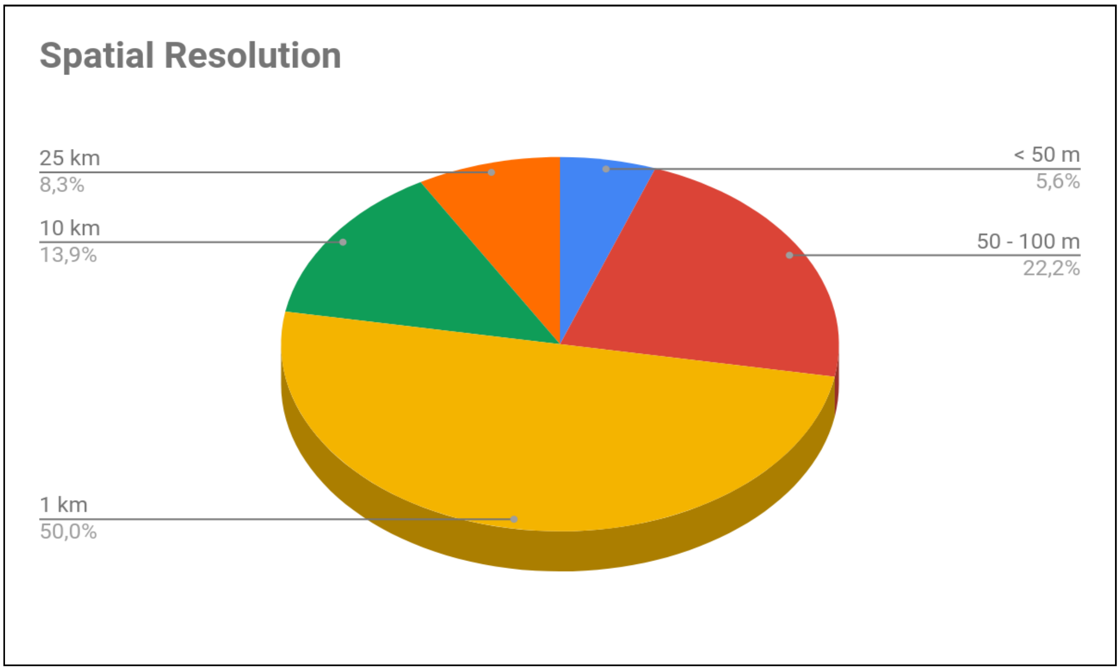


Figure 8: Pie chart showing the demand of minimum spatial resolution

NIS Results for Data format and Product Delivery

For ships operating in the Arctic Sea, the communication bandwidth can be limited at high latitudes (over 80N) or when ships are travelling in the interior of fjords or mountainous regions. The NIS survey feedback from ASF 2018 and AECO presents the data format and delivery preferences from users and provides information on how sea ice products to be more user-friendly in the future. The internal feedback clearly shows the difference on how the user sector uses the data in terms of their operations.

Survey results suggest users depend on receiving easily accessible sea ice information as JPEG/PNG/PDF or a format that is clear and easy to understand for the operator (Figure 9), that is also consistent with preferred data formats desired (Figure 10). Due to potential poor satellite coverage and bandwidth challenges. It is crucial for the information provider to compress and limit the amount of data before transferring out to the ships. From NIS experience with users, preferably at an approximate file size between 1-1000 Kb, depending on the ships capability.

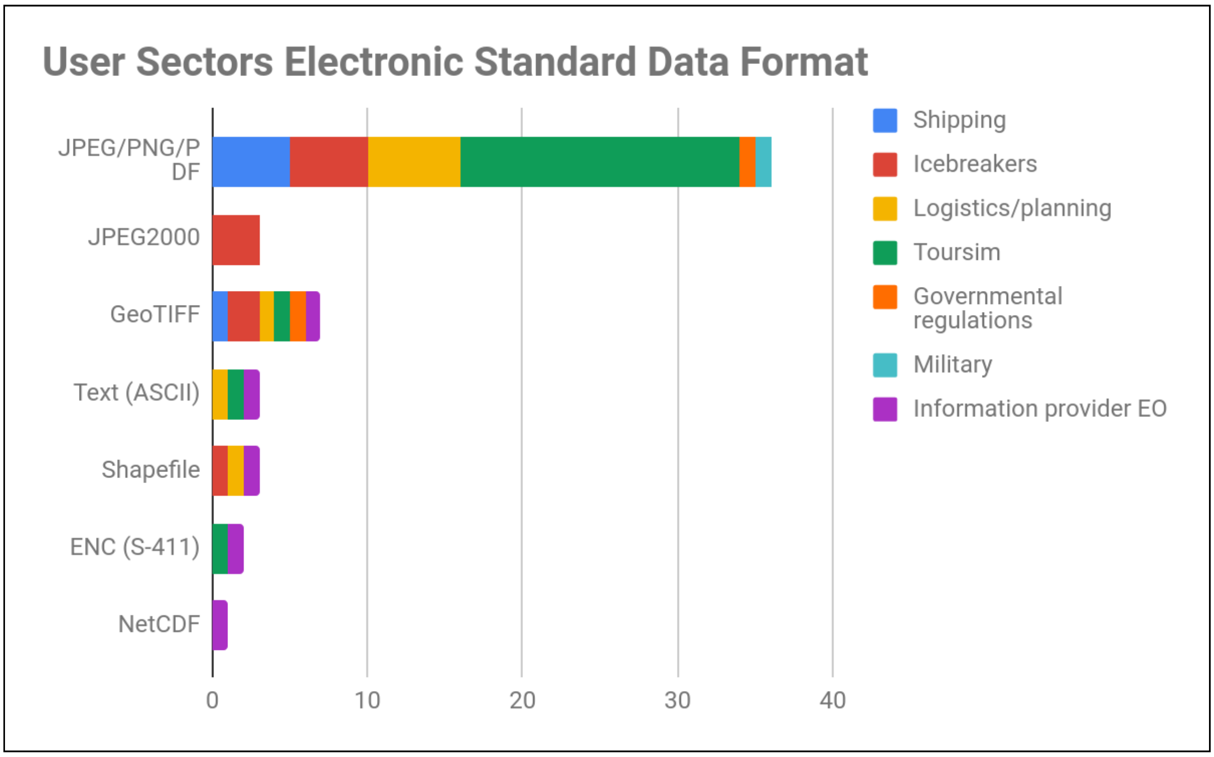


Figure 9: Diagram showing the electronic data the user sector use on a daily basis. Plotted from ASF 2018 and AECO surveys

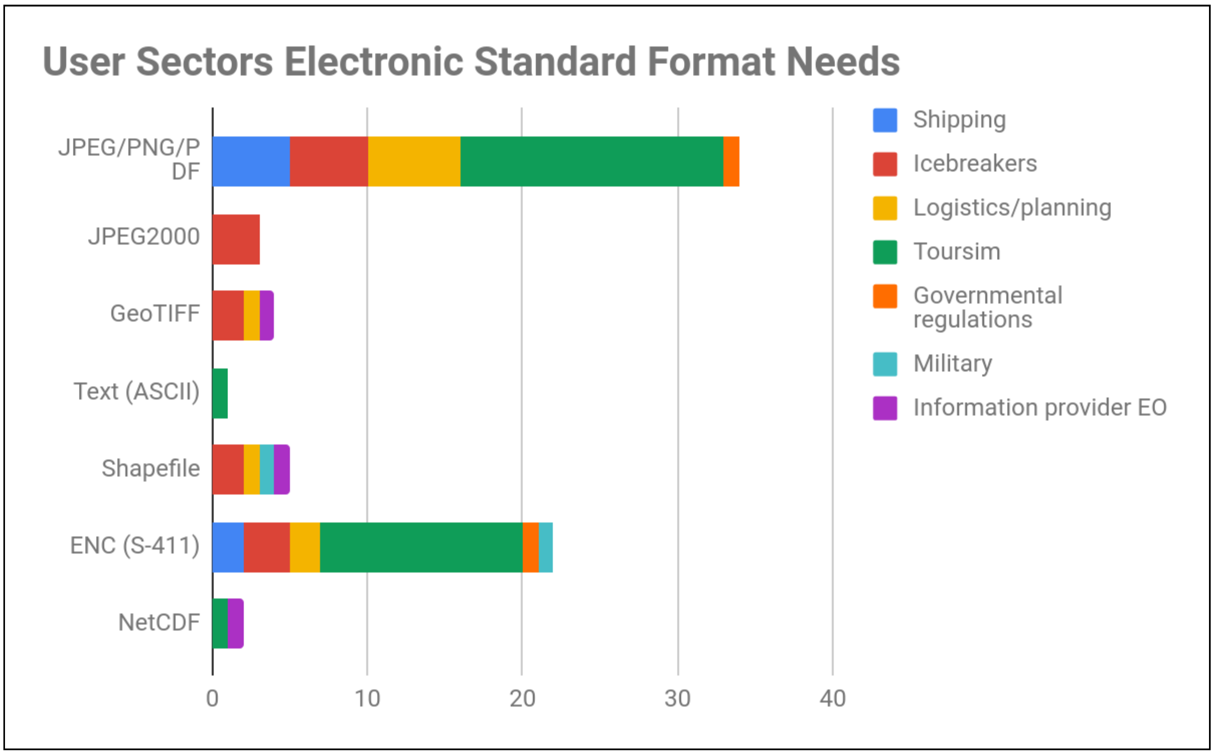


Figure 10: Diagram showing what electronic data format is preferred or what the user sector needs for their specific operations. Plotted from ASF 2018 and AECO surveys

The preference for GeoTIFF, Shapefiles, and NetCDF are primarily useful for information providers (eg. in Earth Observation) and can be government and logistics and planning. These sectors can be end-users and intermediate users, and they are often stationary and located with unlimited internet access at all times. For this reason it makes it easier to work with additional data formats and they are adept at working with other electronic data formats containing sea ice information that may be too large to access from ships or platforms in remote areas or not easy to understand for practical users (Figures 9 and 10).

The AECO survey for polar tourism included additional questions related to NIS ice information provision products and how user-friendly they found the accessibility and data formats to be compared to one another. Figures 11 and 12 show the MET Norway Ice charts are considered to be more user friendly for accessibility and with the data format, with Polarview being secondary, compared to EU Copernicus services. From this suggests there may be a large gap between the expectations and in communications from the end-users and information providers from downstream services, such as the Copernicus Services, on how the sea ice information should be delivered.

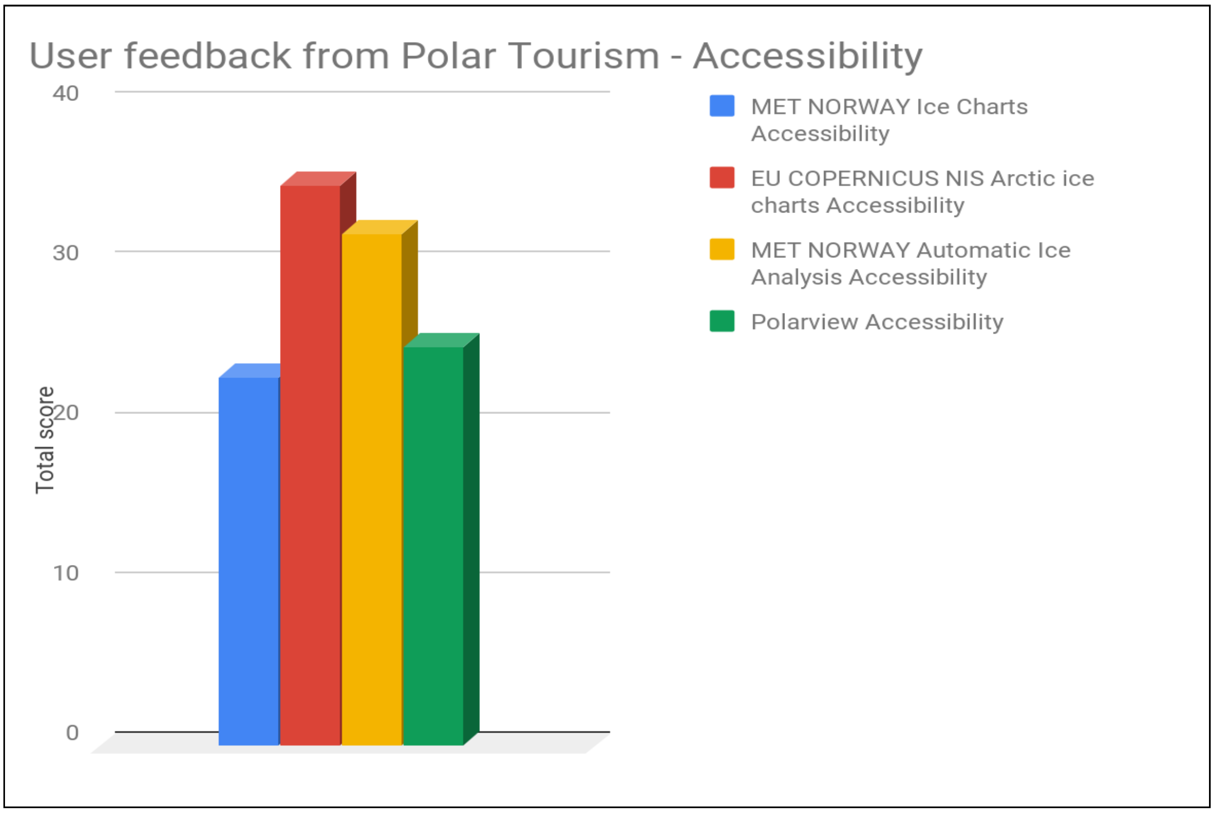


Figure 11: Diagram showing the cumulative feedback from polar tourism of the accessibility from The scale of the user-friendly the accessibility ranges were set from 1 to 5. Grade 1 - Very easy, Grade 5 Very difficult.

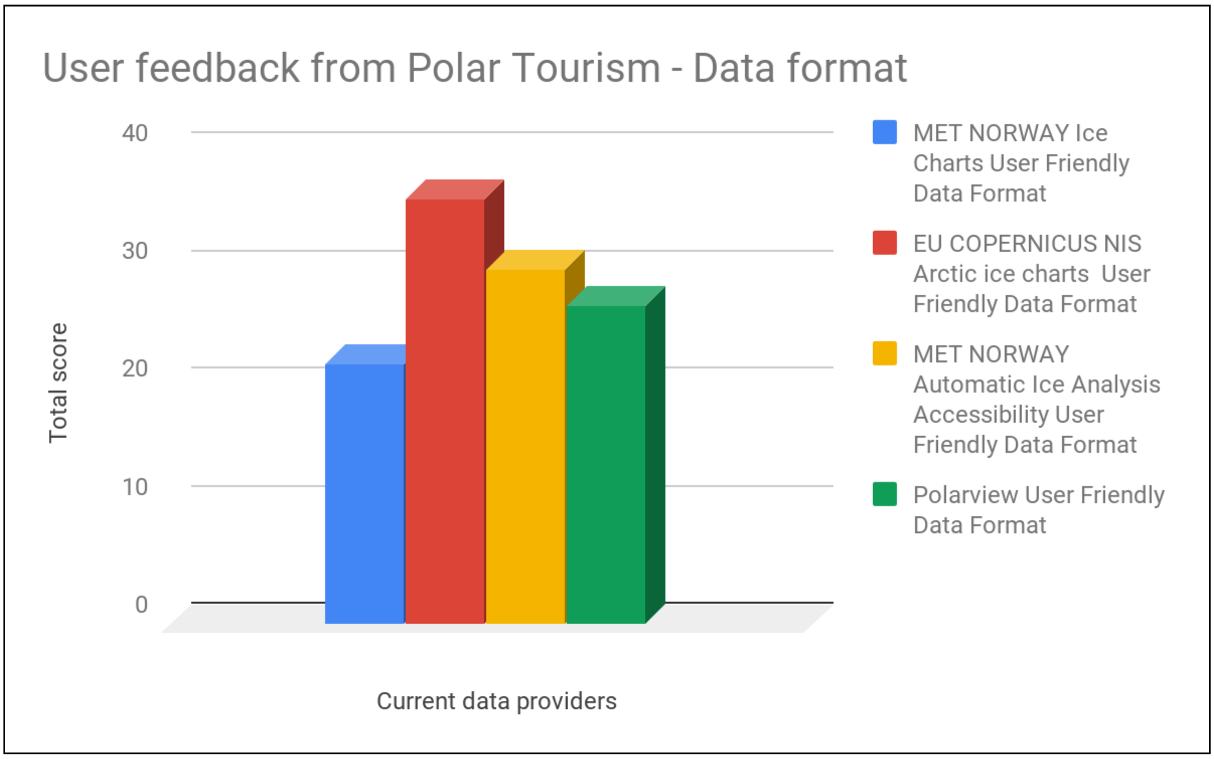


Figure 12: Diagram showing the feedback from polar tourism of the data format from the different data providers. The survey and graded the accessibility and user friendliness in grades from 1 to 5. Grade 1 - Very easy, Grade 5 Very difficult.

NIS Survey Results for Sea Ice Forecasts for Passenger Vessels

There's an overall need from the operational marine community to have reliable, understandable and easily accessible sea ice forecasts available at multiple time-scales. They assist with strategic and route planning (short-term and sub-seasonal), as well as being valuable for long-term planning or logistics (seasonal). Sea ice forecasts typically assimilate passive microwave derived sea ice concentration and, if more advanced, sea ice thickness estimates, both at low resolutions of 5 or more kilometers [27]. Whilst this is felt by some developers to be inadequate, there are few attempts to push for datasets that are more complicated to derive due to the time and resources used in setting up and running these models. Drifting sea ice poses a challenge for sea ice forecasts to accurately assimilate certain parameters such as sea ice type, thickness and concentration, particularly during the late spring and summer seasons due to snow melt. It is especially difficult to convey sea ice in forecasts at the MIZ (Marginal Ice Zone) and along the coastal areas where due to the merging of satellite products from multiple time points and with varying sensor frequency footprints, there is often a smearing of the ice edge and any features of potential interest [37].

Feedback from the NIS survey assessed how sea ice forecasts were useful, the level of user-friendly data formats. The results were based on a scale from 1-5, where 1= very easy and 5 = very difficult. The cumulative average for each data format is summarized in Figures 11 & 12. There were 15 responses and the following summarizes plot graphs from PolarTourism use of current data products. Ice charts from NIS and information from Polarview were considered the most accessible, whereas the largest difficulty was found with those from the EU Copernicus website and second was the NIS automatic ice chart.

The FMI Ice Map as a Product, Observation of the Concept Survey (2017)

Critical sea ice parameters for users (in order of most desired) were daily ice thickness (73%), ice concentration (56%), sea temperature (45%) and ice deformation (32%). All user groups would benefit from a larger amount of ice thickness observations.

The most used product was the daily colored ice chart delivered as PDF. However, more than 60% of the users used a mobile device for reading the ice chart and many considered the data format to be outdated and clumsy. From the survey, 91% of the users found what they were looking for, and 12 % were not satisfied with the information available in the ice charts. Many users could not find such basic products as ice predictions or daily ice maps. They had trouble finding the daily chart at the FMI web service despite searching for it and used the weekly chart instead. Similarly, many users could not find ice predictions. Information in archipelagos and near the coast was considered lacking. Many users desired charts from inland waters with the same resolution as in Sweden.

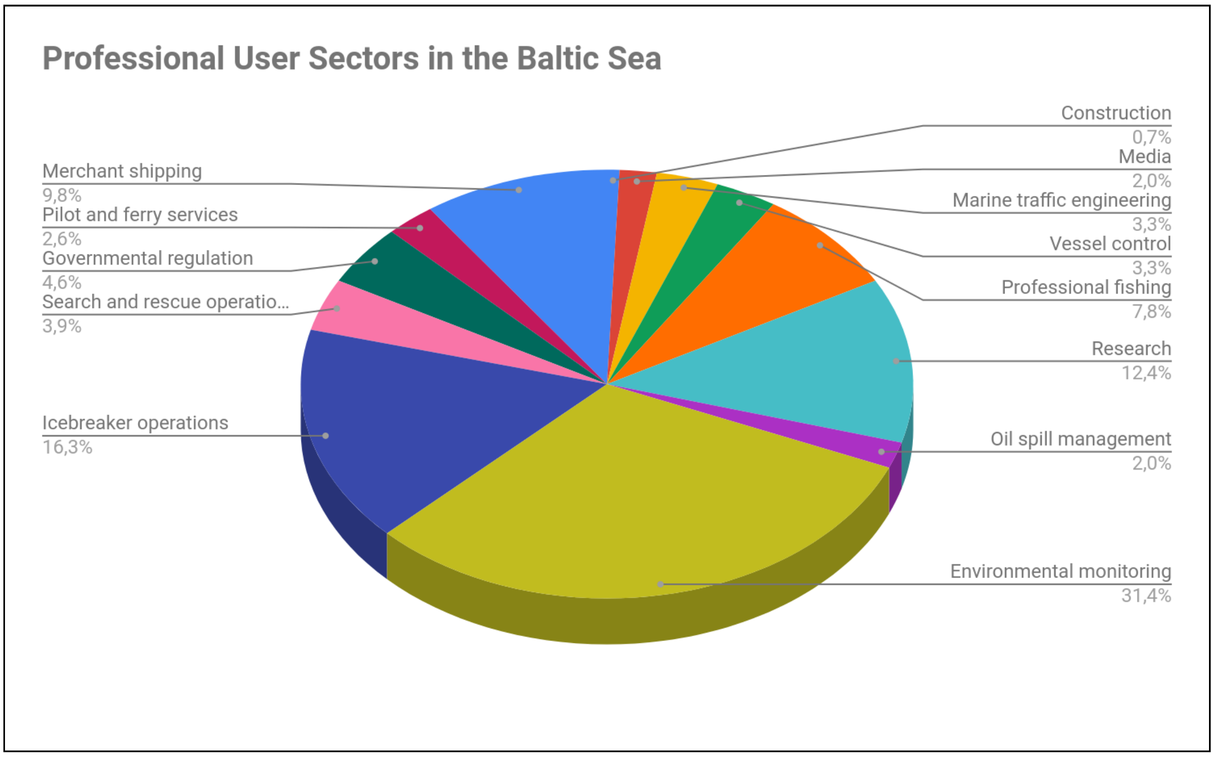


Figure 13: Pie chart showing different professional uses defined by participants in the Baltic Sea

Additional users relied on the ice chart as a reference for planning their own ice mapping. Information on traffic limitation was considered disturbing in some uses and presenting it in another product could be useful. However, many users requested open access to archived ice charts and requested metadata to be available in producing the ice chart.

SMHI Survey (2019)

The most used product (100 % of the respondents) is the detailed ice chart (http://www.smhi.se/klimatdata/oceanografi/havsis). 63 % use a less detailed chart (https://www.smhi.se/vadret/hav-och-kust/is-till-havs). The Swedish ice report is read by 81 % of the respondents. Respondents from the shipping industry tend to use many of our products, compared to other user groups.

geophysical challenges and limitations in the Arctic during spring and summer and there are seasonal, as well as regional variations to when sea ice begins the freeze-up and melt stages. For example, fast ice (ice attached to the land and normally thicker and more stable than drifting ice) can appear different than that of drifting thinner ice types from satellites, depending on the snow loading and the amount of break-up. To reiterate, melting of the snow cover over the ice can result in presenting thicker sea ice types with the same signature as open water when monitoring from satellites. This makes it more time consuming for sea-ice analysts to interpret the satellite images from only one satellite source so they will use multiple sources as a quality control input and assess the situation based on all the latest and greatest satellite, meteorological and oceanographic information available. Additionally, ice analysts have intrinsic knowledge of how ice is changing and behaving in their area of expertise because they consistently follow the patterns, as service-based providers of information. Therefore, their local knowledge allows them to be experts with how the ice conditions are changing in a specific area and more adept at identifying anomalous conditions from the satellite images, rather than another person who is not familiar with local environmental conditions.

Survey highlights and preliminary conclusions from the IICWG Survey:

- **Operational users** - Operational users use many different vessel types and require near-real-time ice information for navigation. All vessel classes are represented in the survey from polar class 1 (PC1) icebreakers to vessels with no ice class. All polar ocean areas and ice regimes are well represented in this survey and 20% of respondents operate without any ice class in ice-covered waters. The need for ice information is to conduct their activities in a safe, more efficient manner and to avoid the potential of an environmental impact. In general operational users require higher spatial and temporal resolution compared to the science users (Figure 19). They may use historical data for strategic planning and design, and forecasts for tactical planning as they often require current information as soon as possible after it is acquired. Very few of these users require low resolution, statistical data; while most of the users in the survey require high-resolution data in near real-time.
- **Information products** - The majority or mariners use SAR or optical data for local and regional route planning, risk assessment and navigation (Figure 18). Many end users are not in a position/time or have the skills to work directly with raw EO data. They need information products and services that provide processed data in accessible formats. The acceptable ice product timeliness is 12 hours or less for 51,6% of the respondents, while the optimal ice product timeliness is 6 hours or less for 51,8% of the respondents (Figure 21). The acceptable ice product update is daily or more for more than 75% but 94% would like it from daily to hourly (Figure 22). Additionally, the access to good metadata is an important component, because the information on data quality and uncertainty needs to be a part of the metadata.
- **Data platforms** - The solution to many of the identified gaps could be achieved through good data platforms and formats that would store sea ice information and provide polar integration. Over 93,7% of the respondents received ice products via the internet and 74,7% receive ice products as digital graphics as email briefings. Over half of the respondents (54,7%) would like to receive ice information in scalable formats in the future. These platforms should in the future use open web services that can be easily used by partners in the development of applications and systems (Figure 24).

The results from this survey clearly show the same issues as the other surveys included in this project; there are multiple preferences for data formats and the different terms of understanding for NRT data among the users. There are some key areas with specific needs for improved operational monitoring with the use of SAR such as the NSR (Northern Sea Route), Svalbard and Greenland waters including the Fram Strait. Climate modeling and research requirements are mainly focused on retrieving long reference datasets over periods of 10-100 years with a coarser resolution compared to what processed SAR images can provide today.

OceanObs19 Key statements:

The paper titles (in italic and underlined) and key messages w.r.t polar observational needs they include are:

Observational Needs of Sea Surface Temperature (O'Carroll et al.)

Notably "Improving SST data quality in the Arctic". One of the main challenges for SST monitoring in the Arctic and at High-Latitude is cloud cover: "Coverage from IR sensors is poor mainly due to persistent cloud, so a priority is to improve PMW data coverage at high latitudes." Hence the priority recommendation (a) : "Ensure continuity and redundancy of the multi-frequency PMW Radiometry constellation for SST including 6.9 GHz V & H channel capability, with resilience to radio frequency interference." as well as "(8) The highly complementary CIMR and AMSR2 follow-on missions should be both pursued, to provide unprecedented coverage, redundancy and revisit of the global ocean and high latitude sea-ice conditions."

A Framework for the Development, Design and Implementation of a Sustained Arctic Ocean Observing System (Lee et al.)

"The Argo program (Riser et al., 2016), which revolutionized climate-scale observing in the ice-free oceans with an array of roughly 4000 profiling floats, has not yet gained traction in the Arctic because of its reliance on satellite services for data transfer an2d geolocation."

"However, there are substantial gaps in in-situ observations of Arctic sea ice variables such as sea ice thickness and snow cover, both in terms of coverage and longevity (Sandven et al., 2018)."

Polar Ocean Observations: A Critical Gap in the Observing System and Its Effect on Environmental Predictions From Hours to a Season (Smith et al.)

"However, there is a significant spread in sea ice concentration products obtained through different retrieval algorithms (Ivanova et al., 2014), which affects the consistency of ocean-sea ice analyses that assimilate those products (Chevallier et al., 2016; Uotila et al., 2018), and the skill of seasonal predictions initialized from those reanalyses (e.g., Bunzel et al., 2016)."

“A better estimation of freeboard and then thickness would greatly benefit from such measurement complementarity” (referring to dual-frequency Ku+Ka altimetry, like the HPCM CRISTAL).

“The current lack of continuity of microwave imagers that can be used to derive global SST is a major concern.” and “The AMSR3 and CIMR missions are highly complementary and in combination would provide improved coverage and sampling in polar regions.”

“With the exception of the CryoSat-2 mission, which covers the Arctic Ocean up to 88°N, altimetry missions do not cover poleward of 82°, leaving a vast region without any measurement.”

Concerning sea-ice drift: “Revisit is the key here: higher revisit of SAR images is naturally required.” and “Joint acquisition of multi-frequency SAR would enable accurate sea ice drift products, which is not possible with stand-alone current mono-frequency SAR missions.”

As part of the recommendations:

“The increasing maturity of satellite sea-ice thickness winter-time products merging several sensors (e.g., CryoSat-2 and SMOS) and its positive impact in preliminary assimilation experiments call for symmetrical efforts in the Antarctic ocean, where such products do not exist at the moment.”

“There is a need for high-resolution (km-scale) remotely sensed snow and ice property data for both the Arctic and Southern Ocean with sufficient temporal resolution to address these relevant features.”

Ocean Climate Observing Requirements in Support of Climate Research and Climate Information (Stammer et al.)

“However, in-situ measurements of these remote sensing products are rare, making calibration and validation of satellite algorithms challenging.”

Ocean Reanalyses: Recent Advances and Unsolved Challenges (Storto et al.)

“To improve model confidence in predicting polar sea ice conditions, satellite missions aiming at retrieving information on Sea Ice Thickness (such as CryoSat2 and SMOS, and their combination, see Ricker et al., 2017) have been found to improve the performance of reanalyses in polar regions (Allard et al., 2018; Mu et al., 2018; Xie et al., 2018).”

Observational Needs for Improving Ocean and Coupled Reanalysis, S2S Prediction, and Decadal Prediction (Penny et al.)

“A microwave satellite radiometer beyond the currently operational Global Precipitation Measurement – GPM Microwave Imager (Skofronick-Jackson et al., 2018) and Advanced Microwave Scanning Radiometer-2 (Kazumori et al., 2016) missions would provide the ability to maintain and further improve CDA at the air-sea interface. There is an immediate need to plan for a satellite salinity measurement mission beyond the 2020–2025 time frame (Durack et al., 2016; Vinogradova et al., 2017 this issue)."

From Observation to Information and Users: The Copernicus Marine Service Perspective (Le Traon et al.)

"In the medium term, a European passive microwave mission for high-spatial-resolution ocean surface temperature, sea-ice concentration, sea-ice drift, thin sea-ice thickness and sea-surface salinity should be developed. Continuity (with improvements) of the Cryosat-2 mission for sea-ice thickness and sea-level monitoring in polar regions should be ensured."

SKIM, a Candidate Satellite Mission Exploring Global Ocean Currents and Waves (Ardhuin et al.)

"The high latitudes including ice-covered regions, and in particular the Arctic, are other regions with poor measurements of surface currents. These currents are important from a climate perspective as they transport freshwater from river run-off in the Arctic basin and melting of the Greenland ice sheet, to the North Atlantic where it can modify the intensity of deep water formation (e.g., Lique et al., 2016), impacting the global ocean circulation. Retrieving geostrophic currents from altimetry in ice-covered regions is now possible (Armitage et al., 2017, 2018), albeit at too low resolution compared to the dominant energy-containing structures, with horizontal scales characterized by the Rossby deformation radius, typically smaller than 10 km in these regions. Both small-scale eddies and wind-driven currents must be resolved in the ice-covered regions to better quantify and understand the cross-shelf fluxes of heat and freshwater (e.g., Spall et al., 2018; Stewart et al., 2018), the location and evolution of the polar and subpolar gyres (Armitage et al., 2017, 2018; Dotto et al., 2018), as well as the regions of deep water convection (e.g., Lique and Thomas, 2018)."

"The Arctic marginal ice zone is a "mare incognitum" that, by the year 2030, is predicted to expand significantly, under the combined effect of atmospheric and oceanic warming, enhanced ice fragmentation by waves (Aksenov et al., 2017) and increased influence of ocean mesoscale activity (Manucharyan and Thompson, 2017). Measurements are missing to address the questions on freshwater transport and ice edge evolution. SKIM will be the first mission to provide much needed data on surface currents, ice drift and wave spectra (e.g., Stopa et al., 2018), at higher spatio-temporal resolution than is available today. These observations are needed to improve the parameterizations of turbulent fluxes, sea ice rheology, wave-ice interactions, and ocean circulation in climate models and weather forecasting systems."

Putting It All Together: Adding Value to the Global Ocean and Climate Observing Systems With Complete Self-Consistent Ocean State and Parameter Estimates (Heimbach et al.)

"A major focus of ASTE [Arctic State Estimation] is the finding of data used in Arctic research that are not necessarily part of global data repositories and assessing their use in state estimation (Nguyen et al., 2017). Emerging challenges are the use of satellite observations of sea ice (and snow) thickness, as well as remotely sensed drift data to constrain sea ice velocities.”

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