KEPLER Deliverable Report

Report on Deliverable D1.3

Milestone name	Report on weather and climate forecasting needs			
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Context of deliverable within Work Package

Tasks 1 and 2 of Work Package 1 “Stakeholder Needs” aim to explore the needs of end-users of products that build on polar environmental observations. In contrast, Task 3 “Climate and Weather Forecasting Needs” explores the needs of intermediate users that transform polar observations into usable products, with a focus on 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. The outcomes of this Task (and the whole Work Package 1) feed into other KEPLER Work Packages (see Figure 1).

The deliverable happens to coincide in timing with the most important conference setting the agenda for the Ocean Observing community in the 10 coming years, namely OceanObs19, held in Sept. 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.

Explanation of delays

No delay.

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Supplements

Supplement 1: Presentation of intermediate outcomes of the questionnaire, presented at the IICWG-DA Workshop, held 17-19 June 2019 in Bremen, Germany

Supplement 2: All questionnaire responses (with personal information removed), merged into one document

Report

To explore the polar observational needs of the weather, sea ice, and climate prediction communities, we have developed a questionnaire composed of eight questions to be 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 this deliverable 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 following subsections 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.

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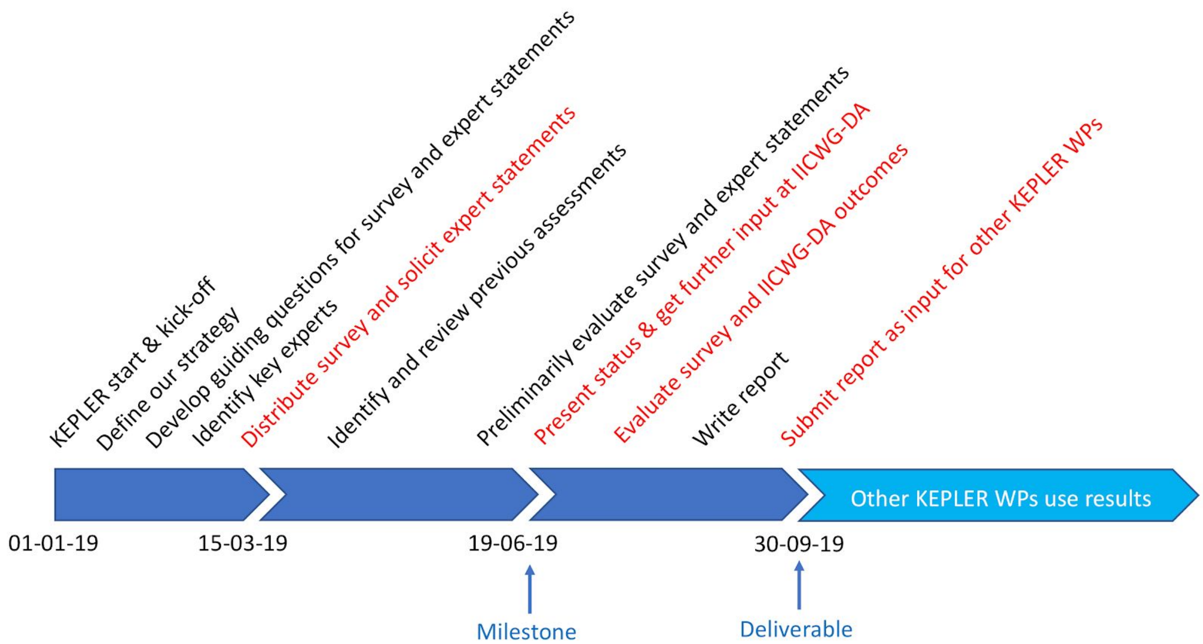

Figure 1: KEPLER WP1 Task3 Timeline

0) 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 1). 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. Examples include the Copernicus candidate mission CRISTAL (“whole product lines can depend on one instrument”) as well as (higher-resolution) Passive Microwave data (“services will be very much degraded if none of CIMR or AMSR3 fly”).

- In addition to continuity, there are high expectations toward **improved (and new) capability** of sensors and products, regarding both well-established as well as more recent and

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experimental product types. The improved capabilities of e.g. CIMR and CRISTAL compared to previous sensors will help to better address user needs (for example in terms of resolution and accuracy of sea-ice concentration and thickness data). 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.

- **Making more of the existing** routine (research) **observations** available for NRT applications should have high priority ("I get discouraged when the discussions devolve to planning a hypothetical observing network that in my mind largely already exists"). Aspects include more data-denial type research, 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.

Note that the questionnaire responses and hence this report do not cover the requirements of ECV users to the extent originally planned, and will be further addressed separately in WP4. Similarly, the requirements of CMEMS are treated separately in WP2.

i) Background information provided with the questionnaire

KEPLER is an initiative built around the operational European Ice Services and Copernicus services to prepare a roadmap for Copernicus to deliver improved European capacity for monitoring and forecasting the Polar Regions. KEPLER aims at assessing the polar observational needs of the weather, ocean, sea ice, land, and climate prediction and research communities, and how this need is expected to develop over the next 10 years and beyond. The outcomes of KEPLER will be used by the European Commission to help guide the development of its Earth monitoring program: the Copernicus Services, and to help develop future research funding calls related to the polar observing system.

By answering this questionnaire you and/or the institution you represent can have your say in these strategic considerations for the future evolution of the polar observing system and services.

The questionnaire targets intermediate users of polar observations. Intermediate users are defined as those who use observational data to produce value-added products ("information") that are used either by end-users directly, or by further downstream intermediate users. Intermediate users are thus at the same time information/service *providers* (Figure 2).

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The questionnaire is intended not to be too specific so that most of the questions should apply to different kinds of intermediate users/providers (including, for example, NWP centers, national ice services, Copernicus services, as well as climate research centers). If you find that one or the other question is not relevant for you and your centre/institution, please feel free to omit to answer it.

The questionnaire aims to tap your expertise regarding two different types of needs, namely (i) the downstream user needs you are trying to address as a provider of products and (ii) your own polar observational needs resulting from the former.

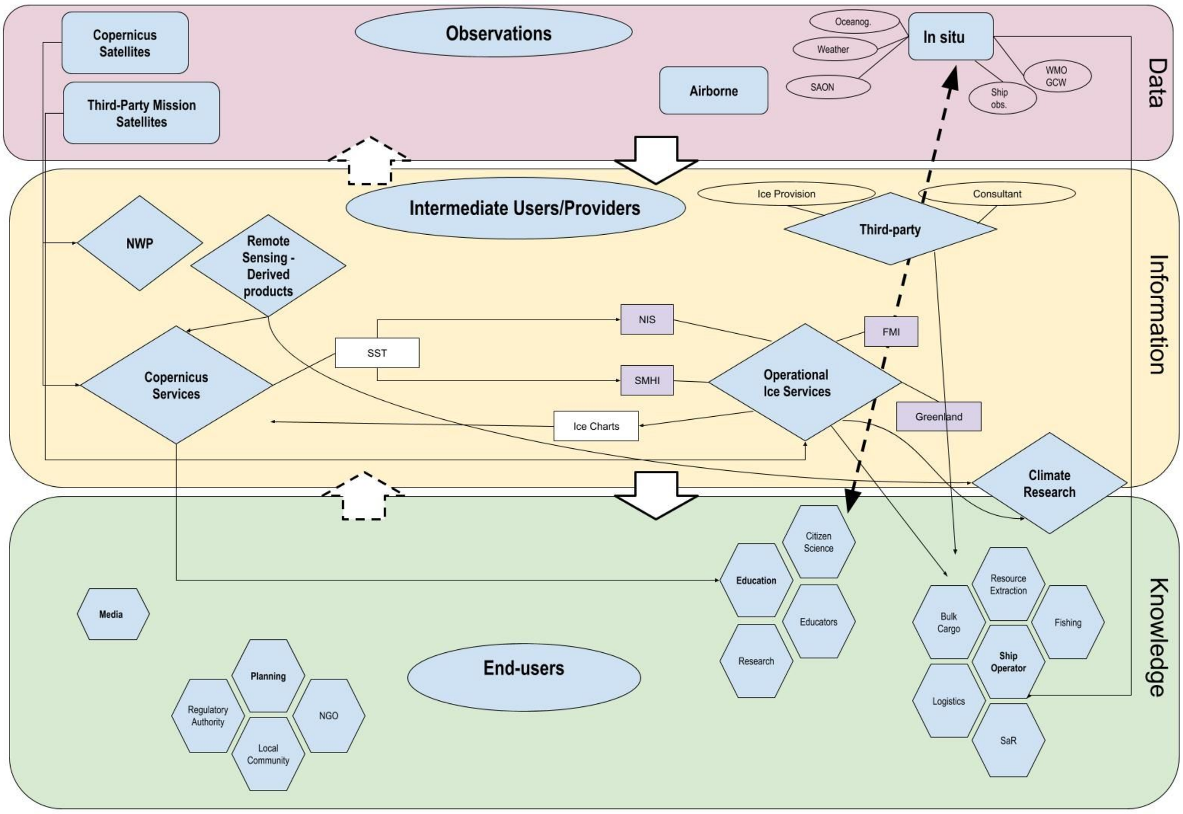

Figure 2: The "user-scape" of polar observations. This questionnaire targets Intermediate Users/Providers, those groups assembled in the yellow box. Note that specific groups and links are exemplary.

When answering the questions, please consider any aspects that appear most relevant to you. The questions are intentionally relatively broad and not multiple-choice based so that you can focus on points that you consider important. However, where applicable, you might also consider the following attributes:

- Which parameters (e.g. ice-edge location, ice pressure, ice concentration, temperature, winds/gusts, visibility, wave height, snow water equivalent, permafrost, river discharge, biological production, etc.) are needed?

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- What resolution is required (in space and time)?
- In the case of forecasts, which range is of the highest interest (hours, days, months, years)?
- Is timeliness/latency an issue for you?
- Is the method of delivery appropriate?
- Is the quality of existing data sufficient / which accuracy is needed?
- Are explicit uncertainty estimates required and/or (if already contained in existing products) reliable in your experience?
- Are existing products sufficiently well documented?

It has been a conscious decision to organize this questionnaire as a text document instead of using an online survey tool. This way we hope to facilitate the sharing of the questionnaire including draft answers with your colleagues so that you can work jointly toward a set of answers more representative of your institution or group of colleagues.

Please return the filled questionnaire via email to Helge Goessling (helge.goessling@awi.de) before June 5th 2019; if you need more time, please let us know. If questions related to the answering of the questionnaire arise, please feel free to ask your KEPLER contact person at any time. Your support is highly appreciated!"

ii) Questions asked within the questionnaire

The following questions are asked in the questionnaire. We asked the respondents to consider the attributes mentioned in the bulleted list of the background part where appropriate in their answers.

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?

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Question 4: The definitions of the terms "near real-time" (NRT) and "high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?

Question 6: Regarding Figure 2, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?

iii) Identified experts and expert groups (Table 1)

	Institution/Group	**Sub-section**	**Expert name(s)**	**Response**
Key institutions/groups/experts identified in advance				

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Ice/Marine Services (Responses: 10)	MetNo	Norwegian Ice Service	Nick Hughes	YES
	DMI	Greenlandic & Danish Ice Service	Keld Qvistgaard	YES
	FMI	Finnish Ice Service	Antti Kangas	YES
	SMHI	Swedish Ice Service	Lisa Lind	YES
	IMO	Icelandic Ice Service	Theodor Hervarsson	
	BSH	German Ice Service	Juergen Holfort	
	AARI	Russian Ice Service	Vasily Smolyanitsky	
	SHN/SMARA	Argentinian Ice Service	Alvaro Scardilli	YES
	ECCC	Canadian Ice Service	Adrienne Tivy and Scott Weese	YES
	SCANEX group			YES
	SHOM	French Navy	Camille Daubord,Christel Lucion, Mathilde Faillot, Ronan Creach, Cyril Lathuiliere	YES
Private Sector (Ice/Marine Services)	Sintef oil spills		CJ Beegle-Krause	YES
	StormGeo		Nina Winther-Kaland	
	Viking Ice		Erik Almkvist	
	CIRFA		Torbjorn Elftoft	
	DriftNoise		Lasse Rabenstein	
	Equinor (Statoil)		Sigurd Teigen	YES

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Weather Services (Responses: 6)	ECMWF	NWP & ice/ocean forecasting	Steffen Tietsche	
	UKMO	NWP & ice/ocean forecasting	Holly Titchner, Ed Blockley	YES
	MetNo	NWP & ice/ocean forecasting	Malte Mueller	YES
	FMI	NWP & ice/ocean forecasting	Timo Vihma	
	Météo France	NWP & ice/ocean forecasting	David Salas y Melia / Hervé Roquet	YES
	ECCC/Dorval/Montréal	NWP & ice/ocean forecasting	Greg Smith	
	ECCC/CCCMA Victoria	ice seasonal forecasting	Bill Merrifield	
	DWD			
	MRI/JMA		Takahiro Toyoda	YES
	AEMET		Sergi Gonzalez Hererro	YES
	NOAA/IASOA		Taneil Uttal	YES
Satellite Production Research/Service (Responses: 7)	MetNo	Sat-products	Thomas Lavergne	YES
	DMI/ASIP	Sat-products	Mathilde Brandt-Kreiner	
	University of Bremen	Sat-products	Gunnar Spreen	
	University of Hamburg	Sat-products	Stefan Kern	YES
	AWI	Sat-products	Stefan Hendricks (Cryosat)	YES
	AWI	Sat-products	Lars Kaleschke (SMOS)	

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	UCL/CPOM	Sat-products	Andrew Shepherd (Cryosat), Julienne Stroeve (snow on ice)	
	CIRFA	Sat-products	Anthony Doulgeris, Thomas Kræmer	
	NERSC	Sat-products	Torill Hamne	
	FMI	Sat-products	Marko Makynen	
	IFREMER	Sat-products	Fanny Girard Ardhuin, Fabrice Ardhuin	YES
	DTU		Leif Toudal Pedersen	YES
	Norwegian Computing Centre	Sat-products	Rune Solberg	YES
	MATC/UWM	Antarctic AWS Network + sat-composite services	Matthew Lazzara	YES
Forecast research (Responses: 1)	EU-ArcticCluster: APPLICATE	*not applicable*	Thomas Jung, Luisa Cristini	
	EU-ArcticCluster: INTAROS	*not applicable*	Stein Sandven	
	EU-ArcticCluster: BlueAction	*not applicable*	Steffen Olsen, Chiara Bearzotti	
	EU-ArcticCluster: Nunataryuk	*not applicable*	Hugues Lantuit, Leena Viitanen	
	Bjerknes Center (UiB, NERSC, NORCE, IMR)		Stefan Sobolowski	
	Hadley Center		Doug M. Smith	
	CMCC	ice/ocean forecasting	Dorotea Iovino, Simona Masina	

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	SIMIP (shall be distributed to SIMIP-contributing modelling groups)		Alexandra Jahn, Dirk Notz	
	WMO ArcRCC	long-range forecasting	Helge Tangen	
	AWI-SIO			YES
Copernicus Services (Responses: 2)	CMEMS		Gilles Garric	(Note: CMEMS as KEPLER participant provides extensive input to KEPLER through WP2)
	C3S		Jean Noël Thépaut, Harald Schyberg	YES
	Copernicus in-situ component		Erik Buch	
	CLMS		Greet Meanhout (JRC) global CLMS, Chirs Steenmans (EEA) regional CLMS	YES
Grand total:				**26 responses**
Lists for broader distribution				
polarprediction@climate-cryosphere.org (this is the YOPP mailing list, about 600 subscribers)				N/A

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Copernicus Office: support@copernicus.eu				N/A
SIOS: Shridhar Jawak <remotesensing@sios-svalbard.org>				N/A
CRYOLIST (send to cryolist@lists.cryolist.org)				N/A

iv) IICWG-DA workshop

The *9th International Workshop on Sea Ice Modelling, Data Assimilation and Verification* was held 17-19 June 2019 in Bremen, Germany. The workshop was organized and sponsored jointly by the International Ice Charting Working Group (IICWG), the Year of Polar Prediction (YOPP – the flagship activity of the Polar Prediction Project by the World Weather Research Programme (WWRP)), GODAE Oceanview (GOV) and KEPLER. The overall workshop objective was to advance international capabilities for automated sea ice analysis and prediction on timescales from hours to a season. This includes the development of more mature and meaningful methods for sea ice verification as well as cross-cutting issues in sea ice modelling and data assimilation and how deficiencies of current systems can be more efficiently diagnosed and addressed.

The workshop started off with a session dedicated to KEPLER, with Nick Hughes presenting the status of the project overall, Thomas Kaminski presenting on the Quantitative Network Design (QND) analyses of observational scenarios within KEPLER, and Helge Goessling presenting preliminary results of the KEPLER 1.3 questionnaire, which is the focus of this report. The KEPLER session was followed by sessions on (i) sea ice observations and uncertainties, (ii) sea ice model parameterizations and coupling to ocean and atmosphere models, (iii) sea ice data assimilation, and (iv) verification approaches for sea-ice analysis and forecasts. In the following we summarize the intermediate results of the questionnaire as presented at the workshop and the subsequent discussion.

Until June, 17 responses to the questionnaire had been collected and preliminarily analysed. Until then, 7 responses had come from **Ice/Marine Services** (including private sector), 4 from **Weather Services**, 1 from a **Forecast Research** group, 4 from **Satellite Production Research/Service** groups, and 1 related to a **Copernicus Service**. In order to increase the overall readability of this report, the intermediate results from these responses as presented at the workshop are not provided here, but the corresponding presentation is provided as a supplementary document. The intermediate results are of course contained in the overall outcomes presented in the subsequent section.

Figure 3: Group photo from the 9th International Workshop on Sea Ice Modelling, Data Assimilation and Verification, where KEPLER and preliminary outcomes of the questionnaire were presented and discussed.

One aspect that was received considerable attention at the workshop was that the gap between what automatic satellite products and model-based forecast systems can deliver and what end-users "want" in terms of spatial resolution (and real-time delivery) 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 latency of forecast products (and the underlying observational products) on the one hand, but also by optimising the way forecast products are used, such that they become useful also with resolutions previously considered too coarse.

v) Outcomes of the questionnaire

In total we have received 26 responses to our questionnaire, that is, 9 in addition to the ones included in the preliminary analysis presented at the IICWG-DA Workshop (see previous section). In total, 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.

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The responses from **Ice/Marine Services** (including private sector) reflect a need for more frequent SAR imagery, in particular in the Southern Hemisphere, but also in the 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 semi-automated analysis of SAR data and integration of short-term forecasts and are in need for better and more detailed ice 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. 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 in very detailed sea-ice thickness information (especially in coastal areas).
2. 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.
3. To provide accurate short-term forecasts of ice condition and iceberg drift (with little latency), exploiting high resolution ocean – sea-ice - wave models with data assimilation is (and will be) required. "Improved polar NWP capacity will lead to improved results in high-resolution regional sea ice models, which is important for ship routing and planning offshore operations". (Example of improved resolution of ocean-sea-ice models: 1/12 degr UK MetOffice; Barents-2.5km MET Norway; 6 km resolution set up of the pan-Arctic Copernicus marine ocean, sea-ice, wave and biogeochemistry forecast and reanalysis system, 3 km resolution for deterministic forecast). Satellite observations at matching spatial resolutions will be required.
4. *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 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 ("I get discouraged when the discussions devolve to planning a hypothetical observing network that in my mind largely already exists"). They would like to get hold of more lower-troposphere observations, especially over sea ice,

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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 ocean and sea-ice information.

Specific points raised by Weather Services:

1. High-quality NRT operational satellite data (Copernicus-Sentinel-based wind retrievals, SIT and SIC, SID retrievals, snow data, SST) are needed. With respect to wind retrievals for operational use, there is a demand to reduce latency (to below ~1h). These products (not yet all) are assimilated to provide optimal initial and boundary conditions for 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 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 to use information of relatively low quality (with lower weights, accordingly).
4. *In situ* meteorological observations, as expected, are of a very high demand, since the conventional polar observation network is still quite sparse (especially over the sea-ice and ocean). The observed information on 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. “Aeolus and follow-ups could fill this gap”.

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 measurements. 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”, indicating that CIMR would be even better. They call for open and timely access to reanalysis and Earth Observation data and to algorithms, and would benefit from better technology to overcome bandwidth limitations. Additional needs relate to the readiness of satellite observations for automatic product generation and to better NWP forecasts with higher resolution in time and space (e.g., for the application of weather filters). One group criticized an

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artificial barrier between NWP satellites (EUMETSAT) and Copernicus satellites (Sentinel), noting that e.g. CIMR serves both.

Specific points raised by Satellite Production Research/Service groups:

1. Satellite observations with improved quality, resolution and cloud screening (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. Complementary combination of data from different sensors is regarded as an opportunity, e.g., combining SAR and microwave radiometry information: "*a multi-sensor/multi-temporal approach that fuses optical and PMR for snow cover monitoring": "AVHRR GAC and SMMR+SSM/I"*
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. Some satellite retrieval algorithms applied in NRT would benefit from more accurate weather forecasts for improved weather filtering.
7. An artificial barrier between NWP (EUMETSAT) satellites & Copernicus satellites is being criticized.
8. A lack of in-situ observations for CalVal is stressed.

Finally, the **Forecast Research group** points out that advances can be made at many fronts. Using satellite-based sea-ice concentration, thickness, drift, snow on 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:

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1. Detailed information on the observational data uncertainties (including error covariances) are 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 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). 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 modelling), wind-profile observations (Aeolus and follow-on missions), and denser surface observations (e.g., drifting buoys). The CIMR mission is highlighted once more as 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 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. <u>Satellite observations (missions, sensors and products, quality of the retrievals)</u>. There is an urgent need for observations that allow to estimate 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. <u>Synergistic use of the information from different sensors (sources)</u>. "Another important challenge is the capability to utilize SAR data in synergy with data from other sensors and models to improve the surface (not only!) analysis." Partly inconsistent information: some of the respondents commented on the usefulness of PM data (also merged PM/SAR

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products) for ice services (latency, resolution degradation by merging, space/time coverage increase with PM).

3. Data compression and communication methods.
4. *In situ* observations (more new, and exploitation of historical) on the coupled sea-ice – ocean – atmosphere system's state. Again, exploitation of existing historical observing system 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. Modelling and data (also Level 2/1) assimilation. For short-term forecasting application 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. 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 questionnaire 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 10km). 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 latency of forecast products (and the underlying observational products) on the one hand, but also by optimising the way forecast products are used, such that they become useful also with resolutions previously considered too coarse.

vi) Complementary information from the OceanObs'19 review papers

In the following we provide key messages related to polar observational needs that have been expressed in a large number of review papers issued for the OceanObs'19 conference. Taking place 16-20 September 2019, this conference is "a community-driven conference that brings people from all over the planet together to communicate the decadal progress of ocean observing networks and

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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

Summary of statements and relation to questionnaire outcomes:

Below is a list of key statements with respect of polar observational needs from the OceanObs'19 review papers. Overall, the statements corroborate the outcomes of the KEPLER questionnaire. For example, the urgent need to ensure the continuity of altimetry and high-resolution passive microwave data alike is pointed out (for example it is mentioned several times that the highly complementary CIMR and AMSR2 follow-on missions should be both pursued, not only for sea-ice properties but also for SST), 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.

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 Passive Microwave (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.)

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“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 and 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.)

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“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.,

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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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KEPLER

Questionnaire

to explore the polar observational needs of the weather, sea ice, and climate prediction communities

WP1: Stakeholder Needs and Network Coordination
Task3: Climate and Weather Forecasting Needs

Helge Goessling (AWI), Penelope Wagner (METNO),
Steffen Tietsche (ECMWF), Thomas Lavergne (METNO), Laurent Bertino (NERSC),
Gilles Garric (MERCATOR), Svetlana Loza (AWI), Nick Hughes (METNO)

9th IICWG-DA meeting, Bremen, 17—19 June 2019

Goal

to explore the polar observational needs of the weather, sea ice, and climate prediction communities

... to help guide the development of Copernicus' Earth monitoring program and to help develop future research funding calls related to the polar observing system

Scope

Process studies

Parameterization development

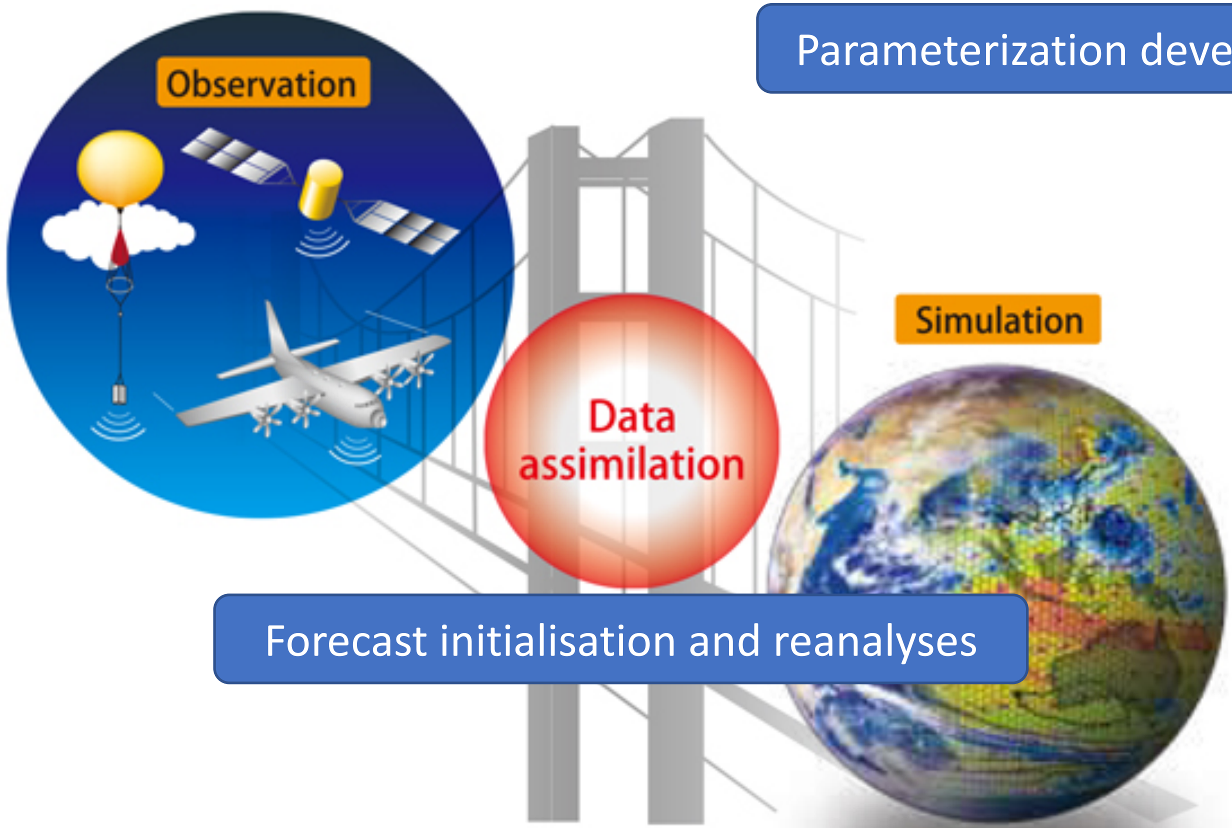


Figure from http://daconf15.umd.edu/

Forecast initialisation and reanalyses

Model / forecast evaluation and calibration

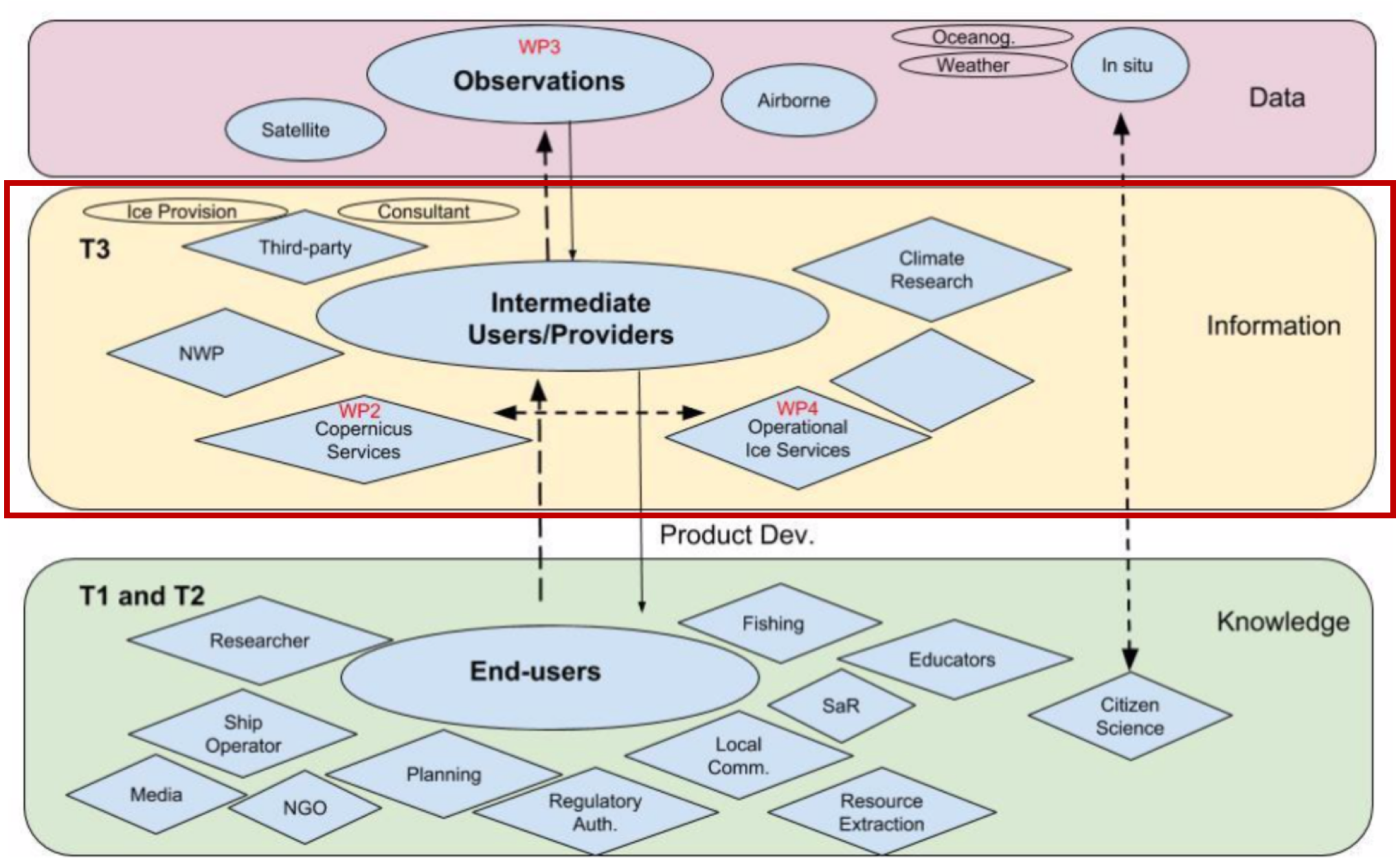
Services

Climate monitoring

Methods

+ Review of previous assessments

User-scape



This task / questionnaire

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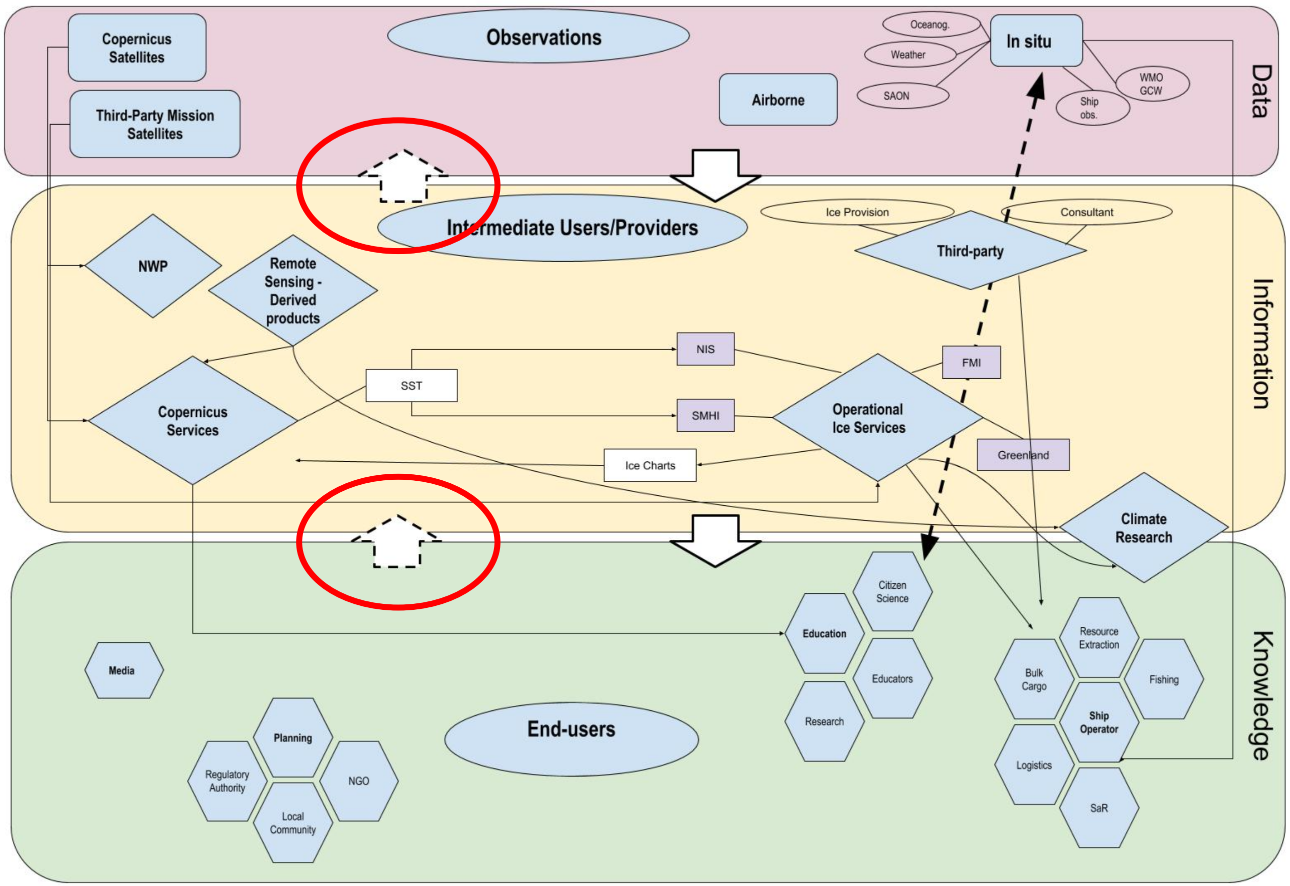
WP1-T3

User-scape


Copernicus Satellites
Third-Party Mission Satellites
Observations
Airborne
Oceanog.
Weather
SAON
In situ
WMO GCW
Ship obs.
Data
Intermediate Users/Providers
Ice Provision
Consultant
Third-party
NWP
Remote Sensing - Derived products
NIS
SST
FMI
SMHI
Copernicus Services
Operational Ice Services
Greenland
Ice Charts
Climate Research
Information
Citizen Science
Education
Educators
Research
Media
Planning
Regulatory Authority
NGO
Local Community
End-users
Resource Extraction
Bulk Cargo
Fishing
Ship Operator
Logistics
SaR
Knowledge

Key expert(-group)s

- NWP Centres
- Ice Services
- Polar Climate Research Centres
- Private sector intermediate users
- Copernicus Services
- Relevant Projects and Organisations
- Data developers

~40 groups/individuals (mostly Europe) asked
+ broad distribution via email lists
(non-European contributions more than welcome!)

Questions asked (selected)

2.

What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?

„Attributes“:

- Parameter
- Resolution (space and time)
- Timeliness/latency
- Way of delivery
- Quality (random and systematic errors)
- Explicit uncertainties
- Retrieval level
- Documentation
- …

Questions asked (selected)

3.

Which future products/services are you currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?

„Attributes“:

- Parameter
- Resolution (space and time)
- Timeliness/latency
- Way of delivery
- Quality (random and systematic errors)
- Explicit uncertainties
- Retrieval level
- Documentation
- ...

Questions asked (selected)

5.

How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?

„Attributes“:

- Parameter
- Resolution (space and time)
- Timeliness/latency
- Way of delivery
- Quality (random and systematic errors)
- Explicit uncertainties
- Retrieval level
- Documentation
- ...

Questions asked (selected)

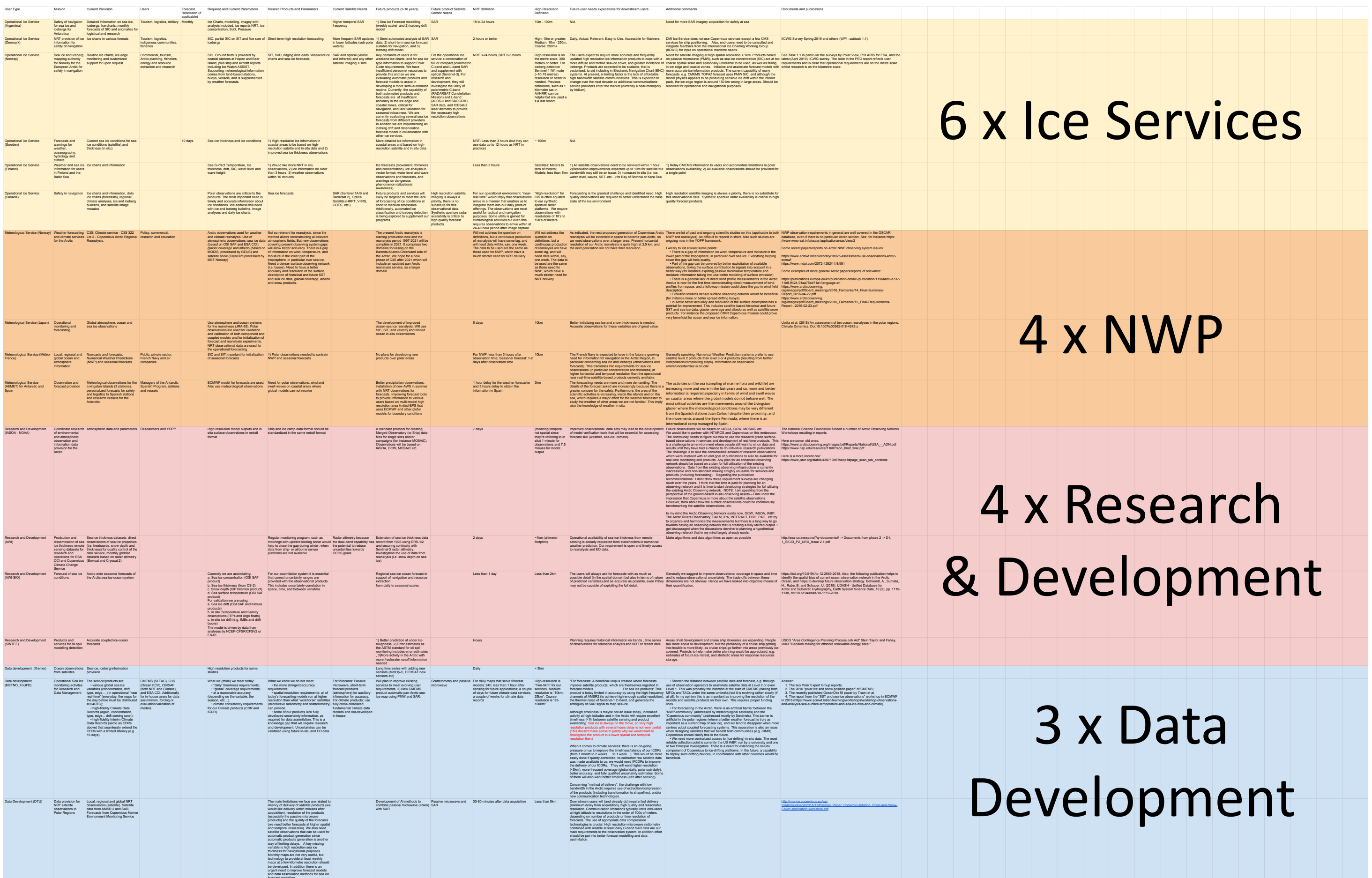
7.

Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?

„Attributes“:

- Parameter
- Resolution (space and time)
- Timeliness/latency
- Way of delivery
- Quality (random and systematic errors)
- Explicit uncertainties
- Retrieval level
- Documentation
- ...

17 responses to date …



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WP1-T3

17 responses to date ...

Ice services ...

- need higher-frequency SAR imagery, in particular in the Southern Hemisphere, but also in sub-Arctic
- expect increasing demands w.r.t. latency and resolution
- call for better technology to overcome high-lat bandwidth limitations
- ask for better (single-point) access to in-situ obs. (e.g. ice drifter data)

17 responses to date ...

Ice services ...

- work on semi-automated analysis of SAR data and integration of short-term forecast
- need better and more detailed ice thickness data, in particular in coastal areas

17 responses to date ...

Met services ...

- are in need of better obs/forecasts for wind and swell waves on coastal areas where global models do not behave well
- call for making more of the existing routine (research) observations available for NRT applications (*"I get discouraged when the discussions devolve to planning a hypothetical observing network that in my mind largely already exists"*)

17 responses to date ...

Met services ...

- need consistent in-situ obs. and corresponding model data to enable generation of merged obs/model observatory data files for system verification and development (“YOPPsiteMIP”)
- more lower-troposphere obs., esp. over sea ice
- better wind profiles; Aeolus and follow-ups could close this gap
- denser surface obs. (e.g. drifting buoys)
- *“CIMR Copernicus mission could prove very beneficial for ocean/sea-ice info”*

17 responses to date ...

Data (sat-product) developers ...

- require more accurate radar altimetry and more/better in-situ obs. for alg.dev & CalVal, and continuity, e.g. by CRISTAL (Copernicus mission)
  - "*whole product lines can depend on one instrument*"
- call for open and timely access to reanalysis and EO data, and algorithms
- call for better technology to overcome bandwidth limitations

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17 responses to date ...

Data (sat-product) developers ...

- call for continuity and higher resolution of Passive Microwave data
  - *"our services will be very much degraded if none of CIMR or AMSR3 fly (CIMR would be better)"*
- need better forecasts (higher time&space res.)
- call for readiness of sat-obs for auto products generation
- criticise artificial barrier between NWP-sats & Copernicus-sats (Sentinel) (e.g. CIMR serves both)

17 responses to date ...

R&D (ice forecasting) ...

- need sat-based SIC, SIT, Drift, snow on ice, ocean T&S (incl. in-situ) for data assimilation ...
  ... with less latency, higher resolution, explicit uncertainties (ideally with cross-covariances)
- prefer ultimately level-2(1) products for assimilation, but work on better observation operators is required (similarly, independent rather than merged products preferred)

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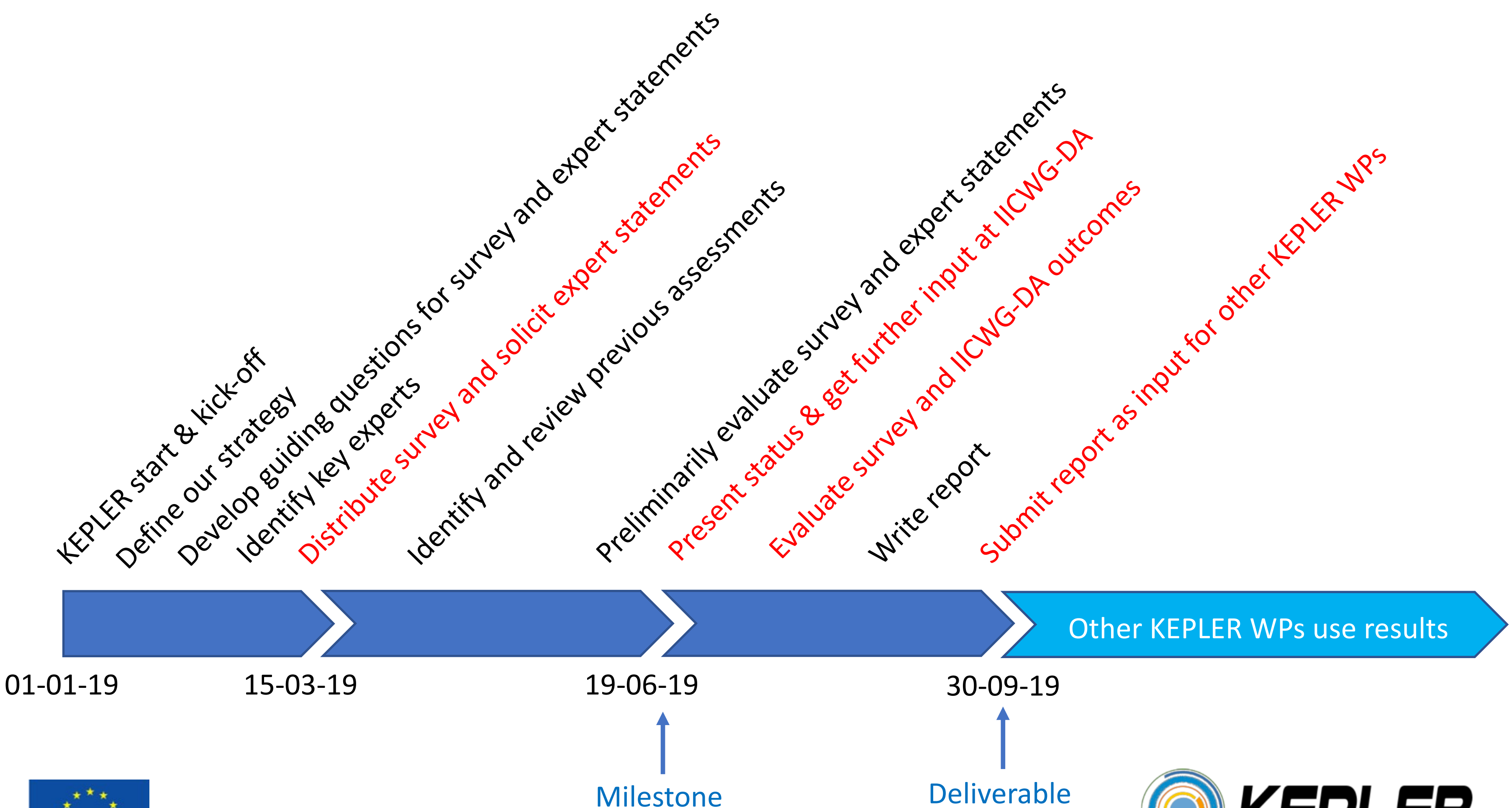
17 responses to date ...

Miscellaneous ...

- Huge difference in definitions of “near-real-time” (1h—7 days) and “high resolution” (10m—10km)
- Partly inconsistent information
  Example: usefulness of PM data (also merged PM/SAR products) for ice services (latency, resolution degradation by merging, ...)

Timeline



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WP1-T3

This document contains all original responses to the questionnaire of KEPLER WP1-Task3. Responses are ordered by the following groups:

- Ice/Marine Services (including private sector): 10 responses
- Weather Services: 6 responses
- Satellite Production Research/Service: 7 responses
- Forecast Research: 1 response
- Copernicus Services: 2 responses

Ice/Marine Services (including private sector):
Responses: 10 (7 before IICWG-DA)

1)
Argentinian Ice Service:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: The Mission of the Naval Hydrographic Service (SHN), in which it is included the Argentine Ice Service, is to provide the public service of Safety of Navigation in the Southwestern Atlantic Ocean (NAVAREA VI), including part of the Antarctic continent.
The detection and monitoring of sea ice and icebergs results of great interest and application in various domains. For operational purposes (Antarctic safety of navigation, route selection and logistic tasks, search and rescue operations, etc.) and for the development of scientific studies (diagnosis and impact of climate change, forecast of sea ice concentration and extension, etc.).
The Argentine Ice Service elaborates products with detailed information of the conditions of sea ice and icebergs in order to provide the public service of nautical safety in waters with presence of ice. Additionally a monthly forecast of sea ice concentrations and anomalies is provided for logistical and research purposes.
Polar observations are the most important resource for our ice charts development and validation of sea ice forecast.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: Users needs are focus in all kind of sea ice and iceberg information: ice charts, modelling, imagery with analysis included, ice reports in near real time, ice concentration and state of development and pressure.
The limitations we have in Southern Hemisphere are the low frequency of SAR imagery, especially during the Austral winter. In the last few years there was some improvement in the amount of SAR images but yet not enough, especially with tourist ships from all over the world visiting Antarctica.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: Sea Ice forecast modelling in weekly scale and iceberg drift and deterioration model with daily forecasts. These will be based in SAR imagery.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution“ vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: NRT: As soon as we can get a clear vision of sea ice conditions. Within the 18 to 24 hours is acceptable, as the sea ice has slow motion.
HR: SAR imagery with 100 meters scale is very acceptable. In case of small icebergs it will be needed a 10 meters resolution.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: Not clear so far.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: -

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: Our focus is with SAR imagery and in Southern Hemisphere the biggest issue is related to frequency of acquisition, especially considering that safety at sea is more compromised every year.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: -

2)
SINTEF:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: R&D leading to products and or services.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: Accurate coupled ice-ocean forecasts with best physics.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: Better prediction of under ice roughnesses

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: Tactical – near-realtime means hours and quality hindcasts to estimate environmental variability. Error estimates would be appreciated, as the ASTM standard for oil spill modeling includes error estimates.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: More activity in the Arctic with more freshwater runoff information.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: Planning requires historical information on trends, time series of observations for statistical analysis and near-real time or recent data.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: Areas of oil development and cruise ship itineraries are expanding. People talk more about oil development, but the probability of a cruise ship getting into trouble is more likely, as cruise ships go further into areas previously ice covered. Projects to help make better planning would be appreciated, e.g. estimates of future ice retreat, and stratedic areas for response resources storage.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: USCG „Area Contingency Planning Process Job Aid"
Stein Taylor and Fahey 2003 „Decision making for offshore renewable energy sites."

3)

FMI (Finnish Ice Service):

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer:
Our mission is to provide weather and sea information services for the users in Finland and Baltic Sea.
We are generating information and services but also just relaying CMEMS information to users.
We are also developing various sea ice products for the Arctic (e.g. Barents and Kara Seas), and participating ESA SICCI for providing sea ice thickness data from radar altimeters.

We understand the limitations in polar observation availability and accommodate to it. Of course we hope more observations, but know they do not exist currently.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer:
Baltic Sea: timely information: ice information should be no older than 3 hours. Weather observations preferrably 10 minutes. Used observations: SST, ice thickness; movement; concentration (satellite based), water level, wave height.
In situ observation are sparse in time and space, but the big latency in delivery is fustrating, as we need NRT observations, old ones are not as important.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer:
Ice forecasts (movement, thickness, concentration), ice analysis in vector format, water level and wave observations and forecasts. Warnings on dangerous phenomenon.

Question 4: The definitions of the terms "near-time time" (NRT) and "high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer:
NRT less than 3 hours. High resolution: Satellite resolution meters or thens of meters. Model resolution less than 1 km.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer:
All observations need to be within 1 hour time.
Resolution improvements expected, up to 10 m satellite. But bandwidth is limiting usefulness greatly at the sea.
More insitu obse needed, at least one for each parameter (ice, waterlevel, waves, sst etc.) for one sea area, such as Bay of Bothnia of Kara sea.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer:
Pretty mess up figure ;DDD
Frankly speaking, it needs to be re-drawn by someone who has experience in simplifying visual outlook.
Sorry, can't help here.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer:
Collecting all available observation from chosen field (such as insitu ice observations) and providing them from single point would be usefull.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: FP7 POLAR-ICE, Integrated Requirements Report, and Appendix B: End User Consultations
ESA Sea Ice Climate Change Initiative: Phase 1
User Requirement Document (URD)
Doc Ref: SICCI-URD-01-12
Version: 1.0
Date: 01 June 2012
H2020 SPICES
Deliverable: D9.5
Innovation Management and Service Development Plan
Sections 4.1 adnd 4.2

4)
DMI (Danish Ice Service):

Question 1: What is the general mission of your institution, in what sense are you

intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: 365/24 NRT provision of ice information for safe and efficient navigation in ice-covered waters

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: ice analysis in various formats containing total ice concentration, partial concentration on ice thickness and floe size, icebergs.
NOT able to: short term high resolution forecasting, frequent SAR update in lower latitude (sub-polar waters)

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: a solid iceberg product based on satellites, semi-automated analysis of SAR data, short term forecast for areas with ice and critical for navigation

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: NRT: two hours or better
High resolution: 10m pixels or better, medium resolution 10-250m, coarse resolution 250+m

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: daily, actual, relevant, easy to use, accessible for mariners

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: NO, DMI Ice Service does not use Copernicus services, except a few CMS services (ship positioning)

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: consult users, International Ice Charting Working Group

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we

should take into account?
Answer: IICWG survey and others documented in WP1.1

5)
SMHI (Swedish Ice Service):

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: Forecasts and warnings (weather, oceanography, hydrology, climate). I will however focus specifically on the needs of our national ice service in this questionnaire.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: Current ice conditions (satellite based) including thickness (preferably from in situ). Ice forecasts for coming 10 days.
We are not able to deliver high resolution information in coastal areas, and do not have enough thickness observations today.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: More detailed ice information in coastal areas. Would be based on high resolution satellite and in situ.

Question 4: The definitions of the terms „near-time time” (NRT) and „high-resolution“ vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: NRT would be less than 3 hours (but we use data up to 12 hours as NRT in practice), and high resolution in the magnitude of 100 meters.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: N/A

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: N/A

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: N/A

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: Yes. We will share the outcome of our user survey with the project.

6)
Canadian Ice Service:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: The Canadian Ice Service is required to provide timely and accurate information about ice in Canada's navigable waters. We work to promote safe and efficient maritime operations and to help protect Canada's environment. We are an operational ice service. Our service and product offerings include image analyses, daily ice charts (forecasts), regional climate analyses, ice and iceberg bulletins, and satellite image mosaics. Polar observations are critical to our service.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: The most important need is timely and accurate information about ice conditions. We address this need with ice and iceberg bulletins, image analyses and daily ice charts. These products are primarily based on synthetic aperture radar (Sentinel 1A/B and Radarsat-2) and optical satellite imagery (HRPT, VIIRS, GOES, etc.). Forecasts of ice conditions is a need that will be addressed in the near future that is currently not met by our service.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: Future products and services will likely be targeted to meet the lack of forecasting of ice conditions at short to medium timescales. Additionally, automated ice classification

and iceberg detection is being explored to supplement our programs.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: For our operational environment, "near-real time" would imply that observations

arrive in a manner that enables us to integrate them into our daily product offerings. The observations are most useful for tactical and navigation purposes. Some utility is gained for climatological activities but even this requires observations to arrive within at 24-48 hour period after image capture. “High-resolution” for CIS is often equated to our synthetic aperture radar platforms. We require observations with resolutions of 10’s to 100’s of meters.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: Forecasting is the greatest challenge and identified need. High quality observations are required to better understand the base state of the ice environment.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: Nothing to add.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: High resolution satellite imaging is always a priority, there is no substitute for this observational data. Synthetic aperture radar availability is critical to high quality forecast products.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: nothing to provide.

7)
Norwegian Ice Service:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer:
Norwegian Ice Service is the national sea-ice and iceberg mapping authority for Norway, with a responsibility for sea areas around Svalbard including the Barents Sea, Fram Strait and Greenland Sea, as well as the WMO/IMO JCOMM GMDSS NAVAREA-XIX sector up to the North Pole. In addition we support Norwegian users in other waters, including the Peninsula and Weddell Sea sector of the Antarctic. The focus is on providing accurate information to support navigational safety.

We provide the following products and services:
- a routine ice chart every weekday for the European Arctic sector.
- a weekly (Mondays) ice chart for the Antarctic during austral summer (October to April).
- ice edge monitoring for GMDSS NAVAREAs XIX and I (UK).
- customised information support for a diverse range of users.

We are intermediate users in the sense that we process Level-1 satellite data into our our products, and use higher level products (Levels 2 and 3) if they are robustly accurate and of suitable high quality.

Routine satellite monitoring of the polar regions is critical for our service provision, supported by in situ observations. In particular Synthetic Aperture Radar (SAR) and optical (visible and infrared) satellite imaging at high resolution (< 1km) are essential. Products based on passive microwave (PMW), such as sea ice concentration (SIC) are at too coarse spatial scale and seasonally unreliable to be used, as well as failing in ice edge and coastal zones.

This project has received funding from the European Union's Horizon 2020 research and innovation under
grant agreement No. 821984

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?

Answer:

We provide our users with high resolution, quality controlled sea-ice and iceberg information. These are based on Sentinel-1, RADARSAT-2 and COSMO SkyMed SAR, and Sentinel-2, Sentinel-3, VIIRS, MODIS and AVHRR optical satellite remote sensing. We will process raw AMSR2 at the ice service to augment areas lacking high resolution but it is use very sparingly because we have almost total full SAR or visible coverage for our monitoring area. Ground truth is provided by coastal stations at Hopen and Bear Island, plus ship and aircraft reports including Ice Watch ASSIST. Supporting meteorological information comes from land-based stations, buoys, vessels, and is supplemented by weather forecasts.

Key demands of users is for weekend ice charts, and for sea ice type information to support Polar Code requirements. We have insufficient personnel resources to provide this and so we are evaluating automatic

products and forecast models to assist in developing a more semi-automated routine. Currently, the capability of both automated products

and forecasts are of insufficient accuracy in the ice edge and coastal zones, critical for navigation, and lack validation for seasonal robustness. In particular, the types of satellite monitoring systems that scientific studies have shown may potentially resolve this issue, namely a combination of full or compact polarimetric C-band and L-band SAR, are unavailable routinely. This affects the quality of data that can be used to initialise and be assimilated into forecast models, thus reducing the effectiveness of these. Forecast models are typically forced using passive microwave (PMW) derived sea-ice products which are not of adequate quality for operational sea-ice monitoring for navigation purposes, but have some climatological use and can provide information on probability to assist with long-term planning.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer:
Currently our ice charts only provide sea ice concentration (SIC) classes. We are working on including sea ice type, compliant with the Egg Code WMO Stage of Development, using Sentinel-1 SAR, supplemented by
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Sentinel-2 and Sentinel-3 optical. Research and development will also investigate the utility of polarimetric C-band (RADARSAT Constellation Mission) and L-band (ALOS-2 and SAOCOM) SAR data, and ICESat-2 laser altimetry to provide the necessary high resolution observations.
We are currently evaluating several sea ice forecasts from different providers. In addition we are implementing an iceberg drift and deterioration forecast model in collaboration with other ice services.

Question 4: The definitions of the terms "near-time time" (NRT) and "high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer:
NRT is somewhere between 3-24 hours, as opposed to quasi real time which is 0-3 hours.
High resolution is on the metre scale, 300 metres or better. For iceberg detection Sentinel-1 IW mode (~10-15 metres) resolution or better is needed. Previous definitions, such as 1 kilometer (as in AVHRR) can be helpful but are used a s a last resort.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer:
The users expect to require more accurate and frequently updated high resolution ice information products to cope with a more diffuse and mobile sea-ice cover, and greater incidence of icebergs. Products are expected to be scalable, that is vectorised, to aid including in Electronic Navigation Chart (ENC) systems. At present, a limiting factor is the lack of affordable high bandwidth satellite communications. This is expected

to change over the next decade as additional communications service providers enter the market (currently a near-monopoly by Iridium).

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?

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Answer:
I helped produced Figure 1, so this incorporated many of the links I knew about. There may be more linkages between Copernicus Services and Third-Party Providers, but apart from a few case studies the number of these are not well publicised.
The only Copernicus Services product used by the Norwegian Ice Service is SST. Open ocean products seem reliable.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer:
Initialise and assimilate forecast models with more accurate ice information products (such as?). The current capability of many forecasts. e.g. CMEMS TOPAZ forecast uses PMW SIC, and although the model physics appears to be producing sensible ice drift within the interior pack, the ice edge region is around 150 km wrong in large areas. Should be resolved for operational and navigational purposes.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer:
See Task 1.1 in particular the surveys by Polar View, POLARIS for ESA, and the latest (April 2019) IICWG survey. The table in the PEG report reflects user requirements and is clear that operational requirements are on the metre scale whilst research is on the kilometre scale.

8)
SHOM:

Question 1: What is the general mission of your institution, in what sense are you

intermediate users of polar observations, and which services/products are you offering?
How important are polar observations to enable your service provision?
Answer:
Mission: safety and navigation.
Intermediate user since CMEMS products are used to make NRT synthesis products particularly. Polar observations needed for those NRT products dedicated to navigation in polar regions; polar observations needed also at a planning level (data type ~ climatology).

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer:
Needs partly met:
“ice” product for navigation. CMEMS products used:
- NRT icebergs concentration from DMI.
- SST forecasts based on Topaz system.
Not fulfilled:
- sea ice charts: ice charts from DMI
(SEAICE_ARC_SEAICE_L4_NRT_OBSERVATIONS_011_003 /
SEAICE_ARC_SEAICE_L4_NRT_OBSERVATIONS_011_002) should cover west enough (Canadian
coasts).
- sea ice forecasts: need forecasts at short range (1-6 days). No good enough sea ice forecasts (ice edge position, SIC and, SIT, ..) at short range and especially in/near the marginal ice zone to use CMEMS forecasts.
- icebergs: area should cover the Canadian side. Detection of smaller icebergs than 100m would be also required.
Other needs:
- NRT Ice thickness product based on satellite observations produced all seasons.
- Icebergs concentration climatology: monthly statistics per year and uncertainty estimates.
- Iceberg drifting forecasts.
- SIC climatology and uncertainty estimates

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer:
Interested in:
- Improved short range sea ice forecasts (ice edge position first). Waiting for assimilation of sea ice parameters extracted from SAR in operational models. Waiting for improved SIT retrieval from satellite data, for assimilation as well.
- [SI edge, SIC] climatology (monthly mean for each year) based on SAR data
- icebergs climatology and uncertainty estimates.

Question 4: The definitions of the terms „near-time time“ (NRT) and „high-resolution“ vary between users depending on whether this is for tactical and navigation, planning or

climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer:
For our mission, NRT means less than 24 hours.
High resolution for sea ice products: few kilometers.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer:
We expect a development of the needs, because of the increase of area of ice marginal zones and the increase of maritime traffic in Arctic seas.
We wish improvements in sea ice and icebergs products: better NRT estimates, and climatological products over the recent past. At the best space/time (for NRT) resolutions offered by the sensors/modelling tools. With access to uncertainties.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer:

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: regular workshops, seminars about Copernicus product in Ice domain to explain to non ice specialist specificities of this area, constraints, limits, and to have regular occasion to exchange on this thematic.
If possible, extend the product to Antarctic area.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer:

9)
SCANEX:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: we provide a geoportal for shipping companies where they can trace sea ice conditions in real-time.
Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to

meet?
Answer:
MET NEED: The real-time information about sea ice condition (radar and optical images, primary
analysis), location of vessels, hazardous ice features and difficult areas.
UNMET NEED: Hourly provided changes in ice conditions and forecast of sea ice conditions (drift,
compressions zones)
Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer:
- Automatic identification of hazardous areas and sea ice features
- Automatic drift forecast of the hazardous areas and sea ice features
- Data from Asian satellites are planned to be used
Question 4: The definitions of the terms „near-real time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: at that moment, "near-real time" for us is:
- providing radar images in 30 min up to 6 hours
- updating information twice or once a day according to available images
- In future perspectives: providing hourly information of sea ice situation changes.
For large sea scale navigation resolution about 100 m is suitable.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer:
For future requirements Improved temporal resolution and coverage of provided data make the difference. The main needed products are becoming those which reveal is not so straightforward from the visual analysis such as sea ice thickness, compression zones, and the forecast of main sea ice characteristics.
Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: Have nothing to add yet.
Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: the main advice would be to communicate more with end users and get more feedback to let them build the new products outlook.
Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: Unfortunately, can't think of any example.

10)
EQUINOR:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer:
Equinor is a broad energy company engaged in exploration, development and is a production of oil and gas, as well as wind and solar power. Equinor sells crude oil and major supplier of natural gas, with activities in processing, refining, and trading. The company uses satellite imagery (Sentinel, Landsat, Radarsat) to detect and track sea ice and icebergs in connection with marine operations in areas where sea ice or icebergs may occur.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: Most important needs are to monitor and forecast the advancing sea ice edge, characterize sea ice in terms of concentration, floe size and features like MY ice, ridges, rubble fields, etc., and to detect and track icebergs.
Detection of icebergs embedded in sea ice is still being a challenge. Prediction of sea ice drift and iceberg trajectories over multiple days are also interesting challenges.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: Daily coverage of high resolution SAR images will likely improve iceberg and sea ice monitoring for operations and enable development of new services.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: Near-real time means timely enough to be of tactical use (available within 1-2 hours of acquisition). High-resolution depends on the setting, but for sea ice and icebergs, this would mean being able to identify individual ice floes <50 m and iceberg targets < 50
m waterline length.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: Shorter time between image acquisition and analysed product being delivered to operations. Improved automated algorithms for identifying hazardous features.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: Not sure how to illustrate the link, but our industry (resource extraction in Figure 1?) is not only using data/services in an operational setting, but also uses historical data to derive design (e.g. 10-4 yearly exceedance probability) metocean parameters for temporary and permanent structures.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: More accurate prediction of the movement of the Marginal Ice Zone, taking into account wave modelling within the ice pack and sharp gradients in sea surface temperature.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: Not for the moment.

Weather Services:
Responses: 6 (4 before IICWG-DA)

1)
AEMET:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer:
The general mission of AEMET in polar regions is provide both observations and forecasts to users in the Antarctic area of influence of Spain and emit the BUFR of our AWS to the Global Telecommunication System of the WMO. We offer meteorological observations in the islands of Livingston (where we operate 3 stations) and the island of Deception (where we operate 1 station). We also provide personalized forecast for safety and logistics to the Spanish stations and research vessels in the area. We recently provided forecast to the new Spanish polar vehicle Windsled in East Antarctica. We also collaborate or advice different scientific research projects. Polar observations are critical to provide all this information.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon?

Conversely, what are the most important needs of your users that you are not able to meet?
Answer:
We have two kind of users:
- Managers of the Antarctic Spanish Program, stations and vessels need to have accurate forecasts for logistic and safety purposes. Our main tool for forecasts is the ECMWF model which need to be initialized with the scare polar observations in the area. They also need observations in the research station to manage the renewable energy (wind and sun generators) to maintain some research equipment during the wintering.
- Scientist often need meteorological observations to put in context their research. Sometimes they need some observations that we are not able to provide (e.g. specific biological parameters or data from isolated places where we do not have observations, accurate precipitation). Furhtermore, they need meteorological support for safety to do their job: forecasts for different areas of Livingston and Decepcion and wave forecasts for the bays (South Bay and Port Foster). The activities on the sea (sampling of marine flora and wildlife) are increasing more and more in the last years and so, more and better information is required,especially in terms of wind and swell waves on coastal areas where the global models do not behave well. The most critical activities are the movements around the Livingston glacier where the meteorological conditions may be very different from the Spanish stations Juan Carlos I despite their proximity, and the movements around the Byers Peninsula, where there is an international camp managed by Spain.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer:
We are currently working to provide a better precipitation observation in the area. We are also planning to install new AWS in summer with near-real time observations to provide information to the areas the forecaster is not familiar. We also are improving our forecasting tools to provide a better information to the different users we have during the campaigns. The latter is based upon a multi-model high-resolution area limited EPS that uses ECMWF and other global models for boundary conditions.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer:
High-resolution: for models up to 3 km resolution (for example our EPS have 2.5 km)
Near-real time: for observations up to 1-hour delay for the weather forecaster and 3 hours delay to arrive the data in Spain.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer:
The forecasting needs are more and more demanding. The details of the forecast asked are increasingly because there is a greater concern for the safety. Furthermore, the area of

the scientific activities is increasing, inside the islands and on the sea, which requires a major effort for the weather forecaster to study the weather of other areas we are not familiar. This imply also the knowledge of weather in-situ.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer:
Our main link with different kind of users is the Marine Technology Unit (the Managers of the Antarctic Spanish Program)

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer:

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer:

2)
NOAA/IASOA:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: My institution is NOAA. Since IPY we have facilitated www.iasoa.org to allow pan-Arctic views of the environment – so far primarily for research. Now we are utilizing the IASOA network to support model-observation research strategies of the Year of Polar Prediction. The general mission of NOAA is environmental data collection, monitoring, research and development of services. My research is focused on developing a system level approach to understanding the Arctic environment rather than research divided into disciplines.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: Currently the YOPPsiteMIP component of the PPP requires matched, high frequency high resolution model output and in-situ surface observations. The in-situ surface observations for each observatory (or ship or ice camp) need to be integrated into a single netcdf file with compliance with variable naming, units, attribution, etc etc.
This is very challenging. The next YOPP newsletter will have an article describing these challenges and progress. These Merged Observatory Data Files are intended to leap frog

over all the Arctic repositories, portals and data search tools because these are currently not sufficient to create the desired complex integrated data product.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: A standard protocol for creating Merged Observatory (or Ship) data files for single sites and/or campaigns (for instance MOSAiC). Observations will be based on IASOA, GCW, MOSAiC etc.
We would like to partner with INTAROS and Copernicus on this endeavour.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: near-real time is within 7 days. High resolution is 1 min for observations and 7.5 min for model output.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: These observational data sets may lead to the development of model verification tools that will be essential for assessing forecast skill (weather, sea-ice, climate).

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: Are you communicating with Sandy Starkweather? She is developing a tool for creating "value trees" that show how different observations are relevant for different applications. This seems to be the main activity of SAON now. She could send you a sea-ice forecast model value tree which is interesting.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: The community needs to figure out how to use the research grade surface-based observations in services and development of real-time products. This is a challenge in an environment where people still want to sit on data and results until they have had a chance to do individual research publications. The challenge is to take the considerable amount of research observations which were installed with an end goal of publications to also be available for real-time monitoring and products. Any plan for an enhanced observing network should be based on a plan for full utilization of the existing observations. Data from the existing observing infrastructure is currently inaccessible and non-standard making it highly unusable for services and products (including forecasting).

Question 8: Could you please provide any documentation or publications, such as

outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: The National Science Foundation funded a number of Arctic Observing Network Workshops resulting in reports.
Here are some old ones:
https://www.arcticobserving.org/images/pdf/Reports/National/USA_-_AON.pdf
https://www.nap.edu/resource/11607/aon_brief_final.pdf
Here is a more recent one:
https://www.jstor.org/stable/43871389?seq=1#page_scan_tab_contents
I don't think these requirement surveys are changing much over the years. I think that the time is past for planning for an observing network and it is time to start developing strategies for full utilizing the existing Arctic Observing network. NOTE: I am speaking from the perspective of the ground-based in-situ observing assets – I am under the impression that Copernicus is more about the satellite observations. However, think about how the surface observations could be continuously benchmarking the satellite observations, etc.
In my mind the Arctic Observing Network exists now. GCW, IASOA, IABP, The Arctic Rivers Observatory, CALM, IPA, INTERACT, DBO, PAG, etc try to organize and harmonize the measurements but there is a long way to go towards having an observing network that is creating a fully utilized output. I get discouraged when the discussions devolve to planning a hypothetical observing network that in my mind largely already exists.

3)
JMA-MRI (ice/ocean reanalysis):

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: The general mission our institute, Meteorological Research Institute, is to develop a system for use in the operational monitoring and forecasting by the Japan Meteorological Agency (JMA). Global atmosphere, ocean and sea ice observations, including polar observations, are used for validation and calibration of both component and coupled models and for initialization of forecast and reanalysis experiments. Polar observations are potentially important since the observations are sparse and the model representation is relatively insufficient in the polar regions.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: Forecast experiments by JMA are mainly conducted with the same atmosphere and ocean systems for the reanalyses (e.g., JRA-55 atmospheric reanalysis). Near-real-time observational data are used for the operational forecasting.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?

Answer: I am working for developing an improved ocean-sea ice reanalysis. For this, sea ice concentration, thickness and velocity observations as well as limited ocean in-situ observations are/will be used.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: About 5 days and 10 km.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: I consider that our better initializing sea ice and snow thicknesses is needed. Accurate observations for these variables are of great value.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer:

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer:

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: Uotila et al. (2018) An assessment of ten ocean reanalyses in the polar regions. Climate Dynamics. Doi:10.1007/s00382-018-4242-z

4)
Météo-France:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: Météo-France is the french National Meteorological Service. Its operational mission is to provide information about the state of the atmosphere and the ocean surface at various horizontal scales (global, regional, local) and time ranges (from nowcast to seasonal forecast), to public agencies (including defence) and private sector. Polar observations are needed to initialise/constrain our global Numerical Weather Prediction and Seasonal Forecast systems.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: Météo-France provides meteorological information over polar areas mainly to the French Navy and to some air companies. Moreover, accurate sea ice concentration and thickness information is very important for the initialisation of our seasonal forecasts.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: we don't have plans for developing new products/services over polar areas.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do

you define them?
Answer: for our global Numerical Weather Prediction system, "near real-time" means in less than 3 hours after observation time and "high resolution" means better than 10 km. For our seasonal forecast system, "near real-time" means within 1-2 days after observation time.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: the French Navy is expected to have in the future a growing need for information for navigation in the Arctic Region, in particular concerning sea ice and icebergs (observations and forecasts). This translates into requirements for sea ice observations (in particular concentration and thickness) at higher horizontal and temporal resolution than the operational near real-time satellite-based products currently available.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: No.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: Generally speaking, Numerical Weather Prediction systems prefer to use satellite level 2 products than level 3 or 4 products (resulting from further interpolation/compositing steps). Information on observation errors/uncertainties is crucial.

Question 8: Could you please provide any documentation or publications, such as

outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: No.

5)
METNO:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?

Answer:
The Norwegian Meteorological Institute (MET Norway) is the national public meteorological service in Norway. The institute provides information to public authorities, businesses and the general public to secure life and property and in support of economic activity, societal planning and environmental protection. This includes operational monitoring and forecasting for large North Atlantic and Arctic areas.
The duties include:

- Issuing weather and ocean forecasts for the Norwegian land and sea areas and for northern and polar oceans,
- Providing meteorological observations from Norway, adjacent sea areas, and from the Svalbard area.
- Carrying out research and development to ensure that products and services are of the highest possible standard
- Examples of special services for Arctic areas are
- National Ice Service (ice charts for navigation use)
- Responsibilities in Copernicus CMEMS and C3S for Arctic ocean and waveforecasting/reanalysis and for Arctic weather reanalysis.

MET Norway has an open, user-oriented data policy and observations and forecasts to a large spectrum of users are delivered through different data services. The weather forecasts are presented on Yr (app and web), one of the world's most used digital weather services. Both the data and services are digital, public goods. Since 2018 MET Norway are using citizen observations in our (automated) weather forecast production through postprocessing the NWP forecasts updating the forecasts every hour. A novel methodology has been developed which allows about 80% of the observations to be exploited. This includes also the northern part of Scandinavia. At Svalbard, the density is still too low for these observations to be used fully.

In response to the urgent need for Arctic weather prediction, a convection-permitting mesoscale model for the Arctic has recently been introduced into service by MET Norway. AROME Arctic, an operational short-range, convection-permitting prediction system dedicated to the European Arctic, issues forecasts four times per day with a lead time of 66 hours, at a horizontal grid spacing of 2.5 km. NWP models generally show lower forecast capability at high latitudes compared to other regions. The difficulties for NWP in the Arctic are exacerbated by a sparse conventional observation network, especially over the ocean and sea-ice, which is both error-prone and of limited representativeness. Observations play a cross-cutting role in the context of NWP in that they are used for understanding and parameterising physical processes, for model verification, and for model initialisation. For verification and process study purposes over the Arctic, past campaigns (e.g. IPY-THORPEX) have not yet been fully utilized, and several YOPP campaigns are being analyzed and planned. Initial conditions (ICs) for forecasts are generated through a process known as data assimilation (DA), where a statistically optimal blend between a previous forecast or model state, and the currently available observations is obtained. In addition to the radiosonde network, satellite observations are a crucial data source in the Arctic. Retrieval methods are, however, challenged by the prevalence of snow and ice-covered surfaces and clouds resulting in sub-optimal observational data usage and rejection of large data volumes. Traditional 3D-Var DA is designed to use observations around the assimilation time, meaning that only a small fraction of the available satellite data is ingested. State-of-the-art 4D-Var DA, however, allows the assimilation of data at all observation times within an assimilation window, and so introduces flow dependence, which has been shown to lead to tremendous improvements in forecast performance in global models. Ensemble Prediction Systems (EPSs) have been developed to include estimations of forecast uncertainties. Uncertainty is also a key element in DA, allowing the model to acquire observational data where the model is uncertain. Thus, optimizing the capability of DA to exploit the observations to the fullest possible extent and EPS development are closely related key challenges. MET Norway are among other things working to advance atmospheric mesoscale and sea ice DA in the Arctic by using more and new observation types, optimize observation usage and implement state-of-the-art analysis techniques for the benefit of weather prediction. This includes observation system experiments (OSEs) in coordination with YOPP and ECMWF.

A coupled ocean-sea ice model on the same grid as AROME Arctic, based on ROMS and CICE, has been developed and has been running operationally since February 2019 at MET Norway. This system, which is named Barents-2.5km, will constitute the ocean-sea ice components of what could eventually become a fully coupled ocean-atmosphere-sea ice-wave modeling system.

MET Norway is together with the Nansen Environmental Remotescensing Center (NERSC) responsible for the pan-Arctic Copernicus marine ocean, sea-ice, wave and bio-geochemistry forecast and reanalysis system. The ocean and sea-ice model uses an advanced data assimilation technique (the Ensemble Kalman Filter) to constrain the system to six real-time satellite and in-situ observational products. In addition to the dissemination of daily forecasts and a reanalysis, a broad range of product quality assessments are performed on weekly, monthly, and quarterly intervals. In the near future (between November 2019 and February 2020) this system will evolve in a new ocean sea-ice model model setup with a horizontal resolution of 6 km and 52 hybrid vertical levels. The ocean, ice and wave models will be weakly coupled. In addition, a high-resolution (3 km) pan-Arctic sea-ice, ocean circulation and tide model will be run as a deterministic forecasts system, together with a 3-km wave forecasting system issuing 10 day forecasts twice daily. A pan-Arctic setup of the nextSIM sea-ice model will be introduced as a stand-alone sea ice system. The product quality assessment is updated on a weekly basis. A variety of methods is applied for presenting the validation results. The aim is to provide users with information ranging from simple statistics to detailed model/data inter-comparison. More than 60 different metrics are provided for users via cmems.met.no. Novel verification techniques are used, e.g. to perform high resolution satellite and in-situ data based ocean, sea-ice, wave and biogeochemistry verification.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?

Answer:
In the Arctic, the societal value of fundamental weather research is strongly conditioned upon the ability to provide forecasts and warnings that user groups can incorporate in their decision-making processes. In concert with a rapidly changing Arctic climate, the interest, presence and activity in the Arctic has never been greater. The breadth of MET Norway thus encompasses a large number of different end-users and stakeholders. Polar weather prediction is improved when the research results are transformed into better informed decision making for users: Knowledge and data, products and services will be disseminated and co-produced for the benefit of safer and more efficient operations in the Arctic. Through MET Norway's value chain structure we build directly on the existing user and stakeholder mechanisms that are evolving between the service provider and the user community, they will serve also in the exchange of requirements, opportunities and experience. For instance, we select and analyse high-impact weather events and weather prediction verification measures for relevant activities and decision making, and we have priority to enable stakeholders to use the advances of probabilistic forecasting. Our value chain also serves the interests of downstream (operational) models. For instance, improved polar NWP capacity will lead to improved results in high-resolution regional sea ice models, which is important for ship routing and planning offshore operations.

High quality weather forecast are top on the list, including the ocean state
More generally, see previous question.
MET Norway are utilizing available near real time operational observations.
Most important are:
Meteorological network of observations as coordinated by WMO
Operational satellite data provided through the co-operation in EUMETSAT
In addition with increasingly importance comes Copernicus Sentinel satellite data.
Generally there is a constant demand for more and more products about weather and ocean analyses and forecasts with high accuracy. Parts of this demand can be met by innovations and development.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?

Answer:
The products/services in the next 5-10 years will be improved versions of what is currently delivered, including an EPS of AROME Arctic and Barents-2.5km. Forecasting high-impact weather (HIW) events in the Arctic has proven to be especially challenging. Repeated severe forecast misses, aggravated by fast climatic change inducing unusual weather, have had dramatic consequences for local communities. Such HIW events include intense and rapidly

developing mesoscale cyclones known as polar lows embedded in large cold-air outbreaks (CAOs) characterised by convective processes, icing conditions from sea spray during winter, episodes of persistent fog during summer and aviation icing, and avalanche and landslide risks after heavy precipitation. In NWP we collaborate with several partners to improve the uptake of observations. One example is to assimilate citizen pressure observations.

Main priorities are dedicated numerical weather and ocean analysis and prediction models capable of utilizing available observation systems. General focus are on NWP and ocean/ice modelling covering Svalbard area, Barents sea and well into the polar ocean. Two main development lines are:
• Better exploitation of satellite data (level 1 and retrievals; atmospheric sounding and ocean surface) e.g. though new development in data assimilation.
• Earth system model approach through coupling between the atmosphere/ocean/sea ice/wave/land models
There is a very large amount of data from polar orbiting satellites available today, and the main challenge lies in the capability for utilization of these data.
However, it is absolutely required to secure the continuation of the satellite observing system, and as a part of this, improved capabilities are very welcomed. For example, microwave instruments that are capable for monitoring key information from atmosphere and surface ocean-atmosphere fluxes. We expect the next generation of such instruments to able to provide the same information.

Question 4: The definitions of the terms "near-time time” (NRT) and "high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?

Answer:
NRT has traditionally meant within 3 hours in operational meteorology. This is linked to the time frames of synoptic scales and the basic 6 hourly data assimilation cycle and the need to get data in time for this. However with development of continuous data assimilation and higher resolution model systems the NRT is now closer to 10 minutes. For some applications the term is less strict. (For climatological usage the term NRT is not relevant).

Horizontal resolution of analysis and forecast models now in use on regional scale are approximately 2.5 km. We foresee models down to 500 m for local downscaling and short term forecasting. However, there is a tradeoff where increased resolution often goes with larger variability and uncertainty. As a consequence, more resources are being spent on ensemble prediction systems that provide additional information on forecast probability, as very often required from users.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?

Answer:
With increasing human activities in polar regions, there are great expectations in the development of new meteorological services. There is a high-demand of monitoring and forecast information. Users already request this information at, or even below, kilometer-scales resolutions. Thus, observation with high spatial resolution and temporal frequency are needed, as well as, observations of the coupled ocean, wave, sea-ice and atmosphere system, in order to better understand and simulate these coupled processes. It will be crucial to incorporate the processes and/or related uncertainties to disseminate useful products, e.g. close or within the Marginal Ice Zone. Good examples would be, satellite observation which allow to better estimate the sea-ice-ocean-atmosphere energy budget, and also providing capability for improved sea-ice lead and possibly ice-flow-size estimates.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?

Answer:
A complex figure which is not easily transferable. Perhaps it is better to take a end-user centric view focusing on (some of) the different end-users in the Arctic?

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?

Answer:
Surface fluxes are important and improved accuracy and resolution of the surface description has a potential for improvement (e.g. satellite based SST and sea ice data, glacier coverage and albedo as well as satellite snow products). An important contribution for ocean and sea ice information will be the planned CIMR Copernicus mission. Another important challenge is the capability to utilize SAR data in synergy with data from other sensor and models to improve the surface analysis (ocean, ice and land).

Improved capability to measure wind, temperature and moisture in the Arctic atmosphere, along with improved methods for use of this information in synergy with surface data in NWP models.

The radiance data from polar orbiting satellite are key observations in an Arctic regional model. We have proven the good impact from wind retrievals from polar orbiting satellite in our AROME Arctic. Unfortunately, not all produced wind retrievals meet our operational timeliness requirement. It would be good to have all products meeting both global and regional operational NWP requirements.

More resources should be spent on exploiting previous observation campaigns for improved understanding of both physical processes and the design of the Arctic observation system. Future campaigns should also include OSEs or similar as part of the experimental set-up. Also, more focus and resources should be dedicated to exploiting the, at a given time, existing observation system. That is, further develop the physical understanding of polar processes for better representation in the numerical models and algorithms for assimilation of observations in the same model systems.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?

Answer:
https://sios-svalbard.org/sites/sios.metsis.met.no/files/common/D3.4_SIOSInfrastructureOptimisationreport.pdf

relevant recent publications can be found here:
https://www.polarprediction.net/documents-publications/research-publications/

MET No report on the availability of atmospheric motion vectors:
I was not aware until now that this report was not yet put on the web. I'll ask for it next week.

Impact of polar orbiting satellites on regional Arctic NWP model:
Randriamampianina, R.; Schyberg, H.; Mile, M. Observing System Experiments with an Arctic Mesoscale Numerical Weather Prediction Model. Remote Sens. 2019, 11(8), 981; https://doi.org/10.3390/rs11080981

Køltzow, M., B. Casati, E. Bazile, T. Haiden, and T. Valkonen, 2019: A NWP model inter-comparison of surface weather parameters in the European Arctic during the Year of Polar Prediction Special Observing Period Northern Hemisphere 1. Wea. Forecasting, 0, https://doi.org/10.1175/WAF-D-19-0003.1

6)
UKMO:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: General mission is weather and climate services. At the moment we assimilate sea ice concentration observations for initialisation of models and producing analysis products (which are also used as boundary conditions for atmospheric models), and are working on sea ice thickness assimilation (not yet operational). Sea ice concentration observations are also used for validation and verification of models. This covers both short (days) and longer timescales (seasonal, climate). Additionally polar observations are used for monitoring, particularly sea ice concentration.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: Using sea ice concentration observations addresses the needs of our users who are interested in accurate weather forecasts not only for the polar regions but for the wider area influenced by the poles. Currently working on sea ice thickness assimilation to address needs of users who are interested in specific short-term and seasonal forecasts of sea ice. Users would probably be interested in higher resolution forecasts of sea ice variables than we can currently provide.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: Currently working on sea ice thickness assimilation to improve model initialisation for short-term and seasonal forecasting of sea ice concentration, thickness and extent. We may also be interested in other variables such as sea ice temperature, which is of particular relevance to coupled modelling, and sea ice drift. There are plans to update ocean-ice models from using ¼ degree to 1/12 degree orca tripolar grids.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: NRT: Arriving in time for use in operational models, so within 24 hours ideally or up to 48 hours. High-resolution observations could be defined as those on a smaller grid than the model. A high-resolution ocean model would be something eddy-resolving. A high-resolution sea ice model would be something on a small enough grid to provide forecasts at a scale suitable for navigation.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: With the reduction in Arctic sea ice extent, we would expect more activity e.g. shipping to take place, and therefore safe navigation is a major concern. This requires improvements in not only spatial resolution but in the accuracy of Arctic sea ice forecasts (short-term and seasonal) by using high-quality NRT observations of sea ice conditions, with well-defined uncertainty information, to initialise the models. Additionally, exploring the effects on European weather and climate of changing sea ice cover is also of importance. These applications also require polar observations for verification and validation. It is also important to note that a continuous timeseries of observations without gaps for monitoring, assimilation and validation is vital, as is the availability of long, homogenised timeseries of consistently reprocessed observations.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice

Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer:

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: Well-defined and validated observation uncertainty estimates are vital to make the best use of data assimilation for model initialisation. Accurate observations are obviously useful, but we can make use of lower accuracy observations if the uncertainties are well known.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer:

Satellite Production Research/Services:
Responses: 7 (4 before IICWG-DA)

1)
DTU:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer:
We provide a wealth of near real time observations and value-added products of local, regional and global sea ice conditions to end-users operating in or with an interest in Polar regions. Polar Observations from satellite are crucial for our service.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer:
The most important needs of our users are near real time high quality observations at high resolution and with a minimum delay from observation time combined with forecasts. Our service is based mainly on satellite data from Sentinel-1 and AMSR2, and we use forecasts from the Copernicus Marine Environment Monitoring Service. The main limitations we face are related to latency of delivery of satellite products (we would like delivery within minutes after acquisition), resolution of the products (especially the passive microwave products) and the quality of the forecasts (we need better forecasts at higher spatial and temporal resolution). We also need satellite observations that can be used for automatic

product generation since automatic products generation is another way of limiting delays.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer:
We have high expectations for future high resolution (<5km) microwave radiometry such as the potential CIMR Copernicus mission. We are currently working on AI methods to combine high resolution (< 5 km) passive microwave data with Synthetic Aperture SAR data from Sentinel-1.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer:
Near real time to us means delivery in minutes (preferably 30-60) after data collection /acquisition.
High resolution passive microwave data means <5 km that can be used in automatic generation of products.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer:
Downstream users will (and already do) require fast delivery (minimum delay from acquisition), high quality and reasonable resolution. Communication limitations typically limits end-users at high latitude to resolutions in the order of 100s of meters, depending on number of products or time resolution of forecasts. The use of appropriate data compression technologies is crucial. High resolution microwave radiometry combined with reliable at least daily C-band SAR data are our main requirements to the observation system. In addition effort should be put into better forecast modelling and data assimilation.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer:

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer:
A key missing variable is high resolution sea ice thickness for navigational purposes. Monthly maps are not very useful, but technology to provide at least weekly maps at a few kilometre resolution should be developed. In addition there is an urgent need to improve

forecast models and data assimilation methods for sea ice forecast modelling.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer:
http://marine.copernicus.eu/wp-content/uploads/2018/11/Position_Paper_CopernicusMarine_Polar-and-Snow-Cover-application-workshop.pdf

2)
IFREMER:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: We work to process and distribute ocean observation from satellites through an archive center to the scientific community, and analyse them through scientific studies. Our ocean parameters include sea-ice and icebergs parameters with more than 25-year time series with validated data. Some of them are distributed through the CMEMS, some are only available at our archiving portal, other datasets are test data and only available from request because there is still ongoing work. Our data have been produced through scientific projects funded by spaces agencies or Europe.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: High resolution products for some studies. Not a problem since we are working at large scale mainly and other institutes work on high resolution data

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: We aim to continue our long time series with adding new sensors (MetOp-C, CFOSAT new sensors etc). Not sure that we will have them on CMEMS but through our institute archive center

Question 4: The definitions of the terms „near-time time” (NRT) and „high-resolution“ vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: NRT=daily, high resolution = < 5 km

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?

Answer: ?

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: I dont see more links between users.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: no

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: no

3)
AWI-CCI-C3S:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: The sea ice physics section at the Alfred Wegener Institute produces and dissiminates sea-ice thickness remote sensing datasets on an operational basis. Our role it to support European Climate Research activities within the ESA Climate Change Initative and the Copernicus Climate Change Service. Besides the remote sensing data, we rely on direct observations of sea ice properties (freeboard, snow depth, thickness) for the quality control of the data service.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: We provide monthly gridded sea-ice thickness fields with a timeliness of 1 month based on satellite radar altimetry (Envisat, CryoSat-2). Sea-ice thickness information from these sources however currently does not meet the GCOS uncertainty requirement (< 0.1 for monthly gridded data at a resolution of 25 km). In addition, in-situ observations that can be used for quality control and the evolution of satellite retrieval algorithms are even more sparse in the European sector of the Arctic. Regular monitoring program, such as moorings with upward looking sonar would help to close the gap during winter, when data from ship- or airborne sensor platforms are not available. The most important need however is the continuity of high latitude satellite radar altimetry, e.g. by the proposed Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL). Its dual-band capability has the potential to reduce the uncertainties towards the GCOS goals.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: We plan to extent the sea-ice thickness data record back in time (since 1993 with the ERS-1/2 satellite missions) and securing its continuity with the Sentinel-3 constellation. The sea-ice thickness retrieval algorithm for satellite radar altimetry is under constant development and we are investigating the use of data from reanalysis (e.g. snow depth on sea ice).

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: NRT (+2 day), high resolution: altimeter footprint (~ 1km)

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: Operational availability of sea-ice thickness from remote sensing is already requested from stakeholders in numerical weather prediction. Our requirement is open and timely access to reanalysis and EO data.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: We are a middle-man between Copernicus Satellites and Copernicus Users: We are both users and service providers

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: None, besides making data and algorithms as open as possible

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: http://esa-cci.nersc.no/?q=documents# -> Documents from phase 2 -> D1.1_SICCI_P2_URD_Issue 2.1.pdf

4)
MetNo R&D (sat-obs):

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering?

How important are polar observations to enable your service provision?
Answer: The present answer does not encompass all the relevant missions of my institution (the Norwegian Meteorological Institute), but rather focuses on our activities at the R&D dept, section for Remote Sensing and Data Management, specifically for operational sea ice monitoring activities for in-house users, CMEMS (SI TAC), C3S (Ocean ECV), OSISAF (both NRT and Climate), and ESA CCI.
The service/products are:
● various global sea ice variables (concentration, drift, type, edge,…) in operational "near real-time" (everyday, the maps for the day before must be distributed at 04UTC);
● high-fidelity Climate Data Records (again, concentration, type, edge... drift coming soon);
● high-fidelity Interim Climate Data Records (same as CDRs above) that seamlessly extend the CDRs with a limited latency (e.g. 16 days).
The products above are channelled through various European services (OSISAF, CMEMS, C3S, CCI). They are in addition used internally at the institute for data assimilation, forcing, or evaluation/validation of models. They are also prepared for use in daily production of downstream user services, such as sea ice charts at the Ice Service.
Obviously, we are very much reliant on the availability of polar (satellite) observations in order to deliver our services, to the point where loss of a specific satellite sensor (e.g. AMSR-E in Oct 2011) can lead to complete interruption of a product line, or switching to other sensors (SSMIS) with poorer characteristics. In-situ data are also important when we develop our algorithms, and when we validate the products. Noticeably, we are also users of forecast products: short-term forecasts (atmosphere) are used in some of our production chains as auxiliary information to improve accuracy of the satellite products. A beneficial loop is created where forecasts improve satellite products, which are themselves ingested in forecast models.
For our Climate products, we are reliant on the availability of fully cross-correlated Fundamental Climate Data Records: we do not have the expertise to do this ourselves.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer:
What we (think) we meet today:
● "daily" timeliness requirements;
● "global" coverage requirements;
● at a reasonable accuracy (depending on the variable, the season, etc…).
● climate consistency requirements for our Climate products (CDR and ICDR).
What we know we do not meet:
● the more stringent accuracy requirements;
● spatial resolution requirements: all of today's forecasting models run at higher resolution than what "workhorse" satellites (microwave radiometry and scatterometry) can provide.
● some of our products lack fully developed uncertainty information, as required for data assimilation. This is a knowledge gap that will require research and development. Uncertainties can be validated using future in-situ and EO data.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer:
We are not working on many new services, but rather work on the evolution and improvement of existing services to meet evolving user requirements. Thus we need continuation (with improvement) of our work-horses (microwave radiometry and scatterometry). Scatterometry is coming with EUMETSAT EPS-SG satellites (~2023-2040). For radiometry, our services will be very much degraded if none of CIMR or AMSR3 fly. If AMSR3 flies we can continue the service with today's characteristics (already not meeting today's requirements, see Q2). If CIMR flies we can improve our services to meet the documented future requirements (ref Polar Expert Group).
One new product we are developing for CMEMS is an automatic pan-Arctic sea-ice map using microwave radiometry data (AMSR2) and Sentinel-1 C-band SAR in synergy. This product is today limited in accuracy by using the high-frequency channels of AMSR2 (to achieve high-enough spatial resolution), the thermal noise of Sentinel-1 C-band, and generally the ambiguity of SAR signal to map sea-ice.
Although timeliness is maybe not an issue today, increased activity at high-latitudes and in the Arctic will require excellent timeliness (<1h between satellite sensing and product availability). Sea ice is always on the move, so very high resolution products with several hours delay is not very useful.
When it comes to climate services: there is an on-going pressure on us to improve the timeliness/latency of our ICDRs (from 1 month to 2 weeks…. to 1 week…). This would be more easily done if quality-controlled, re-calibrated raw satellite data was made available to us: we would need IFCDRs to improve the delivery of our ICDRs.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: There are some elements of answer above. Basically, "near real-time" means different things to us depending on the service provided:
● max 24h for today's daily maps that serve forecast models;
● <1h after sensing for future applications.
● a couple of weeks for climate data records today;
● a couple of days for future climate data services;
High-resolution is "1km-5km" for our services. Medium resolution is "10km-25km". Coarse resolution is "25-100km".

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: I think I actually addressed this in my answer to Question 3. They will want higher-resolution (<5km), more frequent coverage (global daily, polar sub-daily), better accuracy, and fully qualified uncertainty estimates. Some of them will also want better timeliness (<1h after sensing).
Concerning "method of delivery", the challenge with low bandwidth in the Arctic requires

use of extraction/compression of the products (including transformation to shapefiles), and/or new communication technologies.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: Maybe the “user-scape” could show the Space Agencies and their role both as raw data providers, product providers, and in-situ/Calibration/Validation data providers.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer:
● Shorten the distance between satellite data and forecast, e.g. through use of observation operators to assimilate satellite data at Level 2 or even Level 1. This was probably the intention at the start of CMEMS (having both MFCs and TACs under the same umbrella) but it is evolving rather slowly (if at all). In my opinion this is as important as improving the resolution of the models and satellite products on their own. This requires proper funding lines.
● For forecasting in the Arctic, there is an artificial barrier between the “NWP-community” (addressed by meteorological satellites) and the “Copernicus-community” (addressed mostly by Sentinels). This barrier is artificial in the polar regions (where a better weather forecast is truly as important as a current map of sea ice), and will tend to disappear when more centres adopt coupled forecasting systems. This separation is also an issue when designing satellites that will benefit both communities (e.g. CIMR). Copernicus should clarify this in the future.
● We need more centralized access to (ice-drifting) in-situ data. The most reliable collection point is currently the US IABP, run by a university and one or two Principal Investigators. There is a need for extending the In-Situ component of Copernicus to ice-drifting platforms. In the future, a capability to deploy such drifting devices, in coordination with other countries would be beneficial.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer:
1. The two Polar Expert Group reports;
2. The 2016 “polar ice and snow position paper” of CMEMS;
3. The recently published OceanObs19 paper by Traon et al.
4. The report from the “SST and sea-ice observations” workshop in ECMWF in 2018 (https://www.ecmwf.int/en/learning/workshops/workshop-observations-and-analysis-sea-surface-temperature-and-sea-ice-nwp-and-climate).

5)
Norwegian Computing Center:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: We develop retrieval algorithms for cryospheric observations, including sea ice. Service providers we collaborate with use these algorithms. Our needs are primarily related to satellite observations, including optical, SAR and PMR. However, we use sea ice products from other services for intercomparison and validation.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: We are currently working on algorithms for ice thickness based on the dampening effect sea ice has on thermal emission from the water below the sea ice. This is limited to thin sea ice (< about 0.5 m) with no or a thin snow layer atop. Direct measurement of the snow-layer thickness would make the retrievals more accurate. Our optical/thermal measurements, limited by cloud cover, give 1 km spatial resolution. Alternatives based on microwaves give spatial resolution inferior to this (like SMOS).
We have developed a multi-sensor/multi-temporal approach that fuses optical and PMR for snow cover monitoring. This has been used together with MET Norway for producing a global snow cover ECV from 1982 until present based on AVHRR GAC and SMMR+SSM/I giving daily 5 km spatial resolution products of full coverage (not limited by cloud and polar night). Higher spatial resolution would benefit the user community.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: Sea ice thickness based on thermal observations with significantly improved cloud masking. 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.
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.

Question 4: The definitions of the terms „near-time time” (NRT) and „high-resolution“ vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer:

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer:

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer:

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer:

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer:

6)
Antarctic AWS Network + sat-composite services:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer:
Mission: Research in observational meteorology and the stewardship of meteorological data along with the ability to provide such data and expert assistance to the Antarctic community in support of research and operations.
We are both a user of and "creator"/provider of polar observations. The primary items we do create and provide are observations from Automatic Weather Stations (AWS) and satellite composite imagery.
Polar observations are crucial to our work. We are "observationalists" by trade.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer:
Basic meteorology observations – for supporting weather forecasting, research and climate understanding needs. These are based on our Automatic Weather Station (AWS) network and our Antarctic satellite composite observations.
Not able to do enough observational locations. Not enough types of observations (e.g. 4-component radiation, although we are striving to meet that demand despite the problems in getting those observations 'automatically')…and the problems with having automated observations (e.g. frozen wind sensors, etc.)

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations

will these be based upon?
Answer:
We are building a new AWS electronics “core”….for both climate and weather applications….for Antarctica. This is based off of lessons learned on the current AWS network in Antarctica.

Question 4: The definitions of the terms „near-time time” (NRT) and „high-resolution“ vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer:
NRT – is not seconds like it is in the USA, but it is within an hour to perhaps really on the order of a few minutes to a minute. In a few short years for Antarctic need, it will increase to a fast rate….seconds… But not yet.
High resolution – that is currently on the order of 1 kilometer for spatial satellite imagery…but the high resolution that is around like 0.5 and 0.25 km is handy!

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer:
More sophistication…more detailed need….more specific types of observations to address science questions….more spatial and temporal resolution requirements, etc.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: Not for your diagram per se…but our own US one…which we are striving to have one developed - e.g. an initial start in this abstract/poster at the recent 14 th Workshop on Antarctic Meteorology and Climate (WAMC): (It’s not posted to the web yet, but once it is we can get that to you if you wish…)

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer:
International cooperation is key – and happens despite limited political support (even from funding agencies that do target the polar community). If we did have better agreement in advance at the programmatic level, it would enhance our abilities to be more effective.
Connect the link between the observation and the forecast improvement…not just model… training forecasters to be better at the use of more advanced observations!

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?

Answer:
This is a US-Centric document:
http://amrc.ssec.wisc.edu/CyberinfrastructureReport_August01_2017.pdf

7)
ICDC (Hamburg):

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: I am working for the Integrated Climate Data Center at CEN of the University of Hamburg. Our aim is to provide access to (mostly) climate-relevant Earth observation data products (mostly from remote sensing but also in-situ) in an easy-to-handle way and to provide scientific user support and consultation. We do (almost) not produce any Level 2 or Level 3 data from satellite observations on our own but re-distribute such products obtained from other institutions and agencies such as NSIDC, ESA, Eumetsat. We are, however, engaged in quality assessment of and value-adding to such products, eventually creating Level 4 products on our own.
Customers can download our data via http or ftp and can use them within the CEN network as a registered user. Most data are provided via request. Usage via OpenDap is possible as well.
Among the products we are offering are sea-ice concentration, thickness, age, drift, snow on sea ice, ship-based observations, melt-ponds on sea ice, polynya fractions, lead fractions and locations.
Polar observations are one important ingredient of our repository, which covers data from the ocean and atmosphere as well as over land in addition to cryospheric data.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer: Our principal users are climate researchers – often from a different discipline. Data therefore need to be easy-to-understand with a clear description about the data usage and limitations of it. Data need to be in a format that they can easily be ingested in codes, be it regular programming codes or model codes.
The majority of the polar observations we are offering are based on satellite remote sensing – not surprising since our users mostly require long-term consistent data sets. We cannot meet any near-real-time requirements because we are not a 24/7 institution but belong to a University.
We also cannot meet any need dedicated to a re-processing of a data set since we mostly offer data which are ready-to-use from a different institution.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer: We will simply continue with our service and product portfolio with respect to polar observations. It is currently not foreseen to ingest major new data sets. It is however

likely that we are going to continue and intensify our consultation and quality assessment line to value add products. These will mostly be for the larger scale data sets provided by polar orbiting satellites. We will continue with our product evaluation activities by means of inter-comparing various independent data sets; this might also include standardization of in-situ observations.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer: We don't offer near real time data. My understanding of this is, however, that the time difference between data acquisition and data product provision is less than 24 hours. My understanding of "high-resolution" is connected to the respective satellite and frequency used. While for passive microwave observations a grid resolution of around 5 km I would consider as high-resolution, with optical instruments and/or SAR the grid resolution needs to be 30 m or better to achieve the term "high-resolution" from me.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer: It seems relatively clear that this is a two-sided issue. Climate researchers on the one hand continue to call for long-term, consistent, easy-to-use data. This calls for a reasonable continuation of current satellite missions and, in addition, high-quality inter-sensor corrections and calibrations. On the other hand, model development goes clearly towards smaller spatial scales and resolving smaller-scale processes. This calls for a better handling and improvement in merging of high-resolution data and products. The bottlenecks here are often coverage, cloud contamination, and simply data volume. For our institution it is relatively clear that our capacities will not be sufficient to provide, e.g. global data at 500 m resolution or finer. I am quite sure that future development needs to take download times into account and that online processing and using of storage-intensive data will be required in the future.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: I don't think I feel skilled enough to answer this question.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: Without doubt this systems requires more sustainable in-situ observations to be used for evaluation. Ideas:
- EVERY polar-region going ship records conditions of polar waters / regions with a combination of manual and automatic sensing devices and observing techniques. It cannot be that polar expeditions come back without any report about the ice conditions.

- Development of cheaper buoy systems providing position and sea-ice parameters also in first-year ice regions.
- Continued development of under-ice UAV to get a better handle on the under-ice topography.
- Millions of sea-ice density and snow-density measurements
- More MOSAiCs
- A better communication between the different research disciplines and services. It is of utmost importance that everybody has the same understanding of accuracy, resolution, uncertainty and so forth.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer: I know that within the ESA-CCI sea-ice ECV project phase 1 and 2 user-requirement studies have been carried out which are possibly summarized in the so-called "user requirement documents" URD. You should get access to these via the respective esa-cci web page.

Forecast Research Groups:
Responses: 1 (1 before IICWG-DA)

1)
AWI-SIO:

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: The AWI-SIO consortium is operating a variational data assimilation system to produce Arctic-wide seasonal forecasts of the Arctic sea-ice ocean system. This means we are provider of products, but at the same time we use data products for assimilation into our system.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer:
Currently we are assimilating:
- Sea ice concentration (OSI SAF product)
- Sea ice thickness (from CS-2)
- Snow depth (IUP Bremen product)
- Sea surface temperature (OSI SAF product)

For validation we are using:
- Sea ice drift (OSI SAF and Kimura products)

 in situ Temperature and Salinity observations (ITPs and Argo floats)
 in situ ice drift (e.g. IMBs and drift buoys)
The model is driven by data from analyses by NCEP-CFSR/CFSV2 or ERA5

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?

This project has received funding from the European Union's Horizon 2020 research and innovation under grant agreement No. 821984

Answer:
Ideas for future services include:
 Regional sea-ice ocean forecast in support of navigation and resource extraction from daily to seasonal scales

Question 4: The definitions of the terms "near-time time" (NRT) and "high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer:
NRT means less than a day. High resolution is below 2 km.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer:
The users will always ask for forecasts with as much as possible detail (in the spatial domain but also in terms of nature of predicted variables) and as accurate as possible, even if they may not be capable of exploiting the full detail. We are part of this game.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer: No

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer: Generally we suggest to improve observational coverage in space and time and to reduce observational uncertainty. The trade offs between these dimensions are not obvious. Hence we have looked into objective means of their quantification (see, e.g.
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https://doi.org/10.5194/tc-12-2569-2018)

For our assimilation system it is essential that correct uncertainty ranges are provided with the observational products. This includes uncertainty correlation in space, time, and between variables.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer:
The following publication helps to identify the spatial bias of current ocean observation network in the Arctic Ocean, and helps to develop future observation strategy.
Behrendt, A., Sumata, H., Rabe, B. and Schauer, U. (2018): UDASH - Unified Database for Arctic and Subarctic Hydrography, Earth System Science Data, 10 (2), pp. 1119-1138, doi:10.5194/essd-10-1119-2018.

Copernicus Services:
Responses: 2 (1 before IICWG-DA)

1)
MetNO-ArcticReanalysis (C3S):

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer:
MET Norway: Weather forecasting and climate services. We provide services for Arctic areas.
C3S: Climate service - C3S 322 Lot 2 - Copernicus Arctic Regional Reanalysis. Arctic observations are of course crucial.
Will focus the responses below on the Arctic reanalysis, since that was requested in the mail.

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer:
User needs addressed: Regional atmospheric reanalysis supports a large range of uses, like for instance monitoring changes in the Earth’s temperature, and to understand other aspects of weather and climate change. Users span a range of sectors including policy, commercial, research and education. It features in numerous scientific studies and commercial applications.
Which polar observations based upon: All observations regularly used in NWP. We retrieve data from historical archives and products from EUMETSAT and national weather services. In addition to atmospheric observations, we also use datasets for historical ocean and sea

ice data (based on OSISAF and ESA CCI), glacier coverage and albedo (based on MODIS, processed by GEUS) and satellite snow (CryoClim processed by MET Norway). The observation basis is the same as for NWP, except that we need historical data. (Did you include NWP obs usage for your survey?)
User needs not able to meet: Not so relevant for reanalysis, since the method allows reconstructing all relevant atmospheric fields. But new observations covering present observing system gaps will allow better accuracy.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer:
The present Arctic reanalysis is starting production now and the reanalysis period 1997-2021 will be complete in 2021. It comprises two domains focussing on the Barents/Atlantic/Greenland side of the Arctic. We hope for a new phase of C3S after 2021 which will include an updated pan-Arctic reanalysis service, so a larger domain.

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer:
Will not address the question on definitions, but a continuous production of reanalysis will have some lag, and will need data within, say, one week. The data to be used are the same as those used for NWP, which have a much stricter need for NRT delivery.

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer:
As indicated, the next proposed generation of Copernicus Arctic reanalysis will be extended in space to become pan-Arctic, so we need observations over a larger area. Present horizontal resolution of our Arctic reanalysis is quite high at 2,5 km, and the next generation will not have finer resolution.

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g. SST). Can you identify where there are more links between different users?
Answer:
Nothing particular here.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer:
There are lot of past and ongoing scientific studies on this (applicable to both NWP and

reanalysis), so difficult to repond in short. Also such studies are ongoing now in the YOPP framework.
I will try to list at least some points:
 There is a gap of information on wind, temperature and moisture in the lower part of the troposphere, in particular over sea ice. Everything helping cover this gap will help quality.
 Part of the gap can be covered by better exploitation of available observations, taking the surface contribution to signals into account in a better way (for instance expliting passive microwave temperature and moisture information taking into use better modeling of surface emission)
 There is a general lack of direct wind profile measurements in the Arctic. Aeolus is now for the first time demonstrating direct measurement of wind profiles from space, and a followup mission could close the gap in wind field description.
 Evolution towards denser surface observing network would be beneficial (for instance more or better spread drifting buoys).
 In Arctic better accuracy and resolution of the surface description has a potetial for improvement. This includes satellite based historical and future SST and sea ice data, glacier coverage and albedo as well as satellite snow products. For instance the proposed CIMR Copernicus mission could prove very beneficial for ocean and sea ice information.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer:
NWP observation requirements in general are well covered in the OSCAR database, even if there is no particular Arctic section. See for instance https://www.wmo-sat.info/oscar/applicationareas/view/2
Some recent papers/reports on Arctic NWP observing system issues:
https://www.ecmwf.int/en/elibrary/18925-assessment-use-observations-arctic-ecmwf
https://www.mdpi.com/2072-4292/11/8/981
Some examples of more general Arctic papers/reports of relevance:
https://publications.europa.eu/en/publication-detail/-/publication/1196aad5-d737-11e8-9424-01aa75ed71a1/language-en
https://www.arcticobserving.org/images/pdf/Board_meetings/2016_Fairbanks/14_Final-Summary-Report_2016-04-22.pdf
https://www.arcticobserving.org/images/pdf/Board_meetings/2016_Fairbanks/15_Final-Requirements-Report---2016-02-23.pdf

2)
EC-JRC (CLMS):

Question 1: What is the general mission of your institution, in what sense are you intermediate users of polar observations, and which services/products are you offering? How important are polar observations to enable your service provision?
Answer: The Copernicus programme offers operational thematic services in the fields of atmosphere monitoring, marine environment monitoring, land monitoring,

climate change, emergency management and security The European Commission's Joint Research Centre (JRC) manages the Copernicus Global Land Service and the Copernicus Emergency Management service as entrusted entity. JRC also took care of the Copernicus / Earth Observation uptake study, and issued a 200 pages report for Commission use only with input at unit level for the different policy DGs. A public report will be issued soon.
Additionally, there is a very strong interest for a polar and snow satellite mission and thus, DG GROW called for a group of European polar experts in 2017 with the mandate to update and complete the review and analysis of user needs.
Their full report can be found here:
https://cimr.eu/sites/cimr.met.no/files/documents/EU_PolarExpertsGroup_Report_P2.pdf

Question 2: What are the most important needs of users that you are already addressing with your services/products, and which polar observations are these based upon? Conversely, what are the most important needs of your users that you are not able to meet?
Answer:
Currently provided through the Copernicus Global Land Monitoring Service:
1. Global Land Cover
2. Vegetation (biophysical parameter)
3. Snow cover
4. Snow water equivalent
5. Lake ice extent
6. Land Surface Temperature
7. Surface albedo
8. Water quality (turbidity)
All these are observed using optical and microwave sensors in order to provide spatially and temporally extensive information, across the Northern Hemisphere.

Identified products need (by EU's Polar Expert Group):
1. Floating ice parameters including sea-ice extent/concentration/thickness/type/drift velocity, thin sea-ice distribution, iceberg detection/volume change and drift, ice-shelf thickness and extent.
2. Glaciers, caps and ice-sheet parameters including extent/calving front/grounding line/surface elevation and surface elevation change/surface velocity/mass balance and mass change/melt extent.
3. Sea level/sea-level anomaly (SLA)parameters.
4. All-weather sea-surface temperature (SST) parameter.
5. Surface albedo parameter.
6. Surface freshwater parameters including river run-off and discharge, river and lake ice thickness.
7. Snow parameters including extent/fraction and snow-equivalent water, melt extent.
8. Permafrost parameters including extent/fraction and topography/deformation.
In addition, JRC's product on the global surface water extent will be proposed as new Copernicus product.

Question 3: Which future products/services you are currently working on and planning to provide within the next 5-10 years? Which existing and/or upcoming polar observations will these be based upon?
Answer:
Same as above (Q2) – some of these could be implemented and provided within the Copernicus Global Monitoring / Climate Change / Marine/ Security Services
Missions:
Sentinel-1
Sentinel-2
Sentinel-3
MetOP
TanDEM-X
ICESat-2
CryoSat-2
SP-InSAR
ESA has new activities (CIMR, CRISTAL, LSTM, ROSE-L)

Question 4: The definitions of the terms „near-time time" (NRT) and „high-resolution" vary between users depending on whether this is for tactical and navigation, planning or climatological usage. What is your understanding of these two specific terms and how do you define them?
Answer:
As mentioned in the question, these really depend on the thematic (aka user) requirement and very importantly the technical capabilities of the ongoing and planned missions. „Near real time" = 10 days for us.
Interoperability among existing and future data is key for long term monitoring, and it requires a lot of work to make the data of earlier sensors/instruments compatible with the newer ones (often at higher spatial resolution).

Question 5: How do you expect the needs of downstream users to develop in the foreseeable future, and how does that translate into requirements toward the polar observing system for your institution?
Answer:
The Copernicus Global Land Monitoring Service provides all data products for free and easy to access/download through a dedicated web portal
See it here:
https://land.copernicus.vgt.vito.be/PDF/portal/Application.html#Home
Any future products will be available here or a newer version of it. Additionally, as per current and future data product users, QA/QC products are the minimum requirements and the Programme provide all of its data as such.
We see increasing uptake of the downstream industry and expect that this continues. Apps (e.g. air quality app) are the new type of deliverables. In addition, policy makers are starting to trust the data for their work, but this will require „reference data".

Question 6: Regarding Figure 1, we would like to illustrate how different users interact and exchange data or information. Depending on who the user is, it is not always linear and can be lateral. For example, Copernicus Services use raw data from satellites, as do Ice Services who also sometimes used derived products from the Copernicus Services (e.g.

SST). Can you identify where there are more links between different users?
Answer:
Raw data is generally not provided by the Copernicus Services, so users go the producers such as ESA. Of course, ESA also has a dedicated web portal for data access. Data products are downloaded through the Copernicus Services' web portals. The DIAS systems could serve as an exchange medium as they (in most cases) have the raw and thematic data products stored. Moreover, through the DIASes users not only can access the various data but could build workflows on it.

Question 7: Do you have additional advice, independent of immediate user needs, how the polar observing system shall be developed to enable better forecasts (and thus ultimately enhanced services and products)?
Answer:
Based on the top two priorities (floating ice and ice sheets, ice caps) three generic instrumentation could be proposed:
1. Imaging PMR: a passive microwave imaging multi-spectral radiometer with ~ 10 km resolution and spectral channels for SIC and SST retrievals and a swath width that offers at least daily revisits in the polar regions.
2. SARIn altimeter: a follow-on mission to CryoSat-2, specialised in nadir altimetry in polar regions.
3. SP-InSAR: a SAR imager that includes single-pass interferometric capabilities as demonstrated with TanDEM-X. Such capability could be implemented as a passive bistatic follower with Sentinel-1.

Question 8: Could you please provide any documentation or publications, such as outcomes of earlier requirement surveys related to polar observational needs, that we should take into account?
Answer:
https://cimr.eu/sites/cimr.met.no/files/documents/EU_PolarExpertsGroup_Report_P2.pdf
https://land.copernicus.eu/global/themes/cryosphere
https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Candidate_missions