KEPLER Deliverable Report

Report on Deliverable D2.2

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Context of deliverable within Work Package

Within WP2, which provides a description of Polar Regions provision in Copernicus services, Task 2.2 undertakes an inventory of current products and services from the marine service. This task also introduces planned developments for new products and services. The first gap analysis in the marine

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service is given together with potential changes in light of potential Copernicus satellite missions. Gap analysis and synthesis among Copernicus services are handled in WP3 and WP5.

Explanation of delays / disclaimers

The final deliverable report is due by the end of March 2020, so there are no delays to report here.

Executive summary

The European Commission has recently stressed ("Space solutions of a sustainable Arctic", adopted by the Council at a meeting held on 29 November 2019) the crucial role played by space solutions for the integration of the EU Arctic policy. Considering that many of the challenges and needs of the Arctic are similar to those of other coastal and remote areas, high and increasing demands of Arctic information arise from different stakeholders:

- High demands related to the poor knowledge of this harsh and rapid severe changing environment
- High demands in terms of the relatively poor skills of current operational systems (weather, ocean, and land) compared to other regions.
- Increasing demands related to sustainable economic development challenged by harsh environmental conditions.

Copernicus services are only five years old or less and are called upon to evolve in the near future. Indeed, the landscape of these European services is not yet fully defined and subject to evolution in the 2020s. Within this context, and given the urgency of the situation in the Arctic environment, the satellite missions to be implemented in the Expansion Phase of the Copernicus Space Components (High Priority Candidate Missions, e.g. HPCM) should at best support the service given by Copernicus (and in our case CMEMS) to provide at best the information required by users.

This report gives a complete overview of what is meant by "service" in CMEMS. The evolution of the future Copernicus service that KEPLER is working towards (WP5) has then to take into account all the components of the Service.

A comprehensive description is given depending on the type (Models or Observations) and the sources of the data disseminated in the CMEMS catalogue. The service is not restricted to a portfolio with a list of products. A data policy, commitments on the access and the monitoring of product quality fully support this portfolio. The deployment of cloud-based platform Data and Information Access Service (DIAS) also has to be taken into account in the future access of Copernicus data.

Copernicus services are user-driven and, as such, the CMEMS service desk monitors the users' feedback and needs by regular surveys. The current state of CMEMS polar product users is given and

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highlights the continuous increase in the number of subscribers and a large redistribution of data by intermediate users. These two findings underline the importance of continuity of the current service and the role played by CMEMS as a core service. However, climate monitoring and ice monitoring remain the main areas of application. From the WP1 stakeholder's conclusions, intermediate users such as the national ice services don't use CMEMS products for their needs. From a more general user's feedback, a non-exhaustive and first gap analysis in CMEMS service is given. For instance, the recurrent demand of very high spatial resolution (< 100m) is not reachable at a Pan-Arctic scale in a 10 years perspective and remains beyond the reach of a core information service such as CMEMS for Arctic environment. However, a more complete portfolio of sea ice parameters has to be foreseen and may give guidelines for the roadmap in WP5. There is also an important need in developing a comprehensive in situ sea ice data repository for evaluation and/or assimilation in operational applications (format, access, accuracy). Further, and more related to in situ considerations, this report again highlights important gaps in the description of the biogeochemical state of the polar oceans.

Together with WP3 findings, observations capacities from the HPCM are assessed against CMEMS service commitments. As in the PEG2 report, the CIMR remains the mission that meets best the CMEMS commitments for Polar Regions with high feasibility in the implementation. To a lesser degree, the CRISTAL mission also fulfils CMEMS commitments together with an important degree of feasibility in the implementation. The ROSE-L mission focused on high spatial resolution fulfils partly the role of core service played by CMEMS. Operational models are currently not designed to implement such information in a multivariate and multi-data framework. To take the full benefits of the mission will require many further developments of the service, and this has to be done in concertation to meet the requirements from intermediate users.

However, the possibility of having these 3 missions in synergy brings tremendous opportunities for CMEMS commitments in terms of core and continuity of the service with important improved capacities. Further, this synergy likely will reinforce links between intermediate and Copernicus services in light of end-users requests. This synergy should be handled in the roadmap of the end-to-end operational system foreseen in the WP5.

Summary

Two different categories of data producers are present in CMEMS: Thematic data Assembly Centers (TAC) which process satellite and in situ data and the Modelling and Forecasting Centers (MFC) which provides analysis, forecasts and reanalysis data. The inventory and the analysis of model-based variables are mainly focused on the Arctic MFC. **Data sources** are complemented by the service given by C3S.

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The free access to services and products accessible from a unique Web portal and centralised and managed by a unique service desk constitute the main pillars of the CMEMS **Data Policy**. Other CMEMS commitments of the service are listed. Products format and access of the service are not part of KEPLER's plan and service standards (product user manual, FAQ) and knowledge (training) have been adopted by CMEMS. However, the deployment of cloud-based platforms providing centralised access to Copernicus data and information (DIAS) is a potential game-changer in the evolution for accessing and processing the data. No specific action plan has been defined between CMEMS and DIAS.

A current state of CMEMS **polar products users** (incl. intermediate and end-users) has been established from a statistical analysis done in July 2019. At this date and since the opening of the service in 2009 (incl. MyOcean projects), 400 regular users have downloaded polar (Arctic only + sea ice) products all over the world where European countries remain by far the most representative countries. These users are spread within more than 500 different organisations. The number of new subscribers is continuously increasing. Commercial use is the main subscriber's application within the Business/Private company organisation, the public sector is weakly represented, and this is different from the general use of CMEMS products. In terms of areas, the Climate, Seasonal and Weather Forecasts is the sector that benefits most from polar CMEMS products; Marine Resources is the less representative area. The NRT products are preferred over the reanalysis products. An important part of the users are intermediate users (large redistribution of data).

In CMEMS the production centre, e.g. TACs and MFCs, validate all their products following a well-defined protocol. The validation is using a series of metrics mostly based on the verification of the distribution, mean and mean square of the differences between CMEMS products and reference datasets. All these estimations are made in the observed world (Class4, GODAE) and need, for instance, adequate observation operators for model output. Within CMEMS, no specific accuracy is targeted but **estimated accuracy numbers** at basin scale areas are derived from these verifications. These statistics are documented and regularly updated. In the future, these "statistical" numbers will probably evolve towards scatter index RMS/Mean together with probabilistic forecasting approaches. The evolution of the CMEMS validation protocol is coordinated by Mercator Ocean and relies on a product quality working group involving experts from all production centres (TACs and MFCs).

We have selected the **variables** from the Global Ocean Observing System (GOOS) list of Essential Ocean Variables (EOVs), this selected list intersects the identified oceanic variables given in WP3. These variables have been separated into 5 main themes: Sea Ice (White Ocean), Physical Ocean (Blue Ocean), Sea State (Waves), Biogeochemistry Ocean (Green Ocean) and Atmosphere (Surface). The ocean monitoring indicators which are fully part of the service in both CMEMS and C3S portfolio have

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been briefly listed for CMEMS. These products may be subject to duplication among these two services.

Inventory of parameters - We have split reprocessed, satellite-based observations from model-based, data assimilative, forecasts and reanalysis because of their different nature and purposes. From these two separations, we have further distinguished data available on a long-term period (reanalysis and reprocessed variables) from data available in Near Real Time (NRT) and Forecast. We ended up with 4 Tables in Annex 1-4 listing the variables, their spatial resolution, a measure of their accuracy, and the observations used for their evaluation. Missing variables are flagged with different colours generally depending on their needs, their current and planned developments and the availability of observations for their evaluation.

Links with ***In Situ*** component – In situ hydrographic measurements of temperature and salinity are well collected, updated and designed for forecasting systems. Few biogeochemistry parameters are available but none in situ sea ice products are available in the current CMEMS catalog. In situ sea ice data used for validation purposes are collected from various repositories.

A listing of **planned developments** (CMEMS models) that are going towards users' requirements is given. These concern an increase of spatial resolution together with higher frequency availability of data, a better continuity of the reanalysis with real time and a possibility to get comprehensive uncertainties with the data. Improvements of accuracy also are expected with upgrades planned in the future systems (waves/sea ice/ocean full coupling, lagrangian sea ice dynamics, atmosphere coupling, interactions with continents, and assimilation of new data).

A first **gap analysis** also is outlined in order to provide recommendations (see next section) for the WP5 roadmap.

A final section provides how each polar mission from the **HPCM** could be of interest for the CMEMS Service. A prioritisation is given in light of CMEMS commitments as a core service.

Recommendations for the end-to-end operational system

- The evolution of the future Copernicus service has to take into account all the components of the Service. The future service should ensure the **continuity of the core service** played by Copernicus services at pan Arctic scale. This concerns the parameters already present in the current portfolio but also the monitoring of the data quality and the data policy.
- The future service should intent to close **the gaps** in the current portfolio:
    - A more complete portfolio of **sea ice parameters** has to be foreseen in the future service.
    - No **in situ sea ice parameters** are present in the current Copernicus portfolio.

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    - Important gaps in the description of the **biogeochemical state** of the polar oceans.
    - No **icebergs forecasts** are provided, at least not by core services.
    - A **river hydrological service** should bridge the Land and Marine Services, including river discharge and nutrient loads.
- Even if Copernicus data will evolve towards resolution less than 5km, a very high resolution (less than 100m) required by end-users (WP1 stakeholders conclusions) is not reachable in a 10 years perspective. In order to better meet the end users requirements**, a new interface with intermediate users** where Copernicus services could play the role of the background information has to be defined.
- **HPCM priorities** as they are presented in WP3: the CIMR mission remains the mission which meets at best the CMEMS commitments (core service) for Polar Regions with high feasibility in the implementation. To a lesser degree, the CRISTAL mission also fulfils CMEMS commitments together with an important degree of feasibility in the implementation. The ROSE-L mission, focused on high spatial resolution, fulfils partly the role of the core service played by CMEMS. The possibility of having these **3 missions in synergy** bring tremendous opportunities for CMEMS commitments in terms of spatial and temporal coverage and continuity of the service with potentially important improved capacities.
- Sea level rise, sea ice and wave climate change should be tailored and combined to contribute to the monitoring of **coastal erosion** along the Arctic.

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Table: Acronyms most commonly used in the present report

Acronym	Definition	Link
C3S	Copernicus Climate Change Services	https://climate.copernicus.eu/
CDS	Climate Data Store	https://cds.climate.copernicus.eu/
CMEMS	Copernicus Marine Environmental Monitoring Services	http://marine.copernicus.eu/
CLMS	Copernicus Land Monitoring Services	https://land.copernicus.eu/
EOV	Essential Ocean variable	http://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114
ECV	Essential Climate variable	https://gcos.wmo.int/en/essential-climate-variables
ESA CCI	European Space Agency Climate Change Initiative	http://cci.esa.int/
EMODNET	European Marine Observation and Data Network	http://www.emodnet.eu/
GOOS	The Global Ocean Observing System	www.goosocean.org/
HPCM	High Priority Candidate Missions	https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_High_Priority_Candidates
ICES	International Council for the Exploration of the Seas	http://ices.dk
MFC	Monitoring Forecasting Centre (CMEMS Models)	
PEG	Polar Expert Group	
SeaDataNet	SeaDataNet	https://www.seadatanet.org/
TAC	Thematic assembly Centre (CMEMS Observations)	

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Variables included

For ocean variables, we have considered the Global Ocean Observing System (GOOS) list of Essential Ocean Variables (EOVs) www.goosocean.org/eov instead of the ECV list from GCOS (GCOS, https://gcos.wmo.int/en/essential-climate-variables/ecv-factsheets). These variables are already pre-selected by the scientific community for the feasibility/maturity of the observing systems. We did not attempt to include other environmental and geological variables monitored under - among others - the OSPAR protocol.

Atmosphere ECVs are out of the scope of the KEPLER project except at the ocean surface (winds, precipitation, heat fluxes) where products are available in C3S.

Several ECVs/EOVs have been ignored because they were deemed scientifically too far from the present scope of Copernicus services (not feasible as of the present phase of Copernicus). The inclusion of these variables would entail a shift in the strategy of Copernicus services. For marine services, this concerns Biology and Ecosystem EOVs (plankton, marine habitat properties).

Ocean variables that are not yet flagged as EOVs or ECVs have been added to the list because of their particular importance for the Arctic and because they may realistically benefit from a pan-Arctic observing system within 2028. These include sea ice variables (melt ponds, ice surface temperature, ice age, sea ice albedo, snow depths) and ocean variables (ambient noise, ocean albedo, dimethyl sulphide).

Some variables have been considered for inclusion but not selected because they are formally derived variables from other EOVs (for example fast ice is a special case of sea ice drift when the latter equals zero).

There are differences in terminology used in GOOS and Copernicus documents (see table below), we have hereafter adopted the Copernicus terminology:

GOOS	**Copernicus**	**Example**
Variable	Product	Sea ice
Product	Variable	Sea ice concentration

We have separated this EOVs list in 5 themes (see Table1 in Annex 1) : Sea Ice (White Ocean), Physical Ocean (Blue Ocean), Sea State (Waves), Biogeochemistry Ocean (Green Ocean) and Atmosphere (Surface). Within this macro classification, we have listed variables already present in the CMEMS portfolio and

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relevant and observable variables identified by GOOS. The CMEMS iceberg density product finally is added as a cross-disciplinary theme.

Ocean Monitoring Indicators (OMI): We distinguish **numerical variables** (regionalized 2-dimensional or 3-dimensional variables) from integrated **indicators** (time series of a spatially integrated variables or an anomaly map). For example the sea ice concentrations are a variable and the total sea ice extent is an indicator derived from it. CMEMS and C3S have developed numerous ocean and climate indicators, which we believe are of highest interest for the public.76 OMI distributed in 9 families are currently disseminated in the CMEMS catalogue. 9 OMI representing 4 families concern the Polar Oceans: Arctic and Antarctic sea ice extent, Arctic freshwater content, Arctic chlorophyll-a time series and volume transport time series through the Nordic seas. Selection of OMIs follow the criteria (specificity, traceability, representativeness, significance and relevance) defined by the Scientific and Technical Advisory Committee comprising 12 independent internationally recognized scientific and technical experts. However, the **present inventory concentrates on all geo-localised numerical data** that can be presented on a map, presented in geographical details to the users and plugged into **interoperable information systems and forecast models**.

Type of CMEMS variables

We have further split **reprocessed, satellite-based, observations** from **model-based, data assimilative, forecasts, reanalyses** because they are very different in nature and serve different purposes. Data assimilative models are to date the only way to produce forecasts, would they be short-term (1-10 days) or longer-term (monthly, seasonal to decadal). Within this separation, we further distinguish data available on a long time period (reanalysis and reprocessed variables) from data available in Near Real Time and Forecast.

Analysis, Forecasts and Reanalysis: These products are obtained through the application of a data assimilation procedure including a dynamical numerical model. Upstream observations data, satellite and/or in situ, are used via an assimilation process to constrain the numerical model solution. This "analysed" state is dynamically propagated by the model towards non-observed areas and also serves as initial conditions for the forecasts.

- NRT analysis and forecasts: This process is applied in NRT and provides short term forecasts, e.g. a few days in CMEMS.
- Reanalysis: The same application of a data assimilation procedure (including a dynamical numerical model) for a long past period of time. A reanalysis in CMEMS has a typical duration of 25 years (starting in 1993 until the year Y-1, altimeter periods). Satellite-based CDRs (aka reprocessings) are typically assimilated into these reanalyses and may differ from NRT observed data used in real time analysis and forecasts.

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The above distinction is motivated by the perspective that disseminated products are potentially issued from different forecasting systems in delayed and NR times.

NRT observations and Reprocessing (Observations): The same as above but without the use of a numerical model (i.e., data-driven only) for both types of observations. These data involve the use of Earth Observation (satellite or in situ) retrieval algorithms and possibly spatial and temporal interpolation algorithms but not data assimilation in a geophysical model. The NRT data sets usually span a few years before real-time. It is also characterised by different quality control process and, due to the timeliness, have a reduced number of upstream data than delayed time. A reprocessing is often referred to as satellite Climate Data Records (CDRs) (Yang et al. 2016). CDRs are expected to cover as long a time period as raw satellite observations exist, the longest is currently 40 years long (the late 1970s). They should typically be longer than 20 years. CDRs can be continuously updated (until Y-1) by Interim CDRs. CDRs require that Fundamental CDRs (FCDRs, long time-series of calibrated raw satellite observations) are available.

CMEMS data sources

The Copernicus Marine Service relies on a network of European marine data producers. The CMEMS producers are categorized into two categories:

1. **Thematic Data Assembly Centres (TAC)** process data acquired from satellite ground segments and in situ platforms, Satellite and InSitu Observations into real-time (today) and reprocessed (25 years historic) products. All TACs potentially are concerned by polar latitudes. There are 8 TACs:

    1. Sea Ice TAC
    2. Surface Wind TAC
    3. Sea Level TAC (Sea Level Satellite Data)
    4. INS TAC (In situ temperature, salinity, currents and other variables)
    5. Ocean Colour TAC (Ocean Colour Satellite Data)
    6. Sea Surface Temperature TAC
    7. Wave TAC
    8. Multi Observations TAC

    All observation products relevant for polar oceans are listed in Tables 3-4 irrespective of the TAC source.

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2. **Monitoring and Forecasting Centers (MFC)** run ocean numerical models assimilating the above TAC data to generate reanalysis (25 years in the past), analysis (today) and 10-day forecasts of the ocean. There are 7 MFCs:

1. Global Monitoring and Forecasting Center (GLO MFC)
2. Arctic Ocean MFC (ARC MFC)
3. Baltic Sea MFC (BAL MFC)
4. Atlantic European NorthWest shelves (NWS MFC)
5. Atlantic Iberian Biscay Irish Seas (IBI MFC)
6. Mediterranean Sea MFC (MED MFC)
7. Black Sea MFC (BLKSEA MFC)

Only two MFCs are concerned by polar latitudes: ARC MFC and GLO MFC.

Short description of **ARC MFC**:

- The ARC MFC system is run daily to provide 10 days of forecast (average of 10 members) of the 3D physical ocean, including sea ice; data assimilation is performed weekly to provide 7 days of analysis (ensemble average).

  Arctic MFC has 5 products: two near-real-time forecasting products for the ocean physical conditions and one for the biogeochemical (BGC, restricted to the lower trophic levels (primary and secondary production) forecast and two reanalysis products, physics and BGC. The physics and BGC are consistent in that the biological model is coupled on-line to the physical model. The assimilation of all satellite and in situ measurements are done with an Ensemble Kalman Filter (EnKF). The ocean model has generalized vertical coordinates (HYCOM) coupled to a sea ice model and the biology is simulated by the ECOSMO model. The domain covered is North of 62°N.

  The output consists of daily mean fields interpolated onto standard grids in the NetCDF-3 CF format. Surface fields are provided at hourly frequency. Variables include 3D currents (U, V), temperature and salinity, as well as 2D-fields of sea ice parameters, sea surface height, mixed layer depth and biogeochemical parameters. The resolution for output products is 12.5 km at the North Pole (equivalent to 1/8° in mid-latitudes). The time series starts on October 19, 2011 but only the last two years of NRT time series are available from the CMEMS portal.

- Two reanalysis products are also provided, although these are not directly coupled, the physical reanalysis uses the same system as the near-real-time forecast over a long period starting in 1992

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and updated twice a year. The biological model is NORWECOM for the reanalysis product and only provides a short time series 2007-2010.

- A wave forecast is also available on a pan-Arctic configuration using the WAM model at 3km resolution. The model is forced by ECMWF forecasts and runs twice a day at midnight and 12 UTC for a 5 and 10-days range, lateral boundary conditions are taken from the ECMWF WAM model. The ARC MFC surface currents and sea ice concentrations are taken as input to the wave model, which uses a parameterisation of wave attenuation below sea ice.

- A wave hindcast is ongoing with the same 3 km WAM model for the period 1993-2019 using the ERA-5 reanalysis instead of the ECMWF forecasts. It should be delivered to the public in December 2020. The product is called a hindcast rather than a reanalysis because it does not include any data assimilation for the time being.

Short description of **GLO MFC**: GLO MFC is composed of 3 components called:

- GLO HR:

    o Physics: The Operational global ocean analysis and forecast system at 1/12 degree is providing 10 days of 3D global ocean forecasts updated daily. The time series starts on December 27, 2006.

    This product includes daily and monthly mean files of temperature, salinity, currents, sea level, mixed layer depth and ice parameters from the top to the bottom over the global ocean. It also includes hourly mean surface fields for sea level height, temperature and currents. The global ocean output files are displayed with a 1/12 degree horizontal resolution with regular longitude/latitude equirectangular projection. 50 vertical levels are ranging from 0 to 5500 meters.

    This product also delivers a special dataset for surface current that also includes wave and tidal drift called SMOC (Surface merged Ocean Current).

    o Biogeochemistry: The Operational biogeochemical global ocean analysis and forecast system at 1/4 degree is providing 10 days forecast of 3D global ocean forecasts updated weekly. This product includes daily and monthly mean files of biogeochemical parameters (chlorophyll, nitrate, phosphate, silicate, dissolved oxygen, dissolved iron, primary production, phytoplankton, PH, and surface partial pressure of carbon dioxide) over the global ocean. The global ocean output files are displayed with a ¼° horizontal resolution with regular longitude/latitude equirectangular projection. 50 vertical levels are ranging from 0 to 5700 meters.

    o Waves: The operational global ocean analysis and forecast system with a resolution of 1/12 degree is providing daily analysis and 5 days forecasts for the global ocean sea surface waves. The

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time series starts on March 1st, 2016. This product includes 3-hourly instantaneous fields of integrated wave parameters from the total spectrum (significant height, period, direction, Stokes drift, etc.), as well as the following partitions: the wind wave, the primary and secondary swell waves.

- GLO RAN :

  o Two global ocean reanalysis (1993-2018) for the Global Ocean and Sea Ice Physics : daily means of Temperature, Salinity, Currents, Sea Surface Height and Sea Ice Parameters, at 1/12° and 1/4° horizontal resolution, with 75 vertical levels, forced by ERA-Interim atmospheric variables and covering the 1993-2018 altimeter period, with SEEK/IAU Data Assimilation of Temperature and Salinity profiles as well as Sea Level Anomalies, Sea Ice Concentration, Sea Surface Temperature.

  o Super ensemble of global reanalysis: Global Ocean Ensemble Reanalysis: monthly means of Temperature, Salinity, Currents, at 1° horizontal resolution, with 75 vertical levels and covering the 1993-2018 time period.

  o Biogeochemistry - Global physical and biochemical "reanalysis": The biogeochemical hindcast for global ocean provides 3D biogeochemical fields for the time period 1993-2017 at 1/4 degree and on 75 vertical levels. It uses PISCES biogeochemical model (available on the NEMO modelling platform). No data assimilation in this product.

  Waves reanalysis (December 2019): 1/5° covering 15/01/1993-26/12/2018 This product includes 3-hourly instantaneous fields of integrated wave parameters from the total spectrum (significant height, period, direction, Stokes drift,...etc), as well as the following partitions: the wind wave, the primary and secondary swell waves. DA of Significant wave height (SWH) from altimeters ERS1, TOPEX/POSEIDON, ERS2, GFO, Jason 2 & 3, Envisat, Saral, Cryosat-2 and Sentinel-3A; Sentinel-3 and Sentinel-1-SAR spectrum.

- GLO-CPL: The weakly coupled ocean-atmosphere data assimilation and forecast system is used to provide 10 days of 3D global ocean forecasts, at ¼ degree, updated daily. The system uses an atmosphere configuration at ~ 40 km resolution coupled hourly to a NEMO v3.4 ocean configuration and to the multi-thickness-category sea ice model CICE v4.1 (both on the ORCA025 grid). Atmosphere and ocean data assimilation are using 4D-var and 3D-var respectively. Ocean observations assimilated include satellite SST data, in-situ SSTs from moored buoys, drifting buoys and ships, sea level anomaly observations from CMEMS, sub-surface temperature and salinity profiles (including Argo, moored buoys, marine mammals, and gliders) and sea ice concentration (SSMIS data provided by OSI-SAF as a daily gridded product). The ocean forecast and analysis are provided daily, along with an updated analysis a day later which makes use of more observations. This product includes daily mean fields of temperature, salinity, currents, sea level, mixed layer depth and sea ice parameters (and hourly instantaneous sea surface temperature, sea

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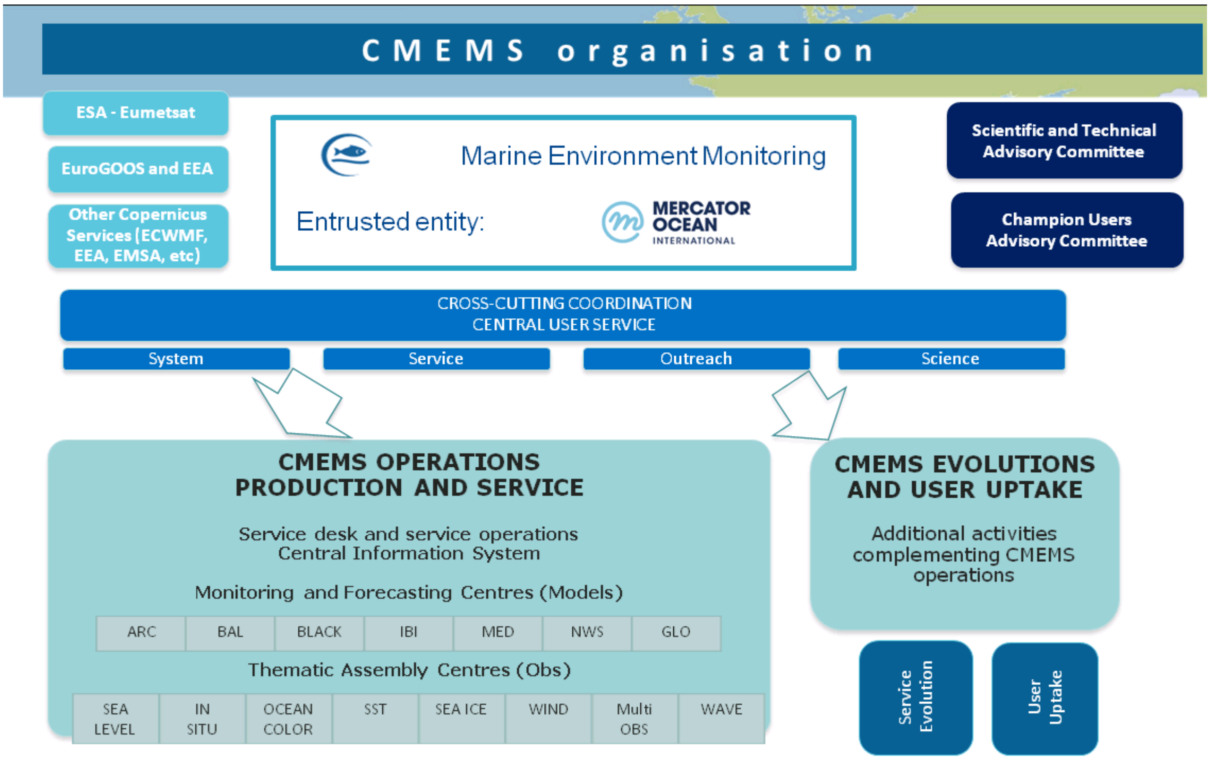
surface height and surface currents). The product files are provided with ¼° horizontal resolution on a regular lat/long. projection and with 43 vertical levels ranging from 0 to 5500 meters.



CMEMS Organisation Overview

C3S Systems, products and services (and CAMS)

A brief overview of various services and parameters designed or available in polar oceans from C3S is listed here.

- The Copernicus Arctic Regional Reanalysis Service: two domains in the European sector of the Arctic; periods: 1997-2021; Model: HARMONIE-AROME at 2,5 km (3D-VAR) and 3-hourly update frequency; Boundaries conditions: ERA5 (30km). None products listed yet.
- The ERA5 global reanalysis: Global domain, 31 km resolution; period covered 1979-present, hourly products; uncertainties estimates; oceanic products : SST (HadISST + CMEMS), SIC (OSI SAF), waves parameters.

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- Multi-system seasonal forecast service. The C3S regularly publishes Seasonal forecasts products. These products are based on data from several state-of-the-art seasonal prediction systems (ECMWF, The Met Office, Météo France, DWD (The German Weather Service,) the CMCC (the Euro-Mediterranean Center on Climate Change) and NCEP (National Centers for Environmental Prediction)). The seasonal forecasts are updated every month, currently on the 13th day at 12 UTC and they cover a time period of six months. SST, sea ice cover and snow depth are provided sub daily (6H) at 1° resolution. Ensemble mean and individual members product types are provided.
- The IFS (Atmospheric Model high resolution from CAMS) system: Global domain, 10-days forecasts, Model: ECMWF; 10km resolution; hourly update; SST (CMEMS), SIC (OSI SAF), waves parameters.
- Global shipping project: Aid the decision-making processes and support medium and long-term planning in the shipping sector; timescales of interests: months to decades, projections of cost availability of arctic route within the next decades and century; conversion of raw input data into useful indicators for decision-making (fuel-consumption, route availability, icebergs presence).
- Sea Ice News: sea ice extent monitoring with data and monthly maps
- Data products (ECVs) as climate data records (consistency and continuity) from satellite observations :
    - SST: CDR from ESA-CCI + short delay extension, 5km, 1991-2010, daily.
    - Sea level: SLA, ADT, Geostrophic currents, (Ssalto/Duacs), 25km, 1993-present, global, daily
    - Ocean colour
    - Sea Ice:
        - Concentration: 12,5km, 1979-present, Global, daily (OSI SAF)
        - Edge: 12,5km, 1979-present,Global, daily
        - Type: 25km, 1979-present, NH, daily
        - Thickness: 25km, 2002-present,NH, monthly (winter months)

Others Data sources considered

- We have taken the **European perspective,** i.e. reviewing initiatives from the European Commission, not individual states.
- Other satellite and in situ data services have been considered that:
    - Include the Arctic and/or Antarctic (possibly as part of a global dataset). Where available, regional Arctic and/or Antarctic products have been preferred over global products (for example, the CMEMS Arctic over the Global products).
    - Are based on a pan-European or global collaboration.

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- Are representing the European Commission and/or the European Space Agency (ESA), and/or the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).
- Aggregate data from different sources and across several disciplines (i.e. not the Euro-Argo ERIC for ocean variables but rather GLODAP and EMODNET)
- Are meant to be sustained. An exception has been made for the ESA CCIs, which are projects limited in time but which deliver a reference data product brokered and sometimes maintained by the Copernicus Services or EUMETSAT.
- Address users at a similar level, that of processed, quality controlled, geophysical values. i.e. the satellite ground segments are ignored.

- The following repositories have been selected for the ocean
  - **GLODAP** (Global Ocean Data Analysis Project): *A uniformly calibrated open ocean data product of inorganic and carbon-relevant variables*. It is an international project beyond Europe but has also been supported by European projects such as CarboOcean, CarboChange among others and constitutes the ocean contribution to the International Carbon Observing System ICOS. https://www.glodap.info/
  - **EMODnet** (European Marine Observation and Data Network) is funded by the European Commission DG MARE. http://www.emodnet.eu/. It has a dedicated initiative called "EMODNET ingestion" to absorb isolated data, it has developed its own metadata standards and runs an Arctic Checkpoint project.
  - **SeaDataNet** (also known as SeaDataCloud) is a PAN-EUROPEAN INFRASTRUCTURE FOR OCEAN & MARINE DATA MANAGEMENT. It federates several European (and other, i.e. Russian) in situ data centers and has a long experience in developing its own standards.
  - **ICES**, the International Council for the Exploration of the Sea has historically been the first initiative to aggregate international in situ data. It focuses on fisheries and marine life but holds a wide breadth of information.
- No mention has been made of satellites, sensors, instruments or other technology used or upcoming, nor of the Copernicus High-Priority Candidate Missions either. These descriptions are supposed to be done within WP3.
- When in situ observations are involved, different databases may be more or less complete or have different quality control practices. We have not entered these topics here as the ingestion/digestion of data can change until 2021. Our focus is more targeted to "who has the mandate to serve data?" than "who is providing most/best data?".
  - Several **other pan-European databases** are relevant for the present Arctic inventory (PANGAEA, ENACT among others) but there are so many of those that they could not have been reviewed exhaustively. We have concentrated on the main "meta-portals", the most federative for which the synchronization to Copernicus services has been on the table. This choice may be revised after the delivery from WP3 (for satellite and in situ data).

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- Arctic cluster projects INTAROS and Nunataryuk do not constitute databases per se but do contribute continuously to the federative databases used here. Their public deliverables as of May 2019 have been taken into account.

CMEMS Data Policy

A “Service Level Agreement” (SLA) or “Agreement” is established between the User and the Copernicus Marine Environment Monitoring Service for the provision of any Copernicus Marine services. Its purpose is to outline the range and level of services that the Copernicus Marine Service will supply to the User.

CMEMS services and products are **free of charge** under the SLA.

All the products are accessible directly from the Web portal: a centralised access with a single password, thus all of them are monitored by the Copernicus Marine Service and then allow a homogeneous level of service.

CMEMS commitments on service

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

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

Concerning the management of the products, the CMEMS has to ensure reliable access to the products and information at any time for external users. CMEMS commitments on the services are as follows:

- Provisions of all kinds of all products listed in the catalogue

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- Provisions of Additional products from another service provider (SeaDataNet, EUMETSAT/OSI SAF, GHRSST, EMODnet, C3S and ESA-CCI) with relevant credit and the same level of service.
- Performance targets in terms of information webpage, of on-line catalogue, of global web portal access, of download capacities and visualisation capabilities.
- Key performance indicators, timeliness and availability of real time products, also are measured and monitored for each product. If the timeliness is delayed by less than 2 minutes of the target delivery time, the product is still considered on time. The availability (viewing and downloading) is measured and refreshed in real time (every 15 min).
- Commitments in the Service Desk element also have their own performance targets (requests and expertise response time). See http://marine.copernicus.eu/services-portfolio/service-commitments-and-licence/ for a complete description of all the defined and measured elements.
- Incident Management
- Service Maintenance (continuity of the products and track changes)
- User feedbacks (confidential information in the form of a completed questionnaire is asked to the user)

The issues of **data ownership**, correct acknowledgment and traceability have not been considered here: we consider the state of available data at a given point in time and **hide the direction of data fluxes** within CMEMS (where is the data generated? is it brokered/disseminated by Copernicus?).

The question remains if the user should be encouraged to access the data where it is produced in order to have access to the latest update but to the potential detriment of the quality.

CMEMS products format and Access of the service

The variables are assumed to be available on a given service, but the **quality of the service** has not been taken into account: **compliance with the INSPIRE directive, FAIR or other best-practice** data delivery principles, ease of access and use. As of the KEPLER work plan, these aspects are not in the scope of the inventory but certainly have vital importance to the users (a data service may be public but not used because of impractical data access).

However, service standards have been adopted by CMEMS to ease the access (Product User Manual document and FAQ) and the knowledge (training) of the available data sets.

Data and Information Access Services (DIAS)

To facilitate and standardise access to data, the European Commission has funded the deployment of cloud-based platforms providing centralised access to Copernicus data and information, as well as processing tools.

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The DIAS online platforms allow users to discover, manipulate, process and download Copernicus data and information. All DIAS platforms provide access to Copernicus Sentinel data, as well as to the information products from Copernicus' six operational services, together with cloud-based tools (open source and/or on a pay-per-use basis).

Each of the five competitive platforms also provides access to additional commercial satellite or non-space data sets as well as premium offers in terms of support or priority. Thanks to a single access point for the entire Copernicus data and information, DIAS allows the users to develop and host their own applications in the cloud while removing the need to download bulky files from several access points and process them locally.

The Arctic has already been targeted for demonstration in one of the platforms, e.g. Wekeo. DIAS is a potential game-changer for accessing and processing Copernicus data and information. No specific action plan has been defined and CMEMS will follow DIAS functionalities in terms of Interactive Tools developments on distance platforms/upload of user products.

CMEMS Data Quality - Monitoring the quality of the products

One of the major objectives of CMEMS is to deliver useful scientific quality information such as reliability of the forecasts, the accuracy of the analyses, quality control of the observations, etc. Moreover, this quality information has to be scientifically sound and as consistent as possible across the variety of products that CMEMS delivers. Validation is usually two-fold: new products have to be validated prior to their entry into service (operational delivery to users) and their quality communicated effectively to users; and the quality of the operational products has to be checked routinely in order to ensure that the quality standards are met.

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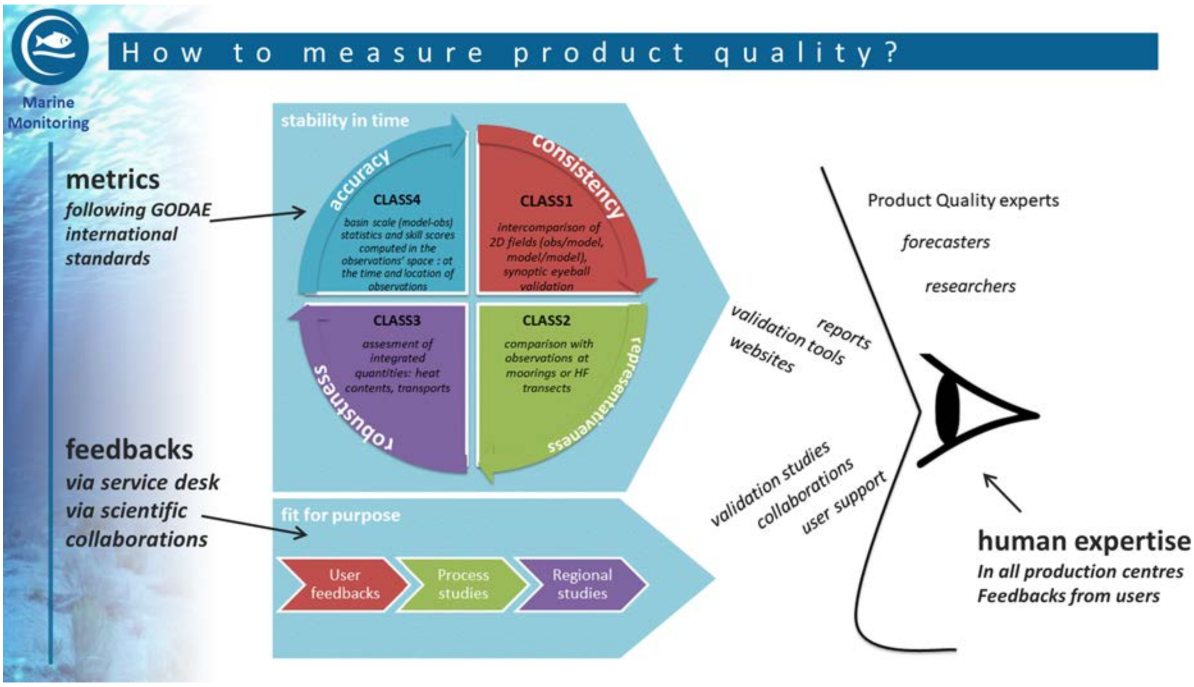

Figure 1: Schematic of the validation methodology within CMEMS

The main validation/verification and quality control of the production, as well as the monitoring of the operational system is performed and managed at the Production Centre (PC) level, e.g. TACS and MFCs. The validation is using a series of metrics mostly based on the verification of the **distribution, mean and mean square of the differences** between CMEMS products and reference datasets. Deviations between climatologies (or available independent) data and observations are used for the control of observations, while differences between observations (or observational products) and their model counterparts are used for the control of model outputs. The scales and processes represented by either models or observational products must be taken into account when producing this verification, and observation operators (as in data assimilation) usually have to be applied to model outputs. Within CMEMS, no specific accuracy is targeted but **estimated accuracy numbers** (EAN) are produced against independent or upstream assimilated observations, the latter giving an indication of the performance of the product. These EANs are surface averaged on a large geographical domain, e.g. full domain or specific regional areas. These EANs provide indicators of the average quality level expected over basin scale areas. For a few quantities, the RMS differences are supplemented by the correlation. These concerns best estimates products and forecasts. For the ARC MFC, the following variables are validated: sea surface temperature, sea ice concentration, the position of the sea ice edge, sea ice drift, temperature and salinity profiles, sea surface elevation, near-surface drift, bottom temperature.

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In the TACs (taking as example the SI TAC), validation is performed against in-situ measurements (when available). The availability of high-quality in-situ observations over sea-ice is a challenge for the Sea Ice TAC. When nothing else can be done, coarser resolution products (like those brokered from the OSI SAF) are compared to manual sea-ice charts from the Ice Services (as available in CMEMS SI TAC) or ad-hoc processed high-resolution satellite imagery (e.g. Sentinel 2). However, the lack of uncertainty information in the charts limits this exercise to be a comparison of products, not a validation. When too few observations are available in near-real-time, validation of products is done once (e.g. scientific validation over several years) and the quality of the product is monitored on a regular basis. In addition to biases and RMSEs, emerging new metrics are adopted like the Integrated Ice Edge Error (IIEE) (Melsom et al 2019 for a review).

Currently, for model products these "statistical" numbers will probably evolve towards scatter index RMS/Mean in the future.

Accuracy is monitored and assessed weekly by human expertise as an internal process; visual checks, metrics computation and assimilation diagnosis are employed. Production and data quality are assessed and reported on a quarterly basis as a comprehensive CMEMS process (Service Management Reports, Quarterly Performance Reports). A document, the Quality Information Document (QuiD), gathers all accuracies and validation information. These QuIDs are associated with each product and can be downloaded from the catalogue together with the product. This document provides a scientific description of the operated system, the validation methods, the performance of the system, and the quality of the product, in particular with Estimated Accuracy Numbers. QuIDs are revised at each upgrade of the systems and changes in the production. The communication through the QuIDs is complemented by the CMEMS online validation reporting (http://marine.copernicus.eu/web/103-validation-statistics.php). This reporting is a collection over the period (i.e. presently the past 3 months) of a series of chosen metrics performed routinely; following the "class 4" methodology (see below) where CMEMS best estimates and forecasts are compared to observations.

The quality of the data products and the production chain is monitored in accordance with CMEMS guidelines and metrics. A cross-cutting tool is the dedicated group of validation/verification experts, the Product Quality Working Group (PQWG), composed from experts working in each Production Centre, together with experts from Mercator Océan International. Its main objective is to define new metrics, later to be implemented in the Production Centres. This group is also making the link with state-of-the-art validation practices and international standards and metrics, such as those defined by MERSEA (Crosnier and Le Provost, 1997) and GODAE OceanView (Hernandez et al., 2015, 2017). In particular, the CLASS4 approach for the computation of the analysis error and of the forecast error in the observation space (at the time and spatial location of the observation), which allows deriving skill scores, was adopted as a standard since the MERSEA project. The PQWG gathers scientists with various backgrounds (observations

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or models, in-situ or satellite, global or regional) and each participant has the opportunity to share his/her own expertise by proposing dedicated metrics for his/her specific variable and/or region of interest.

Following results obtained by the group of experts in PQWG, categorical and site-specific metrics, as well as specific biogeochemistry metrics will be implemented in the future. Users feedback also provide indirect quality measurements - external qualification - through the evaluation of the fit for purpose of CMEMS products for specific applications. The latter approach will be encouraged and developed in the future.

CMEMS and the in situ component

In Situ CMEMS products

The in situ TAC provides access to reprocessed and real time in situ temperature and salinity measurements profiles for the Global ocean. The In Situ delayed mode product designed for reanalysis purposes integrates the best available version of in situ data for temperature and salinity measurements. These data are collected from main global networks (Argo, GOSUD, OceanSITES, World Ocean Database) completed by European data provided by EUROGOOS regional systems and national system by the regional INS TAC components. It is updated on a yearly basis. The current version is a merged product between the previous version of CORA and EN4 distributed by the Met Office for the period 1950-1990. From the near real time INS TAC product validated on a daily and weekly basis for forecasting purposes, a scientifically validated product is created. It's a "reference product" updated on a yearly basis. This product has been controlled using an objective analysis (statistical tests) method and visual quality control (QC). This QC procedure has been developed with the main objective to improve the quality of the dataset to the level required by the climate application and the physical ocean reanalysis activities.

Although few biogeochemistry parameters (Oxygen and chlorophyll) are collected and present in CMEMS catalogue, presently none in situ sea ice products are present in CMEMS catalog. Further links need to be done with the in situ Copernicus component.

Validation of CMEMS products using in situ data

CMEMS products commonly use in situ temperature and salinity profiles from the In Situ TAC.

The ARC MFC uses SST from ocean surface drifting buoys to validate the SST products. As well as the drift trajectories to validate surface currents.

The Arctic MFC and the Global Coupled MFC both use the IABP drifting buoys in their contributions to SIDFEx. See https://www.polarprediction.net/yopp-activities/sidfex/

The Sea Ice TAC uses drifting buoys (collected from IABP, ITP and AWI) to calibrate and validate the satellite ice drift products, both the coarse resolution product (from OSI SAF) and high-resolution SAR-based

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product. At the SST TAC, the Arctic Sea Ice Surface Temperature analysis product uses on-ice buoys for validation, but the quantity, quality and representativeness of the buoys is a challenge there as well.

CMEMS Users

Current State of CMEMS polar products users (July 2019)

These "polar" statistics have to be put in the general context of all CMEMS accounts (MFC and TAC). A total of 13900 active* users with 3400 regular* users have been recorded for all CMEMS products and these users are spread over 3800 different organisations representing 169 different countries. The number of new subscribers is continuously increasing. European countries are by far the most representative countries. Scientific studies (44%) and Commercial use (32%) are the two main applications. Public sector (incl. University) and Business/private companies (43%) share almost all the represented organisation. Climate, seasonal and Weather Forecasts sector leads the area of benefits of CMEMS products followed by Marine Coastal Environment (28%) and Marine Safety (21%). Marine resources remain in the last area of benefiting CMEMS products (19%).

Active user* = user who have downloaded products at least once in the period; Regular user*= user who have downloaded products at least three times during one month at different weeks.

Two figures show users metadata and partition in areas of benefits for **ARC MFC** products only. We have selected the ARC MFC as statistics on GLO MFC obviously are biased towards non-polar latitudes.

- ARC MFC products have 247 Regular Users from 46 different countries, with 708 active users representing 311 organisations in total.
- The most representative countries are, in decreasing order in the number of users: France, Norway, UK, Italy, Russian Federation, USA, China, Canada, Germany, and Denmark.
- A continuous increase in the number of new subscribers.
- Commercial use is by far the main subscriber's application (83%) within Business/Private company organisation (83%), public sector (11%) is weakly represented.
- Arctic analysis and forecasts (Physics, waves and Bio) (⅔ of users for NRT products and ⅓ for multi year products) are the most downloaded products before reanalysis and OMI products.
- Large redistribution of data = Intermediate users.
- Areas of benefits: One-third of users in Climate, Seasonal and Weather Forecasts (CSWF) only 15% of users in Marine resources. ¼ of users are shared equitably in Marine Safety and marine Coastal Environmental sectors.
- Areas of benefits: climate and ice monitoring are the two major domains of applications.

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Two figures showing users metadata and partition in areas of benefits for **Sea Ice TAC** data products. These include Baltic sea ice data.

- SEA ICE TAC data have 166 Regular Users from 37 different countries, with 510 active users representing 225 organisations in total
- The most representative countries are, in decreasing order in the number of users:Most representative countries : France, Norway, UK, Finland, Germany, Russian Federation, Italy, USA, China, Canada, Denmark.
- A continuous increase in the number of new subscribers.
- Commercial use is the main subscriber's application within Business/Private company organisation, the public sector is weakly represented.
- Products from OSI SAF, icebergs detection from SAR and sea ice charts around Greenland and Ice Surface Temperature are the most downloaded products
- Areas of benefits: 40% of users in CSWF, only 11% users in Marine resources, 25% in the two others.
- Areas of benefits: climate and ice monitoring are the two major domains of applications.

The effective linkage between an area of benefits and a specific product is not possible with the current version of the users statistical tool. This may bring more information on which type of products are more orientated onto specific applications.

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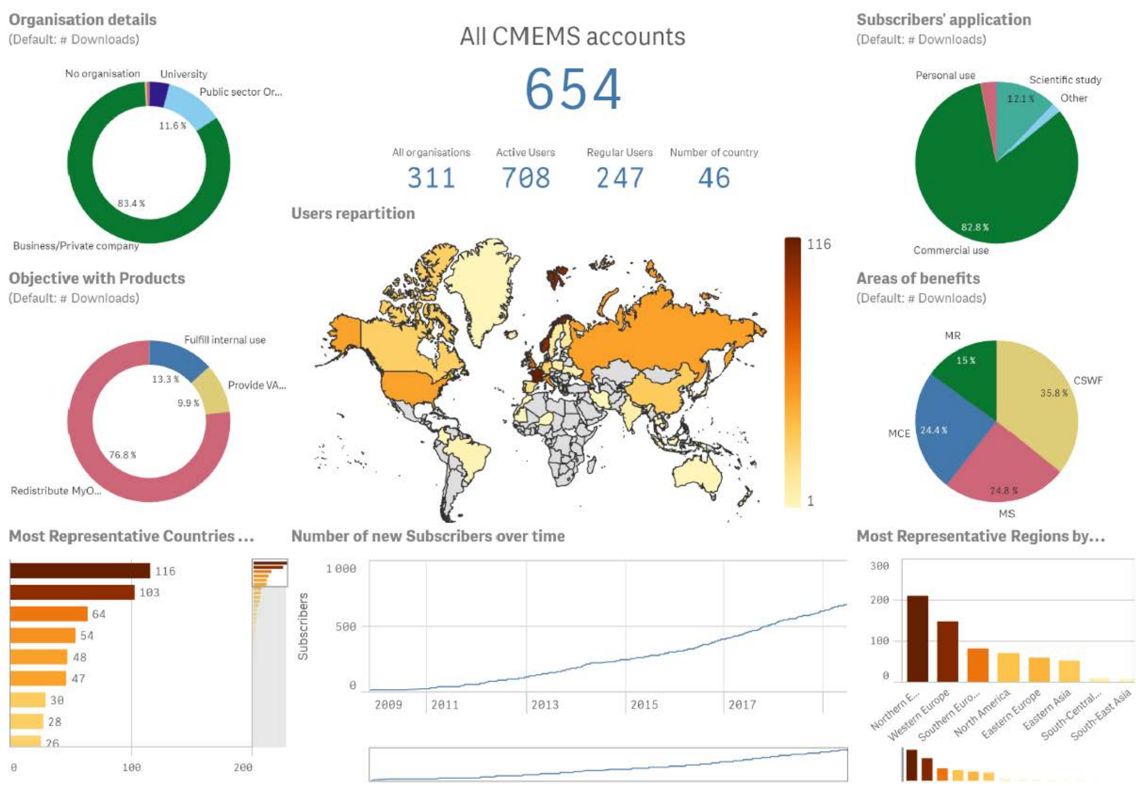

Figure 2: (11th of July 2019). Users Metadata for Arctic MFC products.

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Figure 3: Area of benefits for Arctic MFC products.

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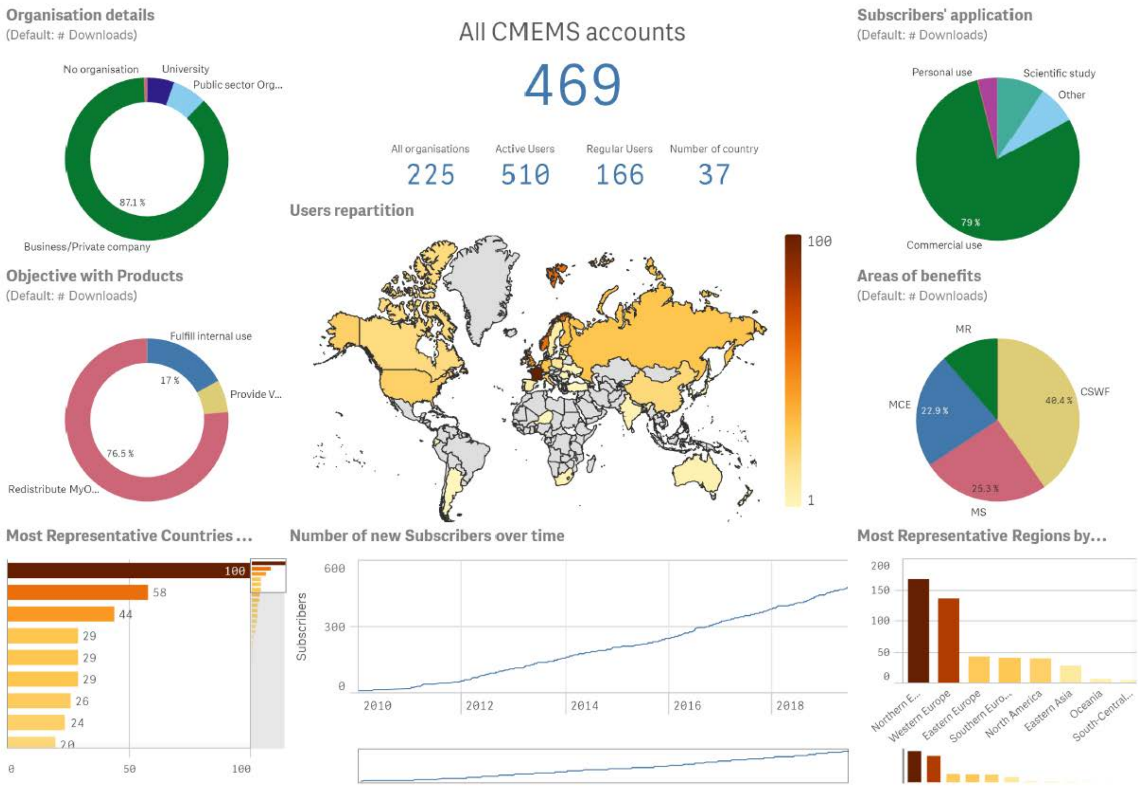

Figure 4: (1th of July 2019). Users Metadata for SEA ICE TAC data products.

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Figure 5: Area of benefits for Sea Ice data (TAC) products.

User Uptake and Use Cases

User Uptake short-term activities aim at increasing satisfaction and confidence, taking into account the users' needs. Copernicus services are user-driven, therefore the User Uptake Strategy is being developed on the basis of feedback from users together with a scientific and technical gap analysis of emerging and existing user requirements as well as the potential to improve the Core Service elements. Guidelines of the User Uptake activities have two key drivers : 1) open CMEMS to new communities, to improve CMEMS users' loyalty and 2) to foster the service uptake by new users and the development of private and public downstream services.

Presently five services concerning polar latitudes have been selected in the frame of the CMEMS' User Uptake:

1. **Greenland Floe Edge service (POLAR VIEW)**: Greenland Community Ice Information Service is an operational service to support traditional ways of life in the Arctic (http://floeedge.polarview.org). Area of benefit: Marine Safety. The service assists in identifying dangerous locations and selecting

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the shortest route around ice ridges and open water. This helps minimize travel time, fuel costs and equipment wear, as well as maximizing the safety of travel on the ice. CMEMS Products used by the service are Sea ice fraction, snow thickness and temperature forecasts from ARC MFC.

2. **ARCTIVITIES (NOVELTIS/QUIET OCEANS)**: Risk indicators relating to sea state, ice and noise pollution (https://arctivities.noveltis.fr). The ARCTIVITIES operational service is fed with the Arctic Ocean CMEMS analysis, forecasts and reanalysis (waves, ice thickness, ice fraction, water temperatures and salinity as well as surface roughness), AIS database for anthropogenic noise levels related to maritime traffic and ECMWF atmospheric forcing (air temperature and wind). The service is linked to several fields of interest, in particular; fisheries and aquaculture, the implementation of the MSP, the MSFD, the adaptation to the impacts of climate change and the maritime safety (navigation, tourism, infrastructures at sea...).
3. **SVALNAV (DRIFT+NOISE / MET NO):** Sea-ice information in line with the Polar Code in the Svalbard region (https://driftnoise.com/svalnav.html). Areas of benefit : Transport security or routing of ships, Weather and ocean forecasts, Coastal and offshore sea ice security; SVALNAV supports shore and offshore activities in ice covered waters for the wider area of Svalbard. It is addressed to National and local authorities, as well as to commercial and non commercial users (tourism, fisheries, research, offshore, surveying vessels). CMEMS Products used by the service are : Arctic Ocean Physics Analysis and Forecast, daily means, hourly-instantaneous, 12.5km x 12.5km grid, Global Ocean 1/12° Physics Analysis and Forecast updated daily, 0.083° x 0.083° grid, Global Ocean - High Resolution SAR Sea Ice Drift, 10km x 10km grid, Global Ocean - Arctic and Antarctic- Sea Ice Concentration, Edge, Type and Drift, 10km x 10km grid.
4. **Polar Code Service (POLAR VIEW/DMI)**: Aggregation of sea-ice information taking into account the Polar Code recommendations; there is not an internet web page yet, this service is under development. Area of benefit: Marine Safety. The Polar Code Service will aggregate the necessary information from a variety of sources (and in particular CMEMS) and make it available in a manner that recognizes the low and intermittent bandwidth conditions available to ships in the polar regions. This service will increase the safety of ships' operation and mitigate the performance impact on people and the environment in the remote, vulnerable, and potentially harsh polar waters. CMEMS Products used are: analysis and forecast (currents, sea-ice velocity, ice fraction, ice thickness and waves) and satellite observations (wind, SST).
5. **SHIPcAPP (DMI)**: High quality sea-ice information for shipping around the Cape Farewell. There is no internet web page yet, this service is under development. Area of benefit: Marine Safety. Based on the Arctic-wide forecasting system run at DMI, the service named SHIPcAPP (Supporting sHIPing around CAPe Farewell with high resolution forecast Products) aims to provide high quality information for shipping. The service will make available the wind, ocean, sea ice and iceberg conditions for the near coastal area around Cape Farewell and the southern tip of Greenland, a challenging area for ships (icebergs, harsh environmental conditions that can change quickly, narrow fjords...). Mariners need relevant high-resolution data. CMEMS products used are : the

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service aims at downscaling the physical forecast from CMEMS to the near coastal area around Cape Farewell a high resolution setup (around 1 km) of a sea-ice-ocean forecast model. Icebergs information from CMEMS will be used too.

At this date, no user uptake feedback has been received.

Use Cases published on the CMEMS website highlights how the CMEMS data is used by companies, institutions and governments. These Use Cases are sorted by country or by market sectors. Currently, there are 14 Use Cases Covering the Arctic and Antarctic basins, and especially 8 of them are dedicated for polar areas. Markets covered are Marine Navigation, Safety & Disaster, Polar environment monitoring, Marine conservation & Policies and Society & Education. For more details see the web site: http://marine.copernicus.eu/markets/use-case-books/ .

Feedbacks of Users Questionnaire for CMEMS

At the end of October 2019 around 2050 feedbacks has been collected and classified following one of these topics:

- Additional or update of products
- Access to products
- Product documentation
- Web functionalities
- Communication to users
- Service (quality and definition)

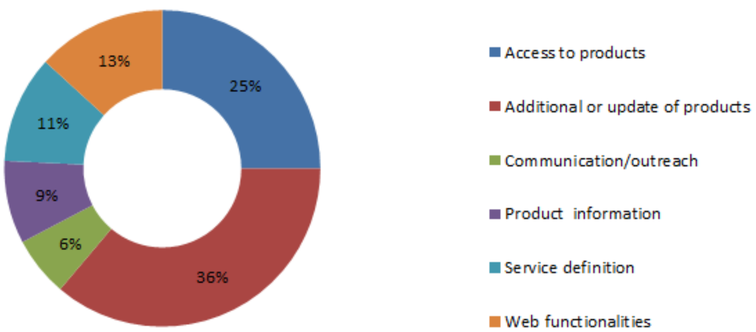

Figure 6: Distribution of users' feedback according to 6 predefined topics.

The ranking of the most frequent user requests are:

1. To provide higher spatial and temporal resolution for products
2. To ease the choice of and access to products to non-experienced users

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3. To have wind and atmospheric products
4. To have waves products
5. To be able to easily download very large datasets
6. The need for easy conversion from NetCDF format to other formats
7. To be able to use various software (e.g. Matlab, GIS)
8. To be able to have maps with user selection products, to ease/make more visible the view
9. To provide more detailed tutorials or video assistance, chat
10. To provide an OPENDAP access
11. The need for tools to calculate basic statistics as mean, maximum and minimum
12. To have products useful in coastal areas

Commentary on the inventory

The inventory tables are provided in Annexes 1, 2, 3 and 4 of this report.

From the EC final report on high-level Polar snow and Ice mission requirements (Duchossois et al., 2018), a list of high priority parameters together with their associated performance requirements was established taking into account the high-level objectives of the EU Arctic policy communication as well as those of the Copernicus programme for the provision of operational products and services to well-identified user communities. This list includes in order of priority the following elements for the marine component only:

- Floating ice parameters including sea-ice extent/concentration/thickness/type/drift velocity, thin sea -ice distribution, iceberg detection/volume change and drift and snow depth on sea ice.
- Sea level/sea-level anomaly (SLA) parameter
- All-weather sea-surface temperature (SST) parameter
- Surface albedo parameter.

These parameters have been marked with an * in the inventory tables.

The definition of the accuracy for models (see above in the CMEMS Data Quality section) is different from the one adopted in the parameter specifications by the PEG. But Estimated accuracy numbers are required for each disseminated product within the CMEMS portfolio.

These tables list the EOV from the GOOS classification.

The assumptions

- We have listed the inventory with the current state of products. Ongoing upgrades until 2021 and in the post-2021 perspective is reported in the following section.
- Baltic Ocean products have not been listed in the Table.

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Parameter Specification

- **Atmospheric parameters**: The ocean surface winds, precipitation (including snowfall) and surface heat fluxes from C3S reanalysis (ERA-Interim and ERA5) and CAMS (IFS) are used in CMEMS ocean models. None surface atmospheric parameters or fluxes or budget are disseminated within CMEMS catalogue although they are available and regularly requested by users. The unique atmospheric surface parameter present in the CMEMS catalogue is the surface wind from satellite observations. Specificities at polar latitudes for this later product need to be further analysed.
- The models Table 1 and 2 (short term and reanalysis, Annex 1 & 2) only concerns the **ARC MFC** system as for instance accuracy numbers for the GLO MFC are given for the global ocean and not in polar areas.
- For short term forecasts models: Given accuracy numbers are indicative of a typical range of errors compared to the chosen observations counterpart. All accuracy for the physical ocean (Blue Ocean) are shown in a range (min/max) corresponding to Nordic and/or Barents seas accuracy numbers. The accuracy numbers for subsurface quantities are given in the range (min/max) of the entire water column.
- Observations of Sea Ice Thickness (SAR) are also available for the Baltic Ocean.
- The **Sea Ice edge** quantity is not mentioned in the Table but it is disseminated in both models and observations.
- **Icebergs detection:** only in observations (none forecasts or analysis) and in South-West Greenland waters, in density units per 10km box.
- The given spatial horizontal resolution for models is the grid mesh resolution.
- H stands for Hours, D for Days, M for Months, W for Weeks
- In Situ: type of platforms available are indicated in the last column of the Table 1 (NRT) only. We don't mention the availability of such platforms in delayed/reanalysis time as the most challenging remain their NRT accessibility. None of the forecasting systems have foreseen the assimilation of such diverse and sparse in situ sea ice data network. Few in situ sea ice data are used within the validation framework.

Presence of a given variable

In each Table, given spatial resolution indicates the mere **presence of a given variable** within the service, regardless of whether or not the product meets the requirements for accuracy, resolution, frequency set forth by the EU, GCOS, ESA or other authorities.

Absence of a given variable

Blank spatial resolution cells indicate the absence of a variable identified as essential in the following cases:

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- There is so far no explicit user demand for this variable in CMEMS
- A pan-Arctic data coverage is out of reach for scientific or logistical reasons (high resolution flow size parameter)
- The variable is used in the processing of related variables but not delivered to the service for any reason (scope, accuracy, data volume or omission).

These cells may or may not change following the outcome of the user consultation.

Orange coloured cells "Partial and can be improved":

Orange colour stands for missing parameters identified as EOVs, for blank accuracy due to various reasons (omission, observations not available) and for EOVs parameters which cannot be derived from models. The orange colour also stands for parameters which can be improved by scientific efforts or by additional observations (that are expected to become available and used within 2028).

Red coloured cells "Low availability and missing data"

These represent variables that require urgent efforts to significantly improve the Copernicus services, mostly by efforts of important models developments,data assembly, processing, formatting and standardization.

The planned development of CMEMS services until 2021 and beyond

Although it remains difficult to make precise plans for the future of the service in 10 years time, we give, in this section, what is already planned within the ARC and GLO MFC and the SI TAC for polar provisions until 2021. The main outlines of the evolution of the service beyond 2021 is also mentioned in terms of roadmap. These items may serve as input for the end-to-end operational system foreseen in WP5.

- One of the main commitments and the leitmotiv of Copernicus services remain the **continuity** of all the provided services without any degradation. This has potentially large consequences in the design of all the components, either the core or the interfaces (inputs/outputs).
- The Increase of the **horizontal resolution** also remains the main concern for CMEMS. The increase of the horizontal resolution is already planned for the ARC MFC system to **3km** by 2021. The ARC MFC reanalysis will also increase to a 6km resolution. Similarly, the GLOBAL MFC deterministic NRT system will increase his resolution to less than 5km in the polar oceans by 2025. Physical reanalysis of ARC MFC will increase to 6 km resolution. The Wave ARC NRT system will increase his resolution to 4km resolution and wave reanalysis at 8km resolution are planned for the ARC MFC system by 2021.
- Increase of **temporal resolution** – Together with increased spatial resolution, high frequency processes is planned to be better resolved. **Tidal** explicit processes will be implemented in the

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higher resolution ARC MFC system and **15 minutes** instantaneous outputs are foreseen by 2021. Hourly outputs for surface fields are planned for the GLO MFC system. Implementation of tides is expected beyond 2021 in the GLO MFC system.

- **Interim reanalysis production** - The continuity of the reanalysis with NRT is undergoing in all CMEMS reanalysis and for blue (+ waves), white and green oceans. The target would be to have a few days delays with NRT. This will bridge the gap between the past and the present and gives the possibility to get climatological products over the recent past. This is in conjunction with C3S/ERA5 production.
- **Reanalysis** - A new physical reanalysis at 6km resolution (1993-2019) and biogeochemical resolution at 25km (1997-2017) is expected by 2021.
- Sea surface **waves** - Full coupling with waves/sea ice/ocean is also underway in the ARC MFC system at 3km resolution and expected by 2021. The assimilation of altimeter data is expected by 2021. Impact on the ice edge accuracy is expected. Wave reanalysis is underway in both ARC MFC and GLO MFC and expected by 2021.
- **Improved sea ice model physics** – The operational implementation of a lagrangian model (the NeXtSYM model) is foreseen by 2021. Better accuracy is expected for all related sea ice dynamics fields. The implementation of ice thickness distribution with explicit different categories also is foreseen within both ARC and GLO MFC systems. The representation of sub-grid processes is expected to be improved. Dissemination of Pressure ridges size and distribution are foreseen within this context.
- **Uncertainties estimates** – The uncertainties estimates with probabilistic forecasts from the ARC MFC ensemble analysis system will be available at 6km resolution. The GLO MFC also foreseen the probabilistic /ensemble approach beyond 2021 at a 15 km resolution in polar oceans.
- **Coupling with atmosphere** – The coupling with an atmospheric boundary layer is expected beyond 2021 in the GLO MFC system. Better accuracy of surface currents and surface dynamics as a whole are expected.
- **Interactions with continents** – Implementation of rivers runoffs from HYPE model is foreseen in the ARC MFC system.
- **The assimilation of new data** – The assimilation of SSS is expected in ARC MFC by 2021. The assimilation of SSS also is foreseen in GLO MFC. The assimilation of Chlorophyll in situ data is expected by 2021 in ARC MFC. The assimilation of Chlorophyll in situ data is expected beyond 2021 in GLO MFC.
- **Better use of existing (in situ) data** – Use UV drifters, SSH, BGC ARGO and SWH in situ data for class4 verification in ARC MFC and GLO MFC systems by 2021.
- **Sea ice thickness** – The assimilation of sea ice thickness is already present in ARC MFC and will be adapted to the ITD model. Class4 evaluation type is underway with satellite data in ARC MFC and expected by 2021. The assimilation of IceSAT2 data is expected by 2021.
- Increase the forecast length (monthly) with ensemble forecasts.

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Gaps analysis in CMEMS polar provisions.

In this section we give the main outlines of a first gap analysis for CMEMS products regarding feedback from users CMEMS questionnaire and from the questionnaire held in WP1. This provides the first recommendations for the WP5 roadmap:

- There is a clear gap in fulfilling the requirements for **very high spatial resolution** products (less than 100m) in CMEMS. For many reasons (computing and storage capacities, model evaluation,...) and because these resolutions will put models into a new paradigm, these resolutions are definitely not reachable at a pan-Arctic scale in the near future.
- Important **sea ice quantities** are **missing** within the current catalog (both models and observations), these shall be partly complemented in the near future. However, an important effort has to be made for the evaluation and validation of such quantities.
- Linked with the previous item, the lack of a comprehensive **in situ sea ice** (thickness) data set for evaluation and/or assimilation is clearly a gap for model developments.
- None of the CMEMS forecasting systems provide **iceberg forecasts**. This information needs important development in iceberg drifting models.
- The lack of observations of **biogeochemistry** parameters is an important gap for models developments
- Having a similar service for **Antarctica** is rather challenging, as no proper regional MFC system exists. Services in the Southern Ocean are part of the GLO MFC system.

CMEMS Service with HPCM

Among the 6 High Priority Candidates Missions, three missions are relevant for CMEMS and polar areas: CIMR, CRISTAL and ROSE-L. Apart from the fact that these missions will bring higher accuracy and/or new parameters of high interest for polar monitoring, the relevance here also concerns the ability of the operational systems to ingest these measurements and provide improved analysis and forecasts. The measurements of interests for CMEMS made by these three missions are listed in WP3.3 and are summarised here:

- CIMR : Sea Ice Concentration (SIC, 1st primary objective), thin Sea Ice Thickness (SIT) (< 0.5 m), Sea Ice Drift, Sea Ice Type, snow depth on Sea Ice, Sea Ice Surface Temperature (SIST), Sea Surface Temperature (SST, 2nd primary objective) , Sea Surface Salinity (SSS), ocean winds
- CRISTAL: Thick SIT (> 1.0m), SI Type, snow depth on SI, iceberg height.
- ROSE-L: SIC (< 100m), Thin SI Thickness (<0.5m), Sea Ice Drift, Sea Ice Type (ice charts), Snow Depth on Sea Ice, Icebergs, Ocean Winds.

For each mission we have listed their relevance for CMEMS and Copernicus services commitments:

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- CIMR: Continuity of the service: SIC, thin SIT, Sea Ice drift and SST are currently assimilated by CMEMS models. Apart from the thin SIT which only has been recently implemented, SIC, Sea Ice Drift and SST are parameters for which operational systems can be relied on (incl. C3S). SIST is part of the CMEMS portfolio.
- CIMR: Sub-daily coverage in the Polar Regions and Adjacent Seas is of particular importance for Copernicus services in their commitments of providing core services for downstream applications.
- CIMR: Measurements of SIC at a spatial resolution of less than 5km will meet the increase of the horizontal resolution (~3km) foreseen beyond 2021 in CMEMS operational systems
- CIMR: Provision of sea surface salinity following-on SMOS. The assimilation of SSS in the Arctic MFC system is currently being investigated within the ESA Arctic+Salinity project.
- CIMR: Spatial measurements (SIST/SST) across the ice edge will bring spatial continuity in the operational systems.
- CIMR, ROSE-L: Concomitant measurements in both missions of various parameters (with different resolutions) are of particular interest in a multivariate assimilation framework.
- CIMR, ROSE-L: Measurements of ocean winds (sea state) ; these new capacities will complement the CMEMS portfolio (core service) in polar areas.
- CRISTAL: Continuity of the service: The Sea Level Anomaly over the open ocean is currently assimilated by CMEMS models. Provision of thick sea ice thickness following on Cryosat-2; assimilation of this type of measurement is currently operational in the ARC MFC and is underway in the GLO MFC.
- CRISTAL: Icebergs detection products will complete the CMEMS portfolio (core service) with measurements made in both hemispheres.
- ROSE-L: Continuity of the service: Provision of SIC, Type at very high resolution in complement to Sentinel-1. These measurements are the core input for the ice charts disseminated in CMEMS.
- ROSE-L: Continuity of the service: Iceberg detection products are in the CMEMS portfolio.

CIMR remains the mission that meets best the CMEMS commitments for Polar Regions and with high feasibility in the implementation. CRISTAL brings an important opportunity to better control (accuracy) and monitor the sea ice volume (continuity with Cryosat-2). Together with the measurement of the SLA (in complement to Sentinel-3), a key parameter for the oceanic operational system, the on-going developments in the assimilation of thick SIT will make CRISTAL of high interest for the core service. ROSE-L has a large potential but major efforts have to be developed in operational systems in order to take full benefit of these measurements, particularly for reliable automated sea-ice-chart-like products. Operational (model) systems are currently not designed to implement such information in a multivariate and multi-data framework.

CIMR, CRISTAL and ROSE-L missions respond to the requirements expressed by CMEMS in their position paper (Bertino et al., 2016) highlighting the need to have continuous measurements of sea ice cover and SST, SIT monitoring and automated ice chart production. Indeed, the three missions used in synergy 1) will

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largely contribute to ensuring the continuity of the service, 2) will reinforce the core service, with further developments in operational systems, by completing a large part of the gaps in the list of parameters mentioned in the previous sections 3) will help to provide better accuracy in disseminated products.

Certain synergies should be noted:

- CIMR and CRISTAL can measure respectively thin and thick sea ice, similarly to SMOS and CryoSAT2, though their higher precision may resolve inconsistencies. The missions should ideally be flying at the same time to harvest most synergies.
- CRISTAL, CIMR and ROSE-L may all deliver information about snow depth on sea ice. A sufficient overlap between these three missions is therefore desirable for cross-calibration.

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Annex 1: Ocean and Sea Ice Short Term Forecast - Table 1

No monthly means in the current portfolio for ARC MFC but it is foreseen. Asterisks (*) refer to variables defined in Duchossois et al., 2018.

Themes	Variable (Unit)	Spatial Resolution GLO/ARC	Accuracy (ARC MFC) Obs used	Comments
Sea Ice (EOV) Forecasts at 10 Days. Temporal Resolution : H+D+M Target Delivery Time for ARC : Daily at 12.00 a.m Target Delivery Time for GLO : Following Day at 00:30 UTC	SIC*	9km/12.5km	18-20% (ARC) Satellite L4 CMEMS	“Independent” satellite data available (SAR) In Situ not NRT: Aircraft and Video Cameras
	SIT*	9km/12.5km	1m (ARC) Satellite L4 non-CMEMS but underway	In Situ NRT : Buoys In situ not NRT: Submarines, Moorings, UAV, EM Birds, Drilling
	SIDrift*	9km/12.5km	5-8 km/day (ARC) Satellite L4 CMEMS	In Situ NRT: Buoys
	ISTemperature*	Quantity available in models but not YET disseminated.		In Situ NRT: Buoys
	SIType*	12.5km (ARC)	0.1-0.2 Mkm2 Satellite L4 CMEMS.	In Situ NRT : Validation with ice charts. Potential NRT: IMB
	SIAge	12.5km (ARC)	Ice Age metrics to be added in 2020	In Situ: Not measurable
	Melt ponds	Quantity is not yet available in models		In Situ not NRT: Aircraft.
	Sea ice Albedo*	12.5km (ARC)		In Situ not NRT: Aircraft. Potential NRT: Buoys
	Ice salinity	Quantity available in models but not YET disseminated.		Potential NRT: IMB...
	Leads detection	Quantity available in models but not YET disseminated.		In Situ not NRT: Aircraft, Submarines, UAV, Drones.
	Pressure ridge size and distribution	Quantity not yet available in models.		In Situ not NRT: Aircraft, Submarines, UAV, Drones.
	snow depths*	12.5km(ARC)		Validation with buoys. In Situ not NRT: Aircraft, field campaign. Potential NRT: Buoys.
Cross-disciplinary	Icebergs Density*	Quantities not yet available in models.		In Situ not NRT : Aircraft, Submarines, AUV, Drones.

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Themes	Variable (Unit)	Spatial Resolution GLO/ARC	Accuracy (ARC MFC) Obs used	Comments
Physical Ocean (EOV) Forecasts at 10 Days Temporal Resolution : H+D+M Target Delivery Time for ARC : Daily at 12.00 a.m Target Delivery Time for GLO : Following Day at 00:30 UTC	SST*	9km/12.5km	0.6-0.8 °C In situ (buoys CMEMS) & satellite (MetopA,B & AVHRR)	In Situ NRT: Buoys In Situ Not NRT: Field campaign
	SSS	9km/12.5km	0.2 In situ (CMEMS)	In Situ NRT: Buoys In Situ Not NRT: Field campaign
	SSH*	9km/12.5km	6cm Satellite L3 (CMEMS)	In Situ NRT: Buoys In Situ Not NRT: Aircraft, Field campaign
	Surface currents	9km/12.5km	In situ	In situ not NRT: Buoys (ADCP), Field campaigns, AUV, Gliers, Floats
	Subsurface Temperature	9km/12.5km	in situ [0-2000m] 0.4-1.0°C	In Situ NRT: Buoy, Floats In Situ not NRT: submarines, AUV, Gliders, Marine mammals
	Subsurface salinity	9km/12.5km	in situ [0-2000m] 0.02-0.2	In Situ NRT: Buoy, Floats In Situ not NRT: submarines, AUV, Gliders, Marine mammals
	Subsurface Currents	9km/12.5km		In Situ NRT: Buo ,(ADCP), Floats In Situ not NRT: Field campaign, AUV, Gliders,
Sea state (EOV) Forecasts at x + 5D (and x + 10D for ARC) Temporal Resolution : Hinst Target Delivery Time for ARC : twice daily at midnight and 12 UTC Target Delivery Time for GLO : daily at 12 UTC	Sig wave heights	6.25km ARC WAV 9km GLO WAV		In situ NRT?:Buoys, Moorings
	Surf. Stress (EOV)	Quantity available in models.		Potentially measurable but complicated
	Spectra	Quantity available in models.		In Situ NRT?: Buoys, Moorings
	Ocean Albedo*	Quantities available in models		In Situ NRT: Buoys In Situ not NRT: Aircraft
Biogeochemical Ocean Forecasts at 10D Temporal Resolution : D+M Target Delivery Time for	Oxygen (EOV)	25km / 12.5km		In Situ NRT: Buoys In Situ not NRT: Submarines, AUV
	Ocean Colour (EOV)	Quantity not available in models.		In Situ NRT: Buoys In Situ not NRT: Aircraft
	Chl profiles (EOV)	25km/ 12.5km		In Situ not NRT: AUV, Gliders, Floats, field campaign

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Themes	Variable (Unit)	Spatial Resolution GLO/ARC	Accuracy (ARC MFC) Obs used	Comments
ARC : Thursday at 12.00 a.m Target Delivery Time for GLO : Following Day at 00:30 UTC	Nutrients (NO2, NO3, NH4, PO4, Si, Fe) (EOVs)	25km/12.5km		GLO only: NO2, NH4 and Fe In Situ not NRT: Field campaign, others?
	Zooplankton (EOV)	12.5km		In Situ NRT: Buoys In Situ not NRT: Field campaigns and moorings.
	Phytoplankton (PHYC+PP) (EOVs)	25km/12.5km		In Situ not NRT: Field campaigns
	Coeff. Attenuation (KD)	12.5km		ARC ONLY In Situ NRT: Buoy In Situ not NRT: Field campaigns
	CFCs tracers (EOVs: transient tracers)			In Situ not NRT: Field campaigns
	pCO2, DIC, Alkalinity, pH (EOVs inorganic carbon)	25km		GLO only In Situ NRT?: Buoy In Situ not NRT: Field campaigns
	Nitrous Oxide (N2O) (EOV)			In Situ:??
	Particulate Matter (EOV)			In Situ NRT: Buoy In Situ not NRT: Field campaigns, AUV
	d13C (Carbon isotope) (EOV)			In Situ not NRT: Field campaigns
	DiMethyl Sulfate (DMS) (not EOV)			In Situ not NRT: Aircraft

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Annex 2: Ocean and Sea Ice Reanalysis - Table 2

This Table concerns MFC reanalysis products, temporal coverage is 1993-(Year-1) (altimeter periods) and temporal resolution is D+M. Biogeochemistry parameters are not listed as findings and gaps from the NRT systems are similar for reanalysis.

Themes	Variable (Unit)	Spatial Resolution GLO/ARC	Accuracy (ARC) Obs used	Comments
Sea Ice	SIC*	9km/12.5km	Satellite L4 10%	
	SIT*	9km/12.5km	Satellite L4 50%	Validation with independent In situ (CDR) and satellite (ICESat) data
	SIDrift*	9km/12.5km	In situ 5 km/d	Validation with independent in situ data (IABP) & satellite L3
	ISTemperature*	Quantity available but not disseminated.		
	SIType*	12.5km	no accuracy given	ARC Only validated in NRT
	SIAge	Quantity available but not disseminated.		
	Melt ponds	Quantity is not yet available in models.		
	Sea ice Albedo*	12.5km	no accuracy given	ARC Only, No albedo observation product in CMEMS
	Ice salinity	Quantity available but not disseminated.		
	Leads detection	Quantity available but not disseminated.		
	Pressure ridge size and distribution	Quantity is not yet available.		
	snow depths*	12.5km	no accuracy given	ARC Only
Cross-disciplinary	Iceberg Density	Quantity is not yet available.		
Physical Ocean	SST* (EOV)	9km/12.5km	satellite L4 0.4 -0.5°C	Use OSTIA (satellite) for accuracy numbers
	SSS (EOV)	9km/12.5km	in situ 1.55	Use of WOA13 for accuracy numbers
	SSH* (EOV)	9km/12.5km	In situ 9-11cm	Validation with independent in situ data (Tide gauges) & satellite L4, L3
	Surface currents (EOV)	9km/12.5km	no accuracy given	No current data below ice

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Themes	Variable (Unit)	Spatial Resolution GLO/ARC	Accuracy (ARC) Obs used	Comments
	Subsurface Temperature (EOV)	9km/12.5km	in situ [0-2000m] 0.3-0.9°C	Use of WOA13 for accuracy numbers, in situ, moorings and models
	Subsurface salinity (EOV)	9km/12.5km	in situ [0-2000m] 0.04-0.33	Use of WOA13 for accuracy numbers, in situ.
	Subsurface Currents (EOV)	9km/12.5km		
Sea state	Sig wave heights	20km / 3 km	satellite L3 no accuracy given	Ongoing work in CMEMS
	Surf. Stress	20km / 3km	no accuracy given	Not provided by the models
	Spectra		In situ (ongoing)	Not provided by the models
	Ocean Albedo	20km / 3km	no accuracy given	Not provided by the models

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Annex 3: Ocean and Sea Ice NRT Observations - Table 3

Themes	Variable (Unit)	Satellite in situ	Spatial Resolution	Temporal Resolution/Target Delivery Time/Frequency/Temporal Coverage/Seasonality	Others sources	Comments
Sea Ice	SIC*	Sat	1km (arc - Svalbard);	WeekDays/3PM/D/2010-Present	High-res imagery (mostly SAR, but also cloud-free visible)	The main SAR source is Sentinel-1 SAR, but other SAR missions are used. MODIS currently more used than S3 OLCI (twilight acquisition issue). Sometimes S2 (coastal).
			1km (arc-Greenlan)	Twice Wmean/twice weekly at 14:00 UTC at day + 1 /TwiceW/2011-Present/ IRR /Within 18 hrs of satellite data acquisition/D/ 2009-Present		
			10km (glo)	D /5AM/D/2005 -Present	SSMIS	OSI-SAF(EUMETSAT)
			5km (arc)	D /5AM/D/2014-present	AMSR2	OSI-SAF (EUMETSAT) Planned in 2020
	SIT*	Sat	25km (arc)	W/W/2010-Present	CryoSat2 and SMOS	Merged CryoSat SMOS
	SIDrift*	Sat	62.5km (glo)	Arc: D/5AM/D/2009-Present Ant: D/5AM/D/2013-Present	In situ	OSI-SAF(EUMETSAT)
		Sat	10km (glo) (mosaic)	12H/24hr after 2nd satellite image/several-time-daily/2016-Present/ IRR/ 24hr after 2nd satellite image/several-time-daily/2016-Present/		S1A/S1B (has used SAR Envisat RADARSAT)
	ISTemperature*	Sat	5km (0.05deg arc)	D /1PM/D/2014 -Present		SENTINEL 3A/B SLSTR SST observations, PODAAC GHRSST NOAA 20 VIIRS_N20-OSPO-L2P, PODAAC GHRSST NAVO-L2P-VIIRS_NPP, OSI-205 a+b EUMETSAT OSI SAF FRN SST in GHRSST format, OSI-401 GLOBAL SEA ICE CONCENTRATION

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						(and in-situ buoys)
	SIType*	Sat	10km (glo)	Arc & Ant D /5AM/D/2005 -Present		OSI-SAF(EUMETSAT)
	SIAge	Sat			R&D product exists	requires sea-ice drift and sea-ice concentration products.
	Melt ponds	Sat			R&D products exist	Sentinel-3 OLCI (as well asl MODIS, MERIS, VIIRS…)
	Sea ice Albedo*	Sat			R&D products exist	Sentinel-3 OLCI (as well asl MODIS, MERIS, VIIRS…)
	Ice salinity	in-situ?				
	Leads detection	Sat			R&D products exist	
	Pressure ridge size and distribution	Sat?				
	snow depths*	Sat			R&D products exist	Many techniques (microwave radiometry, altimetry, SAR,…)
Cross-disciplinary	Iceberg Density	Sat	10km	Irregular weekly-mean Irregular daily at 12:00 day+1		Product solely based on Sentinel1
Physical Ocean	SST* (EOV)	Both	25km 5km	D/ 8 AM/D/2012-Present/Y M+S/12UTC/D/2007-Present/Y D/8AM/D/2007- present/Y		OSTIA SST
			25km	H /5PM/D/2015-Present/Y		OSTIA Diurnal Skin SST
			25km	D/5PM/D/2009-Present)/Y		GMPE
			10km	D/12UTC/D/2010-Present/Y		NOAA-18 & NOAAA-19/AVHRR, METOP-A/AVHRR, ENVISAT/AATSR, AQUA/AMSRE, TRMM/TMI) and geostationary (MSG/SEVIRI, GOES-11
	SSS (EOV)	X Insitu	25km Discrete	W+M/Wednesday at 12UTC/W+M/2014-Present/Y IRR/D/D/2010-Present/Y		ARMOR CORA
	SSH* (EOV)	Sat	25km (glo-L4) 14km(glo-L3)	IRR/12UTC/D/2017-Present/Y INST/2PM/D/2017-Present/Y		No sea level measurements if presence of ice
	Surface currents	Sat (sealevel)	25 km	IRR/12UTC/D/2017-Present/Y		Not in polar areas

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	(EOV)	Insitu	Discrete	IRR/12UTC/D/2017-Present/Y		Not in polar areas
	Subsurface Temperature (EOV)	X Insitu	5km(arc) Discrete	D/13:00 UTC at day +1/D/2014-Present/Y INST/daily, several times per day/D/2010-Present/Y		S3A
	Subsurface salinity (EOV)	X Insitu	25km Discrete	W+M/Wednesdays at 12:00 UTC/W+M/2014-Present/Y INST/daily, several times per day/D/2010-Present/Y		ARMOR
	Subsurface Currents (EOV)	X	25km	W+M/Wednesdays at 12:00 UTC/W+M/2014-Present/Y		ARMOR
Sea state	Sig wave heights	X Insitu	7km Discrete	INST/several-time-daily/D/2017-Present/Y INST/daily, several times per day/D/2010-Present/Y		AL/C2/J3/S3A Arctic ROOS
	Surf. Stress					
	Spectra	X	discrete	3H/12UTC/D/2018-Present/Y 2018 to present		S1A/S1B
	Ocean Albedo					
Biogeochemical Ocean	Oxygen (EOV)	Insitu	Discrete	INST/daily, several times per day/D/2010-Present/Y		Arctic ROOS
	Ocean Colour (EOV)	Sat				Ocean colour measurements are used to compute surface Chlorophyll. See next parameter
	Chl profiles (EOV)	Sat	1km(Arc) Surface only (Ocean Colour)	D+8D+M/At 18:00 UTC (day+1 for NRT, day+5 for DT)/D/2016 to present/Y		**L4&L3** Ancillary NCEP//Ancillary Ozone//AQUA/MODIS NASA L2/SUOMI/NPP VIIRS NASA L2// S3A/OLCI L2//ESA OceanColour L3 CCI
			4 km (Glo) Surface only (Ocean Colour)	D+8D+M/Last day of the period +6 days, at 13:00 UTCMonthly at last day of the month+6 days, at 13:00 UTCDaily at day+1 for NRT and at day+11 for DT, at 13:00 UTC/D/2016-Present/Y D/18:00 UTC (day+1, consolidated 31 days after)/D/2018-Present/Y		**L4** AQUA/MODIS NASA L2// SUOMI/NPP VIIRS NASA L2// S3A/OLCI **L3** AQUA/MODIS NASA L2// SUOMI/NPP VIIRS NASA L2// S3A/OLCI

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		in situ	discrete	INST/daily, several times per day/D/2010-Present/Y		Arctic ROOS
	Nutrients (NO2, NO3, NH4, PO4, Si, Fe) (EOVs)					
	Zooplankton (EOV)					
	Phytoplankton (PHYC+PP) (EOVs)					
	Coeff. Attenuation (KD)	X	1km (Arc)	D+8D/Last day of the period +6 days, at 18:00 UTC)/W/2016-Present/Y D/D,24:00/D/2016-Present/Y		**L4** AQUA/MODIS NASA L2 SUOMI/NPP VIIRS NASA L2 S3A/OLCI L2 ESA OceanColour L3 CCI **L3** Ancillary NCEP//Ancillary Ozone//AQUA/MODIS NASA L2/SUOMI/NPP VIIRS NASA L2// S3A/OLCI L2//ESA OceanColour L3 CCI
			4km (Glo)	**L3**:D+8D+M/Last day of the period +6 days, at 18:00 UTC)/W&M/2016-Present/Y **L4**:D/D,24:00/D/2016-Present/Y		AQUA/MODIS NASA L2 SUOMI/NPP VIIRS NASA L2 S3A/OLCI L2
	CFCs tracers (EOVs)					
	pCO2, DIC, Alkalinity, pH (EOVs)	insitu	discrete	INST/D/IRR/2018-Present/Y		SOCAT
	Nitrous Oxide (N2O) (EOV)					
	Particulate Matter (EOV)	x	1km (Arc)	D/D,24:00/D/2017-Present/Y		L3 Ancillary NCEP Ancillary Ozone AQUA/MODIS NASA L2 ESA OceanColour L3 CCI

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						S3A/OLCI L2 SUOMI/NPP VIIRS NASA L2
	d13C (Carbon isotope) (EOV)					
	DiMethyl Sulfate (DMS) (not EOV)					To be mentioned in Perspective in D5.1

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Annex 4: Ocean and Sea Ice Observations Reprocessing - Table 4

Themes	Variable (Unit)	Sat In situ	Spatial Resolution	Temporal Resolution/Target Delivery Time/Frequency/Temporal Coverage/Seasonality	Other sources In Situ Satellite	Comments
Sea Ice	SIC*	Sat	25km	D/before 12 UTC/D/(2016; -16D)/Y D/Y/Y/(1979-2015)/Y	OSI SAF EUMETSAT (with R&D input from ESA CCI)	ant + arc Nimbus 7 SMMR / DMSP SSM/I / DMSP SSMIS
	SIT*	Sat	25 km(Arc)	D/Y/Y/(2002-2015)/Y	Sat ESA CCI	brokered from C3S
	SIDrift*	Sat	62.5km (Arc)	3D+6D+M/Y/(1999-2016)/Y		ASCAT, QuikSCAT, SSM/IS
	ISTemperature*	Sat				(planned within CMEMS by 2020, details not known yet)
	SIType*	Sat	25km (Arc)	/before 12 UTC/D/(2016; -16D)/Y D/Y/Y/(1979-2015)/Y		available in C3S (not brokered in CMEMS)
	SIAge	Sat			R&D product exists	requires sea-ice drift and sea-ice concentration products.
	Melt ponds	Sat			R&D products exist	Sentinel-3 OLCI (as well asl MODIS, MERIS, VIIRS...)
	Sea ice Albedo*	Sat			R&D products exist	Sentinel-3 OLCI (as well asl MODIS, MERIS, VIIRS...)
	Ice salinity	in-situ?				
	Leads detection	Sat			R&D products exist	
	Pressure ridge size and distribution	Sat?				
	snow depths*	Sat			R&D products exist	Many techniques (microwave radiometry, altimetry, SAR,...)

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Cross-disciplinary	Iceberg Density					
Physical Ocean	SST* (EOV)	sat multiobs	5km (Glo) 25km (Glo) 25km	D/Y/IRR/(1981-2016)/Y D+M+S/Y/IRR/(1985-2007)/Y W+M/Y/Y/(1993-2017)/Y		ESA-CCI ENVISAT/AATSR Re-processed SST satellite data ERS-1/ATSR Re-processed ERS-2/ATSR Re-processed in-situ ICOADS NOAA/AVHRR Historical SST ARMOR
		insitu (GLO)	discrete 50km	INST/IRR/Y/(1950-2018)/Y M/IRR/Y/(1990-2015)/Y		ARGO/DBCP/EGO/GOSUD/GTS/NDBC/OCEANSITES/NRT CMEMS
		insitu (ARC)	discrete	INST/IRR/Y/(1990-2017)/Y		Seadatanet
	SSS (EOV)	multiobs insitu (GLO)	25km discrete 50km	W+M/Y/Y/(1993-2017)/Y INST/IRR/Y/(1950-2018)/Y M/IRR/Y/(1990-2015)/Y		ARMOR SMOS ARGO/DBCP/EGO/GOSUD/GTS/NDBC/OCEANSITES/NRT CMEMS
		insitu (ARC)	discrete	INST/IRR/Y/(1990-2017)/Y		Seadatanet
	SSH* (EOV)	sat	25km(glo) 14km(glo) 25km(glo)	IRR/Y/several-time-yearly/(1993-2019/Y INST//Y/several-time-yearly/(1992-2019/Y IRR/Y/several-time-yearly/(1993-2018/Y		J3, S3A, HY-2A, Saral/AltiKa, Cryosat-2, J2, J1, T/P, ENVISAT, GFO, ERS1/2 C3S
	Surface currents (EOV)	sat sat	25km(glo) 25km(glo)	IRR/Y/several-time-yearly/(1993-2019/Y IRR/Y/several-time-yearly/(1993-2018/Y		J3, S3A, HY-2A, Saral/AltiKa, Cryosat-2, J2, J1, T/P, ENVISAT, GFO, ERS1/2 C3S

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		multiobs multiobs	25km(glo) 25km(glo)	W+M/Y/Y/(1993-2017)/Y 3H+D+M/IRR/Y/(1993-2017)		ARMOR ECMWF ERA-INTERIM wind stress
		insitu	discrete(Glo)	INST/IRR/Y/(1990-2016)/Y		ECMWF/CMEMS/NOAA AOML
	Subsurface Temperature (EOV)	multiobs insitu	id T id S			
	Subsurface salinity (EOV)	multiobs insitu	Id S Id S			
	Subsurface Currents (EOV)	multiobs insitu	Id Currents Id Currents			
Sea state	Sig wave heights	insitu	discrete	INST/IRR/Y/(1990-2016)/Y		in-situ NDBC and ROOSES wave data
	Surf. Stress					
	Spectra					
	Ocean Albedo					
Biogeochemical Ocean	Oxygen (EOV)	insitu(Glo)	discrete	INST/IRR/Y/(1990-2017)/Y		N SITU GLO AND REGIONAL DATASETSNOOS/SeaDataNet NODCS
	Ocean Colour (EOV)	sat				Ocean colour measurements are used to compute surface Chlorophyll. See next parameter
	Chl profiles (EOV)	sat Surface only (Ocean Colour)	1km (arc) 1km (arc) 4 &25km (glo) 4 &25km	D/IRR/IRR/(1997-2017)/Y 8D+M/IRR/IRR/(1997-2017)/Y **L3**: D/IRR/Y/(1997-2018)/Y **L4:** D+8D+M/IRR/Y/(1997-2018)/Y		L3 CCI L4 CCI AQUA/MODIS NASA L2 MERIS ESA L2 S3A/OLCI L2 SeaWIFS NASA L2 SUOMI/NPP VIIRS NASA L2
		insitu (Glo)	discrete	INST/IRR/Y/(1990-2017)/Y		NOOS/SeaDataNet NODCS
	Nutrients	multiobs(	1km(glo)	INST/Y/Y/(2004-2018)/Y		Argo GDAC/GLODAPv2

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	(NO2, NO3, NH4, PO4, Si, Fe) (EOVs)	insitu)				
	Zooplankton (EOV)					
	Phytoplankton (PHYC+PP) (EOVs)					
	Coeff. Attenuation (KD)	sat	4km(Glo)	L3: D/IRR/Y/(1997-2018)/Y L4: 8D+M/IRR/(1997-2018)/Y		AQUA/MODIS NASA L2 MERIS ESA L2 SeaWIFS NASA L2 SUOMI/NPP VIIRS NASA L2 + **S3A/OLCI L2 for L4**
	CFCs tracers (EOVs)					
	pCO2, DIC, Alkalinity, pH (EOVs)	multiobs insitu(glo)	100km 100km-25km	M/Y/Y/(2001-2016)/Y INST/APRIL/Y/(1957-2017)/Y		NCEP/ Menemenlis et al., 2008 GlobColour Jena CO2 inversion s76_v4.1 CMEMS/NOAA SOCAT Takahashi et al., 20019 GLODAP SOCAT
	Nitrous Oxide (N2O) (EOV)					
	Particulate Matter (EOV)	sat (glo)	4km	L3: D/IRR/Y/(1997-2018)/Y **L4**: 8D+M/IRR/Y/(1997-2018)/Y		AQUA/MODIS NASA L2 MERIS ESA L2 SeaWIFS NASA L2 SUOMI/NPP VIIRS NASA L2 + **S3A/OLCI L2 for L4**
	d13C (Carbon isotope) (EOV)					
	DiMethyl Sulfate (DMS) (not EOV)					

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Annex 5: Parameter Specification Scheme adapted by the PEG survey

Table : Parameter specification scheme adapted by the PEG survey (Duchossois et al., 2018).

AOI (coverage)	Area Of Interest to be covered, options are: [0] global, [1] high latitude (>60), [2] regional - in this case provide details (bounding box, shapefile) or map (raster mask at 10-100km resolution)
Spatial Resolution	the sampling distance of measurements in [m], equal spacing in x and y is assumed
TOY (seasonality)	Time Of Year for measurements, options are: [0] year round, [1] seasonal - in this case provide the time window for measurements (months)
Frequency	temporal frequency, options are: [0] 'on demand' acquisitions - estimate nr of acquisitions per year, [1] regular measurements - provide repetition rate in [mn, hr, dy, mo, yr]
Leadtime	in case of 'on demand', what should be the minimum lead time for an acquisition to be scheduled in [hr]
Timeliness	how long after acquisition should the product be available, options are: [0] non time critical, [1] NRT within 6hr [2] QRT within 1hr
Unit	how is the variable assessed [0] as continuous scale, in this case give (physical) units (SI) [1] in different categorical classes - in this case provide reference
Range	dynamic range of measurements in physical units or number (and name) of categories
Accuracy	95% confidence interval for uncertainty (continuous scale variable) or commission and omission errors (categorical variable)
In situ (I)	availability of in-situ observations, options are: [0] hardly accessible, [1] irregular measurements available, [2] various sources exist and (non-harmonised) data are made available on a regular basis, [3] international standardised network
Status (S)	is variable currently monitored by means of EO: [0] no [1] experimental research ongoing, [2] operational service, (ATBDs available); for [1] and [2] provide references
Gaps	If variable is currently observed, give actual specs if different from requirements listed under 1-8 above
Continuity (C)	what are the expectations with respect to future availability of this variable:

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	[0] current status of EO and IS ensured or likely to improve, [1] in-situ at risk, [2] EO not available or at risk [3] availability/quality of both IS and EO at risk to deteriorate
Priority (P)	[0] low, nice to have, dispensable, models and/or proxies available [1] low, but continuity must be guaranteed [2] high, improvements are essential for progress in the domain

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Annex 6: Satellite Observations used today by CMEMS (Models and Observations)

Multi-frequency Passive microwave Radiometry	Low-resolution (~25 km) sea ice concentration, area and extent, sea ice types, and sea ice drift. Sea surface temperature, near surface wind speed.
Altimetry	Sea ice thickness* and freeboard height,. Open ocean sea level and sea surface height and hence dynamic topography and surface geostrophic current.
SAR	High-resolution for iceberg, sea ice deformation, drift,, ice charts (concentration)
L-band passive microwaves	Thin sea ice with thickness less than 0.5 m*, Sea surface salinity but with questionable sensitivity in cold-water regions.
Scatterometry	Medium-resolution (~10 km) sea ice concentration, area and extent, sea ice types, and sea ice drift. Wind vector in ice-free waters.
IR Radiometry	High-resolution sea and ice surface temperature
Spectrometry	Chlorophyll a concentration and distribution. Used for estimation of phytoplankton concentration

* Note that the sea ice thickness presently derived from Cryosat 2 and SMOS is not yet in the list of CMEMS satellite high-level products. However, the data are used for model validation and data assimilation. A near real time sea-ice thickness product will be added in the SI TAC portfolio for CMEMS by 2021.

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