Position paper
Polar and snow cover applications User Requirements Workshop Brussels, 23rd June 2016

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COPERNICUS MARINE ENVIRONMENT MONITORING SERVICE

MERCATOR OCEAN

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1 INTRODUCTION

The operational Copernicus Marine Environmental Monitoring Service (CMEMS) provides regular and systematic core reference information on the state of the global ocean and regional seas. The CMEMS is driven by quality and simplicity: quality of the ocean information provided to users, and simplicity of the access to information. The observations and forecasts produced by the service support any user requesting generic information on the state of the ocean and sea ice, and especially downstream service providers who use this information as an input to their own value-added services to end-users. In particular the following 4 areas benefit from the service: Maritime Safety, Coastal and Marine Environment, Marine Resources, and Weather, Seasonal Forecasting and Climate activities. The CMEMS functionalities offer:

- An integrated Service
- An Open and Free service
- Access to a single Catalogue of products
- A reliable service
- A sustainable service

Both Public and Private users need response to today's climate and marine challenges. The CMEMS supports and contributes to the data and information tools for many domains, such as:

- EU's Integrated Maritime Policy. A good knowledge of the environmental status of the marine waters is necessary, in accordance with the Marine Strategy Framework Directive (MSFD), currently prepared by Member states with the support of the European Environment agency (EEA).
- European and Regional decision makers involved in European policies linked to the Marine Environment and Security (EC Directorate, European Agencies, Regional Conventions)
- Member states' National Agencies and public bodies for their own regional service provision, related to Pollution combat and Monitoring, Coastal Environment, Water Quality, Maritime Safety, Renewable Energies, Offshore activities...

In the following the CMEMS service activities and capabilities are further highlighted in the context of Polar ocean and sea ice applications.

2 CMEMS POLAR OCEAN AND SEA ICE MONITORING ACTIVITIES

Copernicus Marine Service delivers analysis and forecasts of ocean state variables for the polar areas, including, in particular, sea ice and high latitude ocean temperatures, salinity, currents and sea level. The product list (global and regional) covers the range from high resolution ice charts delivered by operational ice services and mainly based on SAR data, via global medium-resolution satellite based daily ice analysis (both provided by the Ocean and Sea Ice Thematic Assembly Centre, OSI TAC), to numerical ocean model analysis, forecasts out to 10 days and reanalysis for the last 20 years (provided by the Arctic Monitoring and Forecasting Centre, ARC MFC, and the Global MFC for the Southern Ocean). For the purpose of giving advice to the EU Copernicus *Polar Ice and Snow Cover Application* initiative, the satellite derived products (of key importance for the Copernicus Marine Service) can be divided in four categories of application: (i) ocean and sea ice analysis and forecasting; (ii) ice charting; (iii) climate projections and predictions; and (iv) weather forecasting.

These categories of applications need all-weather accurate medium resolution sea ice concentration observations (~10 km resolution) 1-2 times per day. The accuracy today is limited by uncertainty in snow cover (snow signature variability) and in melt-ponding during summer. We need reliable observations of the snow on sea ice. Medium resolution microwave radiometry has been the backbone of operational sea ice monitoring since the late 70's. Today's best available instrumentation is the AMSR-2 on JAXA's GCOM-W1 satellites which deliver regular daily sea ice concentration, sea ice type and sea ice drift in addition to all-weather SST.

The current CMEMS Arctic and the next release of the global coupled ice-ocean model system are assimilating sea ice concentration data to constrain the position of the ice edge. Although ice thickness is not assimilated in the products available today, the Arctic system has proven capable of assimilating sea ice thickness data for both thin ice (SMOS) and thick ice (ICESat/Cryosat-2); these data are currently used for validation. Ice drift data are currently assimilated in the CMEMS Arctic system but not as successfully as the other two variables. This point may improve in the coming years thanks to a new generation of sea ice models – using the elasto-brittle rheology - able to reproduce the scaling laws of sea ice deformations as observed from high-resolution satellite data such as ice drift from Sentinel-1. This property is also expected to become an advantage for assimilating other sea ice observations such as sea ice leads concentration data.

Recently, progress has been achieved regarding polar sea level retrievals from altimetry (outside of the sea ice boundary), notably thanks to the improvement in the mean sea surface model and ocean tide corrections. The development of new instrumental processing methods now also allows retrieval of the sea level in the leads (within the sea ice boundary). The availability of these measurements within the Arctic regional product is expected to become highly valuable, notably for climate applications.

The ongoing changes in the context of accelerating climate change call for a vastly improved understanding of the polar ecosystems based on an intensive observation program. Ocean colour remote sensing is certainly one of the most appropriate tools to extensively monitor marine primary production by surface chlorophyll concentrations, and it provides recurrent pan-Arctic and pan-Antarctic observations at relatively low cost. Developments of assimilation of surface chlorophyll data from ocean colour data are ongoing in both ARC and GLO MFC.

3 SATELLITE OBSERVATIONS THAT ARE USED TODAY BY CMEMS

An overview of the high latitude and Arctic Ocean satellite observations used by the CMEMS today is given in the table below.

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.
SAR	High-resolution for iceberg, sea ice deformation, drift, sea ice roughness, leads and ridges.
Scatterometry	Medium-resolution (~10 km) sea ice concentration, area and extent, sea ice types, and sea ice drift. Wind vector in ice free waters.
Altimetry	Open ocean sea level and sea surface height and hence dynamic topography and surface geostrophic current.
IR radiometry	High-resolution sea and ice surface temperature
Spectrometry	Chlorophyll-a concentration and distribution. Used for estimation of phytoplankton concentration.

Altimetry*	Sea ice freeboard height. Snow depth. Sea level in leads.
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.

** 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, data are already used for model validation and data assimilation tests are underway. It is likely that a near real time sea ice thickness product will be added in the OSI TAC portfolio for CMEMS Phase II (2018-2021). The situation is similar for the sea level in the leads for which demonstration products already exist but they are not yet in the CMEMS catalogue.*

4 CMEMS REQUIREMENTS

The future availability of multifrequency microwave radiometry ala AMSR-2 is uncertain and reason for concern. The future MWI on MetOp SG will eventually secure continuation of the SSMI(S) series of coarse resolution radiometry for climate monitoring, but will not fulfil the requirements for medium resolution (< 10 km) sea ice concentration and lead fraction for sea ice charting and which is needed in the near future operational ice/ocean models. MWI also lack the necessary frequencies to measure all-weather SST. A potential future C-band microwave radiometer (EE-10 suggestion) could fulfil the SST requirements, but resolution better than 5 kilometres at frequencies below 40 GHz is not foreseen and will still be needed. Infrared ice surface temperature (IST) and sea surface temperature observations from Polar Regions are also required. However, there is a gap in the operational Sentinel-3 products, where no SLSTR IST product is foreseen over sea ice.

Moreover, we lack the ability for automatic sea ice **chart production** or production of other similarly useful products for the safety of navigation, including high resolution near real time sea ice thickness, sea ice drift and iceberg detection. This is the only way we can address the continuously increasing demand for sea ice information for safe navigation as well as for higher resolution NWP, and ocean and sea ice forecast models. Such production needs a multi sensor approach, but SAR data are and will continue to be the core input. C-band SAR is secured via Sentinel-1 and provides data for automated iceberg detection and for automated sea ice drift computation. SAR data also reveal waves in sea ice, which can break the ice by flexural stress. Waves in ice are an important process in forming the Marginal Ice Zone. However, the remaining major gap is reliable automated sea ice-chart-like products that can be delivered in NRT for navigational aid and as high-resolution input to numerical forecast models. In order to improve and develop automated ice chart processing several options could be exploited including multi frequency and bi-static SAR missions. Especially the potential to measure ice thickness from a bi-static C-band SAR constellation with Sentinel-1 should be investigated. The key here is to demonstrate automation. With increased demand for ice information in a declining Arctic Ocean sea ice cover, robust, standardized automatically generated products are a key requirement.

For climate monitoring of **sea ice thickness**, we need to solve the knowledge gap in snow-depth over sea ice. The altimeters today at best measure sea ice freeboard, and in order to convert this to ice thickness we need to have information about the snow cover (ideally depth and density). Sea ice thickness is a very important indicator of climate change in the Arctic. In view of the uncertainty in the freeboard to sea ice thickness inversion, a Cryosat-3 type mission is an attractive option, preferably in combination with a laser altimeter. A Saral/Altika Follow On mission (in Ka-band) would provide valuable complementary estimates of the snow depth. Note also that a Cryosat-3 type mission will provide valuable sea level measurements in the open ocean bordering the sea ice covered seas as well as in the leads. It is of prime importance, though, that the orbit configuration allows covering the central Arctic Ocean. However, for operational sea ice monitoring, input to sea ice models and sea ice charting, satellite measurements of the thin sea ice below 0.5 m (SMOS- like) is indeed also required. The coverage of this region could even be reinforced as the Northern limit of Altika and Sentinel-3A/B coverage does not allow a satisfactory sampling north of 82°N.

In the Arctic Ocean, the phytoplankton spring bloom often develops around the ice-edge. This highly transient phenomenon lasts about 3 weeks at any given location in the seasonal ice zone (SIZ). And ice-edge blooms may represent most of the annual primary production in the Arctic Ocean. The SIZ is currently increasing in size and may cover the entire Arctic Ocean as early as twenty years from now. The use of ocean colour remote sensing in Polar Regions is, however, impeded by a number of difficulties and intrinsic limitations including the prevailing low solar elevations, the impact of ice on remotely-sensed reflectance, the peculiar phytoplankton photosynthetic parameters, the optical complexity of seawater especially over the Arctic shelves and, persistence of clouds and fog. For operational biogeochemistry monitoring, accuracy of ocean colour data measurements in the sharp marginal ice zone is required.

5 Conclusion

In summary seven (non-prioritized) critical areas are standing out for CMEMS polar and sea ice monitoring activities, notably the need to improve, develop and ensure:

(i) Continuation and improvement of the sea ice thickness time series from Cryosat-2. This is required both for climate and operational sea ice monitoring activities (including assimilation in sea ice models).
(ii) Continuation of the altimetry sampling over the ocean in Polar Regions to constrain ocean models through data assimilation (e.g. for improved ocean currents).
(iii) Reliable retrieval of sea level in the leads to reach the retrieval accuracy required to monitor Climate Change.
(iv) Continuation of SMOS like observations of thin sea ice below 0.5 m.
(v) Sustainable operation of medium-resolution (5-10 km) multi-frequency and - polarization passive microwave observations of SST, sea ice lead fraction and sea ice concentration, area and extent.
(vi) Automated production of ice chart-like products from a combination of SAR data and other data (e.g. bi-static SAR, passive microwave, multi-frequency SAR).
(vii) Reliable retrieval of ocean colour in the marginal ice zone