# Publishable summary 0f work year 2

## A summary description of project context and objectives

The objective of SIDARUS is to develop new sea ice data products from satellite, airborne and underwater platforms as well as ice forecasting from models in order to improve sea ice monitoring services. In addition to analysis of satellite and airborne data, the project will analyze in situ, airborne and under-ice data from previous and new field campaigns. These are essential data for validation of satellite retrievals of sea ice parameters such ice concentration, ice thickness and ice type classification. The data sets and products will be demonstrated to users working in climate research, marine safety and environmental monitoring. SIDARUS will extend the present GMES marine services[1] with new satellite-derived sea ice products, ice forecasting from regional models and validation of sea ice products using non-satellite data. The demand for improved sea ice information in the Arctic and Antarctic by many user groups is growing as a result of climate change and its impact on environment and human activities. The presently observed reduction of the Arctic sea ice extent, in particular during the summer months and an increasing demand for natural resources are key mechanisms driving human activities in these areas. In Antarctic, ice discharge from several ice shelves is a significant climate indicator, leading to enhanced iceberg population in the Southern Ocean.

## Description of the work performed since the beginning of the project and the main results achieved so far

The consortium has continued to contact users of the sea ice products and services. The users include representatives for each of the five application areas where products are being developed: (1) High-resolution sea ice and iceberg mapping by SAR to support marine transportation, offshore operations, and ice-weather forecasting services in polar regions. (2) Sea ice albedo from optical sensors to support sea ice modelling and climate research, (3) Sea ice thickness from satellite data, airborne surveys and other observing platforms providing data for climate research and operational users. (4) ARGOS tracking of marine mammals combined with sea ice maps to support environmental management, wildlife protection. (5) Ice forecasting based on numerical models and satellite data for marine safety. Products in all these five categories have been developed and disseminated to users through workshops, conferences and direct contact.

Sea ice data from several field campaigns have been obtained in the period. In particular in situ ice thickness data have been collected because these data are important for validation of the satellite retrievals from satellite altimeter data. The ice thickness data used in the project includes airborne electromagnetic measurements of ice thickness and ridges (EM-bird), underwater ice draft measurements from multibeam sonars mounted on submarines and AUVs. Also other field measurements of sea ice parameters have been compiled to validate ice thickness, ice types and ridges/leads that are derived from satellite radar altimeter, passive microwave data and SAR/optical data.

Satellite data for the product development in the project have been obtained through several channels. One data source is the GMES Marine Core Services through the MyOcean project. These data are mainly large-scale modelling fields that are needed for the regional models and

[1] http://www.gmes.info/pages-principales/services/marine-monitoring/

some satellite sea ice products provided by the Sea Ice and Wind Thematic Assembly Center in MyOcean. High-resolution SAR and optical images needed for detailed sea ice and iceberg mapping are also obtained from MyOcean and the Data Ware House (DWH). After ENVISAT stopped in April 2012, efforts have been done GMES and MyOcean to replace ENVISAT with RADARSAT2 for SAR data provision. The possibility to develop downstream services using SAR data can be affected by this change. However, the technical development of SAR-based products is not affected by changing from ENVISAT to RADARSAT2. The radar altimeter data and derived ice thickness from CryoSat-2 has been delayed. The reason is that ESA needed to reprocess the level 1b data form CryoSat over sea ice, which implied that validation of CryoSat defived ice thickness data have not started. The third category of satellite data are ARGOS position data for marine mammals in ice covered areas. Access to test data have been obtained by agreement with users who possess data sets to be used in the project. Other satellite data needed to develop thin ice algorithm and albedo retrival have been obtained as planned.

The development of a sea ice albedo parametrization algorithm based on optical satellite sensors has been done and a software package has been implemented (Melt Pond Detection – MDP). This software package generates operational products showing sea ice albedo and meltpond fraction in the period from spring to autumn. The software package involves processing of MERIS data from the initial data (level 1b, full orbits) till the resulting maps which contain melt pond fraction and spectral albedo for each pixel of the scene. The loss of ENVISAT in April 2012 implied that new MERIS data were not available after this date. The work is therefore concentrated on analysis of archived MERIS data, which is most important for climate users who need longer time series. Time series of albedo and meltpond fraction is being produced for the area north of Alaska because of the availability of validation data in this area (Fig. 1).

The development of SAR-based sea ice and iceberg products have been focussed on (1) sea ice classification, (2) iceberg detection and tracking, and (3) sea ice motion and deformation analyses. For sea ice classification, the use of image pairs acquired at HH- and HV-polarization (employing Radarsat-2 ScanSAR dual-polarization mode) was investigated. The separation of water and ice is easier when both polarizations are available, as shown in Fig. 2. For detection of smaller icebergs drifting in open ocean or trapped in sea ice Radarsat-2 ScanSAR-Wide (spatial resolution 50 m) and ScanSAR-Narrow (25m) images have been analysed. The results show that a spatial resolution of 25m increases the rate of reliable detections considerably compared to 50 m. For sea ice drift and deformation monitoring, an algorithm was implemented and tested using Envisat single-polarization images from a polynia region in the Weddell Sea (Antarctic) and dual-polarization ScanSAR images from Radarsat-2, acquired over Fram Strait (Fig. 3). The implementation of the algorithms will be done resulting in toolboxes for users who want to process SAR data themselves.

The ice thickness retrieval from passive microwave data from SMOS has been implemented as a protoype product which will be important for mapping of thin ice areas. The ice thickness from SMOS has also been included into the operational ice service at met.no (Fig. 4). Studies are ongoing where time series of thin ice are analyzed and compared with other data and modeling results. A main activity in the future will be to carry out validation activities, because there is very little in situ data on thin ice. Data on thin ice will be very important because more of the Arctic sea ice is firstyear ice which refreezes every winter. There is presently very little data on thin ice that can be used to validate sea ice models.

Compilation of in situ ice thickness data has continued, which is required for validation of CryoSat ice thickness retrievals. CryoSat data are soon expected to be available for the research community. It is primarily in situ data from multiyear ice that is required because CryoSat will obtain freeboard data for ice thicker than 1 m. It is also important to obtain data on ridge distribution, which has been done by UCAM in recent field experiments.

The sea ice forecasting system for the Barents and Kara Seas is under development and produces forecasts every week for up to 7 days. The present system distinguishes between the sea ice rheology in the consolidated ice pack and in the marginal ice zone. An elastic-viscous-plastic (EVP) formulation is used in the pack ice while a rheology based on statistics of random collisions between solid ice floes is used in the marginal ice zone. A newly developed wave-in-ice model (WIM) propagates surface waves into the ice and may break large pieces of sea ice into smaller floes. The waves at the boundary of the ice edge are taken from forecasts given by a surface wave model. A floe size based criterion then determines the transition from pack ice rheology to marginal ice zone rheology. The assimilated TOPAZ system for the North Atlantic and the Arctic Ocean, provided by MyOcean, is used to produce nested lateral boundary conditions for the regional Barents and Kara Sea model. The regional ocean and sea ice forecast model include tidal forcing at open boundaries, atmospheric forcing from ECMWF regional forecast, and river input based on a climatologically forced hydrodynamic model. Forecast surface wave data from the Norwegian Meteorological Institute are used in the wave-in-ice model. These data are interpolated to the model grid using a nearest grid point approach. The daily forecast is published on a webpage (http://topaz.nersc.no/Knut/IceForecast/Barents/). Work is ongoing to validate the model performance as well as forecast products.

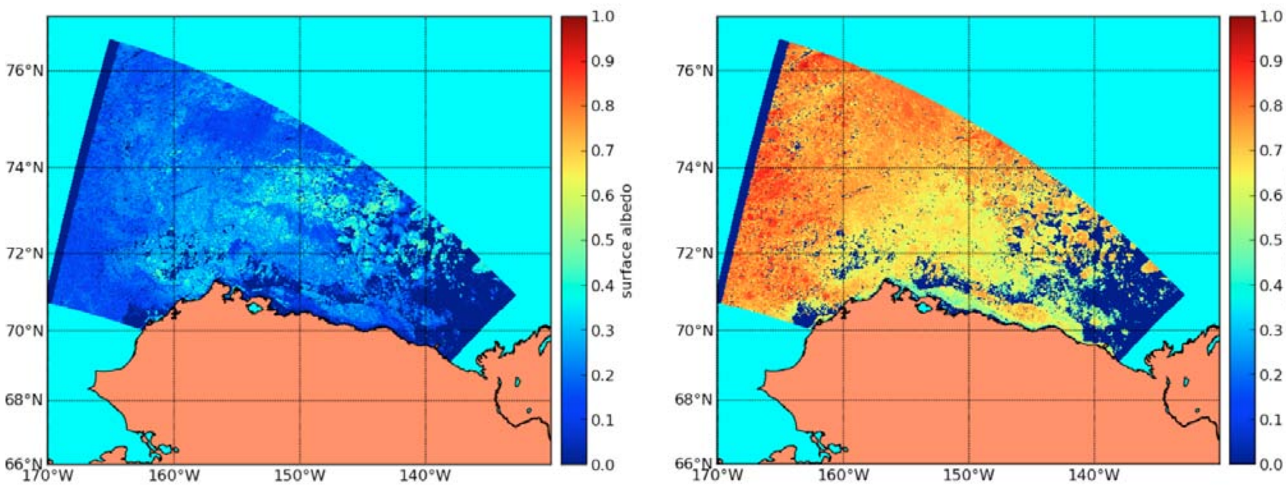
Integration and validation of products has started by the following activities: the Barents and Kara Sea forecasting model is integrated with the TOPAZ modelling and data assimilation system provided by MyOcean. The ARGOS positioning data for marine mammals are integrated with sea ice products from satellite data. Iceberg monitoring and forecasting interated use of satellite data for detection with an ocean forecasting model to prepare iceberg drift forecast.

***The expected final results and their potential impact and use (including the socio-economic impact and the wider societal implications of the project so far),***

The results of the project are expected to have impact on climate research as well as marine operations and environmental protection in polar regions. The Arctic and Antarctic is dominated by ice-covered oceans and coasts. The regions are exposed to climate change with significant impact on the cryosphere and the environment which depends on the presence of ice. In the Arctic the global warming is at roughly twice the global average rate, with a dramatic reduction in summer sea ice extent as one of the clearest indicators of this trend. Physical and biological processes are being transformed across the entire regions while climate feedback mechanisms in the Arctic's changing atmospheric and oceanic dynamics impact at global scales. The Arctic regions offer vast areas of hydrocarbon resources that have just started to be exploited. The Arctic Ocean is surrounded by continental shelves, where in particular the huge Siberian shelf covering the eastern hemisphere, extending from the Barents Sea to the Chukchi Sea.

The ongoing changes in Arctic climate with increasing temperatures and decreasing sea ice cover have stimulated the interest for oil and gas exploration in several Arctic areas. A reduction of the sea ice area opens up the possibility to access new areas of the Arctic Ocean where hydrocarbon resources can be exploited and transported to the markets. The main Arctic areas where large-scale offshore exploration have started are: Sakhalin in Sea of Okhotsk, North Slope of Alaska, Cook Inlet, Grand Banks of Newfoundland, Barents Sea (Snøhvit field and the upcoming Shtokman field) and the Pechora Sea. All these areas have seasonal sea ice cover and some have icebergs that put severe constraints on design and operation of installations and on transport solutions. Even if the sea ice cover is decreasing and is expected to diminish further in the coming decades, the sea ice will still remain a dominant factor in most of the exploration areas in the winter season. In the summer months, however, less sea ice will provide access to offshore areas in Canada, Greenland and on the eastern Siberian shelf that were previously inaccessible due to sea ice.

Improved sea ice end iceberg monitoring and forecasting in the polar regions will have large socio-economic impact due to climate change combined with increased human activities.




*a* *b*

*Figure 1. Example of MERIS products:* (a) *melt pond fraction for 12 June, 2008, region Barrow, Alaska. Zero values indicate pixels which did not pass the sea ice flagging thresholds;* (b) *sea ice albedo for 19 June, 2008. Note the cloud artifacts and decreased albedo at the left hand side of the image.*

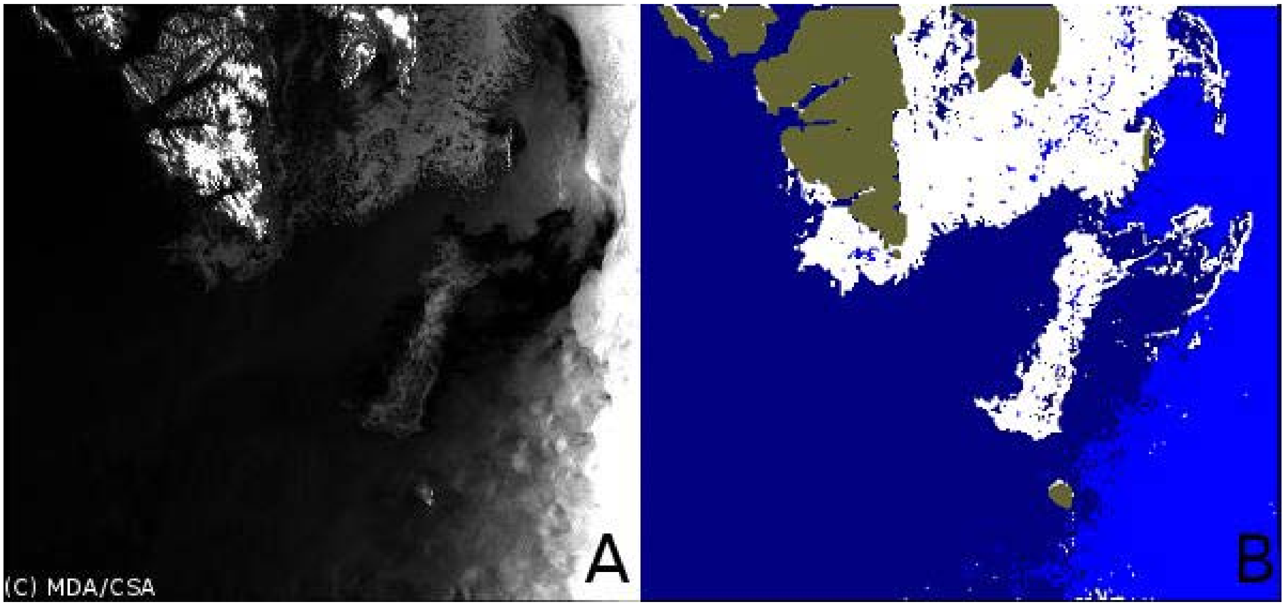



*Figure 2. An example of Radarsat2 image (A) classification (B) into ice (white), calm water (dark blue) and rough water (blue). Greenish color masks land (Svalbard on top and Bear-island near bottom on this image). The raw sigma0 data in HH and HV polarization is used for computing texture characteristics in a moving window using a Gray Level Co-occurence Matrix (GLCM). A neural network is applied at the next step for processing array of the most informative texture characteristics and ice/water classification.*

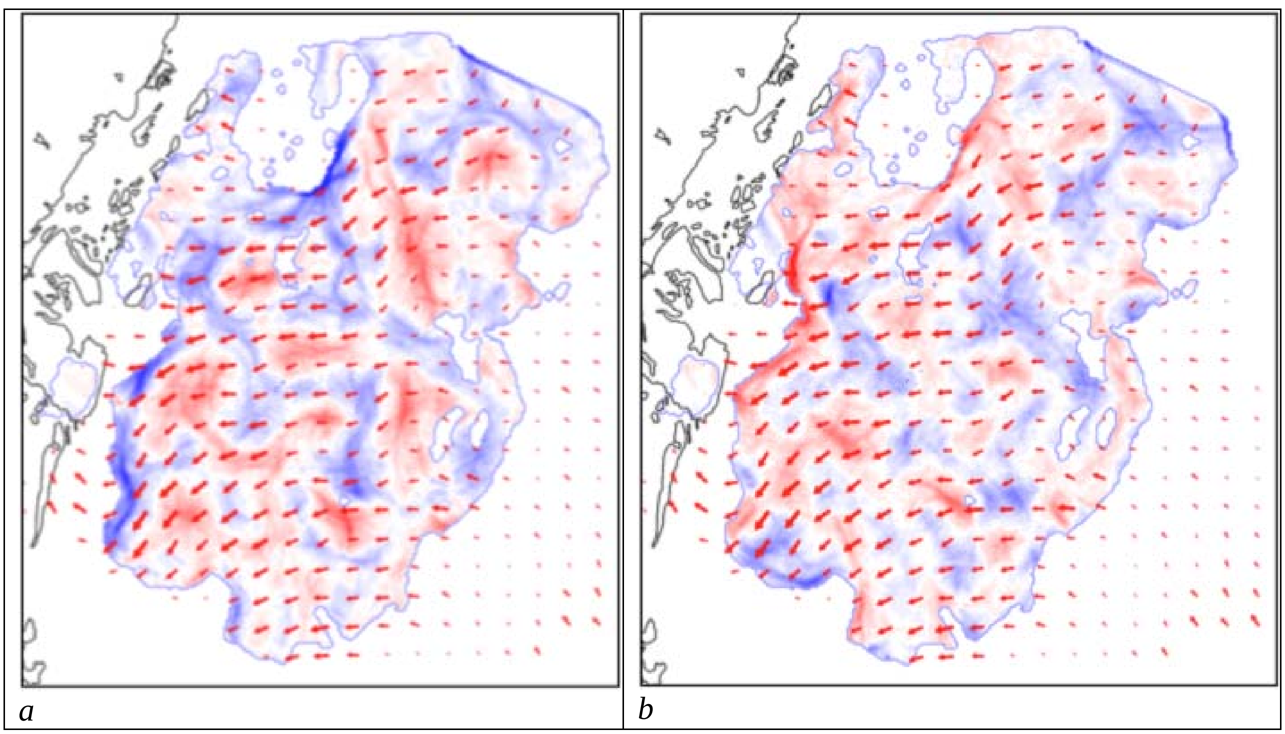



*Figure 3. Examples of ice drift products from SAR: (a) Divergence map derived from Radarsat-2 image pair recorded on 16.09.2012. The red arrows are the calculated velocity field. Red are zones of divergence, blue zones are convergent regions. (b) Vorticity map from the same data set. Red areas rotate in anticlockwise direction, while blue areas rotate clockwise.*

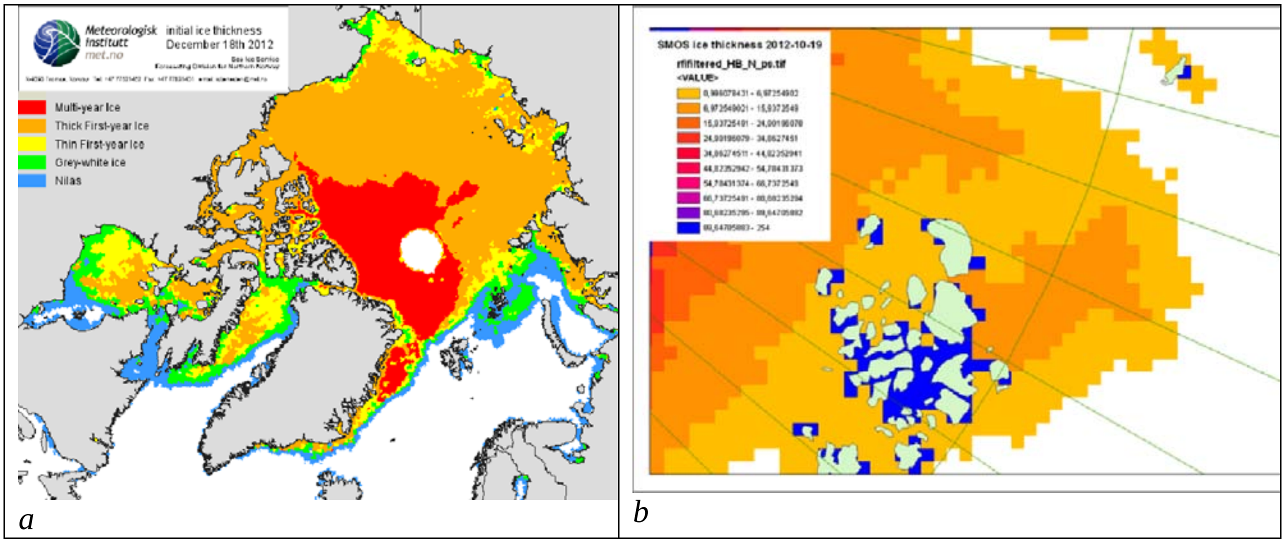



*Figure 4. (a) Example of a sea ice thickness product combining data from SMOS thickness and OSISAF icetype charts; (b) SMOS ice-thickness product from 19. October 2012 provided by University of Bremen.*

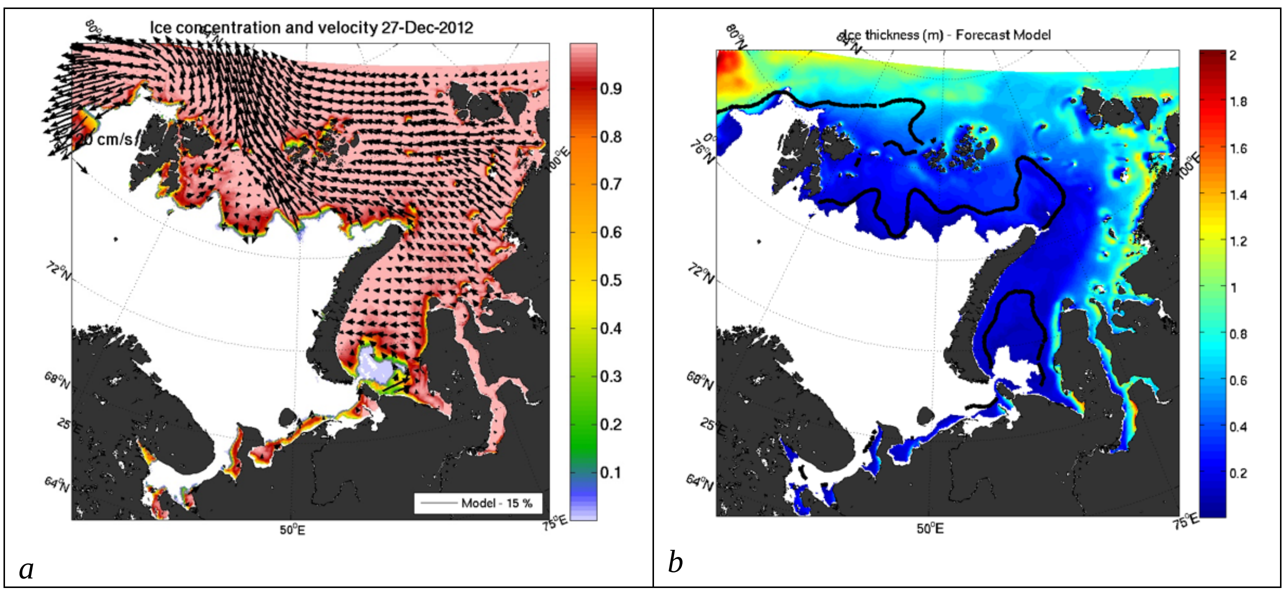



*Figure 5. Results for the Barents-Kara Sea forecasting model: (a) sea ice concentration (colorbar) and velocities indicated by arrows, model 15% sea ice concentration indicated (gray line); (b) Sea ice thickness from model (m), 15% OSI-SAF sea ice concentration indicated (black line).*