ANALYSIS OF SEA ICE PROCESSES IN COASTAL POLYNIAS BASED ON SAR SATELLITE IMAGERY, MODEL SIMULATION AND DATA FUSION

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ABSTRACT

Polynias are gaps in the insulating sea ice cover and of great importance for the energy exchange between ocean and atmosphere in the Polar Regions. Our recent project deals with the observation of polynias using a combination of different sensors. The project has two goals: (1) to gain deeper insights in the evolution of polynia events and (2) to study the potential of the future Sentinel satellite missions. In this paper we briefly describe our studies on sea ice motion in and around the Ronne Polynia, Anarctica and present some first outcomes concerning the combination of multiple sensors for the observation of polynia events and validation of a simple polynia model.

Key words: polynia evolution, sensor combination, model simulation.

Figure 1. MODIS image of the Terra Nova Bay, Antarctica for 25.09.2009 combined with the 70% ice concentration isoline from the sea ice concentration product of the IUP, Bremen. The dark feature in the upper right part is caused by strips of clouds.

1. INTRODUCTION

Polynias are open water areas within sea ice covered regions. Hence they represent gaps in the isolating ice layer between ocean and atmosphere and thereby allow an increased heat- and moisture exchange between both media. While sensible heat polynias occur due to warm water currents melting the ice cover, latent heat polynias form at locations mostly close to coastlines where parts of the ice cover are forced away by e.g. offshore winds. Dependent on the meteorological conditions new ice may be formed instantly in the polynia. Latent heat polynias are therefore sometimes also referred to as sea ice factories. In the past, various studies have been undertaken to analyse polynia events with the help of data from passive microwave sensors (e. g. by [6, 7]). Due to their wide coverage and independence from cloud and light conditions they provide the opportunity to observe the Polar Regions at least on a daily basis. Therefore, passive microwave radiometers are an obvious choice to study general trends and anomalies in drift, thickness and concentration for the sea ice cover. One obvious limitation of this approach is the spatial resolution of the radiometers. Due to its coarseness, smaller polynia events may not be resolved at all. It is also hardly possible to separate different zones in the polynia area (e. g. open water, zones of forming ice and ice compaction, adjacent pack ice). Fig.1 shows a MODIS image of a Polynia event in the Terra Nova Bay from September 2009, combined with the 70% ice concentration isoline, derived from the daily ice concentration maps provided by the University of Bremen [11]. Follwing [9] and [7], the area inside the 70-75% isoline is representing the polynia area. In the situation shown here, this interpretation can be misleading. If one considers only open water as polynia area, the use of a 70-75% ice concentration threshold is a priori not appropriate. In the MODIS image, the open water area is recognized as a small dark patch to the west of the area defined by the isoline. (Note that to the left of the isoline shown in Fig. 1, we have to consider the effect of the landmask in the radiometer data.) If we include also the zone of new ice between the belt of open water to the west and the pack ice to the east as part of the polynia, we obtain a good correspondence between the area inside the isoline and the southern part of the thin-ice zone in the MODIS image. However, this zone extends further to the north, and it is not obvious where the border of the polynia can be located. From the radiometer data, we have the information that the isoline limits an area with ice concentrations of 70% and less, although the real ice concentration is close to 100%. In order to study the evolution of coastal polynias

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in detail, it is therefore necessary to use sensors operating at higher spatial resolutions. One common and approved approach is the observation of polynias with thermal infrared sensors (e. g. with AVHRR, see [5]; or MODIS, see [1]). Infrared and optical sensors are, however, limited to cloud-free conditions. Furthermore, this type of sensor hardly provides information about the structure of the ice itself. To tackle this issue, a number of authors (e. g. [1]) employ additional data from SAR satellites.

2. THE PROJECT

In our project, we study the combination of various sensor types in order to assess the potential of the new Sentinel satellites for polynia research. The objective at this stage is to select suitable data of multiple sensors operating in the optical, infrared and microwave region. Based on such data combinations, we expect to improve the retrieval of different geophysical parameters characterizing polynia evolution and regression, such as ice thickness and ice type distributions within and close to the polynia. Recently we published a study on sea ice motion at the Ronne Polynia, Antarctica, in which we used the combination of a high-resolution drift retrieval algorithm and a coupled sea ice ocean model, focusing on two events of polynia evolution. For our investigations we employed two time series of Envisat ASAR WS images, which were acquired in February and June 2008, respectively. We analysed the time series with a recently developed pattern matching approach to identify the displacement of corresponding sea ice structures and floes as a function of time. Afterwards we compared these observations with simulations from the coupled sea-ice ocean model. Since the atmospheric forcing is the dominating factor for ice motion and the generation of latent heat polynias, the wind data have a strong influence on the simulation results. In the model runs we therefore employed different atmospheric forcings, which vary in temporal and spatial resolution. The simulation results suggest that the general kinematics within a polynia can be realistically reproduced by modern sea ice models. However, they show a strong dependence on the employed atmospheric forcing in the case of fast changing wind conditions. Our study demonstrates that a dense (1-3km) model grid and atmospheric forcing provided at high spatial resolution (<50km) are critical to correctly simulate coastal polynias with a coupled sea-ice ocean model. Besides the kinematics of sea ice in a polynia, we focussed specifically on the changing extent during polynia formation. Therefore we compared the water/ice border visually derived from the SAR images with model results based on thresholds for ice concentration [4].

In the recent stage of the project we identified polynia events in the Polar Regions, which were covered by multiple sensors. This resulted in a database of time series for various polynia regions in the Arctic and Antarctic. In Figure 2, we show as one example for such a time series the data available for the Terra Nova Bay Polynia, Antarctica, for the time interval from September to October

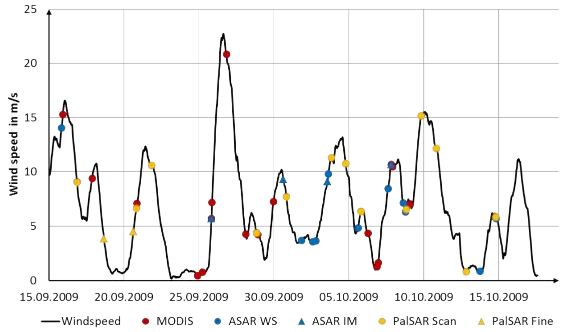

Figure 2. Time series of available satellite data from multiple sensors for the Terra Nova Bay Polynia, 2009.

2009. Since the different sensors are sensitive to different characteristics of the sea ice, their combination allows to discriminate different sea ice zones more clearly. With respect to SAR the different frequencies emphasise different features in the sea ice. L-Band images highlight large scale topographic features, such as pressure ridges, ridge clusters, cracks or rubble fields. In C-Band images, it is easier to separate single ice floes and to distinguish between multi-year and first-year ice, which allows easier differentiation between floes of different origin [8]. An example for the combination of ALOS PALSAR Scan SAR, Envisat WS and MODIS NIR is depicted in Figure 3. It shows the sea ice cover north east of the Terra Nova Bay Polynia. A preliminary qualitative analysis suggests a clear separation between deformed ice (orange in the composite shown to the right), fast ice/old ice (blue) and young/thin ice (green). Some results by [2] suggest that X-band SAR data such as from TerraSAR-X or COSMO-Skymed might provide additional information relative to the C-band data for the thin ice. Since it is not always possible to use a fully coupled finite element sea ice ocean model for the analysis of polynia events, we implemented a new version of a 1-D model for the simulation of polynia width in dependence of wind and temperature originally described by [10] and [3]. The employed definition of polynia width includes the open water area and the adjacent thin ice. We applied the model to the Terra Nova Bay Polynia and compared our simulations of the polynia width with the satellite images. The results of this comparison are shown in Figure 4. The simulated width of the Terra Nova Bay Polynia (black) does not satisfactorily reproduce the observed width (red). To check the model itself we simulated a polynia event at the Ronne Filchner Ice shelf in June 2008 as a test case with a relatively simple topography of the coastal area adjacent to the polynia. During the event we had quite stable wind conditions. The results of the simulations were in good agreement with the observation. This indicates that the unsatisfactory performance of the model for the Terra Nova Bay Polynia event may be due to the complicated spatial wind pattern at this location (Petrelli 2008). Since the wind and temperature data we employed for this simulation are from an automatic weather station (AWS Eneide) located at an unfavourable position relative to the polynia our input data may not representative for the meteorological conditions

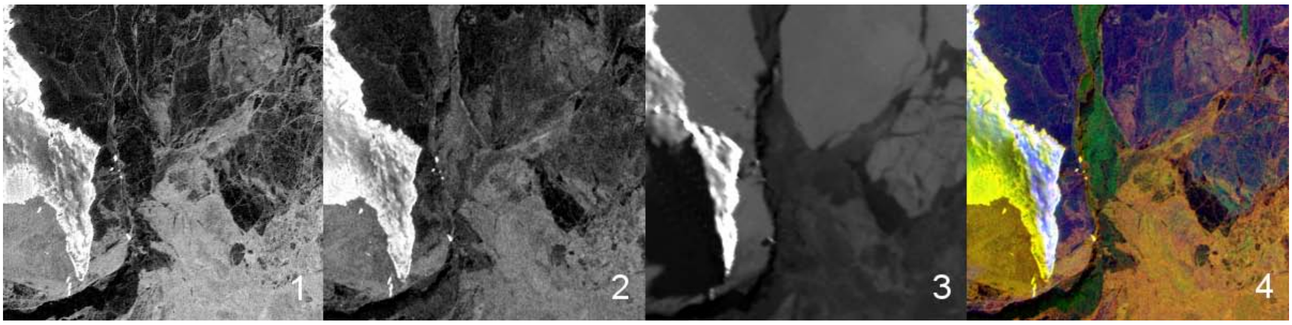

Figure 3. Satellite data from different sensors at the Terra Nova Bay for 10.09.2009 at about 19:30. (1) PALSAR, (2) ASAR, (3) MODIS, (4) Combination.

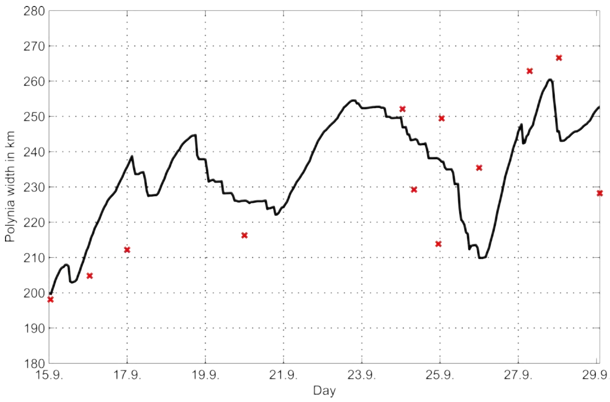

Figure 4. Simulation results for polynia width of the Terra Nova Bay Polynia in autumn 2009. The black line indicates the simulation while the red marks indicate observed widths.

driving the polynia evolution. We expect that a 2-D model similar to [12] is capable of simulating polynia events in the Terra Nova Bay more realistically, provided that the input data adequately reflect the complex wind patterns.

3. CONCLUSION

Based on an analysis comprising (1) high resolution sea ice motion tracking (to get the dynamics), (2) combination of multiple sensors (ice types classification, retrieval of ice thickness and ice formation rate) and model simulations, a strategy will be developed to use the new Sentinel satellites and complementary space missions for systematically monitoring polynias and providing some of the parameters needed for simulating processes such as the rejection of salt into the upper ocean layer and effects on water column stability.

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