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Observation-based validation and calibration of sea ice satellite products and data

S. Gerland[1], G. Spreen[1], T. Eltoft[2], A.H.H. Renner[1], M.A.N. Moen[2], J. King[1], M.A. Granskog[1], N. Hughes[3], A. Fors[2], and P. Wagner[3]

1: Norwegian Polar Institute, Fram Centre, 9296 Tromsø
2: University of Tromsø, Department of Physics and Technology, Tromsø, Norway
3: Forecasting Center for Northern Norway, Norwegian Meteorological Institute, Tromsø

gerland@npolar.no; spreen@npolar.no; torbjorn.eltoft@uit.no; renner@npolar.no;mari-ann.moen@uit.no; king@npolar.no; granskog@npolar.no; nick.hughes@met.no; ane.s.fors@uit.no; penelopew@met.no

Observational sea ice data are necessary for processing and improvement of satellite remote sensing products from SAR (Synthetic Aperture Radar) and altimetry. High resolution, multi-polarisation SAR data from the Radarsat-2 satellite contains additional information besides what one can extract from visual interpretation. However, the optimal way for retrieving the most interesting information about sea ice classes and properties remains a challenge. We have been conducting studies that combined the use of sea ice and snow thickness data, airborne photography, sea ice and snow physical property data, and satellite data. Statistical analysis of Radarsat-2 quad-pol scenes combined with ice thickness and camera helicopter transects reveals the potential of novel SAR image analysis over sea ice. Observational data were used to label statistically-derived segments of sea ice surfaces from SAR data with specific classes, for Arctic sea ice with different characteristics and conditions. The development of methods to derive sea ice freeboard and thickness from satellite-based altimeters using radar or laser has been an active field of research since the 1990's. Airborne and in situ observations are used to evaluate and validate these satellite ice thickness products by direct inter-comparison. Furthermore, in situ data are used to assess the penetration of the radar or laser signal into the snow pack, and to provide updated snow and ice properties for improving freeboard to thickness conversations. An outlook is given focusing on near future calibration and validation over Arctic sea ice in connection with a drift station experiment north of Svalbard in 2015.

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1. Introduction

The sea ice types and properties in the Arctic are changing on different time scales; short term, seasonal and long term. Over the past couple of decades Arctic sea ice has changed to an, on average, younger and thinner ice cover. Its extent is substantially reduced relative to the 1980s and 1990s (see e.g. IPCC 2013). Quantification of the status of sea ice in the Polar regions is crucial in various contexts. In climate science, knowledge of the sea ice mass balance and of the existing ice types are important for climate modeling, and for estimates of effects of climate change. With regard to human activities in the Polar seas such as shipping and exploitation of natural resources, knowledge of physical ice properties is important since they can affect these activities substantially. Satellite remote sensing provides opportunities for large-scale observations of sea ice. However, in situ and airborne observations and measurements are indispensable for the validation and calibration of these observations. Here we briefly discuss combinations of in situ, airborne and satellite remote sensing data from Arctic sea ice, towards the calibration and validation of satellite products.

2. Methods

Airborne Ice thickness measurements

Measuring ice thickness from air with electromagnetics (EM) is a well established method that measures the varying electrical conductivity of seawater, sea ice, and snow cover through the use of emitting and receiving EM fields from one or more pairs of coils (Kovacs et al. 1987; Haas et al. 2009, Renner et al. 2013a). Such systems also commonly include a laser altimeter. In the setup used here, both the electromagnetic coils and the laser altimeter are placed in a torpedo-shaped casing, hanging under a helicopter or aircraft, and flown about 15 m above the sea ice surface (Fig. 1).

Figure 1. Sea ice thickness sensor with electromagnetic system and laser altimeter, hanging under a helicopter, and an automatic camera mounted on the helicopter (Photo: S. Gerland).

The electromagnetic components make it possible to determine the distance from the sensor to seawater under the sea ice, because seawater is a good electrical conductor. The laser altimeter measures the height of the sensor above the sea ice and snow surface. The difference of the two distances infers the total ice thickness (ice plus snow) over a typical measurement footprint of 50 m. Transects of several hundred kilometres can be flown in a single helicopter flight.

Airborne photography
Photography of the sea ice surface from helicopter is used to provide detailed information on sea ice types, characteristic surface features (e.g. melt ponds, ridges), floe size and lead distributions. Previous studies have described imagery analysis with combinations of systematic airborne surveys and ice thickness measurements, using different approaches of ice classification (Pedersen et al. 2009, Renner et al. 2013b). When these measurements are combined with satellite remote sensing, the interpretation of surface features in radar imagery can be improved (see below and Moen et al. 2013).

In situ measurements
Direct in situ measurements often give the best spatial resolution and the highest accuracy levels, but the amount of data that can be collected is rather limited, mainly due to practical constraints. Additionally, measurements are restricted to ice that is thick and safe enough to walk and work on. In situ measurements are frequently obtained to calibrate indirect measurements from the air (e.g. Renner et al. 2013a), or from below the ice (e.g. upward looking sonar, see Hansen et al. 2013). Among direct measurements done in conjunction with the studies reviewed here are: ice thickness and freeboard surveys on individual ice stations using drilling, stakes, ground electromagnetics, snow pit surveys for snow physical properties, and optical measurements (see e.g. Forsström et al. 2011; Haapala et al. 2013).

Satellite surveys
This study has a dual focus on both high resolution SAR satellite observations; and satellite altimetry surveys. Imagery from the Canadian RADARSAT-2 SAR can be obtained in different resolutions; however, the highest resolution and image sizes of 25 km x 25 km, acquired with four polarization channels, were used here (quad-pol, see Moen et al. 2013). The other satellite airborne and in situ calibration and validation measurements were obtained for is CryoSat-2, operated by the European Space Agency (ESA). CryoSat-2 carries a radar altimeter designed for measurements of the Earth's cryosphere (Wingham et al. 2002; Laxon et al. 2013). One of the tasks CryoSat-2 has is to measure changes in sea ice freeboard, from which changes in sea ice thickness can be estimated. The conversion from freeboard to thickness requires realistic estimates of snow and sea ice densities, and snow thicknesses (see Gerland et al. 2013a, b; Ricker et al. 2014).

3. Examples of results
Imagery and products from SAR show variability in sea ice features and characteristics which are not always straight forward to interpret. The amount of detail indicates a large potential to retrieve additional information from such products. In an experiment conducted in spring 2011 north of Svalbard, in situ studies were coordinated with airborne and satellite remote sensing from RADARSAT-2. Several quad-pol images were obtained. For one of them, a coincident helicopter overflight with an x-shape pattern was performed. The helicopter carried an automatic

camera and an ice thickness sensor. A segmentation algorithm was applied on the quad-pol image. The resulting segmentation was compared with airborne and in situ information (Moen et al. 2013; Fig. 2).

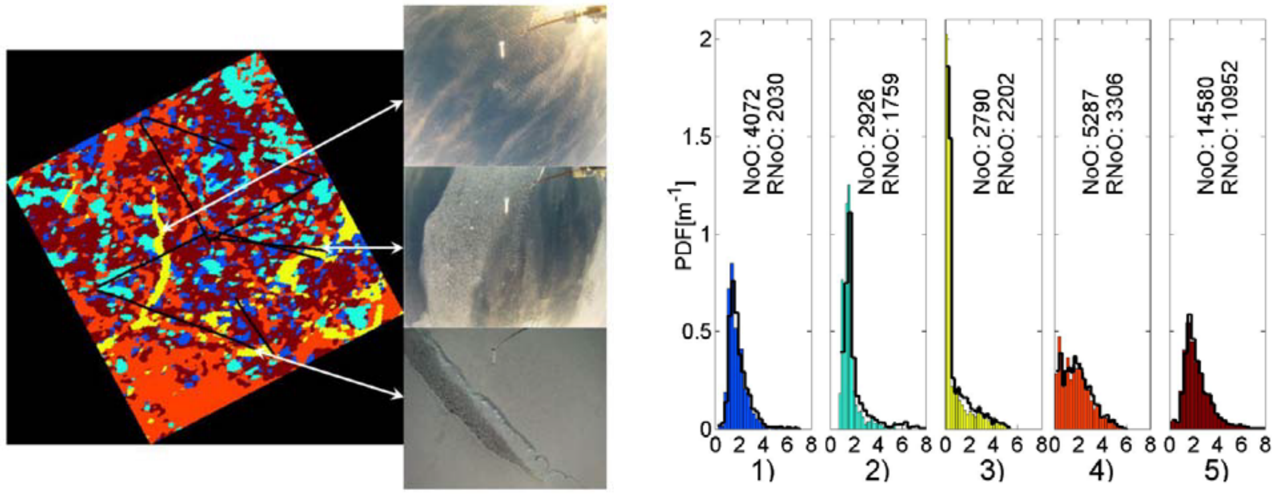

Figure 2. Left: Segmentation result of a RADARSAT-2 quad-pol 25 km x 25 km image, obtained over sea ice north of Svalbard, with the flight line of the helicopter transect (black) and selected photos from airborne photography. Right: Probability density functions for airborne-measured total ice thickness, for the different color-coded segments. From Moen et al. (2013).

Results from this experiment were very promising. As this example contains snow-covered sea ice in spring, it was absolutely essential to have a combination of photography and ice thickness measurements in order to distinguish between different ice classes, since one of the two methods alone would not have been sufficient to detail specific sea ice characteristics. An ongoing investigation will apply these findings to the analysis of several more sea ice images with similar characteristics. Observations were also made over late summer sea ice in Fram Strait with little or no snow cover (Gerland et al. 2013a). Such sea ice can be more readily assessed from photos, but radar responses can be more difficult to interpret, depending on the surface conditions, state of melt, and presence of melt ponds with or without ice cover.

During recent years, since the launch of ICESat and CryoSat-2, enhanced satellite altimetry calibration and validation have been developed as one of the major purposes of these satellites is to measure sea ice freeboard. In our study (see Gerland et al. 2013b), we follow up on three issues: (i) what are representative levels of snow thicknesses on Arctic sea ice for specific regions and times of season, (ii) how do snow properties affect the penetration of the altimeter signal (in our case the radar signal of CryoSat-2) into the snow layer, and (ii) how do ice thicknesses of first year sea ice compare to estimates from CryoSat-2 measurements. Several expeditions of the Norwegian Polar Institute in the regions north of Svalbard and in Fram Strait during past years have contributed to these tasks. The activity in spring 2011 had a coordinated field campaign that combined detailed in situ studies, data collected from helicopter and aircraft, and satellite overpasses (Gerland et al. 2013b). The preliminary results clearly indicated that altimeter radar signals may not fully penetrate spring snow layers over first year sea ice in the Arctic. Preliminary freeboard levels derived from CryoSat-2 and airborne radar data were substantially larger than freeboard derived from in situ measurements (Gerland et al. 2013b).

4. Preliminary conclusions and outlook

Ongoing studies show that in situ and airborne sea ice measurements are essential in validating improved information from SAR and altimetry satellite products. Comparison of sea ice classification from RADARSAT-2 quad-pol imagery by sea ice specialists with a semi-automated method of statistical segmentation and use of airborne photography and thickness measurements showed a significant potential (see Moen et al. 2013). Within radar altimetry, different studies show that penetration of radar signals in snow is not always applicable to Arctic snow cover on sea ice in spring, and that new sensor systems demand research on various issues related to data processing, such as signal retracking (Gerland et al. 2013a, b, Ricker et al. 2014). The three issues of retracking altimeter signals, penetration depth of signals into the snow, and knowledge of snow thicknesses and snow densities, all contribute to the uncertainty of satellite altimeter based ice thickness estimates. An agreement between satellite altimeter sea ice thickness estimates with in situ or airborne measurements does not necessarily mean that all three issues have been sufficiently resolved. It is possible that biases from different measurement techniques or assumptions can compensate each other. However, measurements from other cases that contain different snow and ice properties may not correspond. Therefore we need to include additional datasets to calibrate and validate CryoSat-2 data. Further data analysis and collections are planned in the near future.

In 2015, the research vessel RV "Lance" of the Norwegian Polar Institute will be in first-year sea ice in the Arctic Ocean for a 6 month field campaign, "N-ICE2015". During this expedition, the transition from winter to spring conditions will be monitored, with combined in situ, airborne and satellite surveys. It is anticipated that the results from this project will support and improve our understanding of how the sea ice system functions, how we can model it, and how we can improve the monitoring of it from space.

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