IN-SITU CALIBRATION AND VALIDATION OF CRYOSAT-2 OBSERVATIONS OVER ARCTIC SEA ICE NORTH OF SVALBARD

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ABSTRACT

CryoSat-2's radar altimeter allows to observe the pan-Arctic sea ice thickness up to 88°N on a monthly basis. However, calibration and validation are crucial to assess limitations and accuracy of the altimeter, and to better quantify the uncertainties involved in converting sea ice freeboard to thickness. We conducted four ship-based campaigns 2010-2012 to the pack ice north of Svalbard. Detailed in situ measurements of snow and ice thickness, freeboard, and snow stratigraphy and density were performed. The data were integrated with satellite data, airborne ice thickness observations, and aerial photography. Measurements from a Twin-Otter aircraft carrying a laser scanner and the CryoSat airborne simulator ASIRAS were obtained over one sea ice station. Here we discuss effects of snow properties on the penetration of the radar signal into the snow pack, along with in-situ, helicopter, and aircraft measurements for satellite calibration and validation purposes, based on results from two cruises in 2011.

INTRODUCTION

The thickness of sea ice is a key physical parameter necessary to describe the status of sea ice in Polar regions and its changes. Together with the sea ice extend Arctic sea ice thickness is decreasing in recent decades (e.g. [1]). Satellite observations are the only feasible option to monitor the sea ice mass balance on a monthly basis. The concept of the CryoSat-2 satellite [2] includes the measurement of sea ice freeboard based on radar altimetry. The freeboard, in turn, can be converted to sea ice thickness assuming isostasy. CryoSat-2 was launched in 2010, and since then, different post-launch calibration and validation experiments have been conducted (e.g. [3]).

To convert sea ice freeboard to sea ice thickness the snow depth, snow, ice, and water densities, and their respective uncertainties have to be known (e.g. [4]). For supporting calibration and validation of CryoSat-2 sea ice thickness estimates, experiments conducted in the Arctic and Antarctic help to improve the understanding of how the radar signal of CryoSat-2 penetrates the snow pack, and one can with the use of the experiments better define the uncertainties in freeboard to sea ice thickness conversion (see e.g. [5]). In both contexts, the physical properties and thicknesses of snow and ice play a crucial role. The stratigraphy of the snow pack can affect the penetration of the radar signal and cause reflection or scattering of the signal within the snow pack. The snow and ice density (and to some degree also the seawater density) control along with the snow and ice thickness the hydrostatic equilibrium of sea ice floes. For CryoSat-2's Ku-band radar altimeter it is in general assumed that the main reflected signal origins from the snow-ice interface, i.e. that the radar completely penetrates the snow (e.g. [3]).

Accurate information on snow parameters and thicknesses in time and space for the Arctic are sparse. Often, monthly snow climatologies obtained for the 1954-1990 period [6] are used when processing data from freeboard to thickness. However, snow thickness on sea ice shows large inter-annual variations, which cause errors in the freeboard to ice thickness conversion, and in times of a changing Arctic climate, the validity of a snow climatology from as long back as the 1950s is questionable.

Sea ice, as it can be found north of Svalbard, can be used as an "open air laboratory" for first-year sea ice, which today represents the largest area fraction of sea ice in the Arctic. In its new state, with substantially reduced ice extent, sea ice in the Arctic in general is younger than earlier [7].

Here, we summarize the current status of CryoSat-2 calibration and validation work North of Svalbard, with main focus on preliminary results from observations and measurements obtained in spring, before the onset of melt.

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THE EXPERIMENTS NORTH OF SVALBARD

Cruises with the ice-going vessels RV Lance and KV Svalbard were conducted in late summer 2010, spring 2011 and summer 2012. Here, we focus on the experiment from April-May 2011. This experiment was conducted prior to the regional onset of melt, with substantial snow cover on top of the sea ice. The fieldwork consisted of studies in situ, on the ice (snow and ice thickness and freeboard measurements, snow pit work), as well as work from helicopter (ice thickness transects using electromagnetic induction sounding [8] and digital photography). Figure 1 shows the research area north of Nordaustlandet, Svalbard, with helicopter flight lines marked in two red tones for the cruises with KV Svalbard (April 2011) and RV Lance (April/May 2011).

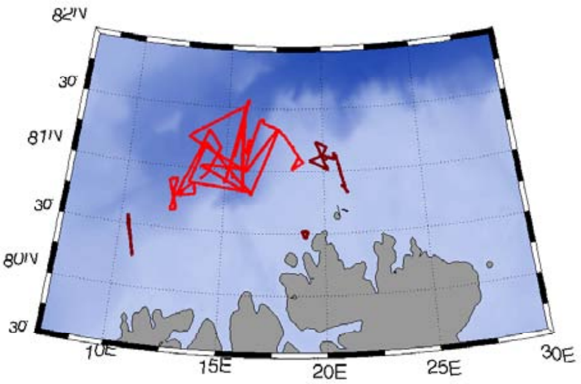

Figure 1: Map of EM-bird flights in spring 2011 north of Svalbard [6]. Dark red=KV Svalbard, red=RV Lance.

The layout of flight lines aimed at generating data to describe the regional sea ice thickness distribution, describe the sea ice cover in the area, and to run specific underflights of CryoSat-2 passes and overflights of on-ice survey sites. For one occasion, the region could be overflown during the experiment by a Danish Twin Otter aircraft (DTU Space) with the Airborne Synthetic Aperture and Interferometric Radar Altimeter System (ASIRAS) on board, similar to the SIRAL radar sensor on CryoSat-2. In total, 17 ice stations with in situ measurements were performed during the two cruises with KV Svalbard and RV Lance.

PRELIMINARY RESULTS AND DISCUSSION

The study area consists of sea ice with total (snow plus ice) modal thicknesses of 1.4 m (KV Svalbard, April 2011) and 1.8 m (RV Lance, April/May 2011, Fig. 2), respectively, as quantified from helicopter-borne electromagnetic ice thickness transects [9].

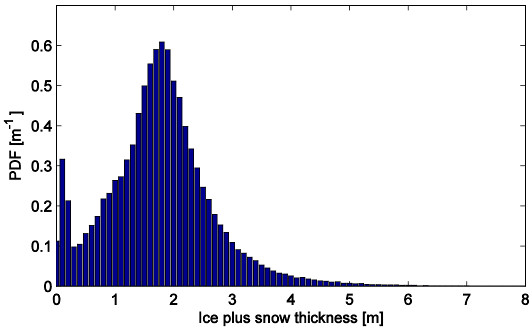

Figure 2: Total ice thickness distribution north of Svalbard in spring 2011 [9].

The increase of modal thickness could have to do with a slight difference in the area overflown (Fig. 1), and additionally the ice thickness might have increased with time. It is also important to note that the ice thickness dataset collected during the RV Lance cruise is larger in number of lines and area covered than the dataset from the KV Svalbard cruise.

As an example from snow pit studies, in Fig. 3 the distribution of snow density measurements is shown for the RV Lance cruise in April/May 2011.

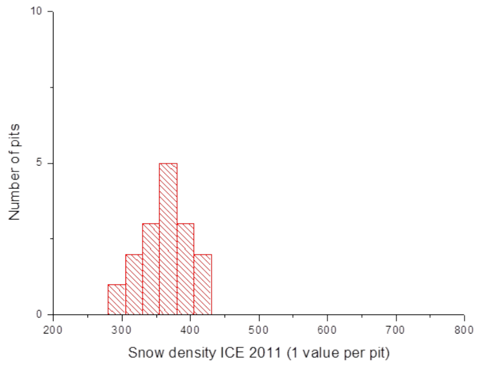

Figure 3: Snow density distribution during the RV Lance cruise 2011; average density per snow pit used.

The data are from 16 snow pits with 83 individual snow density measurements. Snow density is measured by weighing snow sampled horizontally with a 0.5 ltr. tube (see also [5]). The mean of the measurements was 363 kg m^{-3}. This value is higher than the climatological April/May snow density of about 320 kg m^{-3} as given in [6], which often is used for the CryoSat-2 freeboard to ice thickness conversion [3]. For the real modal ice thickness of 1.8 m and following [3] this difference in snow density will cause an underestimation of the CryoSat-2 derived ice thickness by 7 cm.

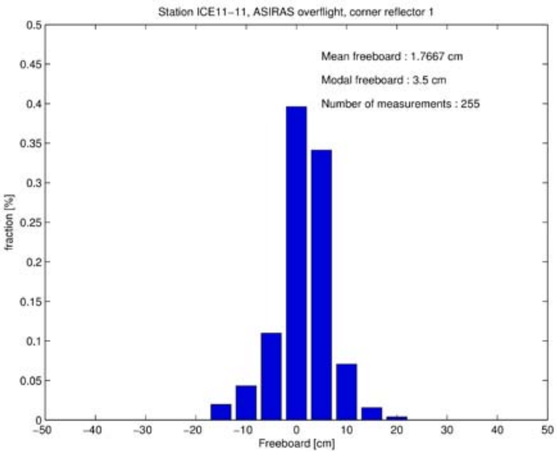

Figure 4: In situ ice freeboard distribution over level sea ice at the ASIRAS overflight site [11].

More important for the hydrostatical equilibrium than snow density is snow thickness [5]. The modal snow thickness in spring 2011 in the research area was 7.5 and 17.5 cm (KV Svalbard and RV Lance, respectively), however, snow distributions had long tails, showing that snow can be accumulated also much thicker than the modal thicknesses. This also contributes to the snow load. The April/May climatological mean snow thickness for the complete Arctic Basin is about 37 cm. However today, for first-year ice about half of that is deemed to be more appropriate [10] and is used for the freeboard to ice thickness conversion [3]. The resulting 18.5 cm are close to the 17.5 cm snow depth measured during the RV Lance campaign and should result in reasonable ice thickness estimates if the radar signal would penetrate the complete snow pack (see below).

Ice freeboard (excluding snow) was measured whenever holes were drilled for direct thickness measurements. At selected sites during the RV Lance cruise, freeboard was measured more extensively using a laser level setup [11]. Measurements of level ice at the floe where the Twin Otter overflight site gave a modal freeboard of +3.5 cm (255 measurements, Fig. 4).

However, corresponding ASIRAS radar freeboard measured from the Twin Otter were substantially higher, ranging levels above +20 cm (Fig. 5, green). Preliminary data processed by The Alfred Wegener Institute for Polar and Marine Research from CryoSat-2 L1b data show also freeboard for this area larger than 20 cm (Fig. 5, blue). Those freeboards measured with radar sensors should be lower and close to the 3.5 cm from in-situ observations, if the signal would penetrate the snow cover fully. The laser altimeter data from the Twin Otter are in the same range as the radar altimeter data (Fig. 5, red). As the laser altimeter measures the snow freeboard (ice + snow cover) this agreement indicates once more that in this case the radar signal does not to fully penetrate the snow pack and mainly backscatters from close to the air-snow interface. If the ASIRAS or preliminary CryoSat-2 freeboard of about 22 cm would be used for the sea ice thickness conversion this would result in an ice thickness overestimation of about 90 cm (following [3]).

Of course, there are a number of uncertainties to consider here, and all data processing is not completed yet. There is also a time difference between the in situ measurements and the CryoSat-2 and Twin Otter passes, but conditions are not likely to have changed substantially during that time. Air temperatures were between -3.6 and -11.1°C during the experiment. However, snow metamorphosis already can happen at these low temperatures and also the temperature history with possible higher temperatures at the observation sites is not known.

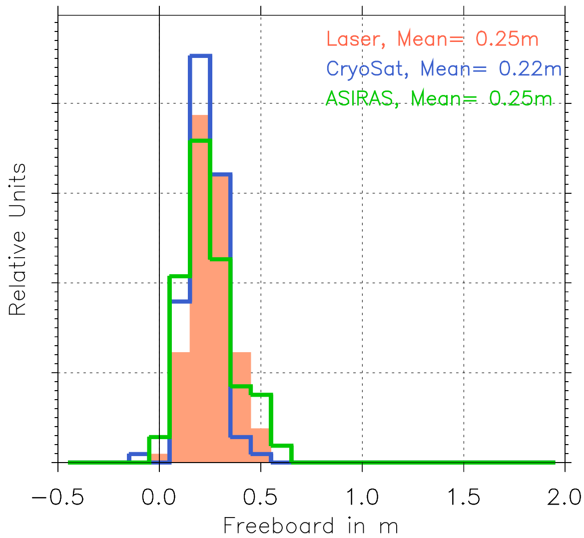

Figure 5: Ice freeboard distribution from laser scanner, ASIRAS and CryoSat-2 measurements, over and in the vicinity of the Twin Otter overflight.

During snow pit work on the two cruises in spring 2011, characteristics were observed that could explain insufficient radar signal penetration into the snow pack: During several occasions, icy layers in the upper part of the snow layer were detected. Second, in the lower part of the snow, brine was found, increasing the (otherwise commonly very low) electrical conductivity of the snow substantially.

It is known that brine can be found at the snow/ice transition over rather young sea ice during the freezing season. Both, ice layers and brine in snow originating from the sea ice below could explain reduced radar signal penetration into the snow from above.

CONCLUSIONS

The study presented was performed over first-year ice. The relative portion of this ice type is increasing, and knowledge about the properties of this ice is highly relevant; both to understand crucial arctic climate processes, and to support satellite remote sensing, such as CryoSat-2 surveys. The only larger other calibration and validation experiment performed over Arctic sea ice for CryoSat-2 was over thicker, multiyear sea ice near Alert, Arctic Canada (see [3]). Final processing of measured data along with new processed CryoSat-2 products for this experiment will hopefully increase the understanding of CryoSat-2 processing and uncertainties in general. For the ongoing work, it is also planned to compare regional ice thickness distributions measured from helicopter with products calculated from CryoSat-2 data for all four cruises in the research area.

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