Sea Ice Freeboard and Snow Accumulation Based on Laser and Radar Altimetry

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Introduction

CryoSat-2 is an ESA satellite to be launched in spring 2009. The main purpose of the satellite is to measure sea ice thickness, which is a fast responding climate indicator. The thickness is not measured directly; instead an advanced radar measures the sea ice freeboard which then can be related to sea ice thickness. The same method has been used by the DNSC for years to measure sea ice thickness with airborne laser.

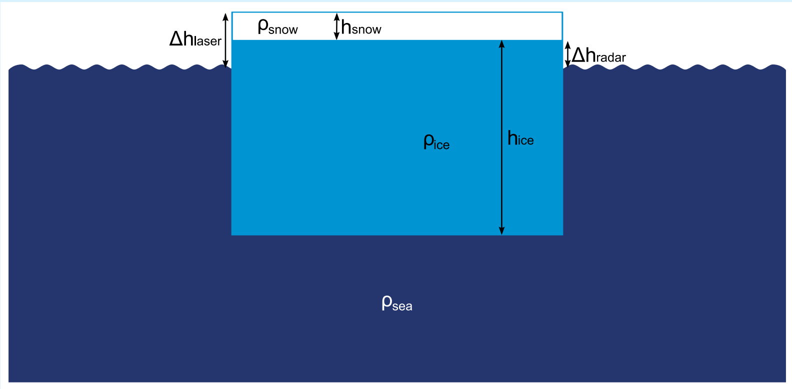

Figure 1: Estimating sea ice thickness from freeboard.

Under the assumption of isostatic equilibrium the sea ice thickness (h_{ice}) can be calculated as a function of the freeboard (Δh_{radar} and Δh_{laser}) measured with radar or laser, see the two following equations.

$$h_{ice} = \frac{h_{snow} \cdot \rho_{snow} + \Delta h_{radar} \cdot \rho_{sea}}{\rho_{sea} - \rho_{ice}}$$

$$h_{ice} = \frac{h_{snow} \cdot (\rho_{sea} - \rho_{snow}) + \Delta h_{laser} \cdot \rho_{sea}}{\rho_{sea} - \rho_{ice}}$$

The method assumes that the density of the ice, snow, and sea is known. Furthermore it is assumed that the snow thickness is known, and this is the greatest error source in the model.

This work will investigate the possibilities in measuring the snow thickness by a combination of radar and laser. Assuming that the laser reflects from the air/snow interface and the radar reflects from the snow /ice interface the snow thickness can be estimated using the equation below.

$$h_{snow} = \Delta h_{laser} - \Delta h_{radar}$$

Field campaign

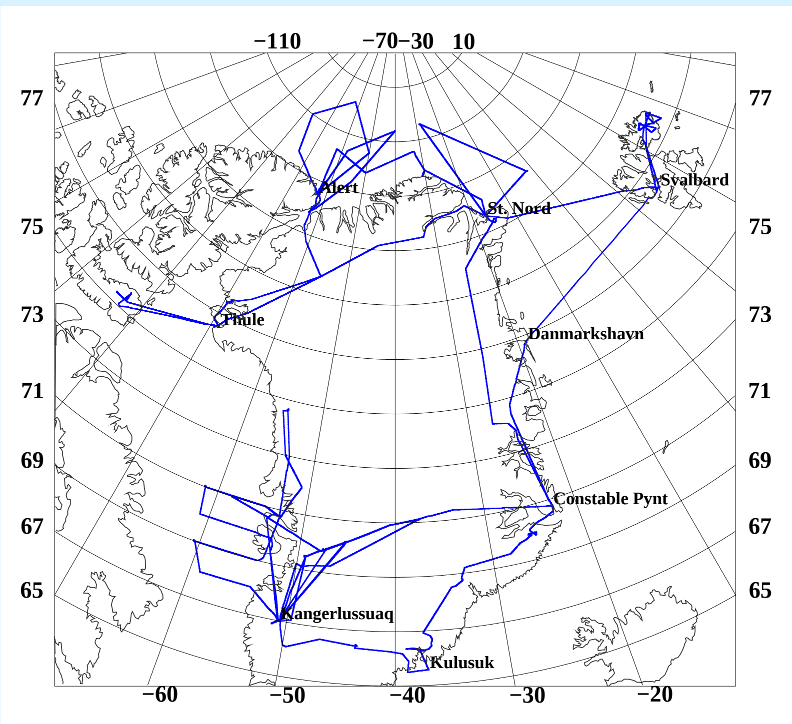

Figure 2: Flight route for the CryoVEx 06 Campaign.

In spring 2006 a major CryoSat-2 pre-launch campaign was carried out in the Arctic to obtain a calibration and validation dataset using laser, the ASIRAS radar and in-situ measurements. The ASIRAS, which mimics the CryoSat-2 radar, was mounted on an aircraft together with a laser scanner and support instruments throughout the five week long campaign.

Calibration of laser and radar

The laser scanner is calibrated using crossing overflights of a building with a known position and height. This calibration is possible because the laser has a narrow and well defined footprint. Since the radar footprint is much larger this method is useless for calibration of the radar, instead it is possible to use leads in the sea ice for the range calibration. This is possible because water and very thin ice will act as a mirror reflecting both laser and radar at the surface.

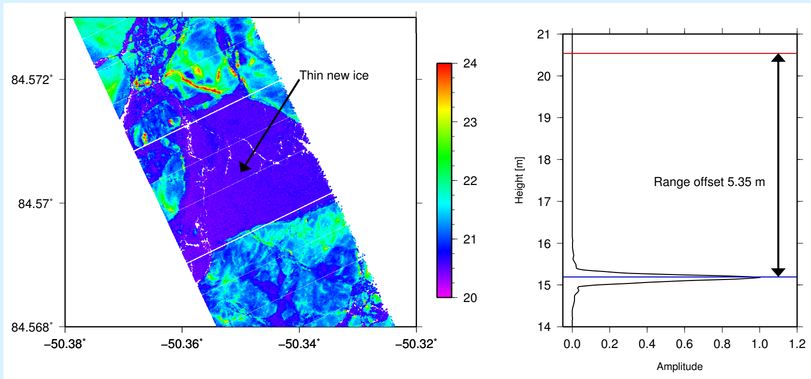

Figure 3: Using a lead to determine the radar range offset.

Snow thickness on sea ice

Below are three examples of snow thickness estimates. The radar pulse is plotted in black, the blue line indicates the height of the surface reflecting the radar and the red line indicates the surface reflecting the laser. The snow thickness in the two left plots is 7 cm and the 3 cm for the right plot.

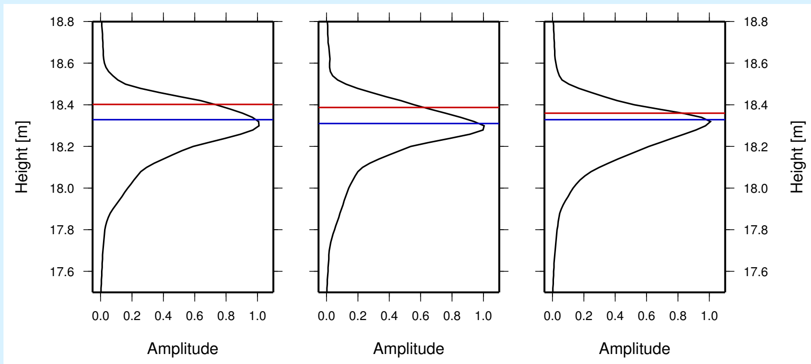

Figure 4: Snow layer on first year ice north of Alert. The detected surface is red for laser and blue for radar.

Accumulation layers in inland snow

Layers are formed in the snowpack by the changing seasons and is detectable several meters down. Below is an example from a site northeast of Kangerlussuaq showing six layers found with manual retracking of the radar data. These layers can be used to estimate the yearly accumulation at the site by combination with a density profile.

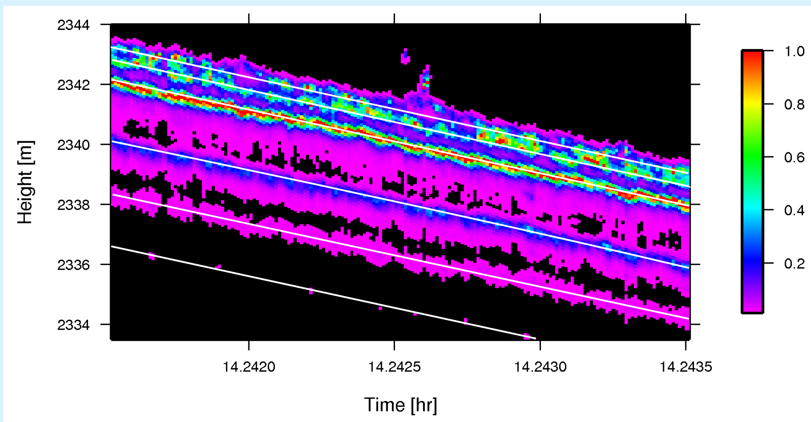

Figure 5: Annual layers in the Greenlandic inland ice.

Conclusion and Future Work

These first tests indicates that the combination of laser and radar can be used to estimate the snow thickness on sea ice. Future work will need to validate the results with collected in-situ data and improve the retracking of the radar data. Methods to automatically detect the sea ice type must also be investigated before the method can be tested on larger datasets.

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