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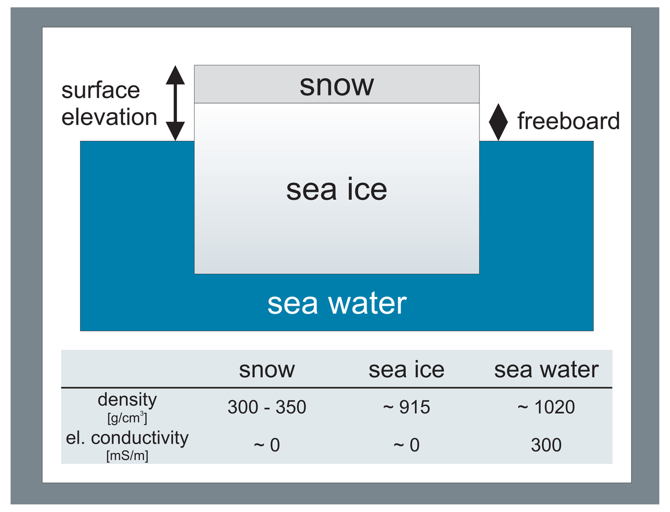
Laser and Radar (LaRa) Surface Elevation Retrieval and EM Sea Ice Thickness Measurements in the Baltic Sea

Introduction

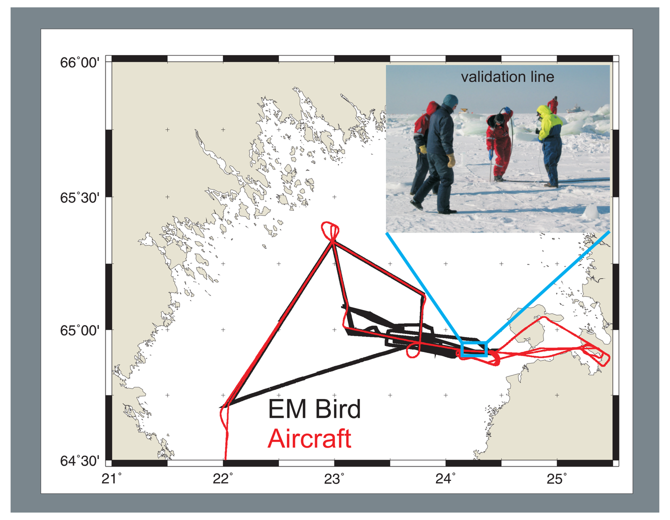
One approach to monitor sea ice thickness from space by means of laser or radar altimetry is to measure the elevation of ice floes above local sea level and to transform the elevation into ice thickness via the assumption of hydrostatic equilibrium. The retrieved surface elevation depends on the altimeter type. While laser beams (ICESat, NASA) are reflected on the air-snow interface, radar beams (CryoSat II, ESA) can penetrate the dry snow layer and are reflected at the snow-ice interface.

Uncertainties in altimeter ice thickness retrieval arise due to several factors: 1) The thickness of the snow layer cannot be obtained by one altimeter type alone. 2) The lateral resolution of the altimeter profiles limits the detection of small open water sites, which are used to calibrate the elevation of the local sea level in the dense pack ice. 3) Sea water intrusion in the blocky structure of deformed sea ice can change the average density of parts of an ice floe.

In the framework of the CryoSat calibration and validation activities of the European Space Agency, airborne elevation measurements with both laser and radar altimeters have been performed in the Bay of Bothnia in March 2005. These measurements were coordinated with direct measurements of the sea ice thickness by a helicopter borne EM system to **validate spaceborne sea ice thickness retrieval**.



Freeboard (measured by radar altimetry) describes the elevation of sea ice above local sea level, while **surface elevation** (laser altimetry) refers to the top snow cover. Deformed ice differs from this idealized picture with thick blocky structures. These so-called **pressure rigdes** consists of a ideally triangle shaped sail (above water line) and keel (below water line) of reattached blocky ice with a certain fraction of void spaces, either filled with air or sea water.



Three aircraft flights were performed from 13th to 14th of March 2005 in the Bay of Bothnia in the northern baltic sea. In addition to the coincident helicopter EM sea ice thickness sounding, a 2200 m long **validation line** was set up close to an ice station of the finnish reseach icebreaker Aranda. Along this validation line information about ice thickness, freeboard and surface elevation was obtained by more than 400 boreholes.

Instrumentation

The altimeter systems were mounted on a Dornier 228 type aircraft of the German Aerospace Center (DLR), while the EM device (Bird) is towed beneath a helicopter.

Aircraft

- ☐ Inertial Navigation System (INS)
- ☐ Two GPS Receiver (DGPS post processing)
- ☐ Airborne Laser Scanner (ALS), Type Riegl LMS-Q280
- ☐ Single beam laser altimeter, Type Riegl LD90
- ☐ Radar altimeter (ASIRAS), Manufacturer : RST

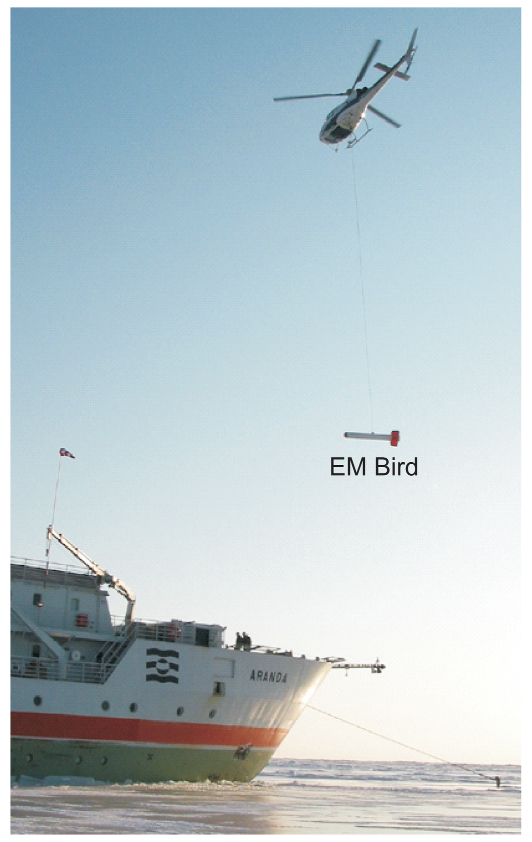
The **Airborne Synthetic Aperture and Interferometric Radar Altimeter System** (ASIRAS) has been developed for validation and calibration of the CryoSat mission. It consists of two Ku band antennas, which can operate in interferometric mode or with a dedicated transmitter and receiver antenna. SAR processing is used to enhance the lateral resolution of the altimeter profile.

Frequency	13.5 GHz
Range bin	11.0 cm
Beam width	2.5° across track 10° along track

EM Bird

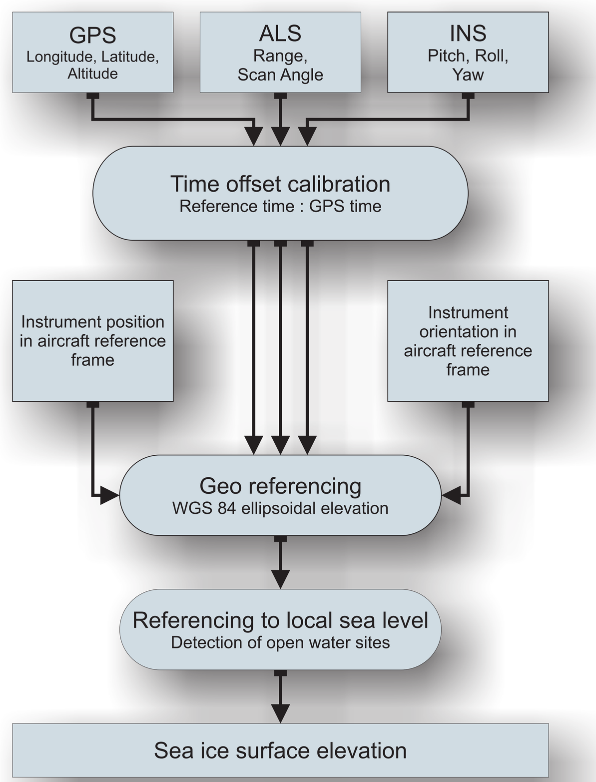
The EM system consists basically of two coils and a laser altimeter. A transmitter coil emitts harmonic electromagnetic waves (primary field), which induces eddy currents in the conductive sea water. These current systems are the source of a secondary electromagnetic field, which is detected with a receiver coil, together with the primary field.

Length	3.4 m
Weight	103 kg
Frequencies	3.68 kHz 112 kHz
Measurement rate	10 Hz
Measurement accuracy	10 cm
Operational height	10 – 15 m

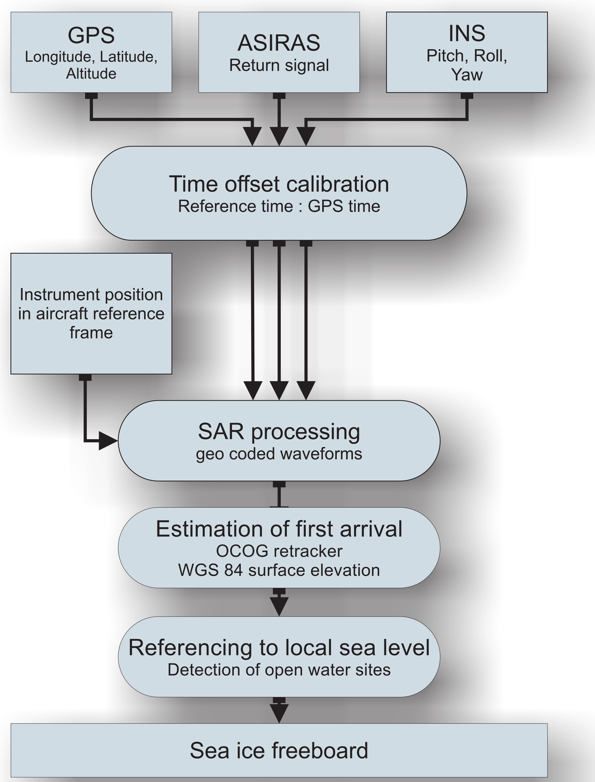


Data Processing

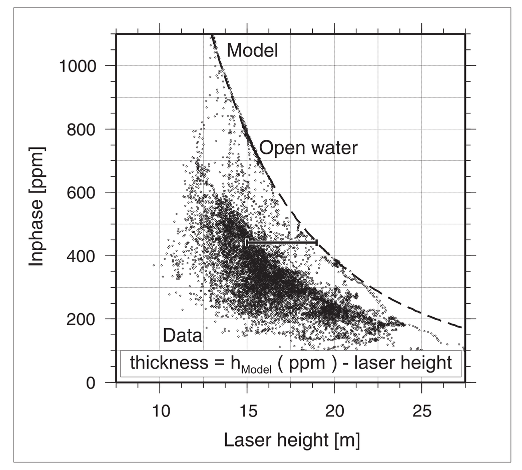
Laser Scanner



Radar Altimeter



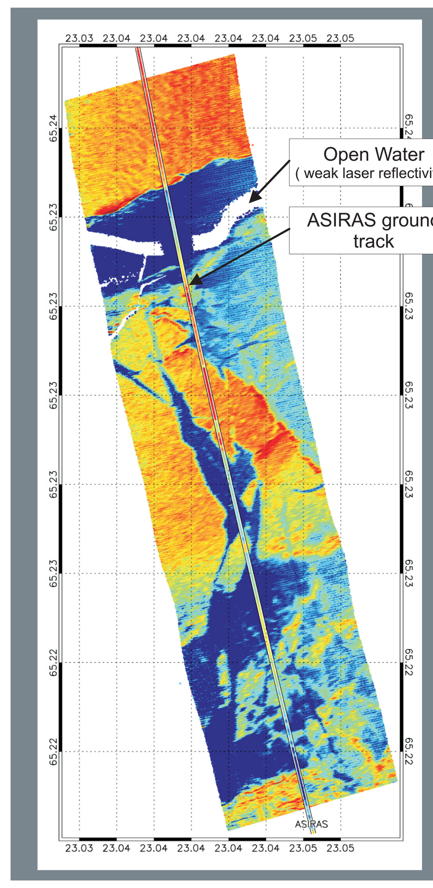
EM Data

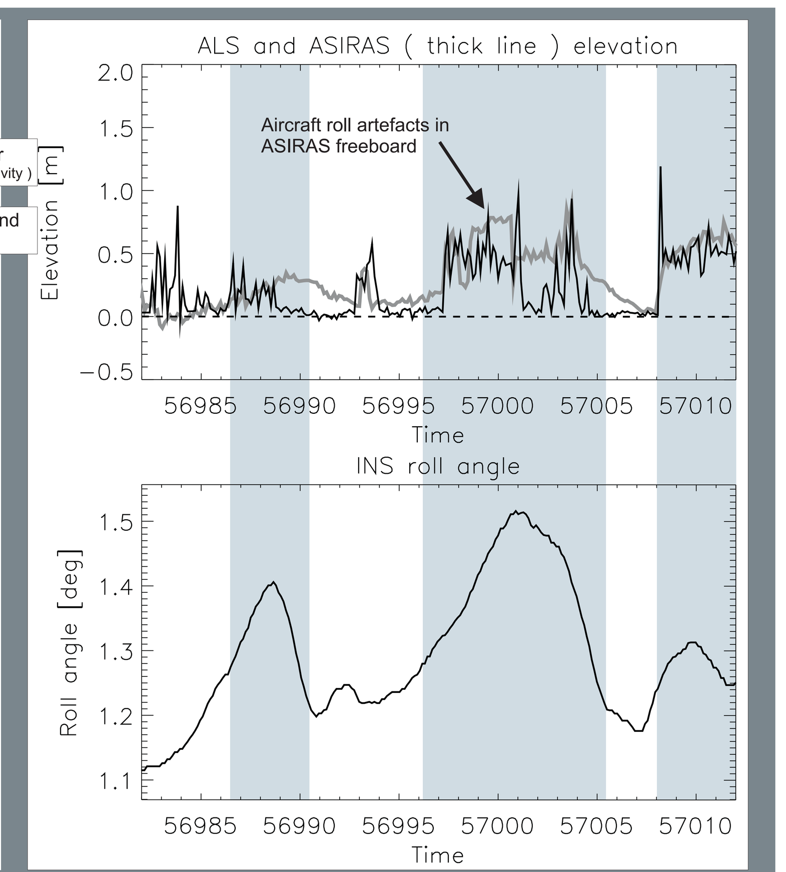


The EM data is processed with a semi empirical technique. The measured EM signal depends on the distance to the conductive sea water, the instrument specifications and the sea water conductivity. The last two factors are known and treated as a constant value. The result of 1D modelling is a model curve which consists of a series of exponential functions, only depending on the distance between the instrument and the conductive layer. The height retrieved by the onboard laser altimeter of the bird differs by the snow plus sea ice (total) thickness from this EM derived distance. As a result the total thickness is given by the difference between laser height and the estimation of height by the model for a given EM value (see figure).

Open water sites can be used for calibration, since both EM and laser distance have to be equal. One measurement represents an area with a diameter of roughly 4 times the height of the EM bird. This leads to a smoothing of the thickness profile and an underestimation of the total thickness of pressure ridges. This is inevitable, because the morphology of a typical pressure ridge is smaller than the footprint of the EM bird. In addition, sea water intrusion can lead to a higher conductivity of the ice layer, which is assumed to be a electrical insulator for the technique described above.

First Results

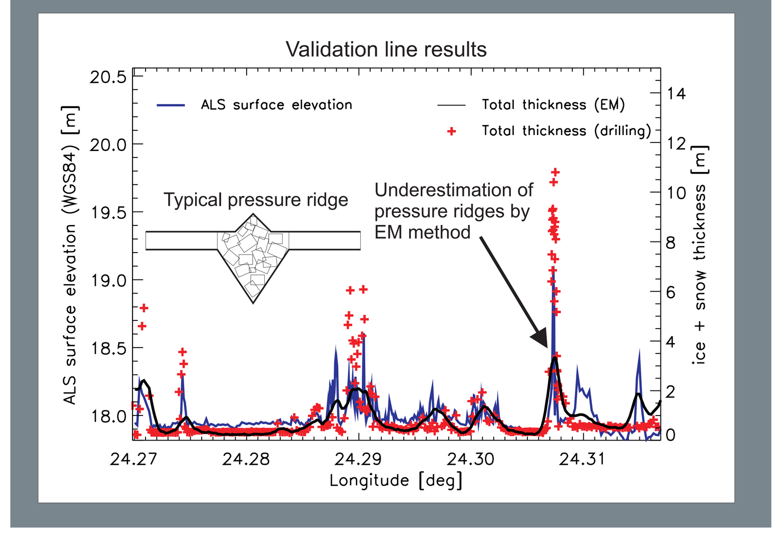




Upper left figure: Sea ice surface elevation map (ALS) with radar freeboard profile.

Upper right figure: Nadir ALS and radar profile comparison (center line in left figure) with aircraft roll .

Lower right figure: Display of total thickness along the validation line by EM and drilling. Surface elevation (not referenced to local sea level) by ALS



Discussion

- ☐ Direct comparison between elevations and EM thickness limited by ice drift
- ☐ Aircraft roll artefact in retrieved radar elevations (partially caused by yet uncorrected time stamps)
- ☐ Detection of open water sites still manual operation
- ☐ Coverage of different ice types : young first year ice, older first year ice, variable snow cover throughout the campaign area
- ☐ EM ice thickness underestimates significantly the thickness of pressure ridges
- ☐ Next campaign area : Arctic ocean northwest of Greenland (May 2006)

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