K_u-Band Radar Penetration into Snow over Arctic Sea Ice

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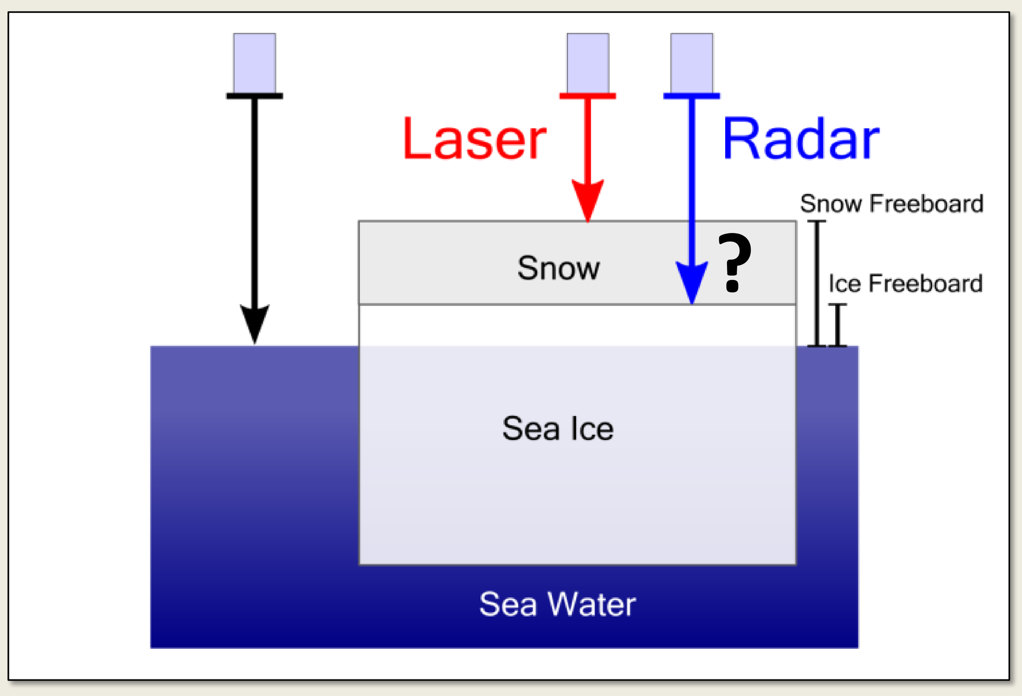
Motivation

CryoSat-2 measures freeboard, the height of the sea ice surface above water level. For the conversion of freeboard into sea ice thickness, the reflection horizon of the radar pulses must be known precisely. It is assumed that a K_u-band radar altimeter penetrates through a cold snow layer and returns the distance to the ice/snow interface. We test this hypothesis by airborne measurements with a K_u-band radar altimeter and a laser scanner. The laser beams are always reflected at the top snow surface and serve as a reference for the radar range retrievals.



Instrument Setup

All sensors were mounted on a Twin-Otter aircraft. Airborne Laserscanners from *Riegl* were used to create a digital elevation model of the sea ice surface. The Airborne Synthetic and Interferometric Radar Altimeter system (ASIRAS) was installed for radar freeboard retrieval. Range data from both instruments was intercalibrated over known targets such as open water and runways. All laser points within the doppler cell of the radar altimeter were averaged to create a comparable laser/radar freeboard data point.

Radar

ASIRAS
Airborne Synthetic and Interferometric Radar Altimeter System

Frequency
13.5 GHz

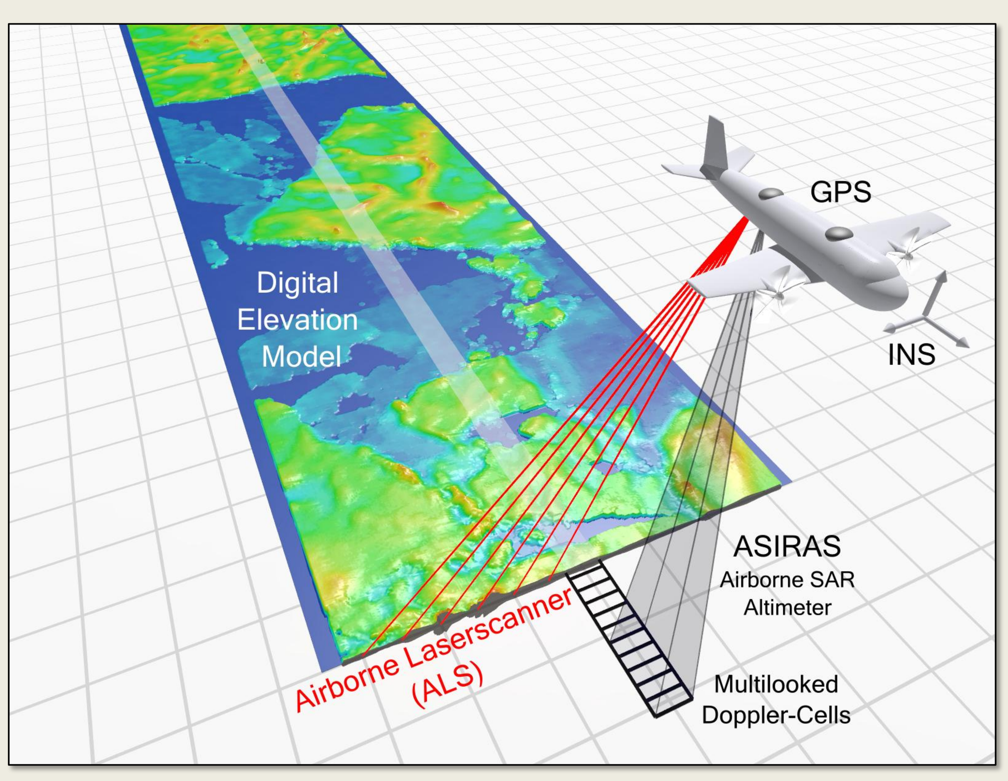
Antenna Beam Pattern
10° Along × 2.5° Across

Laser

Riegl Airborne Laserscanner

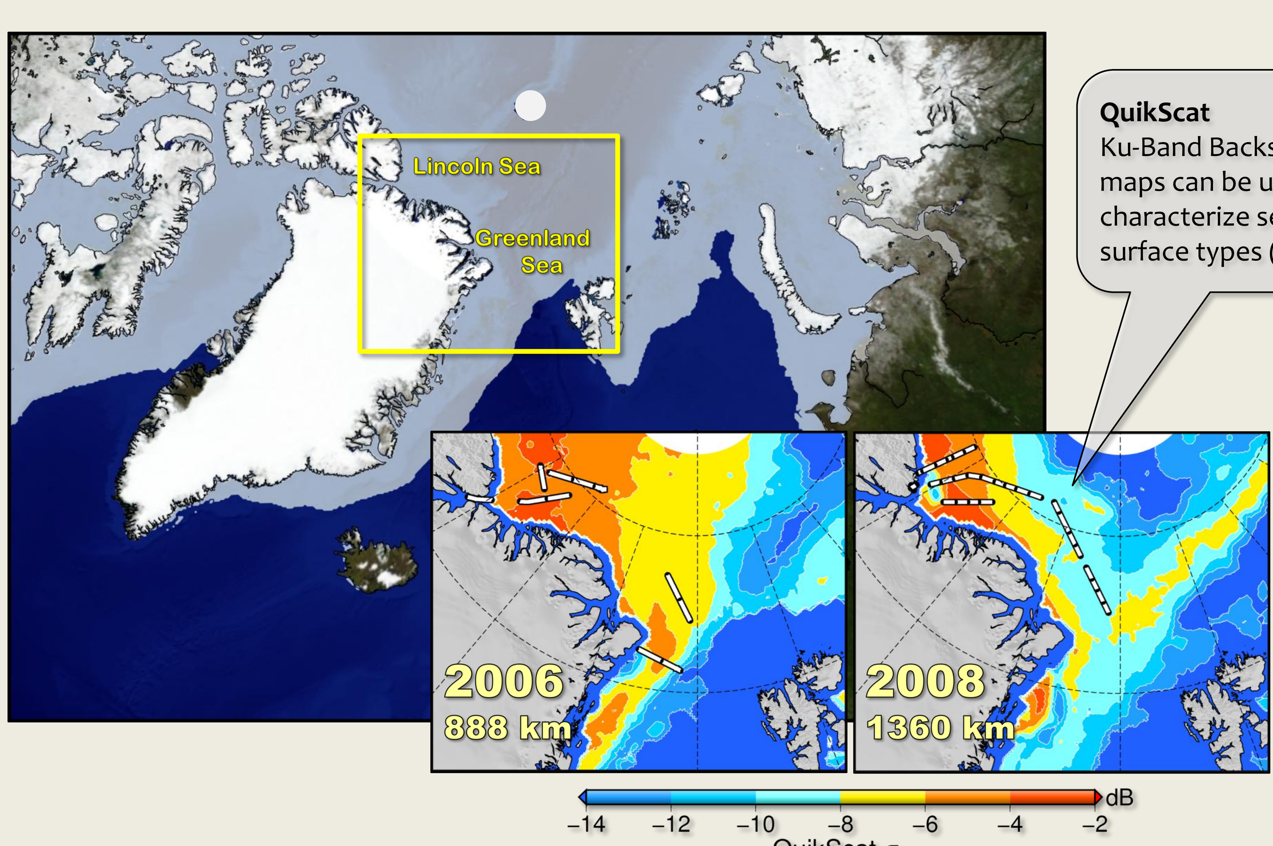
Swath Width
300 – 500 Meter

Point Spacing
1 – 2 Meter



Field Campaigns

Data was collected during the ESA CryoSat Validation Experiment (CryoVEx) in the western Arctic Ocean in late spring during the annual maximum extent of the sea ice cover. The survey region is characterized by multi-year sea ice with a thick snow layer of up to 50 cm in level sections.



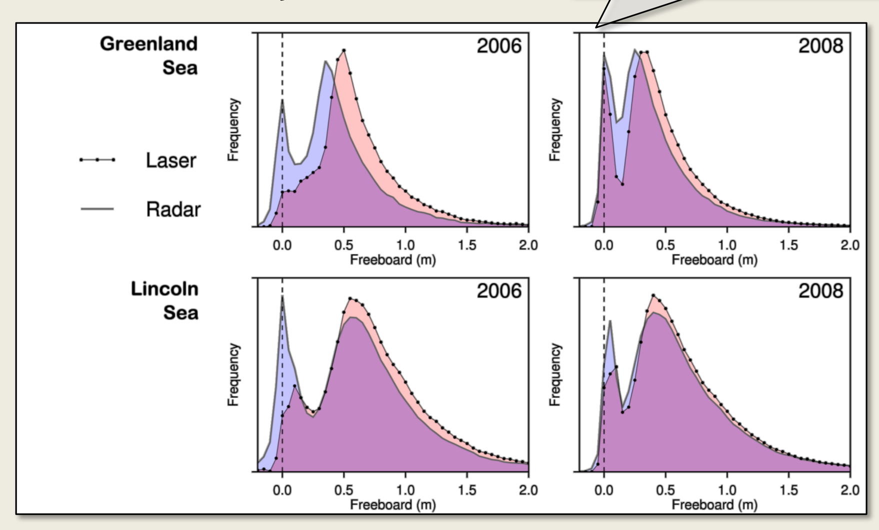
QuikScat
Ku-Band Backscatter maps can be used to characterize sea ice surface types (age)

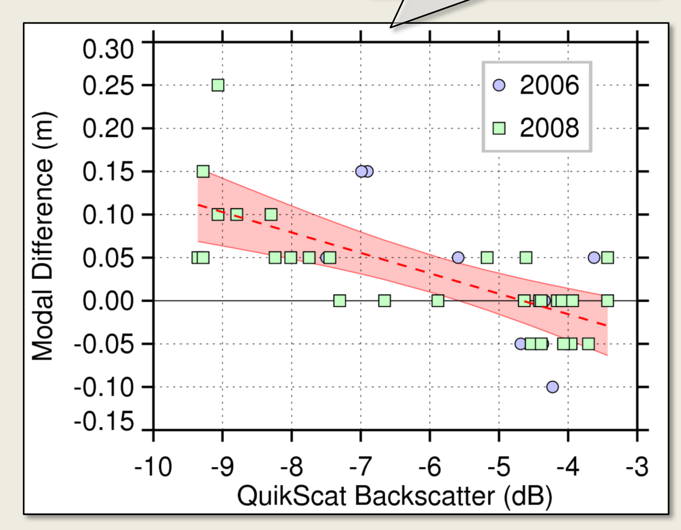
Results

Statistical Analysis

Laser/radar freeboard probability distributions

Apparent penetration for regions of different QuikScat backscatter





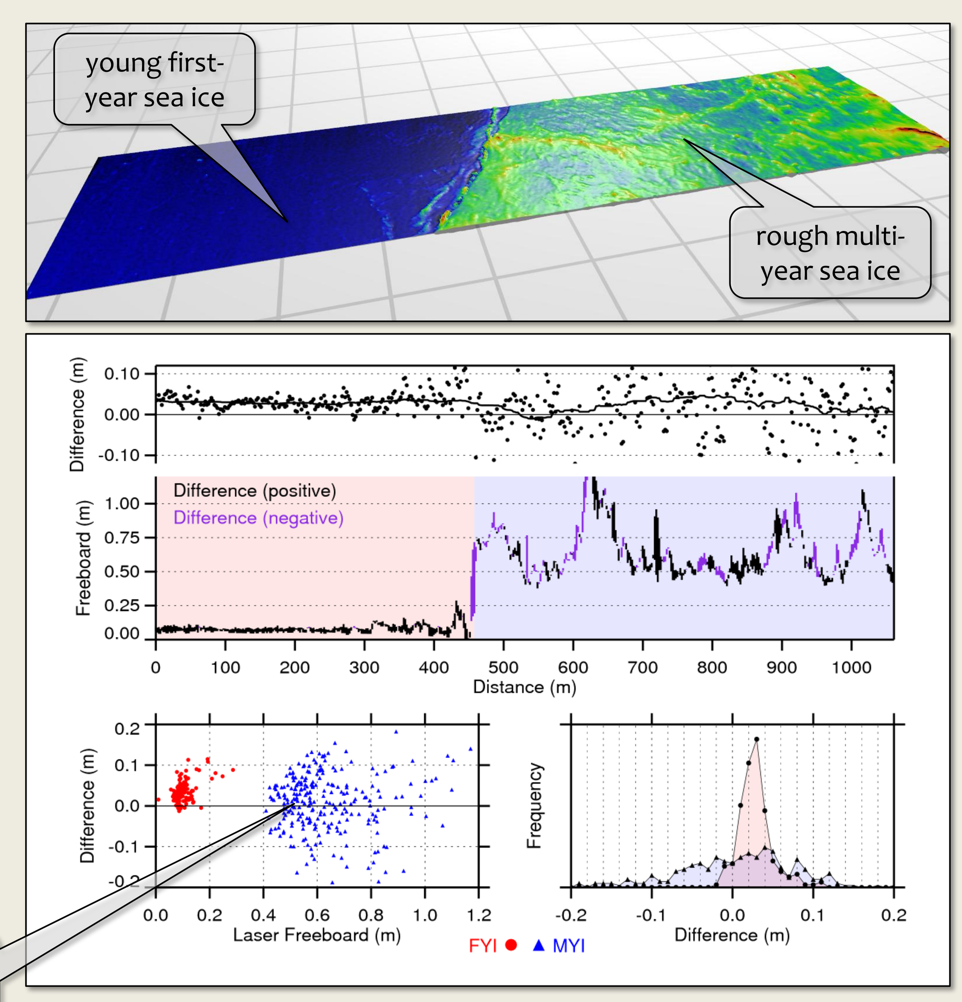
		Apparent Penetration (cm)	Statistical Penetration Snow Density 300 (500) kg/m³ (cm)
Greenland Sea	2006	**15**	**13 (11) ***
	2008	**10**	**8 (7) ***
Lincoln Sea	2006	**0**	**0 ****
	2008	**0**	**0 ****

Apparent Penetration: Difference between modal laser and radar freeboard

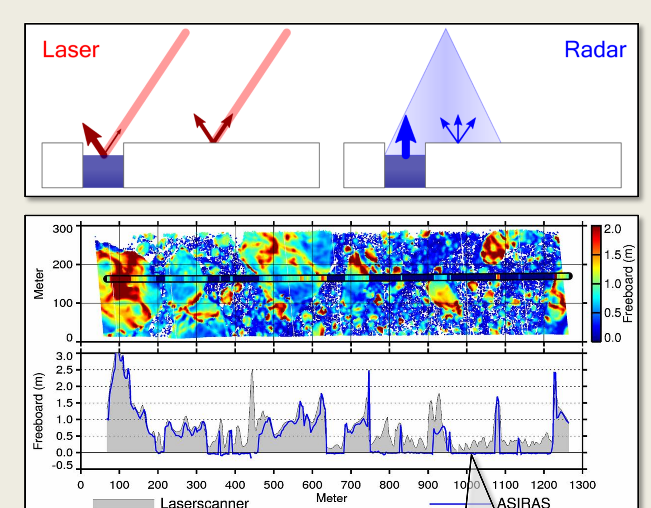
Statistical Penetration: Apparent penetration times radar wave velocity reduction factor in snow layer (depending on snow density)

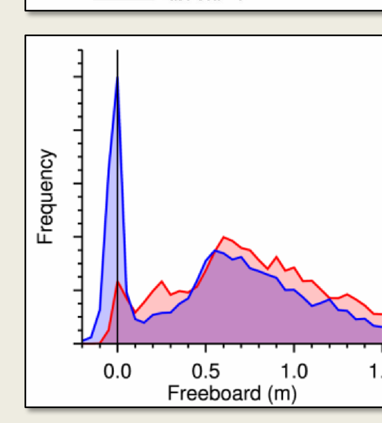
* Expected snow thickness 30 – 40 cm
** Expected snow thickness 40 – 50 cm

Pointwise Differences of Laser and Radar Freeboard



Significant scatter due to surface roughness





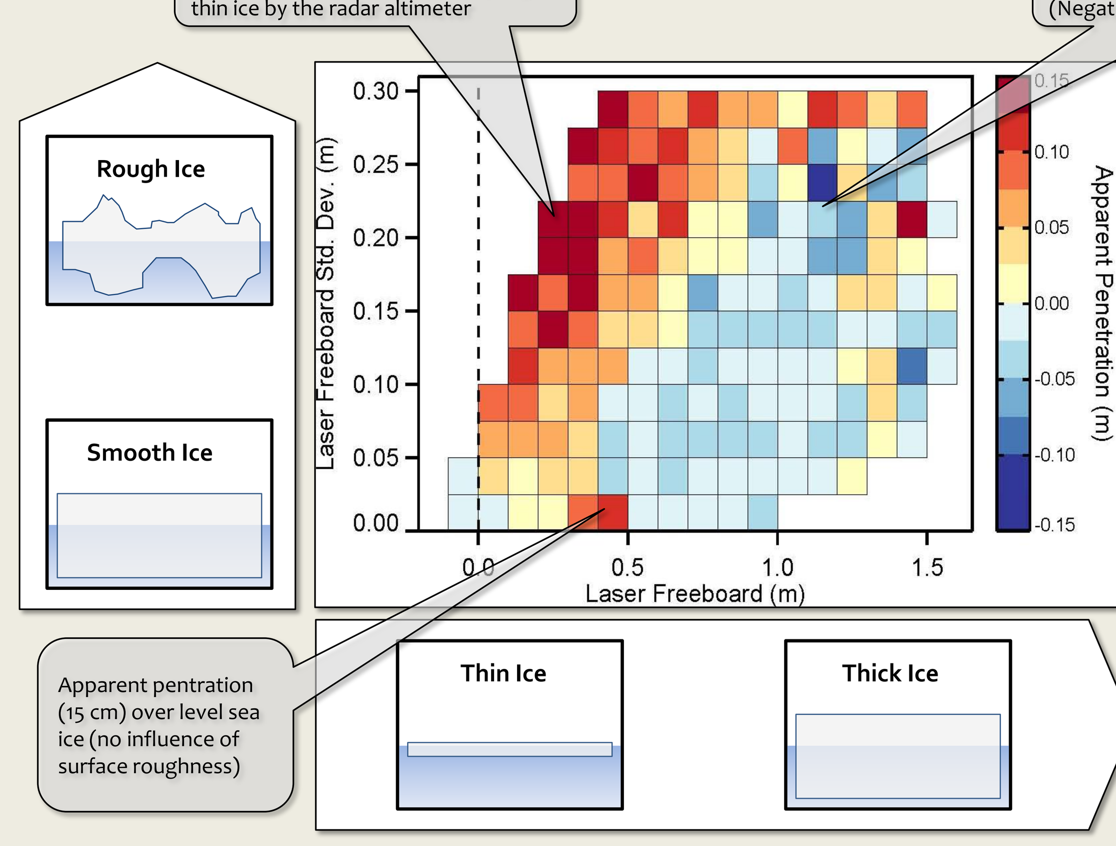
Specular reflection over thin ice and open water results in preferential sampling of both sensors and consequently a statistical bias.

For all surface types:

Description of sea ice types by thickness (proxy: laser freeboard) and roughness (standard deviation of laser points within radar footprint):

Thin Ice: Apparent penetration dominated by preferential sampling of thin ice by the radar altimeter

Thick & deformed Ice: Typically larger radar than laser freeboard. (Negative apparent penetration)



Apparent pentration (15 cm) over level sea ice (no influence of surface roughness)

Conclusions

1. Statistical penetration too small for expected snow thickness in late spring (Greenland Sea region)
2. Observed penetration varies with region
3. Surface roughness has a significant impact on airborne radar/laser freeboard differences (radar echo waveform)
4. Observed penetration over level ice comparable to results from ground radar and corner reflector analysis Willat et al., 2010
5. 2011 validation activities in earlier (colder) period to discriminate the penetration limiting factors of snow wetness and density layering