What are we looking at?
Sources of Uncertainty

Raw Data
- Instrument Calibrations

Geolocated Waveforms
- Retracker Assumptions
- Geophysical Corrections

Freeboard
- SSH Tie Points
- Snow Corrections
- Penetration

Thickness
- Snow Water Equivalent
- Sea Ice Density
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CryoSat-2
Specific
Geophysical Corrections

Geophysical Corrections (mm to cm) vary on the scale of freeboard / thickness gradients
Retracker

Waveform shape is dependent on surface roughness, backscatter, snow properties

**Threshold**

Fixed ‘threshold’ of (first) maxima as first arrival

Same threshold for ice / water (AWI) of combination of thresholds (UCL)

robust but probably to simple

**Waveform Fitting** (Kurtz et al.)

SAR waveform model fitted to waveform

Takes into account changes of leading edge slope

Based on backscatter model, yields range & roughness
Threshold Retracker

TFMRA : Threshold First Maximum Retracker Algorithm
Threshold Retracker
Threshold Retracker

March 2013

November 2013
What is Penetration?

How to separate physical penetration limitations from algorithm properties?

Radar Freeboard near IMB +/- 1 day, radius 50 km

Temporal Evolution of radar freeboard vs IMB snow & ice freeboard

Ricker et al., in preparation
Retracker Intercomparison

D. Price et al., Evaluation of CryoSat-2 derived sea ice freeboard over fast-ice in McMurdo Sound, Antarctica, submitted to Annals of Glaciology
Freeboard Retrieval Remarks

Radar Freeboard

SAR altimeter waveforms needs to better understood (role of snow)

More validation data than for sea-ice thickness

Algorithms

Waveform-model based approaches to be preferred if not outright beneficial (snow properties, roughness)

But how good is your model?

Retrievable snow information in the leading edge?

Freeboard uncertainty is the main contributor to thickness uncertainty
Concept of Uncertainties

Each Parameter may have a bias (offset) and uncertainty (variability)

**Uncertainty**

Regional: Data Noise, SSH Interpolation Error

**Near-insignificant after gridding**

Temporal: Yearly variations of mean snow densities

**Bias**

Constant offsets: Retracker Uncertainty, Snow Depth, Density, ….

Biases have to added, if sign is not known

**Not reduced by gridding, Covariance?**
Uncertainty & Bias

Freeboard uncertainties

Gaussian propagation of uncertainty

- Sea-surface height: 5 – 50 cm
- Speckle noise: SAR: 10 cm, SARln: 14 cm

Random freeboard uncertainty

Retracker threshold + Physical signal penetration + Surface roughness

Freeboard bias

- FYI: 6 cm
- MYI: 12 cm

Thickness uncertainties

Gaussian propagation of uncertainty

- Random freeboard uncertainty: 0.5 – 4 cm
- Ice density: FYI: 35.7 kg/m³, MYI: 23 kg/m³

Random sea-ice thickness uncertainty

Snow depth (ice type classification): -10 – 10 cm
- Ice density (ice type classification): -13 – 13 kg/m³
- Snow depth (inter-annual variability): 50 – 150 kg/m³
- Snow depth (inter-annual variability): 4.0 – 6.2 cm
- Retracker threshold + Physical signal penetration + Surface roughness

Sea-ice thickness bias

- FYI: 60 cm
- MYI: 120 cm
Thickness Uncertainties

(a) Sea-ice thickness (m)
(b) Random sea-ice thickness uncertainty (m)
Summary Remarks

CryoSat-2 sea ice thickness

Uncertainty & Biases

There is not one uncertainty but many
Gridding reduces only random uncertainties
Unknown Bias direction (Knowledge Gap)

All sources added together: Uncertainty much higher than reported in comparison with thickness validation data

CryoSat-2: Freeboard validation is important
Unknows of re-tracking algorithms are a source of uncertainty