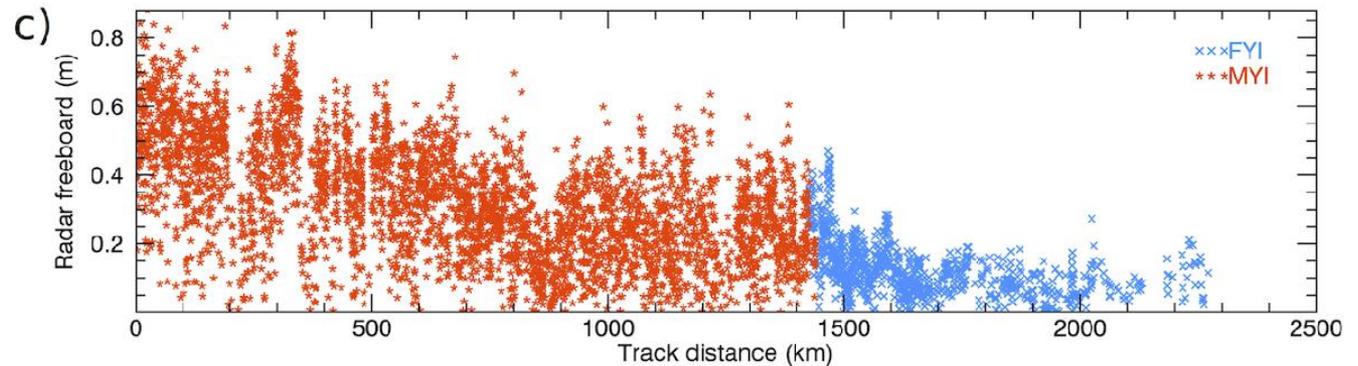
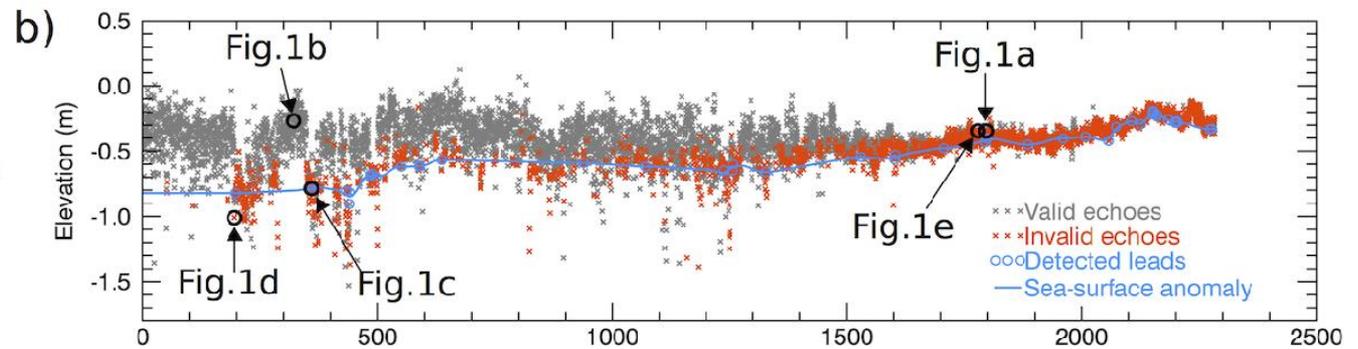
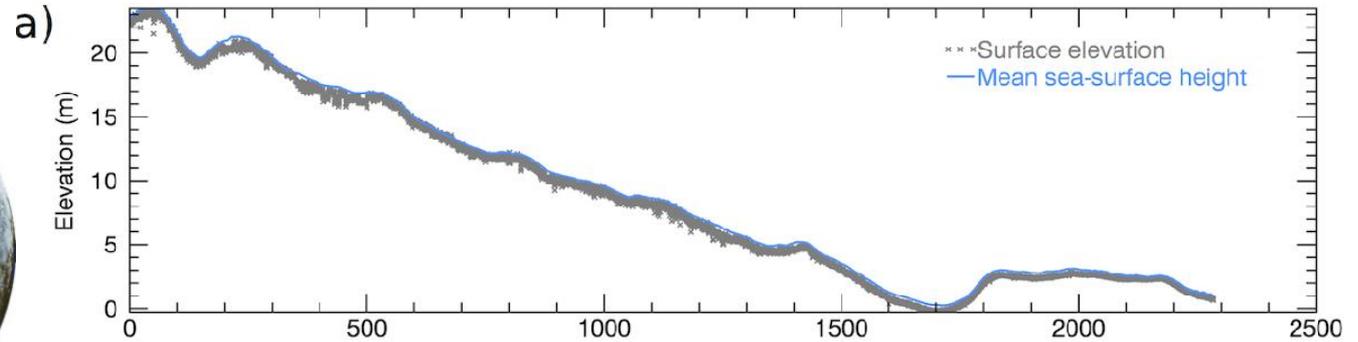
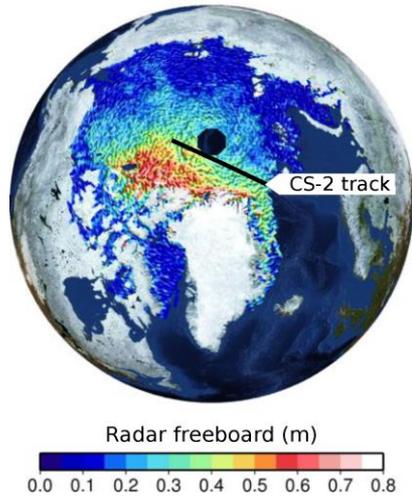




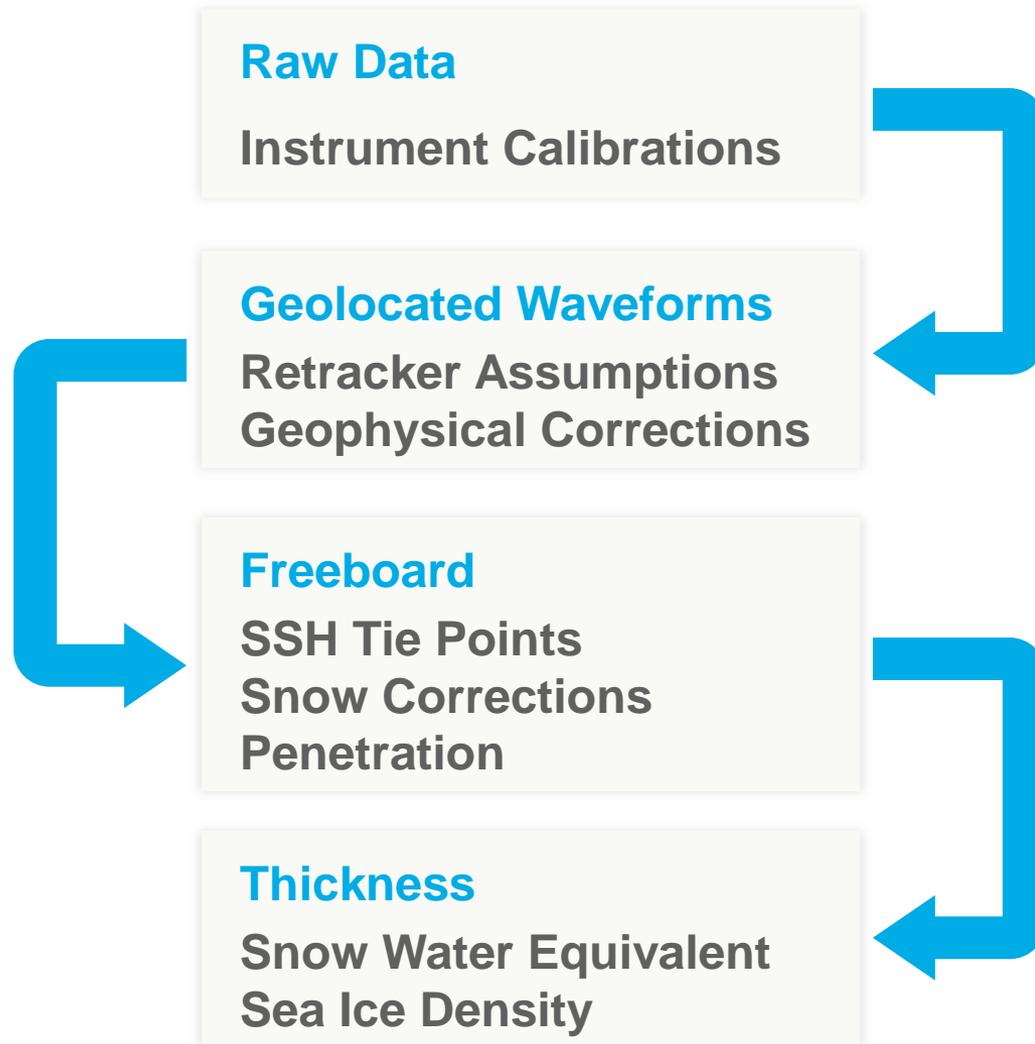
S. Hendricks, R. Ricker, V. Helm, C. Haas, M. Davidson

Uncertainties of Sea Ice Thickness from CryoSat-2

What are we looking at?

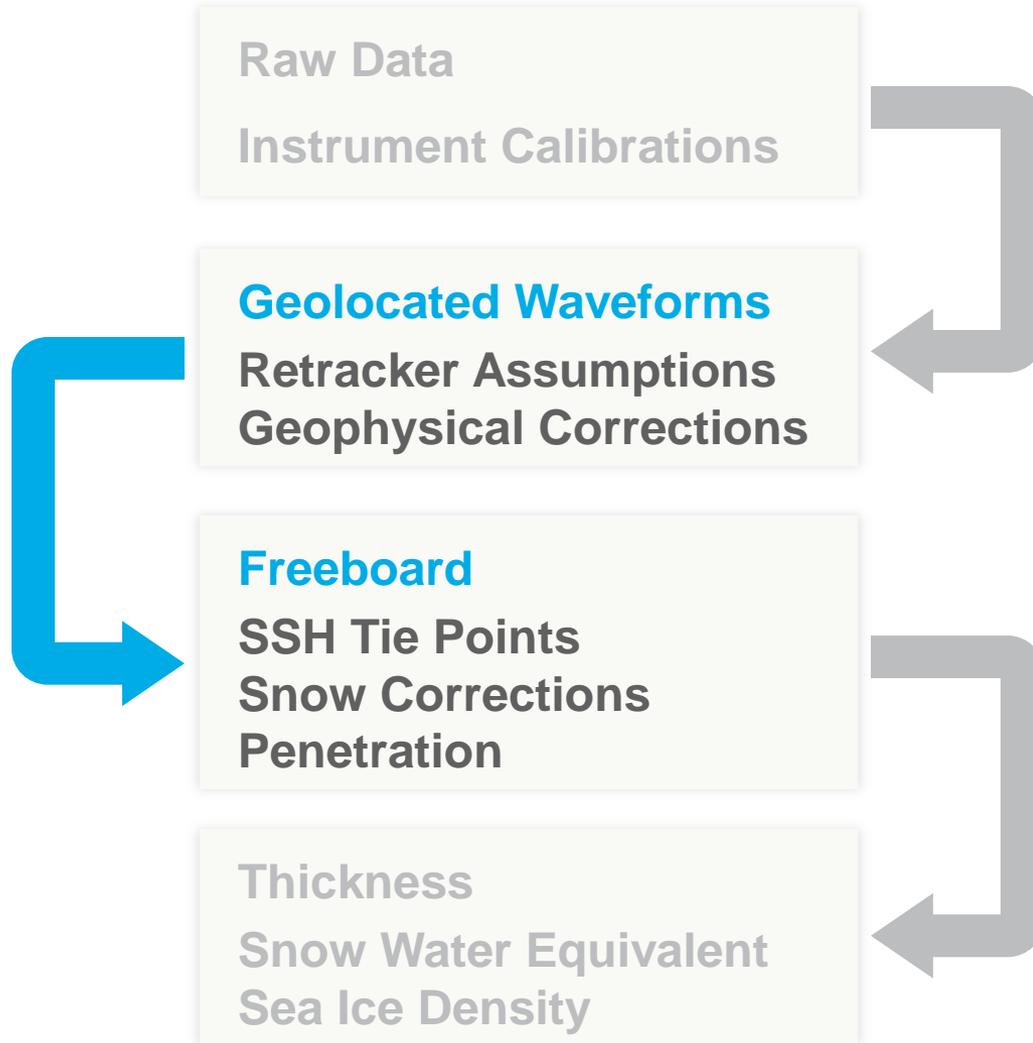


Sources of Uncertainty



Sources of Uncertainty

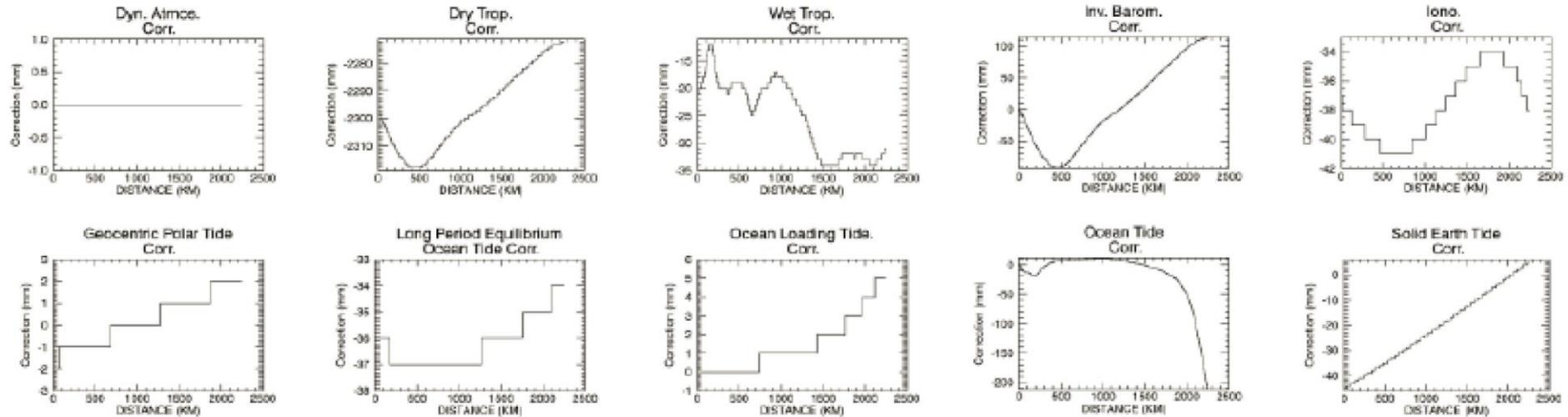
**CryoSat-2
Specific**



Geophysical Corrections



File: CS_L2_20140326T090649
Orbit: 21011 Date: 2014/3/26



↔
2500 km

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 too simple

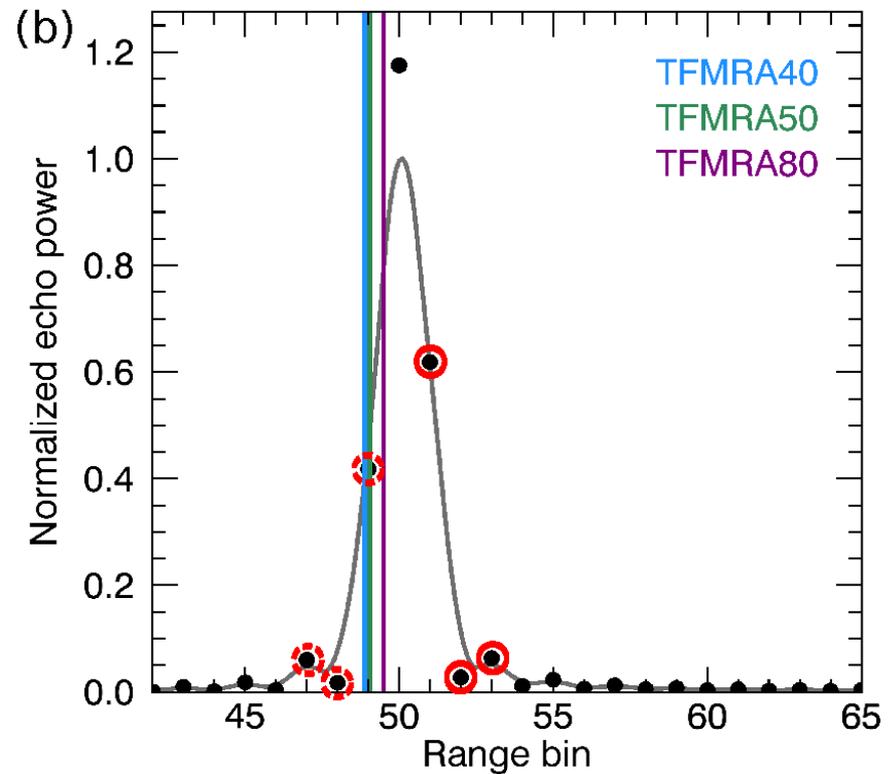
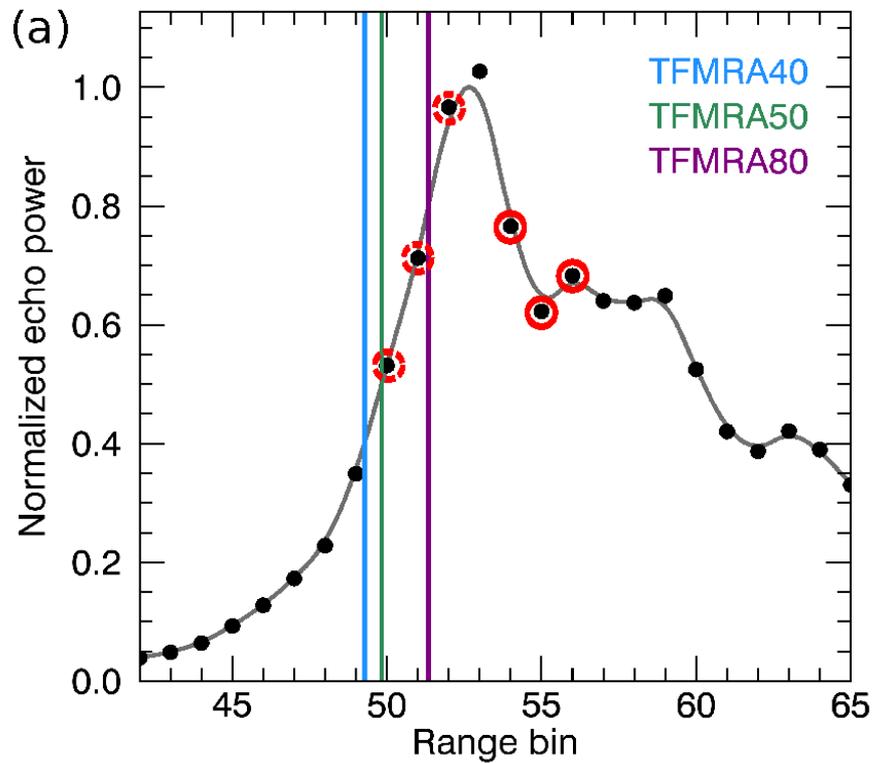
Waveform Fitting (Kurtz et al.)

SAR waveform model fitted to waveform

Takes into account changes of leading edge slope

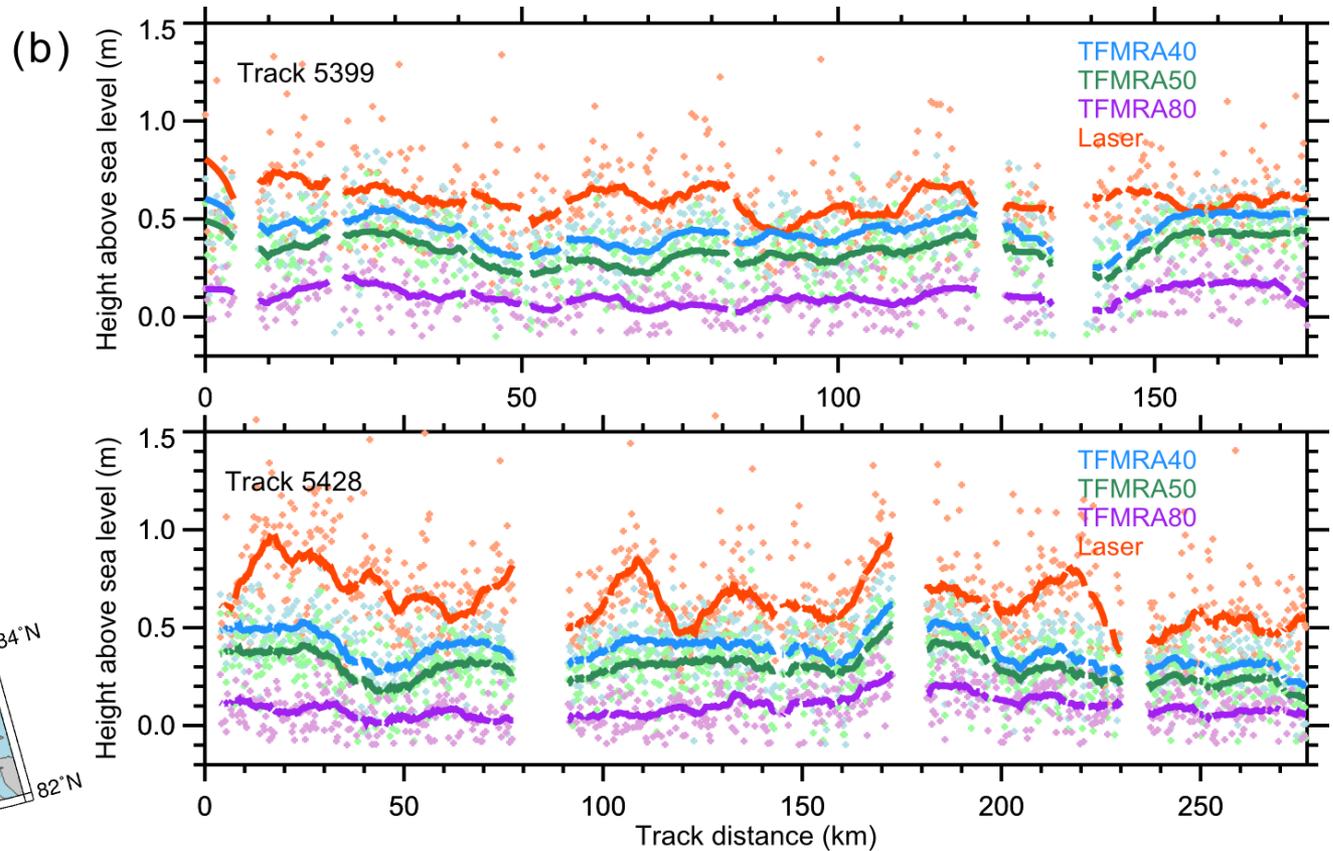
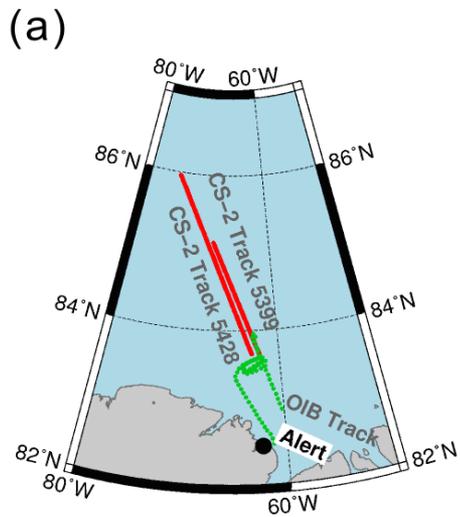
Based on backscatter model, yields range & roughness

Threshold Retracker



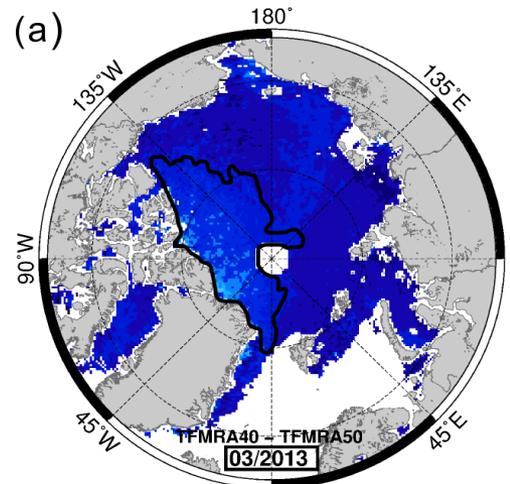
TFMRA : Threshold First Maximum Retracker Algorithm

Threshold Retracker

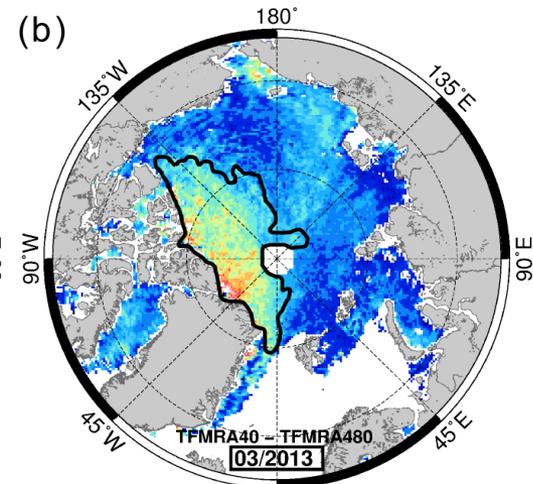


Threshold Retracker

March 2013

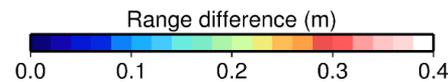
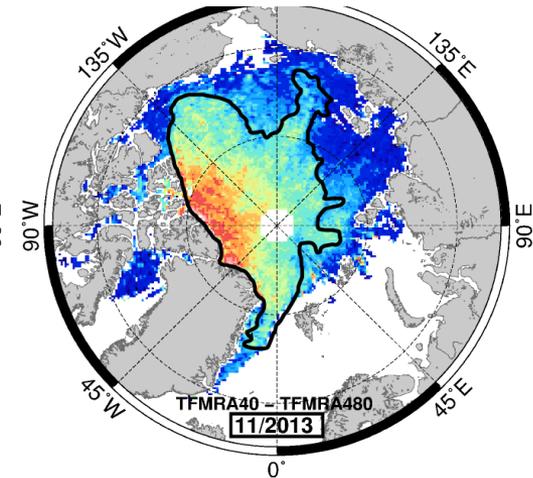
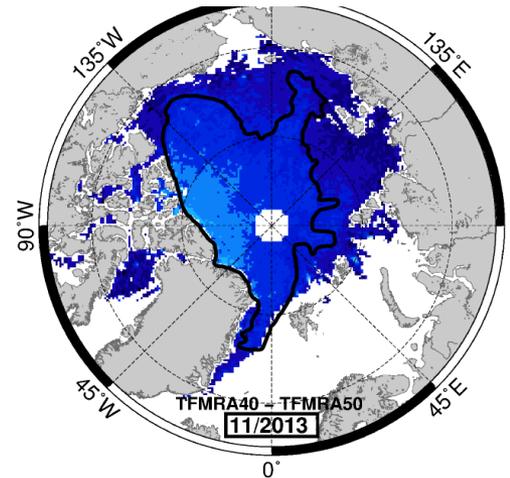


TFMRA40 – TFMRA50



TFMRA40 – TFMRA80

November 2013



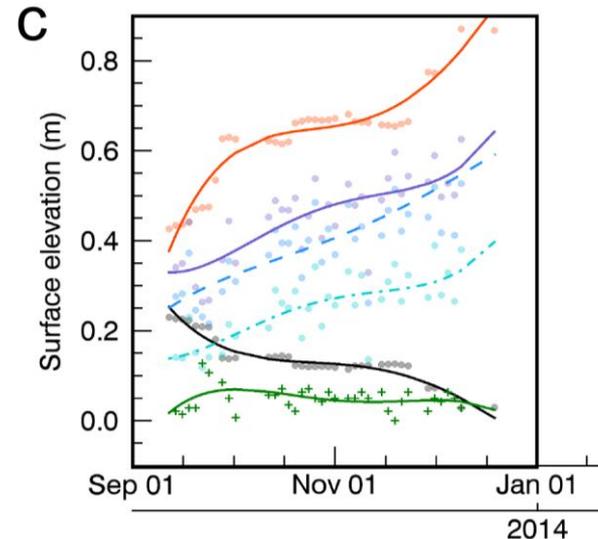
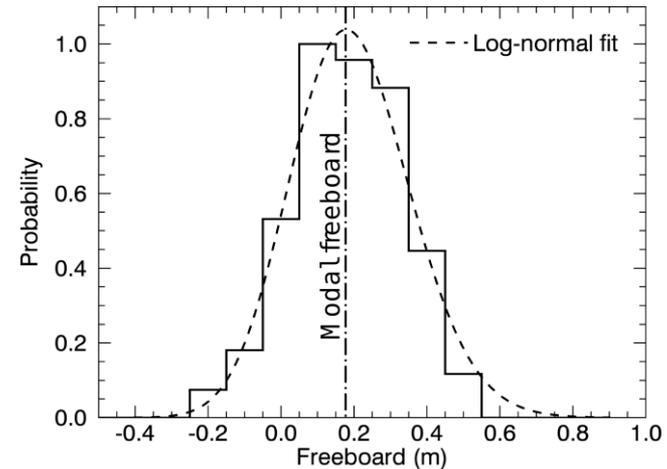
What is Penetration?

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

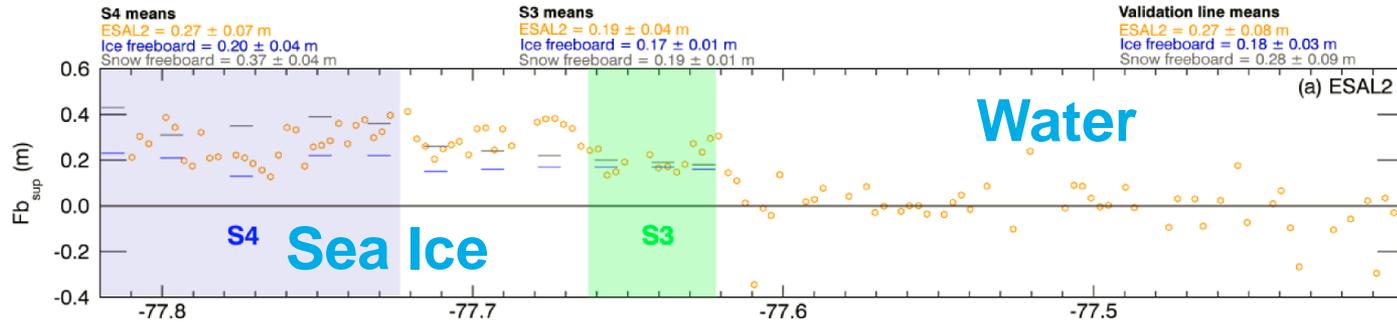
- IMB snow-freeboard
- IMB ice-freeboard
- CS-2 PP_L
- 40% threshold
- - - 50% threshold
- · - · 80% threshold



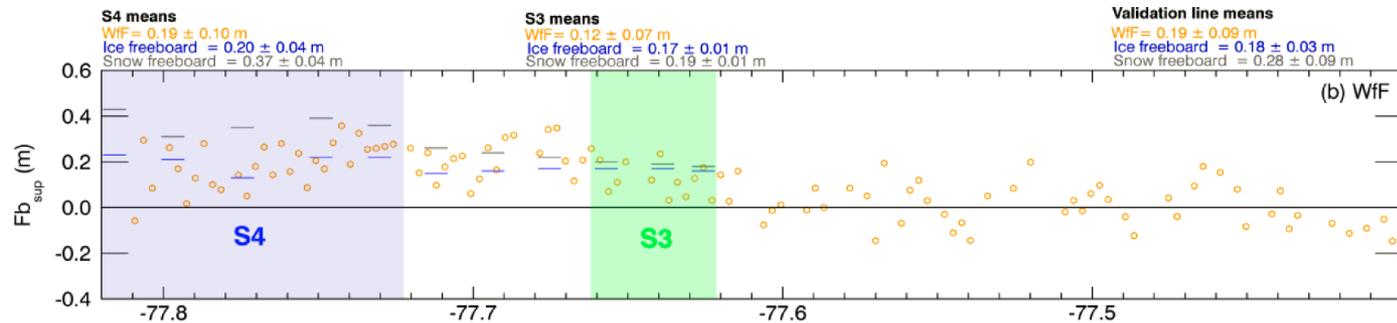
Retracker Intercomparison



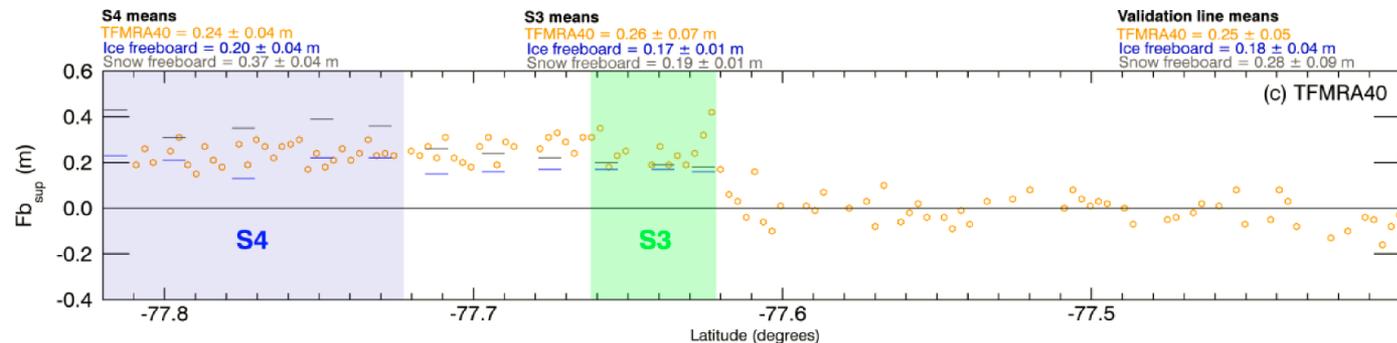
ESA L2



Waveform Fitting



AWI TFMRA40



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

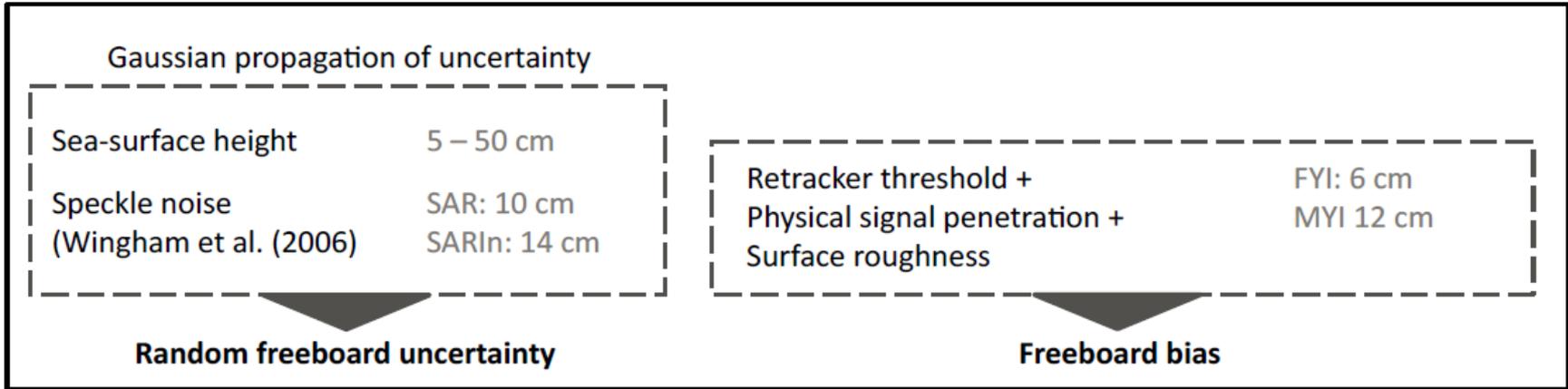
Constant offsets: Retracker Uncertainty, Snow Depth, Density,

Biases have to added, if sign is not known

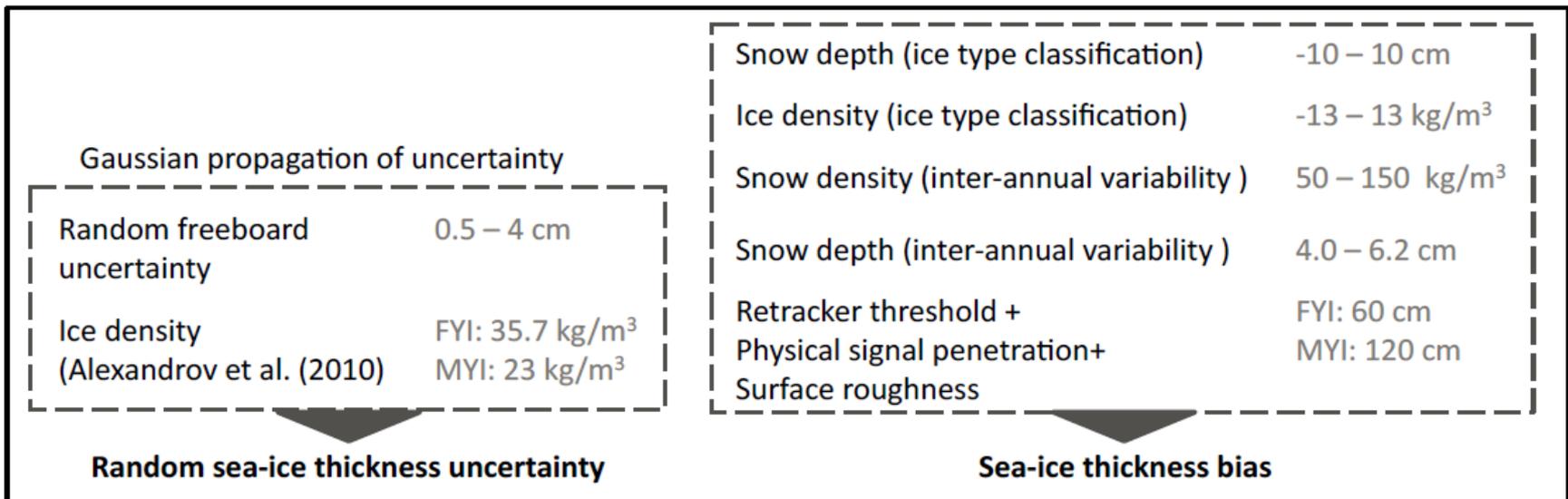
Not reduced by gridding, Covariance?

Uncertainty & Bias

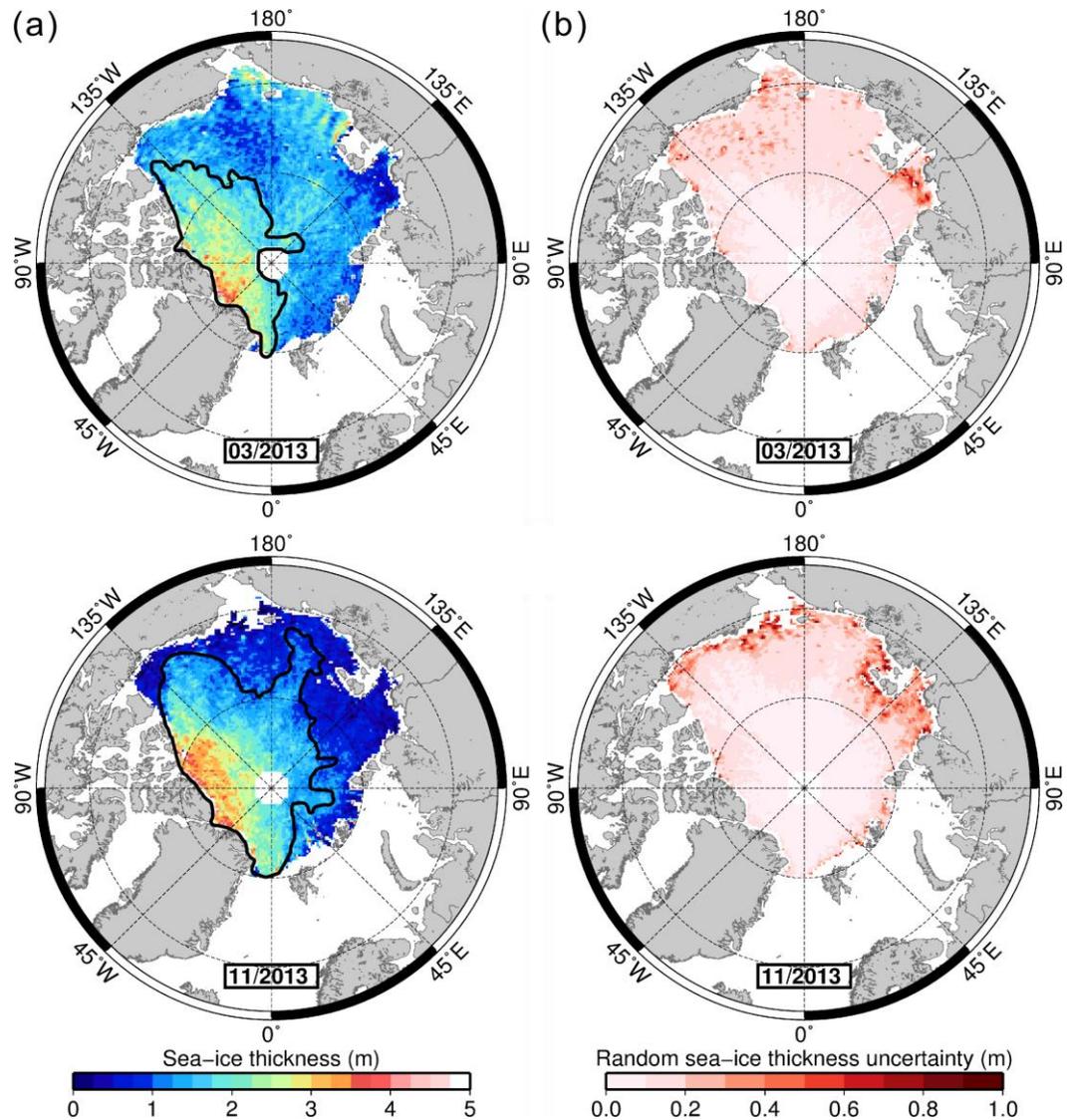
Freeboard uncertainties



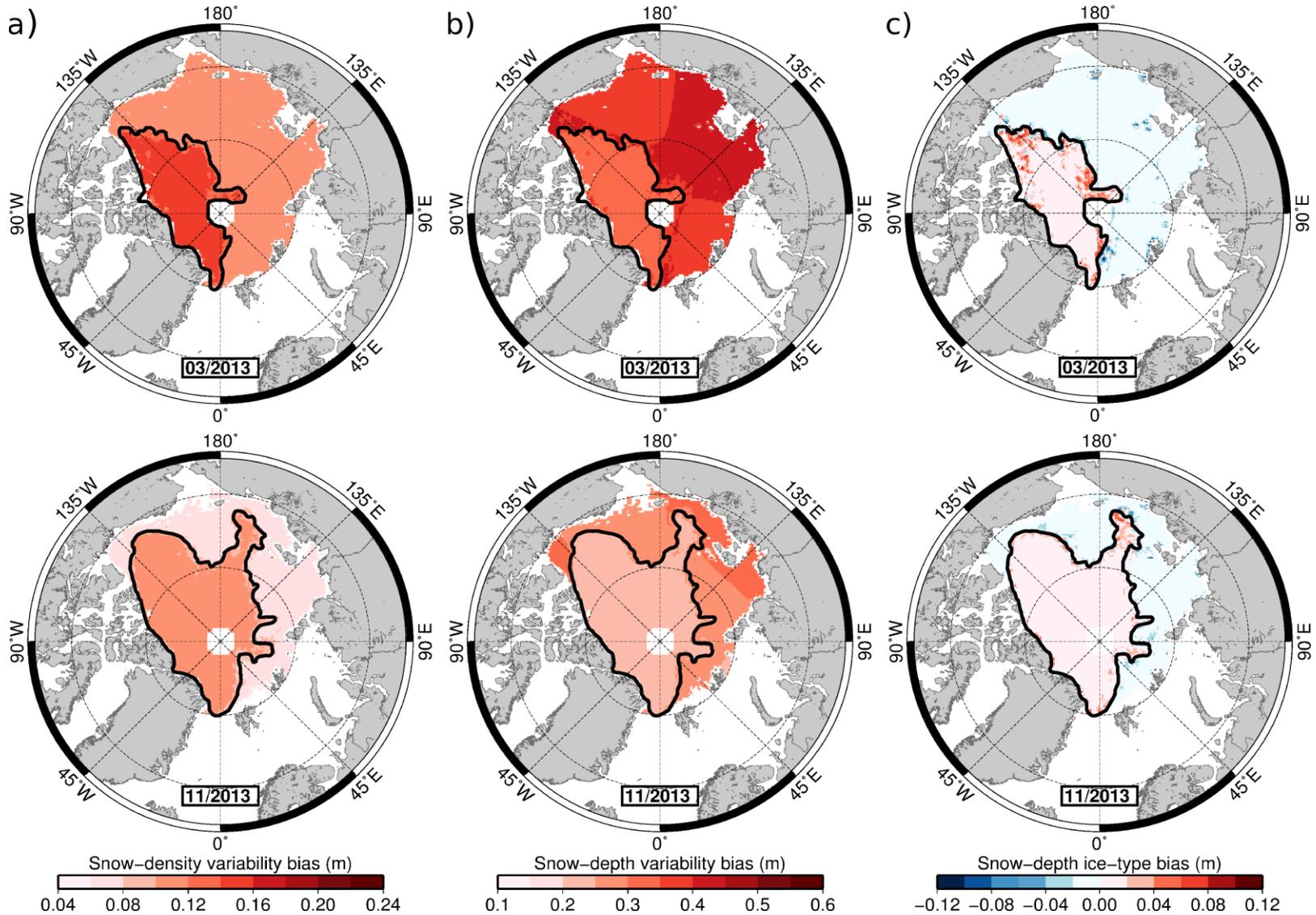
Thickness uncertainties



Thickness Uncertainties



Thickness Biases



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

Unknowns of retracking algorithms are a source of uncertainty