A Novel Model-based Retracker For Sea-ice Covered Regions

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Abstract

This abstract focuses on the description and the preliminary validation of a model-based retracker for sea ice covered regions. Retracking is carried out by fitting an adaptation of the semianalytical model described in [1] to altimeter power waveforms acquired over Arctic sea ice to retrieve values of surface elevation, backscattering efficiency, surface roughness, snow depth and a normalized multilooked peak power. Curve fitting is performed using the Levenberg–Marquardt algorithm which fits the specific model function - i.e. the objective function - to the altimeter power waveform. The potential advantages of such a model-based approach would be, e.g., to account for the elevation bias introduced by threshold retrackers over sea ice and leads, caused by varying surface roughness and by the empirical choice of retracking thresholds.

Preliminary validation of the retracker is performed by comparing CryoSat along-track elevations with those obtained by the SAMOSA+ retracker. Additionally, freeboard estimates from the semianalytical reracker are compared with Operation IceBridge data collected during CryoSat underflights in the Arctic. In order to assess the potential advantage of a joint retracking of sea ice freeboard and snow depth, we investigate differences in freeboard estimates from the semianalytical retracker computed in three different ways: by not applying the snow model, by considering a constant value of snow depth along specific CryoSat tracks, and by attempting to directly retrack the snow depth.

Sea Ice Waveform Model

The received radar echo W as a function of the delay time τ from a uniformly backscattering planar surface can be expressed as the convolution of 4 terms:

$$W(\tau) = X(\tau) * p_t(\tau) * p_z(\tau) * b(\tau)$$

Surface impulse response:

$X(\tau) \sim \sum_{k \in \boldsymbol{K}} X_k(\tau)$

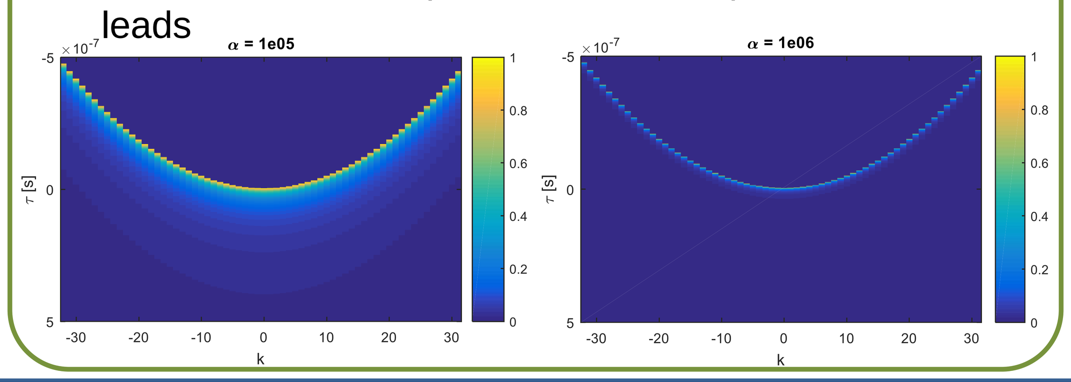
where X_k is the impulse response for the k^th synthetic beam, and **K** is the set of single-looks of the L1B stack included in the multilooking

In order to model diffuse backscattering as well as specular targets, the **backscattering efficiency** is included

$$A_k(\tau) = H\left(\tau + \frac{\eta h \xi_k^2}{c}\right)\left(1 + \alpha \rho_k^2(\tau)\right)^{-\frac{3}{2}}$$

The parameter α tunes the backscattering efficiency from a surface as a function of the incidence angle:

- α = 0 for homogeneous diffuse surface (i.e. ocean)
- α >0 for directive/specular surfaces (i.e. sea ice and leads



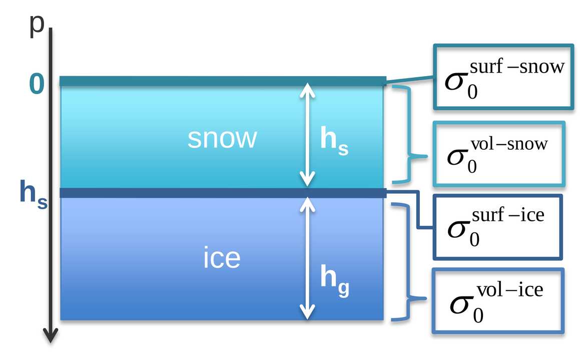
Instrument range impulse response:

$$p_t(\tau) = \left|\frac{\sin(\pi B \tau)}{\pi B \tau}\right|^2$$

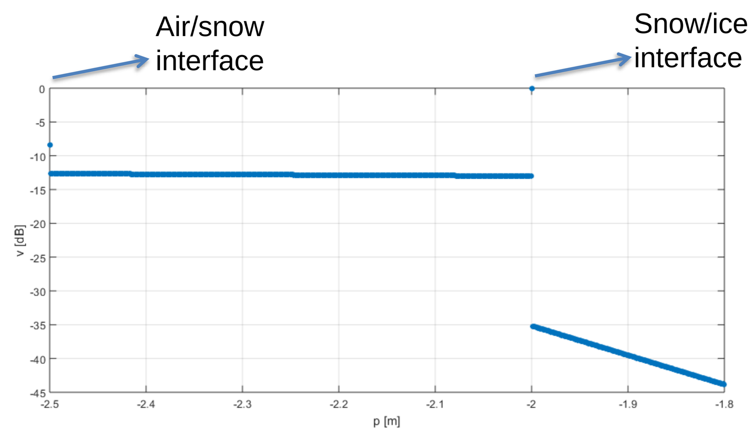
Surface height probability density function:

- Gaussian (ocean)
- Log-Normal (ice)

Scattering cross section per unit-volume including a penetration model



Snow-ice scenario.



Scattering contribution from a 50 cm snow layer and a 20 cm ice layer as a function of delay

Penetration model:

The total backscatter from the surface is obtained by the sum of the snow/ice surface backscatter coefficients and snow/ice integrated volume backscatter:

$$\sigma_0(0°) = \sigma_0^{\text{surf-snow}} + \sigma_0^{\text{vol-snow}} + \sigma_0^{\text{surf-ice}} + \sigma_0^{\text{vol-ice}} = \int_{-\infty}^{\infty} b(\tau)$$

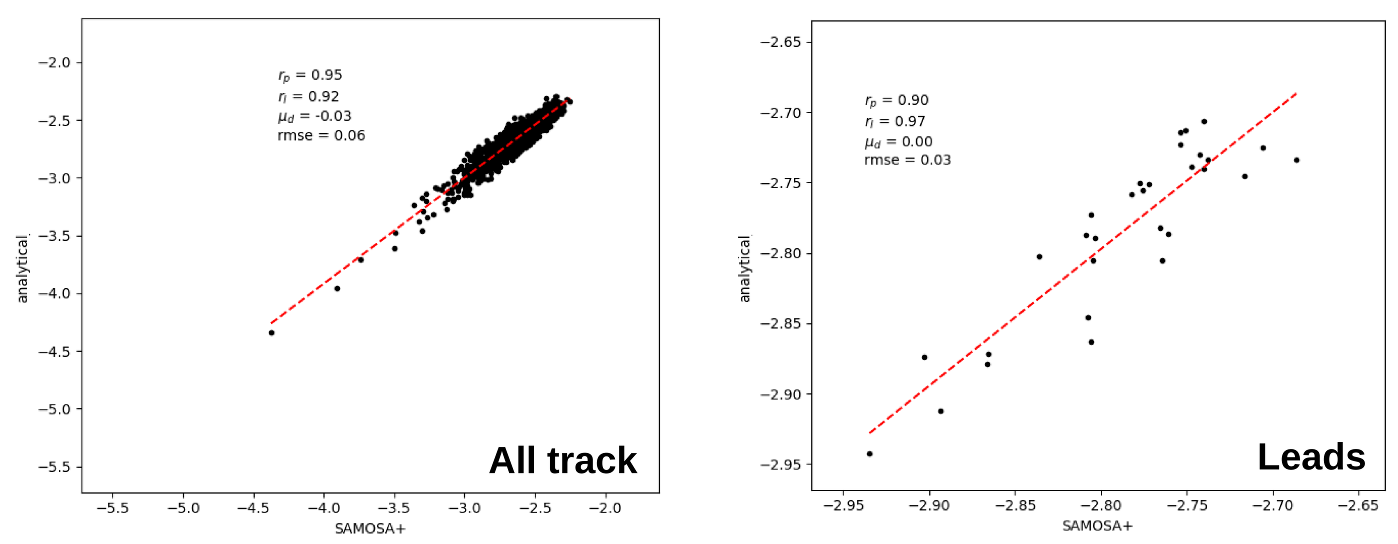
$$v(\tau) = \begin{cases} 0, & \tau < -\frac{2h_s}{c_{\text{snow}}} \\ \frac{c_{\text{snow}}}{2}\left(\sigma_0^{\text{surf-snow}}\delta\left(\tau + \frac{2h_s}{c_{\text{snow}}}\right) + k_{t-snow}^2 \sigma^{\text{vol-snow}} \, exp\left\{-c_{\text{snow}} k_{e-\text{snow}}\left(\tau + \frac{2h_s}{c_{\text{snow}}}\right)\right\}\right) & 0 \le p < h_s \\ \frac{c_{\text{ice}}}{2} k_{t-snow}^2 \, exp\{-2k_{e-\text{snow}} h_s\}\left[\sigma_0^{\text{surf-}ice}\delta(\tau) + k_{t-ice}^2 \sigma^{\text{vol-ice}} \, exp\{-k_{e-\text{ice}} c_{\text{ice}} \tau\}\right], & p \ge h_s \end{cases}$$

The model considers the different propagation speed into the snow and ice layers.

Aresys Sea Ice Model-Based Retracker Results

Validation by comparison with SAMOSA+ elevations

We compare uncorrected elevations from the SAR analytical retracker vs SAMOSA+ along the same CS2 track over sea ice. Contributions from the snow model are not included in this test aiming at validating the Aresys Sea Ice Retracker by comparison with SAMOSA+. Good agreement is found along the entire satellite track (left). Over leads (right), no bias and a small spread are observed.



Comparison with Operation IceBridge freeboard and snow depth

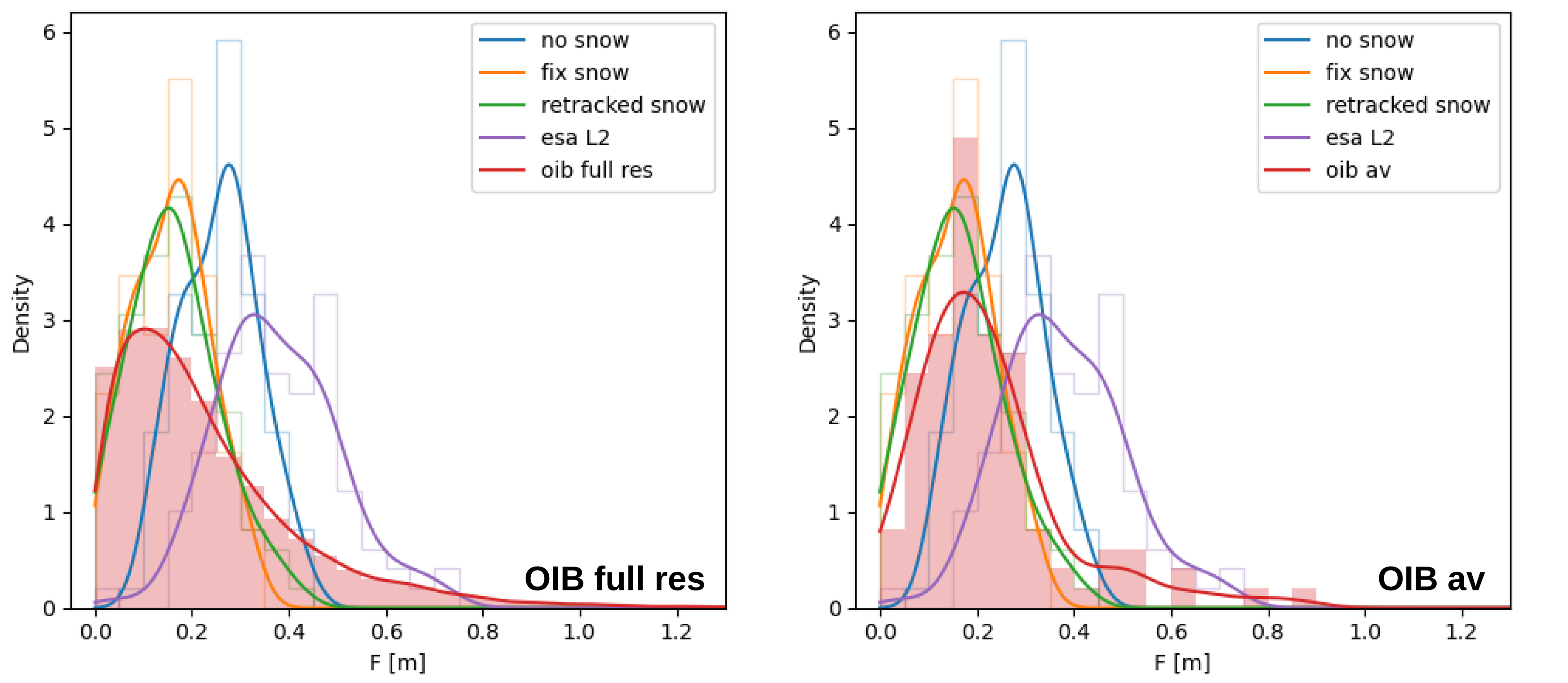
We compare CS2 freeboard estimates from the analytical retracker with airborne measurements from the OIB campaign on 24/4/2013 ($\Delta t = \sim 30$ min). CS2 freeboard is computed in three different ways:

- No snow model applied (***no snow***)
- Contribution from snow model with fix snow depth of 35 cm (***fix snow***)
- Contribution from snow model with attempt to retrack snow depth (***rtck snow***), initial value of 35 cm

ESA L2 freeboard are also included in the comparison. OIB sea ice freeboard is obtained by subtracting the measured snow depth from the total lidar freeboard. Both **airborne** freeboard and snow depth are **averaged to CS2 footprint** ($n = 98$).

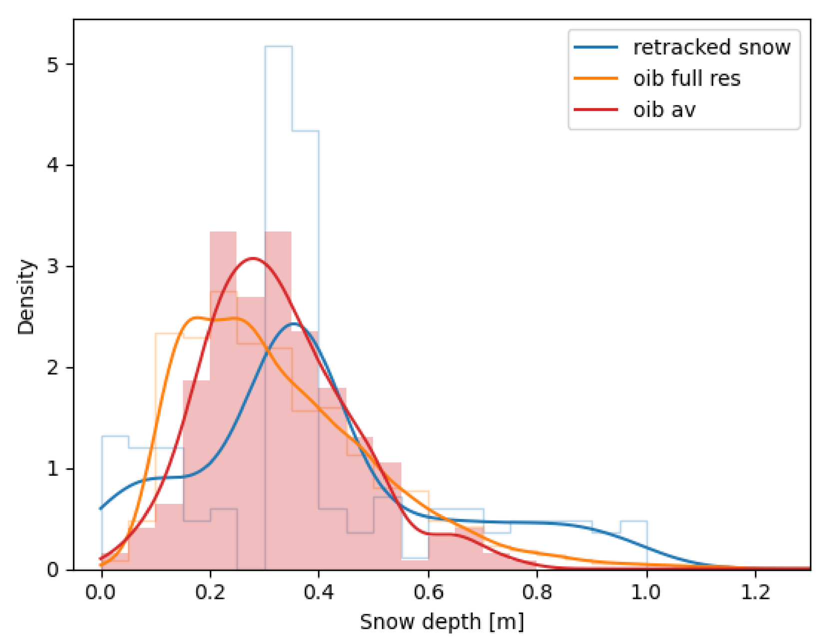
Freeboard

	No snow	Fix snow	Rtck snow	ESA L2	OIB full res	OIB av
F_{mean} [cm]	25.8	15.6	16.3	37.7	23.4	**22.4**
ΔF_{OIB} [cm]	3.4	-6.8	-6.1	15.3	--	--
F_{mode} [cm]	27.5	**17.5**	**17.5**	32.5	--	**17.5**



Snow depth

	Rtck snow	OIB full res	OIB av
SD [cm]	32.5	33.2	**34.5**
ΔSD_{OIB} [cm]	-2.0	--	--



Conclusions

- Model-based sea ice retrackers offer capabilities to potentially improve performance w,r.t. empirical ones
- Snow model needs further testing & careful investigation of snow electromagnetic properties and their variability is required
- **Potential advantage in modelling the scattering from snow** in terms of freeboard agreement with airborne estimates
- While providing reasonable values, **the retracker alone does not retrieve accurate snow depth** (too many fitting parameters?)

References

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[2] Kurtz, N. T. and Galin, N. and Studinger, M. "An improved CryoSat-2 sea ice freeboard retrieval algorithm through the use of waveform fitting". The Cryosphere Vol. 8, N. 4, 1217-1237 (2014). DOI:10.5194/tc-8-1217-2014