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Physically-based Ice Thickness and Surface Roughness Retrievals over Rough Deformed Sea Ice

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The observations of sea ice thickness and ice surface roughness are critical for our understanding of the state of the changing Arctic. Currently, the Radar and/or LiDAR data of sea ice freeboard are used to infer sea ice thickness via isostasy. The underlying assumption is that the LiDAR signal returns at the air/snow interface and radar signal at the snow/ice interface. The elevations of these interfaces are determined based on LiDAR/Radar return waveforms. However, the commonly used threshold-based surface detection techniques are empirical in nature and work well only over level/smooth sea ice. Rough sea ice surfaces can modify the return waveforms, resulting in significant Electromagnetic (EM) bias in the estimated surface elevations, and thus large errors in the ice thickness retrievals.

To understand and quantify such sea ice surface roughness effects, a combined EM rough surface and volume scattering model was developed to simulate radar returns from the rough sea ice 'layer cake' structure. A waveform matching technique was also developed to fit observed waveforms to a physically-based waveform model and subsequently correct the roughness induced EM bias in the estimated freeboard. This new EM Bias Corrected (EMBC) algorithm was able to better retrieve surface elevations and estimate the surface roughness parameter simultaneously.

Both the ice thickness and surface roughness retrievals are validated using in-situ data. For the surface roughness retrievals, we applied this EMBC algorithm to co-incident LiDAR/Radar measurements collected during a Cryosat-2 under-flight by the NASA IceBridge missions. Results show that not only does the waveform model fit very well to the measured radar waveform, but also the roughness parameters derived independently from the LiDAR and radar data agree very well for both level and deformed sea ice. For sea ice thickness retrievals, validation based on in-situ data from the coordinated CRREL/NRL field campaign demonstrates that the physically-based EMBC algorithm performs fundamentally better than the empirical algorithm over very rough deformed sea ice, suggesting that sea ice surface roughness effects can be modeled and corrected based solely on the radar return waveforms.