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Arctic freeboards and snow depths from near-coincident CryoSat-2 and ICESat-2 (CRYO2ICE) observations during the winter 2020-2021: An examination across changing sea ice conditions

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The orbit manoeuvre, known as CRYO2ICE, that periodically aligned CryoSat-2 with ICESat-2, allows for unprecedented near-coincident radar and lidar observations targeted the polar regions. This is of particular interest to sea ice thickness studies, since snow on sea ice remains the largest contributor to altimetry-derived sea ice thickness uncertainties. To date, snow depth estimates from space have been acquired from passive microwave radiometers, and by using dual-frequency observations (Ku- and Ka-band, or laser and Ku-band). However, until now, dual-frequency observations have only been based on monthly averaged estimates at basin-scales, and while passive microwave-derived snow estimates are provided daily, they are only reliable over first-year ice. CRYO2ICE presents the possibility of investigating along-track snow depth on sea ice using observations at two different frequencies, along with an opportunity for further investigation of penetration capabilities and footprint-related issues of high interest to the altimetry community.

Some of the most noticeable differences between CryoSat-2 and ICESat-2 are found in their measurement configuration and sampling rates. This difference in measurement configuration between retrieving surface elevation using conventional ways, such as re-tracking of the synthetic aperture radar (SAR) waveform of CryoSat-2 in comparison to re-tracking the surface from high-density photon clouds of ICESat-2, as well as the difference in sampling rates, presents additional challenges. Here, we investigate the challenge of binning these different type of observation strategies into comparable observations and what we can expect from the CRYO2ICE observations over sea ice. We examine near-coincident radar and laser freeboards from CryoSat-2 and ICESat-2 (CRYO2ICE observations) and the resulting snow depth observations in the Arctic. We utilise three CryoSat-2 products (Baseline-D, CCI and LARM) representing a variety of re-trackers used in sea ice altimetry studies, and the ATL10 product from ICESat-2. Our focus is on how the CryoSat-2 and

ICESat-2 derived freeboards respond along-track to various ice and snow conditions, and how this affects the possibility to retrieve snow depth.

This study investigates the freeboards and the derived snow depth in relation to changes in surface roughness, sea ice concentration and sea ice lead identifications. Here, we find inconsistencies in the radar freeboard estimates across the changing ice conditions. By comparison with sea ice concentration, identified leads and roughness estimates, the inconsistencies relate to retrieval methodology of CryoSat-2 (re-tracking to a backscattering interface using a threshold-based re-tracker or a physical re-tracker) and binning methodology (posing the question of when CRYO2ICE observations are truly comparable). Other inconsistencies relate to how the condition of the surface impacts the radar signal. We also present comparisons of radar and laser freeboards with daily estimates of snow depth based on passive-microwave observations (AMSR-2) and snow evolution models (SnowModel-LG). Here, large discrepancies are observed: AMSR-2 observations show little variation over first-year ice, compared to both estimates from SnowModel-LG and CRYO2ICE observations. CRYO2ICE snow depths are comparable across the used CryoSat-2 products but shows significantly larger variation compared to SnowModel-LG estimates. Future work includes delving more into the changing ice conditions and their impact on the radar signal.