Saline Snow covers on First-Year Sea Ice (FYI) – Friend or Foe for CryoSat-2 derived FYI Thickness Estimates?

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ABSTRACT

Currently operating satellite altimeter data from European Space Agency’s CryoSat-2 (Ku-band altimeter launched in 2010) has demonstrated its potential to provide extensive basin-scale temporal and spatial measurements of Arctic sea ice freeboard and thickness. It has been theorized that Ku-band microwaves attain complete penetration through dry, cold and homogeneous snow, unless the snow cover exhibits highly dense compacted snow layers and/or ice lenses. Based on this theory, CryoSat-2 altimetric returns are assumed to originate from the snow/sea ice interface (assumed to be the main scattering horizon), rather than the air/snow interface. However, in newly formed FYI thin ice (~ 0.10 to 0.6 m) during November-December through to thick FYI (~ 2 m) during February-March, upward brine wicking into the snow cover from the underlying sea ice surface produces brine-wetted snow layers, which usually constitutes the bottom 6-8 cm of a snow cover, with characteristic salinities ranging from 1-20 parts per thousand. This in turn modifies the brine volume at/or near the snow/sea ice interface, thereby altering the dielectric and scattering properties of the snow cover. This likely leads to strong Ku-band microwave attenuation within the snow cover. Recent studies demonstrate that Ku-band penetrates only into the top 2-4 cm of a highly saline 14 cm snow cover (snow surface salinity of 2.5-3%), even under cold conditions. Such significant reductions in Ku-band penetration of saline snow covers on FYI may substantially influence CryoSat-2 derived FYI freeboard and thickness estimates. Therefore, the goal of this study is to evaluate a theoretical approach to estimate snow salinity induced uncertainty on CryoSat-2 derived Arctic FYI freeboard and thickness measurements. Using the freeboard-to-thickness hydrostatic equilibrium equation, we quantify and investigate the error differences between the CryoSat-2 derived sea ice thickness, (assuming complete penetration of CryoSat-2 Ku-band radar signal to the snow/sea ice interface), and the sea ice thickness based on the modeled Ku-band penetration depth for different snow cover cases. We utilized five naturally occurring saline and non-saline snow cover cases (6 cm, 12 cm, 16 cm, 24 cm and 32 cm) from the Canadian Arctic Archipelago, observed during late-winter between of 1993-2012, on newly-formed ice (~ 0.6 m), medium FYI (~ 1.5 m) and thick FYI (~ 2 m). The case studies are based on snow salinity measurements collected from several field campaigns from the CAA between 1993 and 2012. Our results suggest that, irrespective of the thickness of the snow cover overlaying FYI, the thickness of brine-wetted snow layers and actual ice freeboard strongly influence the amount with which CryoSat-2 estimated ice freeboard estimates and thus FYI thickness calculations are overestimated. This effect is accentuated for increasingly thicker brine wetted snow covers overlaying newly-formed ice, which accounted to an overestimated FYI thickness by ~ 250%, when compared to ~ 80% FYI thickness overestimation on thinner brine wetted snow covers, and the uncertainty reduces with increase in FYI thickness. In the case of snow covers devoid of brine, our results show an underestimation of CryoSat-2 ice freeboard estimates and thus FYI thickness (~ 16%), owing to enhanced penetration of Ku-band microwaves through the snow cover and through the sea ice layers. Our results also indicate strong sensitivity of elevated snow temperatures, especially on brine wetted snow covers on all FYI types. With mean snow temperatures ranging between -15°C and -3°C during cold and warm phases in our study, warmer brine wetted snow covers exhibit greater error in FYI thickness estimates from CryoSat-2, when compared to cold snow covers. Our study recommends to the CryoSat-2 sea ice research community to incorporate snow salinity and temperature as two potential error sources along with error sources previously documented, affecting CryoSat-2 derived Arctic FYI freeboard and thickness measurements.