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Using offsets in airborne radar sounding and laser altimetry to characterize near-surface firn properties over the Greenland ice sheet

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In recent decades, the Greenland Ice Sheet (GrIS) has experienced a significant increase in surface melting and meltwater runoff, which is now the main contributor to GrIS mass loss. In areas covered by firn, meltwater percolation and refreezing processes can significantly buffer meltwater runoff to the ocean. However, this process leads to the formation of ice layers and an overall firn densification, which is predicted to limit the firns' meltwater storage capacity in the future. Additionally, the high spatial and temporal variability of ice layer formation and subsequent firn densification can cause large uncertainties in altimetry-derived mass balance estimates. Thus, understanding the spatial and vertical extent of ice layers in the firn is important to estimate the GrIS contribution to sea-level rise.

Due to limited direct observations of firn properties, modeling future meltwater runoff and processes over the rapidly changing GrIS firn facies remains challenging. Here, we present a prospective new technique that leverages concurrent airborne radar sounding and laser altimetry measurements to characterize near-surface firn over spatially extensive areas. We hypothesize that due to their different depth sensitivities, the presence of ice layers in the firn yields an offset between radar sounding- and laser-derived surface elevations (differential altimetry). We compare existing airborne radar and laser measurements to in-situ firn observations and use one-dimensional radar sounding simulations to investigate 1) the sensitivity of the differential altimetry technique to different firn facies, and 2) the techniques' capability to estimate firn density and firn ice content. Preliminary results over the western GrIS show good correlations between differential altimetry signatures and areas of firn affected by percolation and refreezing processes.

Through this technique, we explore the potential to leverage a wealth of radar sounding measurements conducted at low frequencies (< 200 MHz), that typically do not resolve the firn structure, to derive near-surface firn properties. Finally, we apply the differential altimetry technique to data collected as part of NASA's Operation IceBridge between 2009-2019 to derive spatio-temporal changes in the GrIS firn in response to climatic conditions, in particular the

formation of ice layers and changes in firn ice content. Our results can help reduce uncertainties in satellite-derived mass balance measurements and improve firn models, which both contribute to reducing uncertainties in current and projected GrIS contributions to global sea-level rise.