EGU General Assembly 2020

EGU2020-20434
https://doi.org/10.5194/egusphere-egu2020-20434
EGU General Assembly 2020

Correlated Fluctuations in Surface Melting and Ku-band Radar Penetration in West Central Greenland

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Melting at the surface of the Greenland ice sheet has significantly increased since the early 1990s and this affects the degree to which radar sensors can penetrate beyond the snow surface. Indeed, radars are sensitive to changes in the surface and subsurface properties, up to ~15 m below the snow surface for instruments using the Ku-band (13.5 GHz). When melting occurs, meltwater can percolate in the snowpack or refreeze at the surface and in turn, the degree of radar penetration is sharply reduced. Here we use measurements of near-surface density from firn cores and models and airborne radar and laser data collected during the European Space Agency of ESA's CRYOsat Validation EXperiment (CRYOVEX) campaigns along a 675 km transect in West Central Greenland between 2006 and 2017 to examine spatial and temporal fluctuations in the near-surface properties and how this affects radar measurements. From airborne data acquired with ASIRAS at Ku-band, we identify internal layers corresponding to melt layers in the snowpack down to 15 m, in good agreement with a firn densification model. We examine the spatial and temporal distribution of these melt layers and we find that the abundance of melt layers is increasing with elevation and depicts a strong inter-annual variability and that these fluctuations are correlated with fluctuations in the degree of the radar penetration depth. For instance, in 2012, the Greenland ice sheet experienced unprecedented melting and this is seen in the radar data by a reduction of 70% of the penetration in the snowpack following this event. The 2012 melt layer is still visible in data recorded 5 years after the melt event at a depth of 5.1 m. As the frequency and extent of extreme melt events is likely to increase in the coming decades, the effects of fluctuations in Ku-band radar penetration are an important consideration for satellite radar altimetry studies. However, we show that despite large fluctuations in volume scattering, there is a good agreement between Ku-band retracked heights and coincident laser measurements of 13.9 ± 19.9 cm using a threshold retracker. Finally, we also investigate the potential of using higher-frequency KAREN Ka-band (34.5 GHz) airborne radar data to limit the impact of temporal variations in the snowpack properties on backscattered power. We show that surface scattering dominates the Ka-band radar echoes and, overall, they penetrate to significantly lower distances into the near-surface firn by comparison to those acquired at Ku-band. This suggests that Ka-band data are less sensitive to extreme melt events and that the impact of such events on Ka-band data are likely to last for a shorter period of time compared to Ku-band data.