Predicting the Presence of a Firn Aquifer on the Antarctic Peninsula using C-Band Satellite-Borne Scatterometry

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The recent discovery of substantial quantities (~140±20 Gt) of liquid meltwater stored within Greenland's extensive (~70,000 km^2) firn aquifer highlights evolving knowledge of melting, refreezing, and retention processes within the upper layers (<~35 m) of the percolation facies of ice sheets. Firn aquifers are hypothesized to form in regions that experience high melt rates that saturate snow and firn layers with liquid meltwater during the melt season, and high accumulation rates that thermally insulates this saturated layer during the winter season allowing it to be retained in liquid form at decreasing depths as refreezing propagates from the ice sheet surface downward. Little is known about Greenland's firn aquifer – open questions remain on its formation, spatiotemporal variability, the mechanism(s) and time scales associated with the potential transport of liquid meltwater to the base of the ice sheet, and its influence on mass and energy budgets. Observational evidence of Greenland's firn aquifer is currently limited in space and time to field (ACT-10,-11, FA-13) and airborne (IceBridge) observations.

The C-band microwave response is sensitive to near-surface liquid meltwater within Greenland's firn aquifer, as well as winter season decreases in its depth resulting from the refreezing process. When snow and firn layers are saturated with liquid meltwater, surface scattering dominates the response. Electromagnetic energy is significantly attenuated by reflection away from the scatterometer at the smooth air-saturated layer interface, and by absorption and extinction within the top few centimeters of the saturated layer. When snow and firn layers are frozen to penetration depth (<~5 m), volume scattering induced by large embedded ice structures dominates the response. Over Greenland's firn aquifer, the surface-to-volume scattering transition following surface freeze-up results in distinct microwave signatures that exponentially increase on timescales of weeks to months. This response is not observed in adjacent regions of the percolation facies where meltwater is stored in solid form. We developed a microwave signature algorithm that describes this exponential response using a simple two-layer radiative transfer model that defines decreases in firn aquifer depth using time-dependent parameters that are calibrated using thousands of airborne observations. Initial comparisons between the calibrated microwave firn aquifer model and firn aquifer simulations generated by the regional climate model RACMO2 are consistent, suggesting strong potential for spatiotemporal continuous satellite observation over the C-band scatterometer climate record.

While no observational evidence of a firn aquifer is known to exist, similar to Greenland, regions of the percolation facies of the Antarctic ice sheet experience sufficiently high melt and accumulation rates. Here we use C-band backscatter data collected by the Advanced SCATterometer (ASCAT) aboard the MetOp-A satellite and the Greenland-calibrated microwave firn aquifer model to predict the presence of a firn aquifer on the Antarctic Peninsula.