UAV LiDAR for Measuring Snow Interception in Forests

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EXTENDED ABSTRACT

Uncrewed aerial vehicle (UAV) LiDAR presents opportunities to advance knowledge of snow interception by examining the relationships between subcanopy snow accumulation and needleleaf forest canopy structure. A robust understanding of how snow interception varies with canopy structural metrics will aid in estimating snowmelt water availability for streamflow. This could improve drought and flood forecasting, understanding of effects of land disturbance and timber harvesting on hydrology, and anticipation of hydrological responses to future weather patterns in a changing climate (see Varhola et al., 2010 for a review).

Decades of study and field trials have shown that measuring intercepted snow directly in needleleaf canopies is logistically prohibitive at scales beyond that of individual trees (Friesen et al., 2015). Interception models are developed and employed to estimate rates of interception processes but often differ in assumptions of relationships between interception processes and canopy structure metrics (e.g. Hedstrom and Pomeroy, 1998; Moeser et al., 2015; Roth and Nolin, 2019). Further validation is needed to inform which assumptions are most appropriate for a given forest under a given set of environmental conditions, and at which scales.

Snow mass budgeting is a method used to estimate missing terms in the snow mass balance. This can be used to estimate changes in intercepted load over a time interval as the difference between cumulative precipitation above and accumulation below the canopy, corrected for other system fluxes such as sublimation and wind redistribution of snow (Pomeroy and Schmidt, 1993; Lundberg et al., 1998). The spatial resolution and extent of interception estimates from the mass budgeting method depends on the resolution and extent of snow accumulation measurements.

Repeated airborne LiDAR scans have been used to calculate snow depth at horizontal resolutions on the order of 1m and over the scale of basins (Deems et al., 2013). Airborne LiDAR has also been used to characterize the structure of forest canopies with applications to both snowpack energy and mass balances (Broxton et al., 2015; Moeser et al., 2015; Mazzotti et al., 2019). This technology has encountered challenges in dense vegetation due to reduced canopy penetration by the LiDAR beam (Harpold et al., 2014; Broxton et al., 2015; Zheng et al., 2015). High costs have limited the temporal resolution of airborne LiDAR scans in most applications. UAV LiDAR shows promises in overcoming these challenges with reduced overhead and operational costs, allowing for increased temporal resolution of samples (Harder et al., 2016), and increased spatial resolution due to smaller footprints, tighter point spacing, and variable-perspective scans (Popescu et al., 2011; Wallace et al., 2012).

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Figure 1. Layout of field site in the Canadian Rockies depicting the location of snow survey transects, three meteorological stations, and the tree lysimeter.

The purpose of this research is to quantify the spatial variation of intercepted snow with canopy structure at scales from trees to forest stands. Six UAV surveys were conducted within the 2018-2019 winter season over an instrumented forest site at Marmot Creek Research Basin on the eastern slopes of the Canadian Rockies (Figure 1). A DJI M-600 hexcopter UAV mounted with a RIEGL miniVUX-1UAV LiDAR sensor and co-registered Sony a6000 camera collected point cloud and RGB data over a 500 m-by-500 m area from tiered flight paths at altitudes ranging from 40 m-120 m above ground level (see Figure 2). Each UAV survey was accompanied by ground-based snow surveys with georeferenced snow depth and density observations, and upward-facing hemispherical photography. Meteorological data was collected at three stations within the survey area: one below the forest canopy and two in nearby clearings (Figure 1). Wind speed and direction, air temperature and humidity, net radiation and snow depth time series were collected below the canopy and in clearings. Cumulative precipitation was measured in the larger clearing by a Geonor T-200B precipitation gauge. A hanging tree lysimeter adjacent to the forested station provided the mass of intercepted snow in a single tree through the winter season.

Flight paths at multiple elevations were implemented to increase the spatial resolution of subcanopy returns, driven by an increase in the number of possible scanner perspectives of a given ground point. Preliminary results show median forest point densities from the subset of scans at 120m above ground level near 75 points/m2 (Figure 3), and the ability to resolve individual branches within the upper canopy.

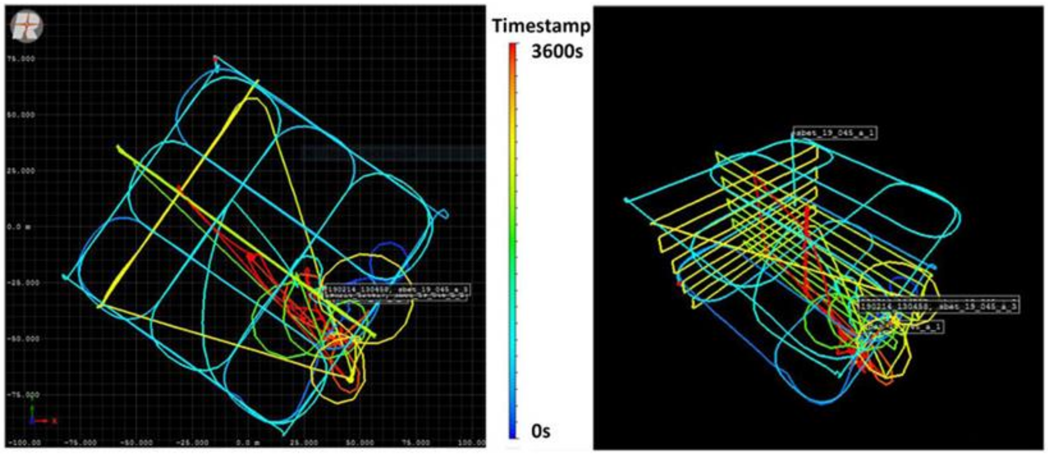

Figure 2. Ice cover (blue) in the middle and lower Chesapeake Bay in Early February 1977.

Further results are expected to inform an understanding of the role of canopy structure in snow interception processes and facilitate the validation and continued development snow interception models. Interception will be estimated from this data using the mass budgeting method. LiDAR derived snow depth models will be validated with manual measurements and converted to snow water equivalent (SWE) using depth-density relationships from concurrent snow survey observations. The change in SWE will be calculated as the difference between successive SWE maps. Canopy structure metrics (e.g. leaf area index and canopy closure) will be calculated from snow-off LiDAR point clouds and validated using similar metrics derived from hemispherical photography. The spatial variation of interception estimates with canopy metrics will be assessed. Analysis will be conducted for interception estimates and canopy structural metrics aggregated to different scales to assess the scale dependence of this method.

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