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Spatial quantification of leafless canopy structure in a boreal birch forest

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ABSTRACT

Leafless deciduous canopies in boreal regions affect the energy available for snowmelt and reduce overall surface albedo during winter, thereby exerting a strong influence on weather and climate. In this work, ground-based measurements of leafless canopy structure, including hemispherical photography, terrestrial laser scanning (TLS) and manual tree surveys were collected at 38 sites in an area of mountain birch forest in northern Sweden in March 2011 and 2012. Photo-derived sky view fraction was strongly inversely correlated ($r < -0.9$) to the total tree basal area in a 5 m radius around the photo site. To expand findings to wider areas, maps of canopy height for a 5 km × 3 km area were obtained from airborne lidar (ALS) data collected during summer 2005. Canopy heights derived from TLS were used to validate the ALS estimates, and simple models were developed to establish relationships between hemispherical sky view and ALS canopy height (RMSE < 5%). The models and ALS data provide useful methods for estimating canopy radiative transfer and biomass over wide areas of birch forest, despite the relatively low ALS resolution (~1 return m^{-2}).

1. Introduction

Arctic snow cover plays an important role in the climate system, due to the high albedo of snow-covered surfaces that reflect solar radiation back to space. The Arctic also contains large areas of forest that act to reduce overall surface albedo, even if snow is held in the canopy (Kuusinen et al., 2012). Under global warming scenarios, the combined effects of earlier snowmelt and expanding boreal forest cover could provide a positive feedback on warming; this is often termed the 'snow-albedo feedback' and has been shown to amplify warming for high northern latitudes in climate model experiments (Brovkin et al., 2009).

However, the interactions between snow and vegetation are very complex, and provide challenges for models of snow melt (Rutter et al., 2009). Trees intercept falling snow that can subsequently sublimate from the canopy top, and decrease the solar shortwave radiation reaching snow, while enhancing the thermal longwave radiation to snow from their warmed trunks and branches (Essery et al., 2007, 2008; Hardy et al., 2004; Link et al., 2004; Lawler and Link, 2011; Mahat and Tarboton, 2012; Pomeroy et al., 2009). Conversely, snow cover could play an important role in future forest expansion; analysis of satellite products shows that snowy backgrounds enhance the absorption of photosynthetically active radiation near forest gaps, by reflecting radiation back up to the canopy (Pinty et al., 2011).

It is therefore important to improve quantification of the combined effects that snow and vegetation have on surface radiation and energy balance, on both local and regional scales. Such work requires detail on forest structure and canopy transmission. Hemispherical photographs ('hemiphotos') taken from the snow surface have been shown to provide excellent detail that can be used to estimate bulk canopy parameters such as leaf area index, or to track sun position for accurate calculations of the direct solar beam radiation component (Musselman et al., 2012a,b). Reid et al. (2013) combined this approach with sub-canopy radiation measurements to compare models of radiative transfer for boreal birch and conifer forests.

Considerably more detail can be obtained using high-resolution terrestrial laser scanners (TLS), which emit laser pulses and receive reflections from surrounding objects thousands of times per second, across a wide spherical field of view from the scanner position. Merging data from multiple scans of a canopy can produce a three

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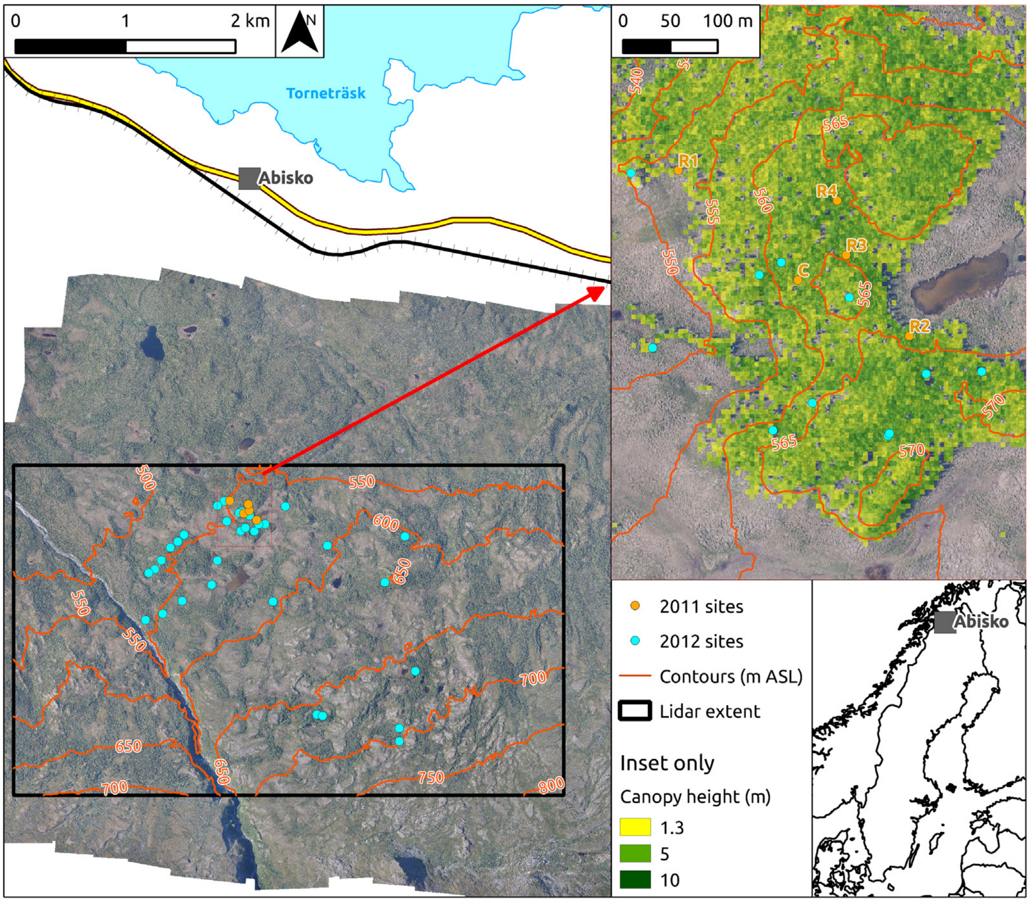

Fig. 1. Map of the Abisko study area with summer aerial photographs (see Acknowledgements) georeferenced onto the 5 km × 3 km ALS area selected for this study. The forest plots established in 2011 and the hemiphoto sites from 2012 are shown, and canopy heights are shown on the close-up. Scandinavian context map taken from http://thematicmapping.org/downloads/world_borders.php; Abisko map details © OpenStreetMap contributors.

dimensional cloud of points on the surfaces of canopy elements, in Cartesian co-ordinates with mm or sub-mm positional accuracy. Although TLS is expensive and time-consuming, it can be used to completely reconstruct trees in a virtual environment (Cote et al., 2009). Other recent efforts include using TLS to produce artificial hemiphotos that compare favourably to real hemiphotos (Seidel et al., 2012) and avoid some issues associated with optical camera methods such as lens vignetting or an insufficient contrast between canopy elements and the sky.

For the wider spatial characterisation of forests, airborne laser scanning (ALS), or lidar, has become widely used. For boreal forests, recent studies with ALS have aimed to quantify biomass (Kankare et al., 2013; Næsset et al., 2013; Nyström et al., 2012) or identify treelines (Rees, 2007; Thieme et al., 2011). ALS with high resolution (several returns per m^2) can be used to extract detailed canopy structure information that compares favourably to hemiphotos and can be extrapolated across large areas for the simulation of processes such as radiative transfer or precipitation interception (Varhola et al., 2012; Musselman et al., 2013). However, there are clear benefits in trying to retrieve canopy properties from relatively low resolution (~1 return per m^2) ALS data, because boreal canopy datasets of similar resolution are becoming available on national scales in e.g. Finland (Vastaranta et al., 2013), Sweden (Bohlin et al., 2012), Switzerland (Swiss Federal Office of Topography, 2013) and the USA (Stoker et al., 2008).

This paper presents canopy structure data collected during the spring snowmelt season in a leafless boreal birch forest. Correlations between the data, which include hemiphotos, manual surveys, TLS and ALS, are examined in order to estimate bulk canopy sky view on a 4 m grid, over several square kilometres.

2. Study site

The area near Abisko in Sweden (68.26–68.39° N, 18.50–18.82° E) contains wide areas of patchy, heterogeneous deciduous forest, mainly of mountain birch (*Betula pubescens* ssp. *czerepanovii*) that remain leafless for over six months of the year. Abisko is one of the world's most widely-studied Arctic landscapes and has experienced warming of 2.5 °C from 1913 to 2006, with mean annual temperatures often exceeding 0 °C and impacts that include changes to the tree-line (Callaghan et al., 2010). The focus of this study is a heterogeneous area of mountain birch forest to the south of Abisko village (Reid et al., 2013).

3. Data acquisition

3.1. Airborne lidar

The ALS data used in this paper were collected between 08:50 and 10:10 on 17 July 2005 using an Optech ALTM3033 scanning lidar belonging to the University of Cambridge Unit for Landscape Modelling (ULM). The instrument was mounted onboard the NERC ARSF Dornier 228 aircraft, which performed nine passes over the region at an average flying height of 2325 m above sea level (m.a.s.l.). Pulses of near-infrared laser radiation were transmitted at 33 kHz, with side-to-side scanning at 22.5 Hz and a swath of 39.6° corresponding to approximately 1250 m sampling width.