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An airborne lidar sampling strategy to model forest canopy height from Quickbird imagery and GEOBIA

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ABSTRACT

High-resolution digital canopy models derived from airborne lidar data have the ability to provide detailed information on the vertical structure of forests. However, compared to satellite data of similar spatial resolution and extent, the small footprint airborne lidar data required to produce such models remain expensive. In an effort to reduce these costs, the primary objective of this paper is to develop an airborne lidar sampling strategy to model full-scene forest canopy height from optical imagery, lidar transects and *Geographic Object-Based Image Analysis* (GEOBIA). To achieve this goal, this research focuses on (i) determining appropriate lidar transect features (i.e., location, direction and extent) from an optical scene, (ii) developing a mechanism to model forest canopy height for the full-scene based on a minimum number of lidar transects, and (iii) defining an optimal *mean object size* (MOS) to accurately model the canopy composition and height distribution. Results show that (i) the transect locations derived from our *optimal lidar transect selection algorithm* accurately capture the canopy height variability of the entire study area; (ii) our canopy height estimation models have similar performance in two lidar transect directions (i.e., north–south and west–east); (iii) a small lidar extent (17.6% of total size) can achieve similar canopy height estimation accuracies as those modeled from the full lidar scene; and (iv) different MOS can lead to distinctly different canopy height results. By comparing the best canopy height estimate with the full lidar canopy height data, we obtained average estimation errors of 6.0 m and 6.8 m for conifer and deciduous forests at the individual tree crown/small tree cluster level, and an area weighted combined error of 6.2 m, which is lower than the provincial forest inventory height class interval (i.e., ≈9.0 m).

1. Introduction

Recent studies have proven the feasibility of using lidar (light detection and ranging) data to characterize forest vertical structure (e.g., canopy height), by generating accurate estimates of forest above-ground biomass and timber volume (Hyyppä et al., 2008; Lefsky et al., 2002; Lim et al., 2003; Means et al., 1999). In these cases, promising results were reported using airborne lidar scanners, whose small-footprint and high-pulse-density returns can accurately estimate forest canopy height at the individual tree level. Compared to data acquisition costs from spaceborne sensors, the cost associated with airborne lidar data is highly influenced by several critical — but varying — factors, such as the project location, topography, the number of flight turns and banks, distance between lidar transects and pulse density, etc.

To reduce airborne acquisition costs while still collecting useful estimates of forest vertical structure, research is beginning to be conducted on the integration of airborne lidar transects and high-resolution optical remotely sensed data. For example, Hudak et al. (2002) combined lidar data and Landsat ETM+ panchromatic imagery to estimate forest canopy height in western Oregon, USA. Here, a lidar canopy height model was sampled in both transect and point patterns with equal spatial intervals of 2000, 1000, 500, and 250 m. Best results were reported by using lidar samples with smaller spatial intervals. Similarly, Wulder and Seemann (2003) developed regression models between lidar and Landsat TM data to estimate canopy height at the stand level. This relationship was then extended to polygons without lidar data to predict/update canopy height inventory information. Their models revealed a correlation (R^2) of 0.61 between digital numbers (DNs) and associated lidar-estimated heights for segmentation-derived polygons. Hilker et al. (2008) further investigated the potential of combining small-footprint lidar transect data and QuickBird imagery to update forest inventories. They found a strong relationship ($R = 0.89$) between the stand height predicted from a single lidar transect and Quickbird imagery, and the stand height from the full-area lidar coverage. Though encouraging results have been obtained by integrating lidar transects and optical imagery, several important lidar transect features such as location, direction and extent are still heuristically defined, which ultimately could decrease the accuracy of estimating canopy height for the whole

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study area. This is because heuristically defined lidar transect locations may fail to represent the height structure of the full-scene — especially over large areas. Therefore, decisions regarding the appropriate selection of lidar transect features are critical for developing robust integrated models.

At a high spatial resolution (<5.0 m), individual pixels typically represent only a small portion of the geographic objects of interest (e.g., individual trees). While this resolution provides details that can further facilitate landscape management, it also creates higher internal spectral variance within each geographic object which can decrease scene model accuracy when using pixel-based approaches (Hay et al., 1996; Strahler et al., 1986). To acquire detailed geographic information while minimizing the effect of high internal spectral variance, *Geographic Object-Based Image Analysis* (GEOBIA) provides a feasible alternative to the traditional pixel-based approach (Hay & Castilla, 2008). GEOBIA is essentially a way to move from the analysis of individual pixels to image-objects (i.e., groups of connected pixels that are relatively homogeneous and different from their surroundings), to the generation of geo-intelligence (i.e., spatial content within context) (Hay & Blaschke, 2010). In high-resolution remote sensing studies, image-objects can be used to represent forest entities ranging from small tree clusters to large stands, etc. Compared to the traditional pixel-based approach, segmented objects are more similar to forest inventory polygons and easier to use within a GIS, and/or modeling environment.

Based on these ideas, the main objective of this research is to develop an airborne lidar sampling strategy to model full-scene forest canopy height from optical imagery, lidar transects and GEOBIA. To achieve this goal, the following sections provide detail regarding (i) data processing; (ii) how GEOBIA was used to define an optimal *mean object size* (MOS) for modeling canopy pseudo-height distribution; (iii) a description of the methods developed to define appropriate lidar transect features (i.e., location, direction and extent) from an optical scene; and (iv) how we modeled full-scene forest canopy height based on a minimum number of lidar transects. Results are then provided and discussed, followed by our conclusions and future work.

2. Data and preprocessing

2.1. Study area

Our study site is located (49°52′N, 125°20′W) approximately 10 km southwest of Campbell River on Vancouver Island, British Columbia, Canada (Fig. 1). The size of the study area is 5.1×5.1 km (2601 ha) and is characterized by conifer and deciduous forests, clearcuts, roads and a river. The study area is comprised of 65% conifer forests, of which ≈80% is dominated by Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], along with small proportions of Western Red Cedar [*Thuja plicata* (Donn.)] and Western Hemlock [*Tsuga*

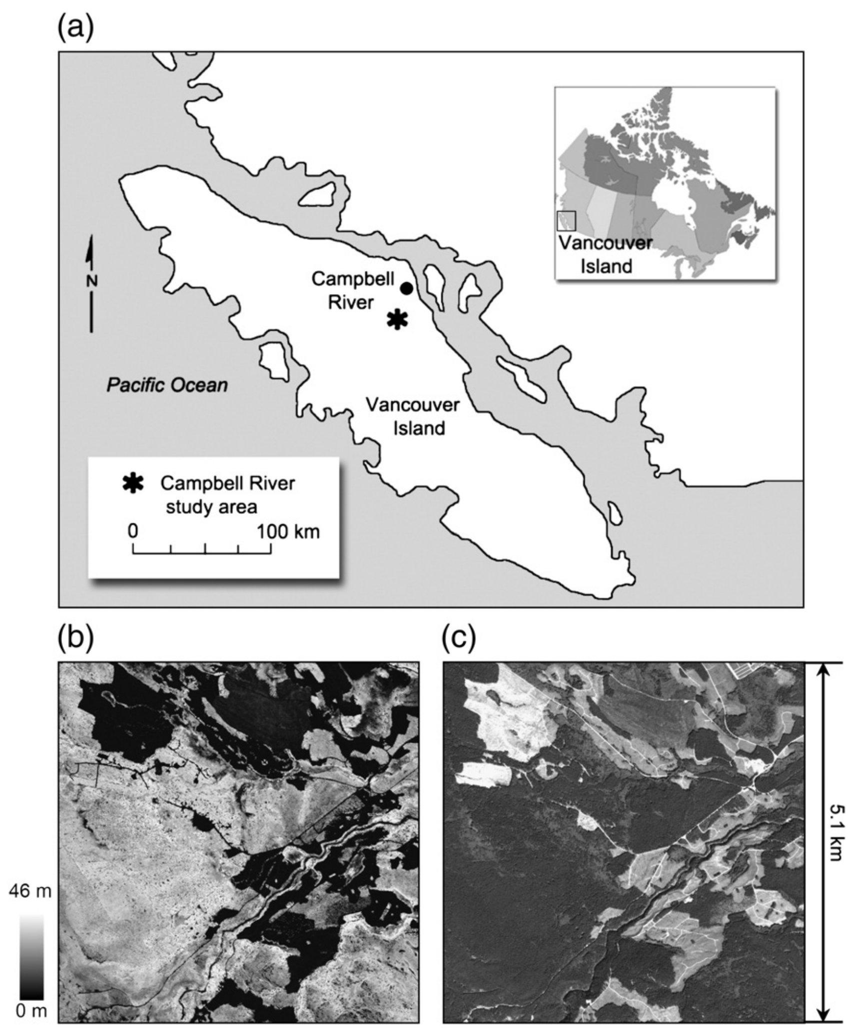

Fig. 1. (a) Study area located southwest of Campbell River, Vancouver Island, Canada. (b) Lidar canopy height segmentation image (CHS). (c) Quickbird grayscale image converted from a false color composite using near infrared (NIR), red and green bands.