Optimal LiDAR gridding parameterization for effective leaf area estimation in the boreal forest Yukon Territory, Canada

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Abstract

The increased availability of LiDAR-based forestry models raises questions about fundamental procedural steps undertaken before published models begin. The processing stage being investigated in this study is the parameterization of routines used for gridding inputs for forestry models. Grids are a valuable format for modelling as they organize scattered point clouds into manageable pixels for sophisticated processing. Our objective was to examine the effect of grid cell resolution and circular search radii for gridding on resulting leaf area index (LAI) data layers. LAI is employed in models at various scales and was therefore of interest for a range of study objectives. We generated 16 gridded estimates of LAI using unique combinations of cell resolution and search radius for comparison with values measured in the field. Our results determined that cell resolution was not important, allowing for more application flexibility without introducing bias, while search radius was critical for obtaining the most accurate estimates. This type of scale sensitivity analysis is important for any modelled variable that will be applied in a variety of spatial contexts.

Keywords: DHP, LiDAR, leaf area index, Yukon Territory

1. Introduction

Leaf area index (LAI), which is defined as half of the total leaf surface area per unit ground area (Chen *et al.*, 2006) is an important input for biogeochemical and ecosystem-atmosphere models. For most forestry applications estimates of this type are required for large study areas, making direct measurement methods practically impossible. Instead, indirect remote sensing solutions are becoming more available and affordable for modelling metrics such as effective leaf area index (LAIe) which includes both leafy and non-leafy components of the canopy and can be used to determine true LAI (Chen *et al.*, 1997). Light Detection and Ranging (LiDAR) data provides a three-dimensional representation of the forest canopy that is ideal for modeling LAIe over large areas. Generating grids is an important time saving step for summarizing irregularly spaced points of LiDAR data and decisions made at this stage will permeate throughout the modelling process. It is important to balance maintaining sufficient variability to represent the natural landscape without compromising computational efficiency or model robustness and reusability. The goal of this paper is to investigate the effect of gridding parameters on estimates of LiDAR-intensity based LAIe and to highlight optimal settings for a boreal forest landscape.

The LAIe model being applied in this study is based on a model for estimating gap fraction published by Hopkinson and Chasmer (2007; 2009) that utilizes pulse intensity, range and echo code. This model is based on a Beer's Law assumption that the canopy can be represented as a turbid medium with randomly distributed foliage, which allows for the estimation of LAIe:

$$LAIe = -\ln(P) \;/\; k \qquad (1)$$

where P is canopy gap fraction and k is extinction coefficient. A model optimization process was also developed using field measurements of LAIe in Morrison *et al.* (2011).

The few forest-related studies that have used intensity values for forest attribute modeling (e.g. Donoghue *et al.*, 2007) generally do not describe under what conditions the data were gridded before analysis. For this analysis, grids were prepared by assigning to each cell the sum of the intensity values within a specified search radius. Four grid cell resolutions and four search radii were used to generate sixteen uniquely parameterized intensity grids to determine optimal gridding parameters for calculating intensity-based LAIe estimates.

2. Study Area

The study area is located in northern Canada near Watson Lake, Yukon Territory (Fig. 1). The Boreal forest in this region is dominated by a mixture of mature spruce and pine with some early successional birch and aspen in areas that have been recently cut. This study is part of a larger project capturing a broad sample of boreal forest conditions across Canada through the collaboration of the Canadian Forest Service, researchers at the University of British Columbia, and the Applied Geomatics Research Group (Hopkinson *et al.* 2011; Bater *et al.* 2011).

3. Methods

3.1 Ground estimates of LAIe using hemispherical photography

Field data were collected July 30 to August 3, 2010. Thirty plots were established along two East-West transects approximately 850 meters apart. Plots along each transect were at least 100 meters apart and included both treed and clearcut areas (Fig. 1). Plot centers were geolocated using differentially corrected GPS receivers (Leica SR530, Leica Geosystems Inc. Switzerland) with horizontal position quality ranging from 1 cm to 1 m depending on the quality control technique used and the canopy density.

Five digital hemispherical photographs (DHPs) were captured per plot: one at the plot center and four located 20 m from the center in cardinal directions (N, E, S, W) using a compass and measuring tape (Figure 1). Photos were captured using a Nikon CoolPix 8800VR camera fitted with a 180° fisheye lens with the exposure set one 'f stop' lower than normal exposure to improve contrast between foliage and sky. For all images the camera was levelled on a tripod 1.3 m from the ground with the top of each photo oriented towards the north.

Figure 1: Map showing location of study area in Yukon Territory, Canada (left), relative position of the plot transects (center), and photo capturing layout (right).

Photographs were processed with Gap Light Analyzer (GLA) Version 2.0 developed by Frazer *et al*. (1999). Image analysis in GLA requires a number of steps. After opening the desired photo within the software the image was registered by identifying geographic orientation and circular extent. Next the configuration settings were edited to suit the type of calculations being performed, including site topography information and projection distortion parameters. Given that all the photos for this study were captured using the same camera, settings, and were within the same general area the parameters for these steps were saved to a configuration file and applied to all images being processed. The next step was to classify each image into sky and non-sky pixels. Using the blue channel, a threshold was set for each image to capture the distinction between vegetation and sky. Once an appropriate classification was achieved the final step was to run the calculations and save the output. LAIe values obtained from GLA for this study were estimated by integrating across zenith angles 0° to 75°. A single LAIe estimate for each 20 metre plot was generated for statistical comparisons by averaging the values for the 5 nested photos captured per plot.

3.2 LiDAR data collection and preparation

An airborne LiDAR survey was completed by the Applied Geomatics Research Group on August 3, 2010 using an Optech Inc. ALTM 3100 at a flying height of 1500 m a.g.l., 50 kHz pulse repetition frequency, and 15° scan angle resulting in approximately 1.1 m point spacing. The point cloud was differentially corrected to the same GPS base station that was used for the field plot set up during DHP acquisition. The software package *TerraScan* (Terrasolid, Finland) was then used to classify points into ground, canopy and echo code classes in preparation for intensity-based modelling (Hopkinson and Chasmer, 2009).

3.3 Gridding parameters analysis

Four grid cell resolutions and four search radii were selected for this analysis, generating sixteen gridding parameter variations (Table 1). Cell sizes of 1, 5, 10, and 25 m were used to include the finest resolution given the density of LiDAR returns, up to a size comparable to satellite imaging products. Search radii range was selected to overlap common field mensuration plot areas (100, 200, 400 and 800 m^2). Grids were prepared using *Surfer 8* software (Golden Software, USA) by assigning each cell the summed intensity value for all returns captured within the given circular search radius based on the point classification required for model input.

Table 1. Sixteen unique combinations of cell size and search radius for gridding treatment layers

		Search radius (search area)			
		5.6 m ($100\ m^2$)	8.0 m ($200\ m^2$)	11.3 m ($400\ m^2$)	16.0 m ($800\ m^2$)
Cell Size	1 m	1m5.6	1m8.0	1m11.3	1m16.0
	5 m	5m5.6	5m8.0	5m11.3	5m16.0
	10 m	10m5.6	10m8.0	10m11.3	10m16.0
	25 m	25m5.6	25m8.0	25m11.3	25m16.0

3.4 Statistical analyses

LAIe statistics were extracted for thirty, 20 m radius circular plots coinciding with geo-registered plots from field data collection including the minimum, maximum, mean and standard deviation for LAIe in each plot. Twenty meter plots were chosen to minimize the spatial uncertainty of the plot positions by combining five photos nested together. Further research needs to be done to determine the optimal plot size for comparison with DHPs in this context as plot size has been linked to the quality of model estimates by Lovell *et al.* (2003) and Morsdorf *et al.* (2006) when determining forest cover. Statistical analyses were performed using R version 2.11.0 (www.r-project.org). Simple linear regression was performed using the 16 gridding parameter LAIe estimates and DHP LAIe. All best fit lines were forced through the origin as there was no logical reason for DHP LAIe at zero to be different from LiDAR modelled LAIe; i.e. if there is no foliage within a plot, then there should also be no laser points above the ground surface. Two statistical tests were used to evaluate which gridding parameters produced optimal LAIe estimates. Root mean squared error (RMSE) was calculated according to the methodology in Kobayashi and Salam (2000) and prediction sum of squares (PRESS) was calculated according to Myers (1986, p106-111). PRESS is a statistical test where data are fit *n* times, and in each iteration one data point is removed, estimated based on the linear model, and then the difference between the actual and predicted are summed and squared. This provides a type of model validation without incurring extra cost in collecting large amounts of field data.

4. Results & discussion

The RMSE and PRESS results are presented in Figure 2. Both statistical tests demonstrate that intensity-based LAIe estimates show no significant difference and are stable across all grid cell resolutions for any given search radius. These observations demonstrate that when modeling LiDAR-based LAIe, the choice of grid cell size can be made according to the intended use of the data, without fear of introducing any systematic bias. Moreover, this insensitivity to grid resolution means that LAIe maps generated at multiple spatial resolutions can be directly compared provided appropriate aggregation routines are used.

In both the PRESS and RMSE test, however, predicted LAIe demonstrates systematic variation with the size of search radius used during grid creation, regardless of the final grid cell resolution. This highlights that the choice of search radius is critical and must be underpinned by some logical rationale. Both tests demonstrate that 11.3m produces the lowest overall error and therefore has the most accurate LAIe predictive capability when compared to DHP validation plots.

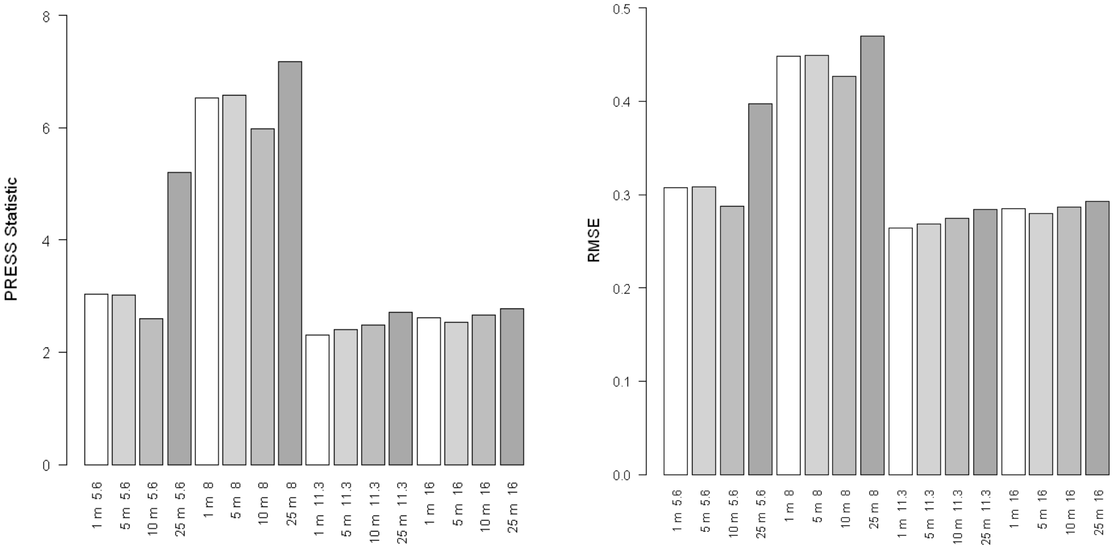

Figure 2. Prediction sum of squares (left) and root mean squared error (right) per treatment (unique cell size and search radius combinations), n=30 for each bar.

Given that the optimal point cloud search radius for recreating plot-level DHP-based LAIe is approximately 11.3 m, the DHP angular field of view between the top of the canopy and the photo capture location can be estimated (Figure 3). While mean plot-level canopy varied between ~ 3m and 20m, the average height was approximately 14.3m. With a DHP capture location of 1.3m above the ground, the approximate optimal full field of view directly above the photo point is ~80º (±40º). While the spatial coincidence of DHP LAIe data and LiDAR point cloud attributes are not directly compared here, this does suggest that the domain of DHP LAIe results extends approximately 11.3 m from the photo location. More search radii need to be tested to see if the correlation between point cloud LAIe model results and DHP data continue to diverge as the search radius is enlarged beyond 16 m.

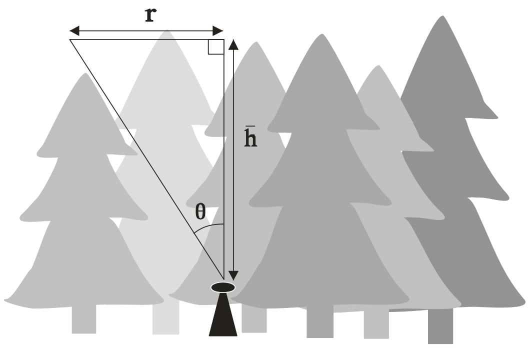

Figure 3. Triangle represents the comparable field of view angle for a hemispheric lens. Given a plot radius (r), and mean canopy height (h) less the height above ground where the camera is positioned.

5. Conclusion

In this study we have demonstrated that LiDAR-based raster LAIe map products are largely insensitive to the final grid cell resolution chosen. This is important because it means high resolution maps can be generated at close to the tree stem level are useful while larger grid cells comparable to wide area satellite coverage data (e.g. Landsat TM) are equally as valid. This is not to say that LAIe will be accurate at, for example, a 1m grid cell resolution, as this cannot be verified from data trained at the DHP plot-level. However, it does suggest that when aggregated to a more 'plot-level' scale, a 1m grid will not introduce any bias. Conversely, the choice of search radius to be applied to the point cloud during grid creation is important, and is likely influenced by the amount of coincident upper canopy surface that can be clearly observed by both the almost planar sampling of LiDAR data and the hemispherically projected DHP image. In this particular boreal forest context, an 11.3 m radius or 80º vertical field of view appeared to provide overall optimal LAIe prediction results and suggests a possible optimal plot size for comparison with DHP imagery. Of some interest is that this radius also corresponds to a typical forest mensuration plot of 400 m^2.

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