

Prediction of vegetation structure from LIDAR and multispectral satellite data in a topographically complex landscape, Eastern Australia

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Abstract - Measures of forest structure provide an important indication of productivity, health and the growth stage of a forest. Using traditional field-based approaches, extraction of such structural parameters is often time consuming and labour intensive. Remote sensing is a cost effective technique for mapping and interpreting some features of vegetation; and LiDAR provides highly accurate measurements in the vertical and horizontal planes of vegetation structure that can approximate field measurements. In this study, we integrated LiDAR and Landsat TM to model the variation of biophysical parameters of a topographically complex landscape. Focusing on eucalyptus-dominated open forests in eastern Australia, this study provides an insight into how integrating small-footprint LiDAR and Landsat data can be used to develop models to assess vegetation structural attributes. This study demonstrates that fundamental forest structure attributes can be modelled with current remote sensing technologies.

Keywords: ecosystem, vegetation structure, LIDAR, Landsat TM, mountainous region, Australia

INTRODUCTION

Topographically complex terrain modifies basic gradients of temperature, soil moisture and insolation across the landscape. This creates heterogeneous environments and increased complexity in vegetation structure and composition. Though much is known about how change vegetation structure in a dissected topography, scant information is available about how to remotely predict such variation over a large rugged terrain. Further, the need to understand the ecology, accurate knowledge vegetation structure is required for sustainable management of forest landscapes for multiple purposes, including the provision of wildlife habitats, timber production and fire hazard reduction.

Assessment of changes to vegetation structure is challenging over topographically diverse areas. Remote sensing has been a commonly used data acquisition tool in vegetation studies. However, passive remote sensing systems still require a considerable amount of field data for calibration and they tend to lack vertical information that is required for understanding complex multi-layered vegetation structure. This is one of major drawback in vegetation studies of large areas using passive remote sensing. LiDAR technology offers the ability to investigate forest stand structure and variation of biophysical parameters from point clouds (Clawges, et al. 2007). Due to single spectral band information limitations, LiDAR has normally been integrated with other multi spectral remotely sensed data to derive comprehensive information about biophysical attributes of vegetation (Armston et al., 2009; Hudak et al., 2006). Through the integration of LiDAR and multispectral data strengthen of

passive and laser based technologies can potentially be captured and will improve predictions of vegetation structure as influenced by topographic and microclimatic variations. Many of the studies related to monitoring of vegetation changes in Australia have been limited to relatively uniform flat area. There were few studies examining the effects of topography on vegetation structure (Bale et al., 1998, Specht et al., 2001). The objective of this study was how integrating small-footprint LiDAR sensor and multispectral data can be useful for developing models to assess of structural changes in vegetation structure in a topographically complex landscape.

MATERIAL AND METHODS

Study area

The study was conducted in Richmond Range National Park (Latitude, 28.69°S and Longitude, 152.72° E); representing eucalyptus-dominated open forest with mesic understorey in the north-east coastal region of New South Wales Australia. Topography varies from hill escarpments to low relief terrain, with elevation ranging from approximately 150 to 500m in the study area. Within the forested portions of the study area, the maximum slope average 30 degree.

Image acquisition and processing

LiDAR data were provided by The Land and Property Management Authority, NSW. Data has been acquired in August 2010 using a Leica ALS50-II LiDAR sensor that was mounted on a Piper Navajo PA-31 small aircraft. This aircraft had a mean flight altitude of approximately 2km above ground level. The average point spacing was 0.85m, and all ranges were measured by the laser at off-nadir angle. Data were provided in LAS Format as per specification 1.2. LiDAR returns were classified as ground and non-ground by the data provider using proprietary software. According to the data provider, vertical accuracy of the LiDAR elevation was +/-30cm at 95% confidence. All subsequent data analyses were conducted using John's processing code based on IDL (Armston, et al. 2009) and ArcGIS 9.2.

Data analysis and model development tasks for image processing involved two steps. In the first step LiDAR points statistically related to field measured vegetation attributes. At end of the first step several data products were generated using LiDAR including a Digital Terrain Model (DTM), a Tree Canopy Model (TCM), slope and an aspect map. A DTM with a 1m grid cell size was generated using the filtered returns classified as representing the ground via kriging with the 6 nearest neighbours and later re-sampled into 25x25m pixels to be equivalent to a field sampling site. At the second step an alternative strategy for characterizing forest structure over large landscapes using combined Landsat TM5, LiDAR and field data was observed.

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LiDAR fractional cover estimates calculated by aggregating all points into 25m spatial bins using equation-(1)

$$1 - \frac{P_{\text{first}}}{P_{\text{total}}} = \frac{C_v(z)}{C_v(0) + C_g} \quad (1)$$

Where $C_v(z)$ is the number of first returns higher than Z m above the ground and C_g is the number of first return points from the ground level (Lovell et al., 2003). Z was set to 0.5m with the objective of including all understorey shrubs and saplings in the vertical profile and avoiding herbs, ferns and other ground objects. Maximum overstorey heights were calculated using first returns in each bin. LiDAR and field data were used to develop a calibration curve from LiDAR fractional cover to Foliage Projective Cover (FPC) and are described in detail by (Armston et al., 2009).

A cloud free TM 5 Landsat image (26 November 2009, path/row-89/80) was acquired from USGS. The image was first radiometrically corrected to at-sensor spectral radiance. The geometrically corrected image was resampled into 25mx25m pixel to be equivalent to the size of a sampling site. FPC product (Lucas et al., 2006) was generated using a topographically normalised TM image. After 2 x 2 pixel blocks were extracted from this image, cell values were averaged and then matched to 2 x 2 LiDAR bins of 25m spatial resolution.

As an alternative to aspect and slope, we calculated the predicted diurnal solar radiation measurements to provide information about slope, aspect and altitude into single linear values that could be easily incorporated with structural attributes of vegetation. 25m resolution DTM derived by LiDAR was used to calculate predicted diurnal insolation within the study area. Solar Radiation Analysis Tools of the ArcGIS was used to calculate mean insolation values for the whole year over each plot. Insolation was regarded as potential measures as it does not consider the presence of clouds. However, as insolation often only covers small areas, larger spatial differences in cloudiness were not expected, and therefore potential values were assumed to be relatively to actual values.

Field survey

The field sampling was conducted to measure overstorey and understorey foliage cover and overstorey height of vegetation for image calibration. Data collection was conducted from January to March 2010. Fifteen sites were sampled within the LiDAR transect. These sampling sites had a relatively homogenous canopy cover with a range of tree basal areas and mature stand of eucalyptus vegetation and uniform slope and aspect. Care was taken to sample the vegetation from homogenous underlying geology to eliminate the effect of geology and soil. The Statewide Landcover and Tree Study (SLATS) methodology were used with 50m transects (approximately 0.5ha in area) (Milne et al., 2007). The centre of each plot was located at the intersection of the three transects that was accurately recorded using a GPS (GARMIN 62S) while slope and aspect of each site were also recorded. Physical attributes of the vegetation such as foliage projective cover (Specht & Morgan, 1981) measured by a densitometer and average maximum overstorey height were recorded. Maximum overstorey heights measurements were taken by a SUUNTO Clinometer.

The relationships between field observed data and LiDAR and Landsat derived data were observed using scatter plots

and stepwise regression analysis in the SPSS 17. Candidate predictor variables were derived from LiDAR and Landsat TM5 was then average and used for modelling. General Linear Model approach was employed to choose the best linear model for predicting overstorey FPC and overstorey height. For each model, the levels of significance, R-square goodness of fit statistics and root mean square error were calculated.

RESULTS

Initial overstorey heights measured from the 15 sample sites were regressed against the predictor variable derived from distribution of first and last returns of LiDAR hits. Within the study area, LiDAR data were found to be effective for characterising maximum overstorey heights ($R^2=0.76$; $P<0.01$) (Table 1, Figure 1). Overstorey heights from LiDAR data were typically estimated as using mean error of 3.4m and an RMSE of 1.83.

Table 1. Association between reference (field measured) and LiDAR and Landsat TM5 derived (modelled) overstorey height and FPC. *** $P<0.001$, ** $P<0.01$, * $P<0.05$

	Model	RMSE	Model significance
Overstorey height (m)	$Y = - 8.692 + 1.164 X$	1.82m	$R^2=0.76$; ***
Overstorey FPC (%) (vs LiDAR FPC)	$Y = 37.31 + 0.4190 X$	4.17%	$R^2=0.70$; ***
LiDAR FPC (%) (vs Landsat FPC)	$Y = 11.25 + 1.398 X$	7.21%	$R^2=0.87$; ***

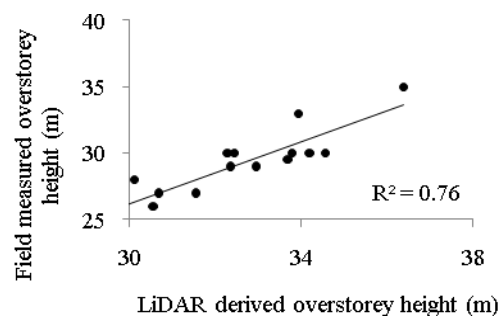


Figure 1. Correlation of field overstorey height and LiDAR derived overstorey heights across sampling sites.

FPC measurements were performed in the field at all sites and could therefore be compared to the LiDAR derived FPC. Table 2 and Figure 2 show a good linear relationship between field and LiDAR FPC for data collected across sampling sites ($R^2=0.70$; $P<0.01$). A lower RMSE and higher coefficient of efficiency for LiDAR FPC (Figure 2) shows that prediction of FPC from LiDAR FPC has a better match to the field data. However LiDAR derived FPC are higher than the field observation. In this study, Landsat TM5 derived FPC was calibrated against the measurements obtained and validated LiDAR and derived FPC. A comparison of the Landsat FPC with LiDAR derived measurements showed a high level of association between both measurements ($R^2=0.87$; $P<0.01$) (Table 2, Figure 3).

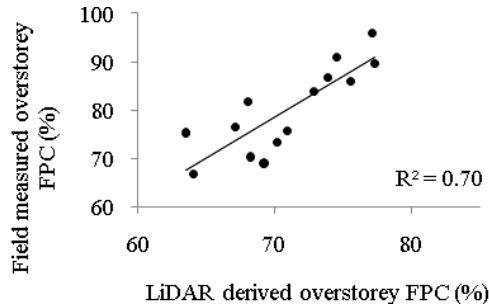


Figure 2. Correlation of field overstorey FPC and LiDAR derived overstorey FPC across sampling sites.

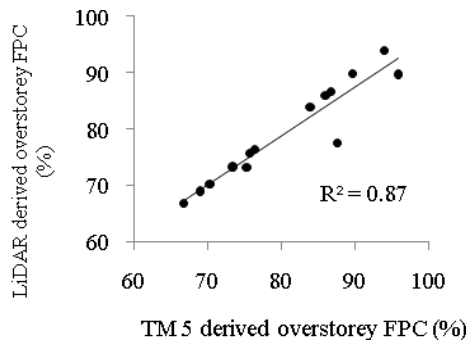


Figure 3. Correlation of TM 5 derived and LiDAR derived overstorey FPC across sampling sites.

Validation of the regression model prediction

The predicted diurnal insolation (Figure 4) illustrates the variation found in solar radiation across the study area for different aspects, ranging from 16 to 12 MJm⁻²/day. North facing inclination receive significantly higher amount of insolation compared to south facing inclinations. These results are consistent with a similar study was conducted in NSW Australia by Kumar & Skidmore (2000). However, our study showed that there was no relationship between slope and insolation over the study area. Further, developed models were employed to estimate the overstorey FPC and overstorey heights. As expected, the regression analysis illustrated a relationship between the variation in the percentage of overstorey FPC and predicted insolation in the terrain (Figures. 5 and 6) with a high significance ($Y = -172.6 + 38.16 X - 1.461 X^{**2}$, $R^2=0.73$; $P<0.01$). Similar to FPC, the estimated overstorey height was significantly related to the insolation ($Y = 58.19 - 1.860 X$, $R^2=0.72$; $P<0.01$). The results indicated that higher percentages of overstorey FPC in areas with southerly aspects had relatively higher stem heights. However, no significant relationships were identified between slope and overstorey FPC ($R^2=0.02$; $P=0.4$) and between slope and overstorey height ($R^2=0.04$; $P=0.7$).

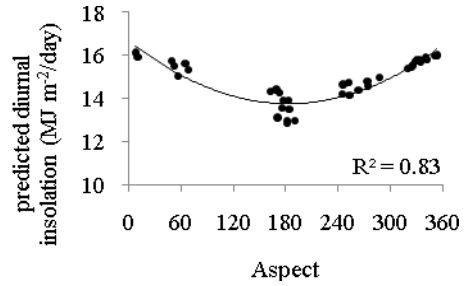


Figure 4. Scatter plot of the insolation vs aspect. The predicted values were obtained from the best-fit non-linear regression model.

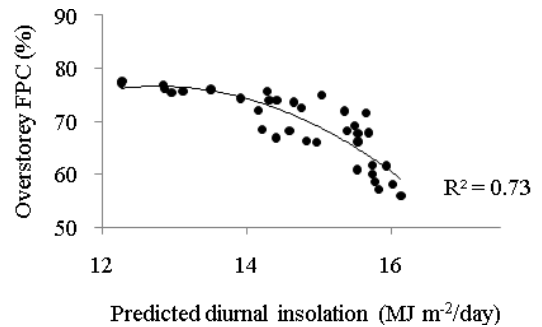


Figure 5. Relationship between overstorey FPC estimates and predicted diurnal insolation.

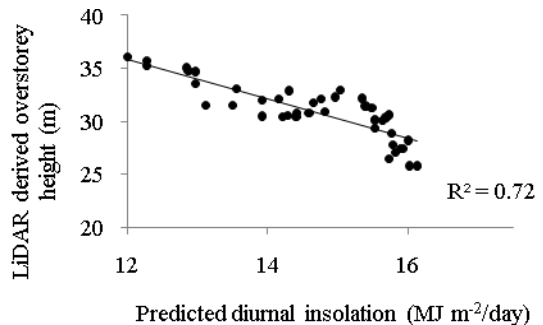


Figure 6. Relationship between overstorey height estimates and predicted diurnal insolation.

DISCUSSION

The analysis found that when quantifying biophysical attributes of the vegetation, LiDAR data and Landsat TM5 were effective predictors of open tall eucalypt dominated forests. We evaluated the effectiveness of LiDAR data for replacing field observed data to parameterise statistical models (based on Landsat TM5) for several sampling points within the study area. The inclusion of LiDAR data allowed the incorporation of the vertical distribution of the forest structure. Further, the incorporation of LiDAR data allowed the generation of DTM which is an essential input into this study for producing aspect and slope products and to estimate potential insolation data in the study area

In relation to the assessment of vertical structure, LiDAR data have been good predictor. However in this study, the error over 3m in height difference was found to overestimate the overstorey height using LiDAR. The variables of incline terrain, significantly high overstorey and understorey canopy cover, low average point spacing density (0.85m) and high flying attitude limited the accurate estimation of overstorey heights in this study (Gatzliolis et al., 2010) or more likely the ground measurements underestimate height. In these areas, the proportion of returns decreases rapidly with canopy depth and with number of strata and only a small percentage was identified in the lower half of the canopy. Consistent with findings in other studies (Amrston et al., 2009) this study also highlighted that LiDAR overestimates FPC in relation to the field estimates due to LiDAR based FPC measuring total density.

Abiotic factors such as insolation and the slope of the terrain are directly related to water availability in plants and to soil properties, and it is expected that they will have a noticeable effect on vegetation (Specht, 1988). Several studies (Specht and Specht, 1999; Specht et al., 2001) demonstrated that aspect and slope related vegetation differences by the variation in the prime environmental variable of solar radiation. In this study we quantified solar exposure at a local scale using point solar radiation, and examined the variation of structural attributes of vegetation with different slopes and aspects. Our results confirm that exposure on north versus south-facing slopes was the most important topographic factor associated with structure and composition of vegetation, and such changes in vegetation structure (eg. overstorey FPC and height) can be effectively predict by integrating LiDAR and Landsat TM data. Forest structure can expected be to vary with changing microclimate as water stress is reduced, conditions become more favourable, and productivity normally rises. However, it is still important to recognise that within this plant community, vegetation structure is not correlated with variation in intensity of slope on the terrain, though interaction of aspect and slope does impact vegetation structure through modifying insolation. This is not surprising since the level of accuracy of vertical measurements of LiDAR data decomposes as the angle of the terrain increases, mainly because of the error due to tree lean (Gatzliolis, et al., 2010) and it may also be affected on horizontal measurements by changing viewing angles.

This study has provided an evaluation of integration of LiDAR data Landsat TM5 for predicting vegetation structure changes in eucalyptus dominated tall open forest in Eastern Australia. Our finding demonstrated that remote sensing techniques can be used with some limitation for the predicting and monitoring of vegetation structure on a topographically complex landscape.

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