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# A voxel-based model of LiDAR point cloud for estimating forest canopy closure

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## ABSTRACT

Within UNFCCC framework, forest monitoring should be capable of detecting emissions from not only deforestation, but also from forest degradation. In fact, determinants of deforestation are relatively more detectable using remotely sensed data than determinants of forest degradation. Forest canopy closure is one important determinant of forest degradation. In this case, loss on forest canopy closure indicates forest degradation. As part of our activities in developing methodology for estimating forest canopy closure, this paper describes our methods on estimating forest canopy closure based on ALS LiDAR point cloud through the development of a three dimensionally explicit voxel-based model of forest canopy using an open-source modelling platform of NetLogo 3D 5.3.1. Window area in South Sumatra, Indonesia was selected as the study site. Estimated canopy closure resulted by our model was compared with the results from commercial software (i.e. LiDAR360). The results of this study suggest that using a simple voxel-based model with 2 parameters within open source platform; it is possible to estimate forest canopy closure based on ALS LiDAR point cloud at relatively small deviation (around 25.04%), as compared to similar commercial software, which algorithm is usually hidden. However, validating the model with ground measured data on canopy closure should be carried out.

**Keywords:** Canopy closure, forest, LiDAR, NetLogo, point cloud, voxel-based model

## 1. INTRODUCTION

Within UNFCCC framework, forest monitoring should be capable of detecting emissions from not only deforestation, but also from forest degradation. In fact, determinants of deforestation are relatively more detectable using remotely sensed data than determinants of forest degradation. Forest canopy closure is one important determinant of forest degradation. In this case, loss on forest canopy closure indicates forest degradation.

Light detection and ranging technology (LiDAR) is capable of measuring the physical structure of trees [1]. However, LiDAR data should be transformed from point cloud into three dimensionally explicit model. Modelling studies to measure similarity of various canopy shapes were done by [2]; [3], which principle was based on algorithm developed by [4]. Figure 1 illustrates 3D shape signature of three canopy shapes with different geometry, measured using algorithm developed by [4]. Thus, algorithm to measure similarity or dissimilarity of 3D geometry based on their shape signatures [4] is useful to recognise 3D canopy shapes of forest point cloud. Nevertheless, such algorithm is not applicable when we are dealing with big data of point cloud.

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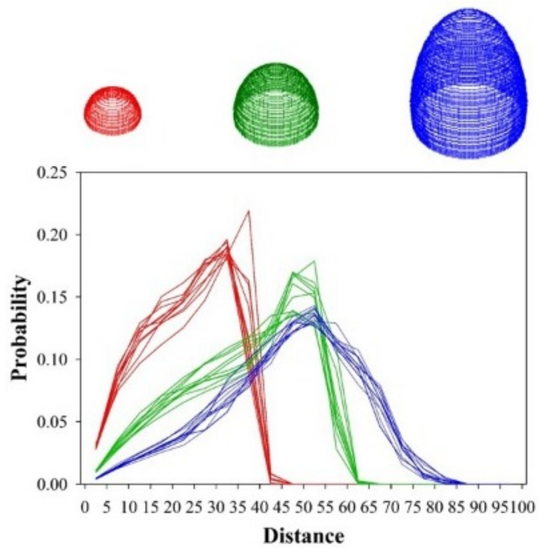


Figure 1. Three dimensional shape signature of three canopy shapes with different geometry.

Thus, as part of our activities in developing methodology for estimating forest canopy closure, this paper describes our methods on estimating forest canopy closure based on airborne laser scanning LiDAR (ALS LiDAR) point cloud through the development of a three dimensionally explicit voxel-based model of forest canopy using an open-source modelling platform of NetLogo 3D 5.3.1 for prototyping [5]. The model was developed as simple as possible, with regards to its applicability in handling big data of point cloud. Since ground measured data on canopy closure was lacking, we compared the results from our model with the results from commercial LiDAR processing software, i.e. LiDAR360 Version 2.1 (Build 0226) trial version [6].

# 2. WINDOW AREA AND DATA

## 2.1 Window area

A site situated in South Sumatra, Indonesia was chosen as the window area to evaluate the model (Figure 2).

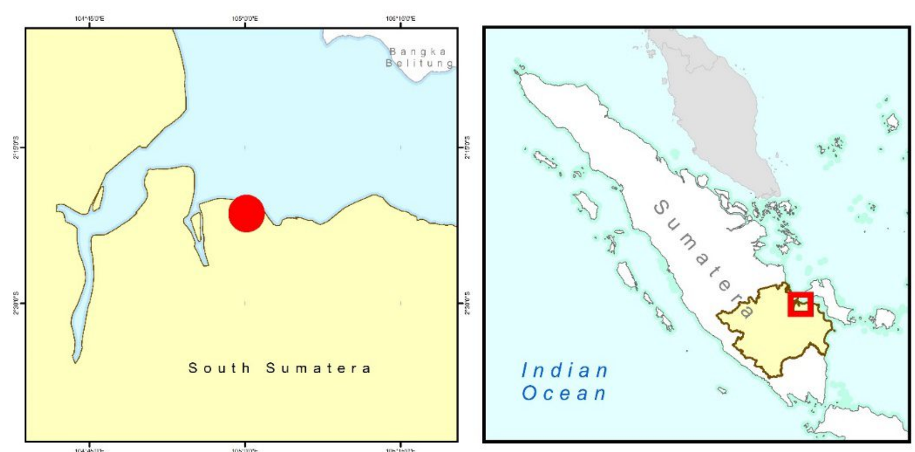


Figure 2. Window area of the study (red), situated in South Sumatra, Indonesia.

## 2.2 Data

The main data used for evaluating the model were a subset of ALS LiDAR point cloud from Indonesian Ministry of Environment and Forestry (MoEF) through BIOCLIME/GiZ funded Project, taken on October 2014 in South Sumatra.

# 3. METHODS

## 3.1 Conceptual framework of the model

Conceptual framework of the model is shown in Figure 3. The 3D extent of ALS LiDAR point cloud of vegetation with height ≥ 5-m was segmented into voxels with dimension of 5-m x 5-m x 5-m. Thus, if the extent of the point cloud is 125,000 $m^3$, the number of voxels is 125,000 / 125 = 1,000 voxels. Later, point concentration (points/voxel) was calculated for each voxel.

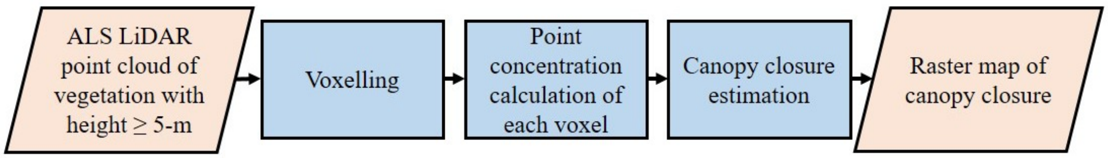


Figure 3. Conceptual framework of voxel-based model for estimating forest canopy closure based on ALS LiDAR point cloud.

Canopy closure was then estimated based on point concentration of each voxel. First, we assume that point concentrations (points/voxel) are correlated with canopy closure (%) of their associated pixel. In this model, we introduced a simple threshold parameter ($C_{max}$), referring to maximum point concentration that determines a fully closed canopy (canopy closure = 100%):

$$CC_v = \frac{PC_v}{C_{max}} \tag{1}$$

Where, $CC_v$ denotes estimated canopy closure of particular voxel (%) based on point concentration of particular voxel (points/voxel); while PCv denotes point concentration of particular voxel (points/voxel).

The next step is to determine significant voxels with regards to their $CC_v$. For such voxel-masking-procedure, we applied another thresholding, through a parameter $t_{mask}$, so that, voxels with $CC_v < t_{mask}$ were removed from the analyses. This procedure is aimed at shaping the overall geometry of voxels through a fine-tuning with overall canopy shape.

Finally, canopy closure (%) of each associated pixel was determined as the average of canopy closure of all vertically overlapping voxels.

## 3.2 Model availability

Source code of the voxel-based model can be obtained from the authors upon request.

## 3.3 Parameters used in LiDAR360

Using the same point cloud dataset, we applied canopy closure estimation in LiDAR360 at 2D resolution of 5-m x 5-m, with height break of 5-m.

## 3.4 Benchmarking

Since ground data on canopy closure were at the moment still lacking, comparing the results from our model with the results from LiDAR360 is not aimed at validating the results. We assume that either our model or LiDAR360 can deviate from ground measured data. Thus, in this comparison analysis, we applied root mean square deviation (RMSD), instead of root mean square error (RMSE):

$$RMSD = \sqrt{\frac{(x_1 - x_2)^2}{n}} \tag{2}$$

Where, $x_1$ and $x_2$ denote estimated canopy closure of each pixel (%), resulted by either the voxel-based model or LiDAR360; and n is number of pixels data-pair under comparison.

## 4. RESULTS AND DISCUSSIONS

Figure 4 shows 10 maps of estimated canopy closure (%) resulted by the voxel-based model at various combination of parameters $C_{max}$ and $t_{mask}$ (Figure 4 B-J), as compared with estimated canopy closure (%) resulted by LiDAR360 (Figure 4 A). It is obvious that at relatively small $C_{max}$, i.e. 0.25 (Figure 4 H-J); the patterns of estimated canopy closure (%) from the model was closer to the result from LiDAR360; which was confirmed by RMSD of the model with LiDAR360 (Table 1). The results suggest that relatively low point concentration of about 0.25 points/voxel is perhaps the threshold used by LiDAR360 to determine a fully closed canopy.

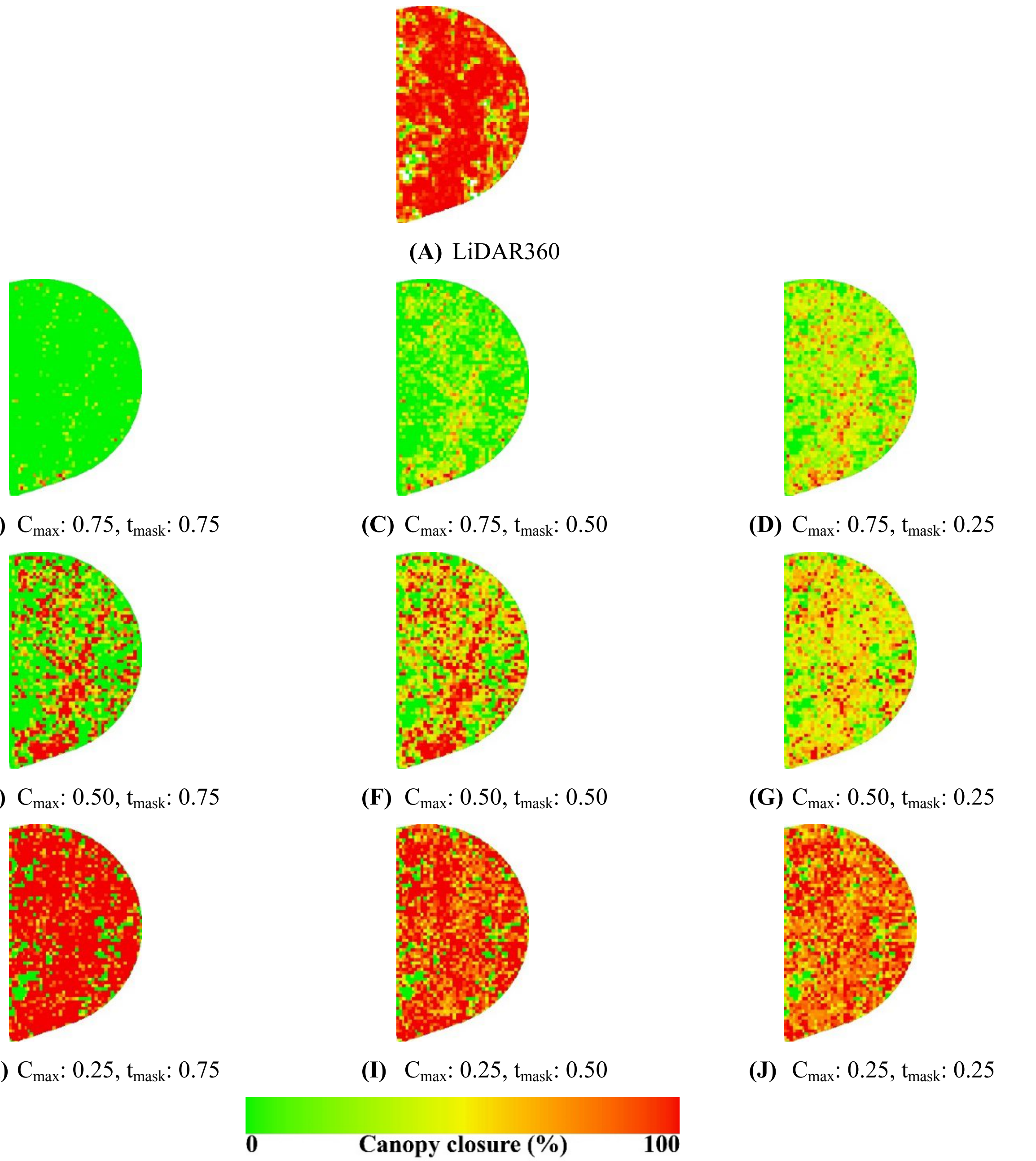


Figure 4. Estimated canopy closure (%) resulted by the voxel-based model at various combination of $C_{max}$ and $t_{mask}$ (B-J), as compared with estimated canopy closure (%) resulted by LiDAR360 (A).

Table 1. RMSD between estimated canopy closure (%) resulted by the voxel-based model at various $C_{max}$ and $t_{mask}$, as compared with estimated canopy closure (%) resulted by LiDAR360.

| $C_{max}$ | $t_{mask}$ | RMSD (%) |
|---|---|---|
| 0.75 | 0.75 | 84.50 |
| 0.75 | 0.50 | 56.86 |
| 0.75 | 0.25 | 46.44 |
| 0.50 | 0.75 | 52.02 |
| 0.50 | 0.50 | 34.22 |
| 0.50 | 0.25 | 35.08 |
| 0.25 | 0.75 | 27.93 |
| 0.25 | 0.50 | 25.20 |
| 0.25 | 0.25 | 25.04 |

Finally, we compared estimated canopy closure (%) from LiDAR360; voxel-based model at Cmax=0.25 and tmask=0.75 with the least RMSD (25.04%); and orthophoto of the study area taken on the same acquisition date of the ALS LiDAR (Figure 5). It is obvious that from the texture variation of the orthophoto, especially within the maximum canopy closure area (the red pixels); LiDAR360 may not capture such variation properly. However, the next study should validate results from both models using ground measured data (e.g. based on canopy hemiview).

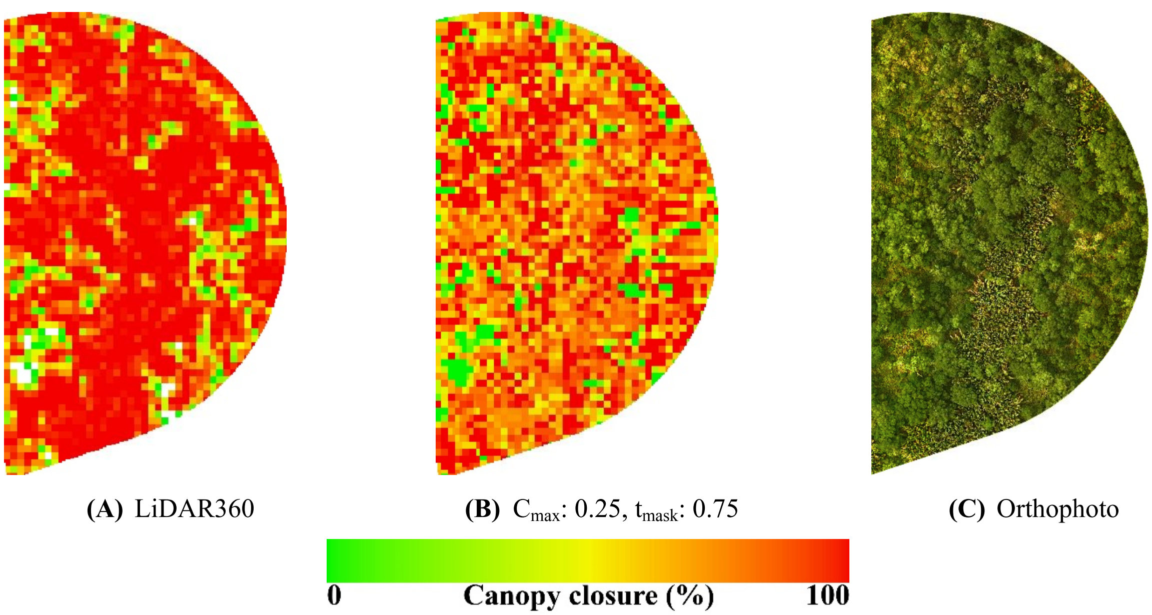


Figure 5. Comparison between estimated canopy closure (%) from: (A) LiDAR360; (B) voxel-based model at Cmax=0.25 and tmask=0.75 with the least RMSD (25.04%); and orthophoto of the study area taken on the same acquisition date of the ALS LiDAR.

## 5. CONCLUSIONS

The results of this study suggest that using a simple voxel-based model with 2 parameters within open source platform; it is possible to estimate forest canopy closure based on ALS LiDAR point cloud at relatively small deviation (around 25.04%), as compared to similar commercial software, which algorithm is usually hidden. However, validating the model with ground measured data on canopy closure should be carried out.

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