Retrieval of Savanna Vegetation Canopy Height from ICESat-GLAS Spaceborne LiDAR with Terrain Correction

Ehsan Khalefa, Izak P.J. Smit, Alecia Nickless, Sally Archibald, Alexis Comber and Heiko Balzter

***Abstract*—LiDAR (Light Detection and Ranging) remote sensing enables accurate estimation and monitoring of vegetation structural properties. Airborne and spaceborne LiDAR is known to provide reliable information on terrain elevation and forest canopy height over closed forests. However, it has rarely been used to characterize savannas, which have a complex structure of trees coexisting with grasses. This paper presents the first validation of spaceborne ICESat-GLAS full waveform data to retrieve savanna vegetation canopy height that uses field data specifically collected within the GLAS footprints. Two methods were explored in Kruger National Park, South Africa: one based on the GLA14 product, and the other using GLA01 with terrain correction. Both methods use Gaussian decomposition of the full waveform. Airborne LiDAR was also used to quantify terrain variability (slope) and canopy height within the GLAS footprints. The canopy height retrievals were validated with field observations in 23 GLAS footprints and show that the direct method works well over flat areas (Pearson correlation coefficient r=0.70, *p*<0.01, n=8 for GLA01) and moderate slopes (r=0.68, *p*<0.05, n=9 for GLA01). Over steep slopes in the footprint, however, the retrievals showed no significant correlation and required a statistical correction method to remove the effect of terrain variability on the waveform extent. This method improved the estimation accuracy of maximum vegetation height with correlations (R^2=0.93, *p*<0.05, n=6 using terrain index (g) generated from airborne LiDAR data; and R^2=0.91, *p*<0.05, n=6 using GLAS returned waveform width parameter). The results suggest that GLAS can provide savanna canopy height estimations in complex tree/grass plant communities.**

***Index Terms* — ICESat, GLAS, LiDAR, Canopy height, Terrain correction, Savanna, Kruger National Park.**

I. Introduction

LIDAR remote sensing provides an accurate and efficient means of estimating and monitoring vegetation structural properties. It has the potential to directly measure three-dimensional structure of vegetation canopies including tree canopy height, density and indirectly above ground biomass, as well as terrain surface [1], [2], [3]. While LiDAR from the airborne and spaceborne platforms has been proved to be effective in forestry applications [4], [5], [6], [7], [8], [9], few studies exists for savanna so its usefulness in that environment has to be further investigate. However, some studies have used airborne LiDAR in savannas [10], [11], [12]. The full waveform spaceborne satellite LiDAR data, the Geoscience Laser Altimeter System (GLAS) aboard the Ice Cloud and land Elevation Satellite (ICESat), has not been thoroughly evaluated in savanna systems using field data specifically collected within the GLAS footprints yet. A study by [13] showed potential results of mapping above ground biomass over tropical Africa using multiyear MODIS satellite observation and a wide range of field measurements and compared the results with GLAS LiDAR height metrics. GLAS has been shown to provide accurate estimates of forest canopy height and aboveground biomass in several studies of closed forests [14], [15], [16], [17], [18], [19].

This paper evaluates the capability of satellite LiDAR data from GLAS for retrieving savanna canopy height in a landscape with highly complex vegetation structure due to the tree/grass coexistence. Airborne LiDAR data is utilized to investigate the terrain variability within the GLAS footprints and its effect on the canopy height retrieval accuracy. An accuracy assessment of savanna canopy height using plot measurements within the footprint locations collected during a field campaign is carried out. Terrain elevation is also evaluated.

II. Methodology

A. *Study site and data*

The study area is inside Kruger National Park in South Africa. The park covers 19,485 km² and is one of the largest protected areas in Africa. Various habitats and ecological regions exist within the boundary of the Kruger Park, with at least 16 recognized ecozones, each characterized by specific vegetation, geology, soil, rainfall rate, and temperature [20].

All GLAS footprints were located in the Sabie/Crocodile Thorn Thickets ecozone, which is characterized by a very dense growth of thorny shrubs.

GLAS data

Two data products of GLAS release 29 were used in this study: Level 1A Global Altimetry data (GLA01), and Level 2 Global Land Surface Altimetry data (GLA14). ICESat-GLAS data were acquired in February-March 2009. GLA01 contains the transmitted and received echo waveforms. This product contains variables such as the filter threshold value for signal detection in digitizer counts, laser transmitter energy, received energy from all signals above threshold, sampled transmit pulse waveform, 4ns background mean value, and standard deviation [21]. GLA14 contains the sensor position and pointing information as well as the calculated footprint position, size and shape, and land surface elevation. Transmit pulse and recorded waveforms are represented with characteristic shape parameters only. The recorded waveform is decomposed into a series of Gaussian peaks, as described in [21] and [22].

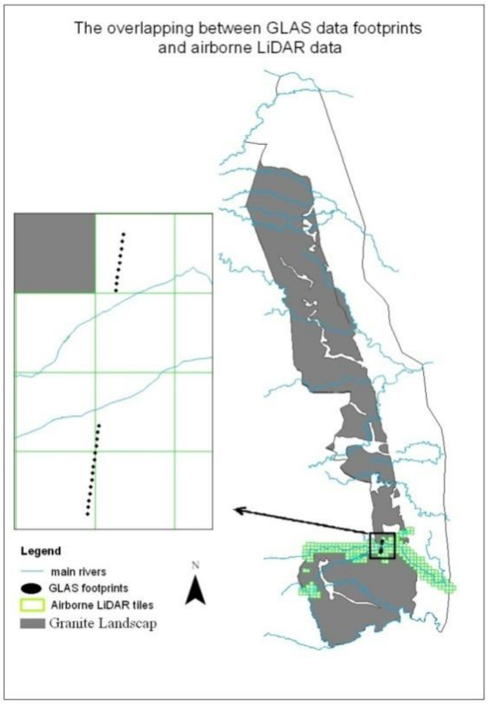

Fig.1. The location of the GLAS footprints which overlap with airborne LiDAR data tiles in the study area. The footprints are situated in the granitic bedrock region of Kruger National Park (grey), in the Sabie/Crocodile Thorn Thickets ecozone.

Airborne LiDAR data

The discrete return airborne LiDAR dataset was acquired during the period August 24 - September 9, 2004 by the University of Witwatersrand. Subsets of airborne LiDAR data were created using a radius of 35 m for each geolocated ICESat/GLAS footprint position. The analysis of airborne LiDAR indicated that the topography over the GLAS footprints for the selected footprints can be classified into flat terrain (0°-15° slope), moderate slope (15°-30°) and steep slope (> 30°).

Field data

Fieldwork was conducted in August 2010. The entire selected GLAS footprints (n=23) for field data collection are located in the granitic areas (Fig. 1). The criteria for selecting the field plot locations were based on the overlap between spaceborne LiDAR data and airborne LiDAR data, as well as considerations of accessibility and travel times. In the field campaign, vegetation canopy height was measured using four sampling plots within the GLAS footprint. The GLAS footprints are elliptical with roughly 70 m diameter and varying eccentricity, separated by about 170 m along track. For analytical purposes we approximated the footprints with circles of 35 m radius. One circular subplot in the centre of the GLAS footprint was measured, followed by three further subplots whose centre position was 20 m to the north, south-east and south-west from the footprint centre at angles of 0º, 120º and 240º. The subplots were 10 m in radius. Tree heights of all woody vegetation, including trees and shrubs, taller than one meter above ground were systematically measured using a clinometer or a woodland stick.

B. Data processing

GLAS data processing

Two methods that retrieve savanna canopy height from different waveform parameters were developed. The direct method utilizes the waveform parameters derived during the operational GLAS processing, mainly the Global Land Surface Altimetry Data Product (GLA14). The statistical method analyzes the waveform shapes from Global Altimetry Data Product (GLA01), using a DEM to adjust the waveform extent, which proved important in rugged terrain. All calculations were performed using the statistical analysis program package R 2.9.0.

Direct method

In open and sparsely vegetated areas, the majority of the signal is likely to be returned from the terrain surface, which manifests itself in a ground peak with the largest amplitude in the waveform. In denser canopies, the laser energy penetration is reduced resulting in a ground peak of lower amplitude [23]. The GLAS14 product provides waveform parameters estimated by a multiple Gaussian decomposition. The ICESat-GLAS Visualizer software iteratively fits six Gaussian curves to the waveform. This was used to compare Gaussian parameters. It is assumed that the Gaussian component with the largest amplitude corresponds to the ground return, and the difference in elevation between the centroid of the ground peak and the beginning of the waveform signal is the maximum vegetation height [24]:

$$H_{max}=H_s-GP \qquad (1)$$

Where H_{max} is the maximum canopy height (m) estimated from LiDAR, H_s is the signal start (m), and *GP* is the ground peak (m).

Height estimates were also calculated from GLA01. As was explained earlier, raw waveforms have ambient system noise at the beginning and the end of the waveform signal. Therefore, the real signal of the waveform was identified by thresholding the raw waveforms. In this study, the threshold value for each raw waveform was individually determined to the mean background noise value estimated in the GLA01 product (GLAS product variable: d_4nsBgMean) plus 4 times the standard deviation of the background noise (GLAS product variable: d_4nsBgSDEV) [15]. To detect the ground peak location, the maximum amplitude was used as a reference. Hence, the peak with maximum amplitude was designated as the ground return.

Statistical method

To consider the contribution of topographic relief on waveform shape, a terrain index (g) was calculated for each footprint location using a 7x7 subset DEM generated from airborne LiDAR data for each of the 23GLAS footprints [25]:

$$H_{max} = b_0 * w - b_1 * g \quad (2)$$

where w is the full waveform extent and b_0 and b_1 are regression coefficients.

If an external DEM is not available, the terrain index g has to be substituted by another parameter. The width of the ground peak (i_Gsigma in GLA14), expressed as 2σ is a potentially suitable indicator of the terrain effect on the waveform in sloped areas. On the assumption that the terrain index g can be replaced by the waveform width (2*σ), vegetation canopy height can be estimated by:

$$H_{max} = b_0 * w - b_1 * (2 * \sigma) \quad (3)$$

This method was adopted by [23] and offers a means of extracting GLAS canopy height estimates from the Gaussian decomposition parameters provided with the GLA14 product or extracted from GLA01 parameters. Crucially, it does not require an external DEM for terrain correction.

Airborne LiDAR processing

The airborne LiDAR footprints were classified into vegetation and ground hits, from which digital surfaces model (DSM) and a digital terrain model (DTM) were generated. Using eCognition Developer 8 and ESRI ArcMAP™ 9.3.1.These data were also used to calculate terrain slope within each GLAS footprint (n=23). A canopy height model (CHM) was calculated as the difference between DSM and DTM following the method by [26]. CHM values <1m were excluded from the dataset in order to eliminate the effect of grasses and understory vegetation. Within each GLAS footprint, H_{max} was estimated by using the local maxima and minima of the generated CHM. The results from the airborne processing were used to validate H_{max} from the field plots and H_{max} obtained from the spaceborne LiDAR system.

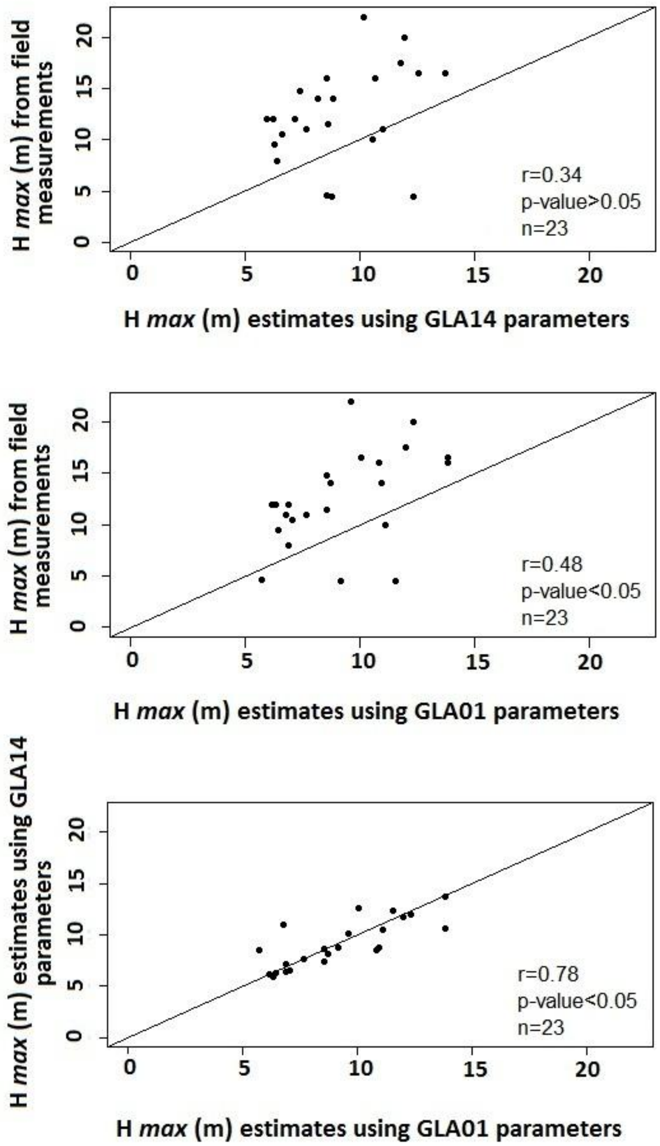

Fig.2. Scatterplots of Pearson's correlation coefficient between H_{max} estimates using GLAS parameters of Gaussian decomposition and field measurements of H_{max}. Upper plots show GLA14, middle plot GLA01. The lower plot shows the correlation coefficient between H_{max} using GLA14 and GLA01 parameters. In general, the results indicate a weak correlation when the comparison is made for all 23 footprints without considering terrain variability.

III. Results and discussion

A. Direct method using parameters of GLAS products

Comparison of maximum canopy heights derived from GLA14 and GLA01 products gives a Pearson correlation r = 0.78 for the selected study plots. To validate the previous results, a comparison of the results of H_{max} from the field plots and H_{max} obtained from the spaceborne LiDAR system parameters (GLA01 and GLA14) is shown in Fig. 2.

The analysis of the airborne LiDAR data indicated that the topography over the selected GLAS footprints can be classified into terrain with low (0°-15°), moderate (15°-30°) and steep slopes (>30°).

As a result of this stratification, 8 GLAS footprints were in flat terrain; 9 footprints in moderate terrain and 6 footprints in steep terrain. In order to quantify the effect of terrain slope on both LiDAR systems, a comparison between results of H_{max} from field measurements and H_{max} obtained from both LiDAR systems stratified by terrain slope in the GLAS footprints was carried out. The results show that both LiDAR systems give a similar relationship to the field measurements of H_{max} (Fig 3).

In flat terrain the correlations between H_{max} from GLAS and airborne LiDAR (AL) with the field measurements were highest (r=0.70 for GLAS and r=0.78 for AL respectively; both p<0.001).

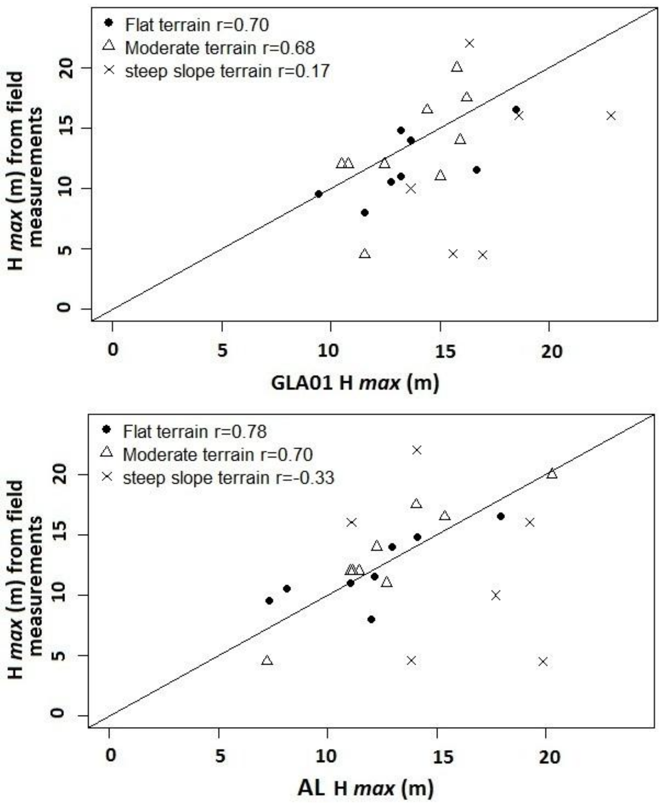

Fig.3. Scatterplots between H_{max} within the GLAS footprints stratified by terrain slope. Top: H_{max} from field measurements and from GLA01; bottom: H_{max}. from field measurements and from airborne LiDAR. This figure shows that r decreases when the terrain slope increases.

Correlation coefficients were statistically significant in moderate terrain for both GLAS and AL when compared to field measurements of H_{max} (r=0.68; $p<0.05$ for GLAS and r=0.70; $p<0.01$ for AL). In steep terrain, the correlations with field measured H_{max} were not significant anymore (r=0.17; $p>0.05$ for GLAS and r=0.33; $p>0.05$ for AL). Because of the small sample size, a bootstrap correlation analysis was carried out which fully confirmed these conclusions. The results show that the estimation of H_{max} from both air- and spaceborne LiDAR systems is affected by terrain slope. Therefore, statistical methods are required to incorporate this important factor in estimating vegetation height in steep terrain.

B. Statistical methods of terrain correction

Two methods of terrain correction were applied. The first method uses the waveform extent (w) extracted from GLA01 parameters and a terrain index (g), which is generated from airborne LiDAR data within the GLAS footprint. g is defined as the difference between highest and lowest elevation within a 7x7 subset of the DEM from airborne LiDAR. It is an indicator of the slope effect on the waveform extent.

In order to improve the relationship between the waveform extent and terrain indices, a multiple regression with field measurements of $H_{\max}$ was used (n=6), following [18]. The resulting equation which uses the airborne LiDAR terrain index is:

$$H_{max} = 1.47\, w - 1.19\, g \quad (4)$$

with $R^2=0.93$ and RMSE=3.64 m (both $p<0.05$).

The analysis showed the capability of estimating H_{max} from the GLAS waveform with consideration of terrain effects on the waveform structure. However, the largest variation was obtained for very steep slopes (n=6). The validation of H_{max} estimated from GLAS waveform parameters with field-derived H_{max} suggests that the terrain index is related to waveform structure. However, this approach to terrain correction requires terrain elevation data of appropriate resolution to aid the GLAS analysis.

In order to have a self-sufficient approach to slope correction, which relies only on GLAS waveform parameters for estimating H_{max}, the second method of terrain correction uses a multiple regression with the GLAS waveform width σ replacing the airborne LiDAR terrain index g:

$$H_{max} = 1.65^{*}\, w - 1.44^{*}\, \sigma \quad (5)$$

with $R^2=0.91$, RMSE=3.92m, Both coefficients are statistically significant ($p<0.05$).

These results were similar to those from eq. 1 but this time without relying on a terrain index from airborne LiDAR data within the GLAS footprints. This suggests that the potential for estimating H_{max} from GLAS waveform parameters can be achieved by using only the waveform width (σ), which becomes wider as the terrain slope in the footprint increases [5]. The analysis was repeated using the bootstrap analysis for the multiple regressions above and for the first method this resulted in:

$$H_{max} = 1.53^{*}\, w - 1.36^{*}\, g \quad (6)$$

with $R^2=0.95$, RMSE=3.6 m (both $p<0.05$).

The second method gave:

$$H_{max} = 2.12^{*}\, w - 1.91^{*}\, \sigma \quad (7)$$

with $R^2=0.95$, RMSE=2.42 m, Both coefficients are statistically significant ($p<0.05$).

The results demonstrate the validity of estimating H_{max} from GLAS waveform parameters directly using statistics based on multiple regression analysis (Figure 4).

A limitation of this study is the limited sample size, which is further reduced by the stratification according to slope. It was constrained by the logistics of the fieldwork in a difficult environment, but such studies would be more statistically robust if more GLAS footprint locations were visited and sampled in the field. Nevertheless, the statistical inference presented here was confirmed by bootstrapping.

An additional possible limitation of this study is that over the five years between the airborne and spaceborne LiDAR acquisitions the savanna vegetation is likely to have changed to a certain degree. Fires, however, rarely destroy the woody vegetation in Kruger Park, because many trees are adapted to fire. Mega-herbivores such as elephants may have destroyed some trees. While tree growth tends to be slow, some growth will have happened. These factors introduce additional uncertainty into the data analysis, which implies that for concurrent data collection, the quality of fit is likely to be better than that reported.

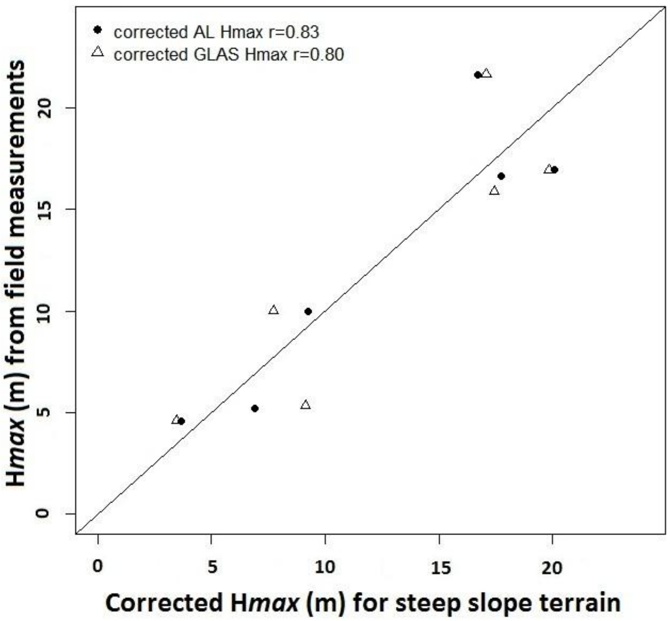

Fig.4. Scatterplots between corrected H_{max} within the steep slope terrain GLAS footprints using statistical method of terrain correction and the H_{max} from field measurements. This figure shows that R increases when the terrain slope is corrected using the terrain index (g) extracted from Airborne LiDAR data r= 83 and it also shows that the terrain correction could be done using the waveform width (σ) from GLAS parameters only r=83 for the selected GLAS footprints.

IV. CONCLUSION

The results of the validation of maximum vegetation canopy height derived from GLAS and airborne LiDAR show that the direct method can be used in moderate terrain, while the statistical method of terrain correction should be applied in steep terrain to obtain accurate estimates of H_{max}. Better results could be achieved for estimating H_{max} using only the GLAS waveform parameters 'waveform extent' and 'waveform width' over sloped areas.

ACKNOWLEDGMENTS

This study was supported by the UK Natural Environment Research Council (NERC), CORSAR project, Grant number NER/Z/S/2000/01282. H.. Balzter was supported by the Royal Society Wolfson Research Merit Award, 2011/R3.

REFERENCES

[1] M. Nilsson, "Estimation of tree heights and stand volume using an airborne LiDAR system", *Remote Sensing of Environment,* 1996, vol. 56, no. 1, pp. 1-7.

[2] R. Nelson, R. Oderwald, and T.G. Gregoire, "Separating the ground and airborne laser sampling phases to estimate tropical forest basal area, volume, and biomass", *Remote Sensing of Environment,* 1997,vol. 60, no. 3, pp. 311-326.

[3] M.A. Lefsky, W.B. Cohen, D.J. Harding, G.G. Parker, S.A. Acker and S.T.Gower, "Lidar remote sensing of above-ground biomass in three biomes", *Global Ecology and Biogeography,* 2002, vol. 11, no. 5, pp. 393-399.

[4] J. Rosette, P. North andJ. Suarez, "Vegetation height and stemwood volume estimates for a mixed temperate forest using satellite LiDAR", *Journal of Forest Planning, Special Issue: LiDAR Application in Forestry,* 2008.

[5] G. Sun, K.J. Ranson, D.S. Kimes, J.B. Blair, and K. Kovacs, "Forest vertical structure from GLAS: An evaluation using LVIS and SRTM data", Remote Sensing of Environment, 2008, vol. 112, no. 1, pp. 107-117.

[6] S.C. Popescu, K. Zhao, A. Neuenschwander, and C. Lin, "Satellite LiDAR vs. small footprint airborne LiDAR: Comparing the accuracy of aboveground biomass estimates and forest structure metrics at footprint level", *Remote Sensing of Environment,* 2011, vol. 115, no. 11, pp. 2786-2797.

[7] L.I. Duncanson, K.O., Niemann and M.A. Wulder, "Estimating forest canopy height and terrain relief from GLAS waveform metrics", *Remote Sensing of Environment,* 2010, vol. 114, no. 1, pp. 138-154.

[8] Q. Chen, "Retrieving vegetation height of forests and woodlands over mountainous areas in the Pacific Coast region using satellite laser altimetry", *Remote Sensing of Environment,* 2010, vol. 114, no. 7, pp. 1610-1627.

[9] S.C. Popescu, K. Zhao, A. Neuenschwander, and C. Lin, "Satellite lidar vs. small footprint airborne lidar: Comparing the accuracy of aboveground biomass estimates and forest structure metrics at footprint level", *Remote Sensing of Environment,* 2011, vol. 115, no. 11, pp. 2786-2797.

[10] Q. Chen, D. Baldocchi, P. Gong and M. Kelly, "Isolating individual trees in a savanna woodland using small footprint lidar data", *Photogrammetric Engineering and Remote Sensing,* 2006, vol. 72, no. 8, pp. 923-932.

[11] S.R. Levick, and K.H. Rogers," Structural biodiversity monitoring in savanna ecosystems: Integrating LiDAR and high resolution imagery through object-based image analysis. Object Based Image Analysis", 2008, p.477-491.

[12] J. Wu, J.A.N Van Aardt, G.P. Asner, R. Mathieu, T. Kennedy-Bowdoin, D. Knapp , K. Wessels, B.F.N. Erasmus and I.Smit, "Connecting the dots between laser waveforms and herbaceous biomass for assessment of land degradation using small-footprint waveform lidar data", *International Geoscience and Remote Sensing Symposium (IGARSS)*, 2009, pp. II334.

[13] A. Baccini, N. Lapote, S.J Goets, M. Sun, and H. Dong, "A first map of tropical Africa`s above-ground biomass derived from satellite imagery", *Environmental research letters*, 2008, vol.3, no.4.

[14] D.J. Harding, and C.C. Carabajal, "ICESat waveform measurements of within-footprint topographic relief and vegetation vertical structure", *Geophysical Research Letters,* 2005, vol. 32, no. 21, pp. 1-4.

[15] M.A. Lefsky, M. Keller,Y. Pang, P.B. De Camargo and M.O. Hunter, "Revised method for forest canopy height estimation from Geoscience Laser Altimeter System waveforms", *Journal of Applied Remote Sensing,* 2007, vol. 1, no. 1.

[16] J.A. Rosette, P.R.J. North, ,J.C. Suárez, and J.D. Armston, "A comparison of biophysical parameter retrieval for forestry using airborne and satellite LiDAR", *International Journal of Remote Sensing,* 2009, vol. 30, no. 19, pp. 5229-5237.

[17] J. Boudreau, R.F Nelson,, H.A. Margolis, A. Beaudoin, L. Guindon and D.S. Kimes, "Regional aboveground forest biomass using airborne and spaceborne LiDAR in Québec", *Remote Sensing of Environment,* 2008,vol. 112, no. 10, pp. 3876-3890.

[18] M.A. Lefsky, , D.J. Harding, , M. Keller, W.B. Cohen, , C.C. Carabajal, F. Del Bom Espirito-Santo, , M.O. Hunter and R. de Oliveira Jr., "Estimates of forest canopy height and aboveground biomass using ICESat", *Geophysical Research Letters,* 2005,vol. 32, no. 22, pp. 1-4.

[19] R. Nelson, J. Boudreau, T.G Gregoire, H. Margolis, E. Næsset, T. Gobakken, and G. Ståhl, "Estimating Quebec provincial forest resources using ICESat/GLAS", *Canadian Journal of Forest Research,* 2009, vol. 39, no. 4, pp. 862-881.

[20] L. Gillson, and K.I. Duffin, "Thresholds of potential concern as benchmarks in the management of African savannahs", Philosophical

Transactions of the Royal Society B: Biological Sciences, 2007, vol. 362, no. 1478, pp. 309-319.

[21] A.C. Brenner, H.J.Zwally, ,C.R. Bentley, B.M. Csatho, D.J. Harding, M.A. Hofton, J.B. Minster, , L.A. Roberts, J.L . Saba, R.H. Thomas and Y. Yi, "Geoscience Laser Altimeter System (GLAS) - derivation of range and range distributions from laser pulse waveform analysis for surface elevations, roughness, slope, and vegetation heights", *Algorithm Theoretical Basis Document - Version 4.1*, 2003.

[22] H.J. Zwally, B. Schutz, W. Abdalati, J. Abshire, C. Bentley, A. Brenner, J. Bufton, J. Dezio, D. Hancock, D. Harding, T. Herring, B. Minster, K. Quinn, S. Palm, J. Spinhirne and R. Thomas, "ICESat's laser measurements of polar ice, atmosphere, ocean, and land", *Journal of Geodynamics*, 2002,vol. 34, no. 3-4, pp. 405-445.

[23] D.J. Harding, M.A. Lefsky, G.G. Parker and J.B. Blair, "Laser altimeter canopy height profiles methods and validation for closed-canopy, broadleaf forests", *Remote Sensing of Environment,* 2001, *vol*. 76, no. 3, pp. 283-297.

[24] J.A.Rosette, P.R.J.North, J.C. Suárez and J.D. Armston, "A comparison of biophysical parameter retrieval for forestry using airborne and satellite LiDAR", *International Journal of Remote Sensing,* 2009,vol. 30, no. 19, pp. 5229-5237.

[25] M.A. Lefsky, D.J. Harding, , M. Keller, W.B. Cohen, C.C. Carabajal, F. Del Bom Espirito-Santo, M.O. Hunter and J. R. de Oliveira, "Estimates of forest canopy height and aboveground biomass using ICESat", *Geophysical Research Letters,* 2005, vol. 32, no. 22, pp. 1-4.

[26] S.A. Hinsley, R.A. Hill, P. E. Bellamy, and H. Balzter, "the Application of LiDAR in Woodland Bird Ecology: Climate, Canopy Structure and Habitat Quality", *Photogrammetric Engineering and Remote Sensing*, 2006, 72 (12), pp. 1399-1406

Ehsan Khalefa holds a BSc in Agricultural Engineering from Damascus University, and moved to the UK for her postgraduate studies in 2007. In 2008 she was awarded the MSc in Sustainable Management of Natural Resources in the Geography Department at the University of Leicester. In July 2012, Ehsan was awarded the PhD in Physical Geography from the same university for her remote sensing research with Professor Heiko Balzter and Dr. Alexis Comber. Dr. Khalefa is working as a research associate in the University of Leicester's Space Research Centre G-STEP office.

Izak P.J. Smit was born in Pretoria (South Africa) in 1975. He was awarded a BSc (Ecology and Mathematical Statistics) and BSc (Hons – Environmental Management) from the University of Pretoria in 1996 and 1997 respectively. This was followed by MSc (Environmental Protection and Management) from the University of Edinburgh (Scotland) in 1999. In 2003 he received an MPhil (GIS & Remote Sensing) from the University of Cambridge (England), followed by a PhD from the same institution in 2007.

He is a Scientist in Geographical Information Systems (GIS) and Remote Sensing for the South African National Parks (SANParks), based in the Kruger National Park. He conducts research on the use of GIS and remote sensing for detecting spatiotemporal ecological patterns which have relevance for the effective management of conservation areas.

Alecia Nickless (South Africa, 18 November 1982) has an MSc. in mathematical statistics (March 2009) from the University of the Witwatersrand, and is currently studying towards a PhD in statistics from the University of Cape Town, on the topic of inverse modeling to obtain estimates of carbon fluxes. She is currently a researcher at the CSIR, South Africa, where she specializes in the measurement and modeling of carbon fluxes through the eddy covariance method, and measurement of atmospheric carbon dioxide.

Ms. Nickless is a member of the South African Society for Atmospheric Sciences and has published in the area of modeling biospheric fluxes, the use of allometric equations for tree biomass estimates, and using a ground-based Lidar scanner to obtain tree biomass estimates.

Sally Archibald has a PhD from the University of the Witwatersrand and an MSc from the University of Cape Town in South Africa. She is currently a Principal Researcher at the CSIR in Pretoria with a joint lecturing position at the University of the Witwatersrand. She works on fire ecology, biogeochemistry and savannah structure and function. Her research is progressive in its integration of modeling, field data, eddy-covariance data, and remote-sensing technology to improve our understanding of savannah ecology. This research not only helps to ensure that southern African systems are correctly represented in global biogeochemical models, but also has implications for the management of savannah parks and rangelands.

Dr Archibald is a member of the South African Association of Botanists the Society for Conservation Biology and the Southern African Fire Network. She received the Ecological Society of America Mercer award for the best publication by a young scientist in 2012.

Alexis Comber has a BSc in Plant Sciences from the University of Nottingham in 1997 and a PhD in Computing Science from the University of Aberdeen in 2001.

He is currently a Reader in Geographic Information at the University of Leicester. His research interests are in spatial analysis and geo-computation applied across a range social and environmental of domains, as reflected in his publications, research funding successes and PhD supervision.

Heiko Balzter was awarded the degree of Dipl. Ing .agr. (equivalent to an MSc) in1994from Justus-Liebig-University, Giessen, Germany, and the Dr.agr. (PhD) from the same University in 1998.

He is a research professor and director of the Centre for Landscape and Climate Research at the University of Leicester, UK. Before joining the University of Leicester he was Head of Section for Earth Observation in the Centre for Ecology and Hydrology, Monks Wood, UK, where he worked from 1998-2006. His research interests include interactions of the water cycle with ecosystems across multiple spatial and temporal scales, pressures from climate change and land use change on ecosystem services, and the effects of spatial patterns and processes upon biological populations in evolving, three-dimensional landscapes.

Prof. Balzter is a member of the American Geophysical Union, British Ecological Society, Remote Sensing and Photogrammetry Society and Chartered Management Institute, as well as fellow of the Royal Geographical Society, and the Royal Statistical Society. He is coordinator of the European Centre of Excellence in Earth Observation Research Training GIONET, and recipient of the Royal Society Wolfson Research Merit Award 2012. He won the President's Cup for the Best Paper at the annual Remote Sensing and Photogrammetry Society conference 2009and serves on the International Geosphere/Biosphere Programme (IGBP) UK National Committee, European Space Sciences Committee (ESSC) of the European Science Foundation (ESF), LULUCF Scientific Steering Committee for the Department for Energy and Climate Change, AATSR Science Advisory Group to DEFRA (Department for Environment, Food and Rural Affairs), and the Natural Environment Research Council (NERC) Peer Review College.