Comparing the vertical structure of tropical forests as seen by space- and airborne lidar and P-band SAR tomography

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1. Introduction

Forests cover 31% of the global land area, and monitoring forest resources are therefore critical for understanding earth's ecosystems. The NASA's Global Ecosystem Dynamics Investigation (GEDI) mission uses a full-waveform lidar system to measure forest structure from space (Dubayah, R., et al., 2020). However, lidar observations are impacted by cloud cover and haze in tropical forests. Synthetic Aperture Radar (SAR) can penetrate clouds. In addition, the long-wavelength SAR system such as P-band can record backscattered signal under the canopy. As the first P-band SAR satellite in the world, ESA's BIOMASS satellite is planned to launch in 2022 (Le Toan, T., et al., 2011). During its SAR tomography (TomoSAR) phase, multi-pass SAR images with different elevation angles will be processed to retrieve the reflectivity profiles of forests. TomoSAR profiles show some similarities with lidar waveforms because they are continuous indicators of the vertical structure of forests. Therefore, the difference in wavelength, imaging geometry and operating spatial coverage between GEDI on the International Space Station and BIOMASS in a polar orbit create the potential for forests measuring and monitoring at a global scale in temperate and tropical ecosystems. Here, we compare full-waveform lidar observations from GEDI and airborne systems with TomoSAR images in P-band as acquired by the AfriSAR2016 campaign over Lopé, Gabon.

2. Data and Methods

2.1 Data

Our research area is located in Lopé National Park (Figure 1), where is mainly covered by savanna (0 to 15 m in height) and forests (30 to 50 m), with tree canopy cover ranging from 0 to 0.99. The maximum terrain slope can reach 20^{o}. In order to exclude the influence from background solar illumination, we only use GEDI data acquired at night. The GEDI L1B Version 1 product (Dubayah, R., et al., 2020) and GEDI L2A Version 1 product (Dubayah, R., et al., 2020) are filtered according to quality and degrade flags. GEDI and LVIS can achieve 1 m vertical accuracy, determined by the 15 ns and 11 ns bandwidth. The airborne lidar data and airborne P-band SAR data were acquired by NASA's Land, Vegetation and Ice Sensor (LVIS) team (Blair, J. B., et al., 2018) and by DLR's F-SAR system, during AfriSAR2016 campaign (Hajnsek, I., et al., 2011). Some key parameters of the data are listed in Table 1.

Table 1. Key parameters of the data.

Sensor	Platform	Wavelength	Acquisition time	Resolution	Reference ellipsoid	Geolocation accuracy
GEDI	Spaceborne	1064 nm	14.08.2019	25 m	WGS-84	10-20 m
LVIS	Airborne	1064 nm	02.03.2016	18 m	WGS-84	1 m
FSAR	Airborne	69 cm	10.02.2016	2 × 3.84 m	WGS-84	0.15 m

2.2 SAR Tomography

SAR Tomography (TomoSAR) assumes the recorded complex value in each azimuth-range cell is the integration of backscattered signal along cross range direction. The multitrack SAR images acquired at different positions can then be used to estimate reflectivity profile, which indicates the volumetric information of imaging objects. For our forests scenario, a 20 m × 20 m multilook window was used to generate covariance matrix from 10 Single Look Complex (SLC) images at HV polarization.

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We applied the popular Capon method (Lombardini, F., et al., 2003) and then transform retrieved profiles from SAR geometry to a geographic coordinate system (Pardini, M., et al., 2018). The vertical Rayleigh resolution of TomoSAR changes from 8 m (near range) to 40 m (far range) along slant range direction, which is determined by the imaging geometry and wavelength. However, Capon can achieve better vertical resolution (Cazcarra-Bes, V., et al., 2019). Considering the similarity with lidar waveform, we use the term “waveform” to describe these derived profiles as well. Based on the local maxima above 0.1 in normalized TomoSAR waveform, we estimated the relative height (RH) metrics.

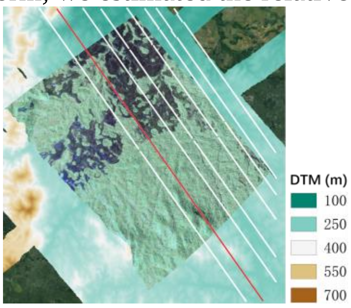


Figure 1: Lopé. From Google basemap to top: LVIS DTM, P-band Pauli SLC and GEDI footprints.

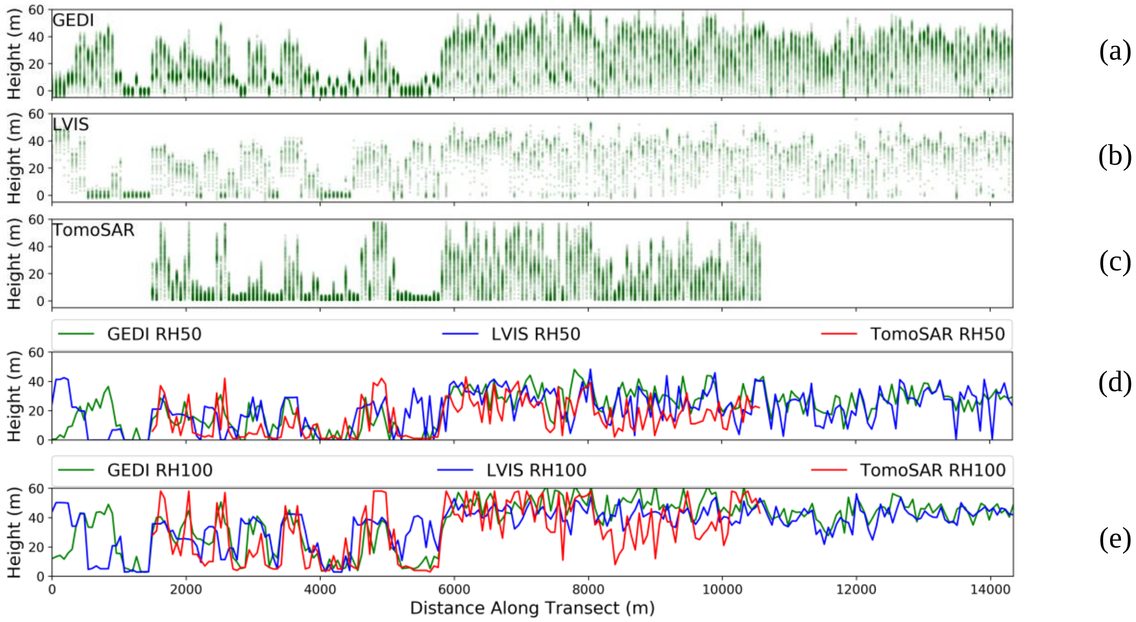
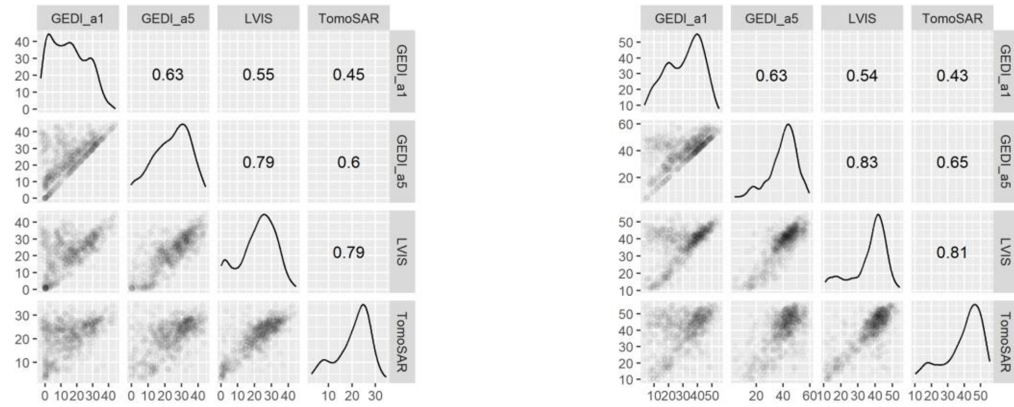


Figure 2: (a)-(c): Slice of RH0 to RH100. (d)-(e): Slice of RH50 and RH100.

3. Results and Discussion

In Figure 2 (a)-(c), we plot the RH0-100 along a full power beam BEAM1000 (i.e., red points in Figure 1). The coverage beam and full power beam are two beam patterns of GEDI, and full power beam has a design specification to detect the ground through 98% canopy cover. Note RH0-100 from GEDI L2A Version 1 product and TomoSAR are sampled with 1% while only RH in step of 5% is available for LVIS. In the overlapped area (1500~10500m), these three sensors present similar forest top height. The distribution of GEDI RH metrics is more consistent with LVIS than TomoSAR, especially in the hilly area from 8000 m to 10000 m (see Figure 1). As we can see from Figure 2 (d)-(e), TomoSAR RH50 and RH100 both generally matches well with lidar. It means, besides forest top height, there is also similarity in the vertical distribution of waveforms as well as corresponding forest structure.

We also analysed the RH50 and RH100 from LVIS and TomoSAR with all GEDI data processed using two different algorithms, i.e., a1 (default) and a5, to figure out the influence of ground detection algorithms in dense forests. The main difference between a1 and a5 is the threshold and smoothing settings used to interpret the received waveform. LVIS metrics are highly related with TomoSAR for both RH50 and RH100 (Figure 3). However, the GEDI metrics derived with a5 and selected with minimum sensitivity of 0.96 show significantly improved relation with LVIS and TomoSAR.



(a) RH50 (b) RH100

Figure 3: (a): RH50 with GEDI_a1 and a5. (b): RH100 with GEDI_a1 and a5. (upper triangle) Pearson correlation, (diagonal) variable distribution, and (lower triangle) scatterplots of each pair are showed.

4. Conclusions

In this abstract, we compared the relative height (RH) metrics from GEDI, LVIS and airborne P-band TomoSAR. Both GEDI and TomoSAR show some consistency with LVIS data. The agreement between GEDI and the BIOMASS TomoSAR RH metrics may be affected by coarser resolution and the three-year time lag between both observations. Nevertheless, the continuous spatial and temporal coverage of SAR data provides us an opportunity to measure and monitor forest vertical structure at a larger scale than lidar. The retrieved vertical profiles can then be converted to biomass profiles (Caicoya, A., et al.). Thus, the use of GEDI products as reference points in forests without airborne lidar or in-situ plots is likely to be a fruitful avenue for the development of 3-dimensional forest biomass products from future BIOMASS TomoSAR observations.

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References

Dubayah, Ralph, et al. "The Global Ecosystem Dynamics Investigation: High-resolution laser ranging of the Earth’s forests and topography." Science of remote sensing 1 (2020): 100002.

Le Toan, Thuy, et al. "The BIOMASS mission: Mapping global forest biomass to better understand the terrestrial carbon cycle." Remote sensing of environment 115.11 (2011): 2850-2860.

Dubayah, R., et al. (2020). GEDI L1B Geolocated Waveform Data Global Footprint Level V001 [Data set]. NASA EOSDIS Land Processes DAAC. Accessed 2021-04-16 from https://doi.org/10.5067/GEDI/GEDI01_B.001.

Dubayah, R., Hofton, M., Blair, J. B., Armston, J., Tang, H., Luthcke, S. (2020). GEDI L2A Elevation and Height Metrics Data Global Footprint Level V001 [Data set]. NASA EOSDIS Land Processes DAAC. Accessed 2021-04-16 from https://doi.org/10.5067/GEDI/GEDI02_A.001.

Hajnsek, I., et al., “Technical assistance for the development of airborne SAR and geophysical measurements during the AfriSAR campaign,” Eur. Space Agency, Paris, France, Final Tech. Rep. 4000114293/15/NL/CT, 2011. [Online]. Available: https://earth.esa.int/documents/10174/134665/AfriSAR-Final-Report.

Blair, J. B. and Hofton, M. 2018. AfriSAR LVIS L1B Geolocated Return Energy Waveforms, Version 1. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/ED5IYGVTB50Z. [Date Accessed].

Lombardini, Fabrizio, and Andreas Reigber. "Adaptive spectral estimation for multibaseline SAR tomography with airborne L-band data." IGARSS 2003. 2003 IEEE International Geoscience and Remote Sensing Symposium. Proceedings (IEEE Cat. No. 03CH37477). Vol. 3. IEEE, 2003.

Pardini, M., et al. "L-and P-band 3-D SAR reflectivity profiles versus lidar waveforms: The AfriSAR case." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 11.10 (2018): 3386-3401.

Cazcarra-Bes, Victor, et al. "Comparison of tomographic SAR reflectivity reconstruction algorithms for forest applications at L-band." IEEE Transactions on Geoscience and Remote Sensing 58.1 (2019): 147-164.

Caicoya, Astor Toraño, et al. "Forest above-ground biomass estimation from vertical reflectivity profiles at L-band." IEEE Geoscience and Remote Sensing Letters 12.12 (2015): 2379-2383.