Improving GEDI Footprint Geolocation using a High Resolution Digital Terrain Model

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1. Introduction

In 2018, NASA launched the Global Ecosystem Dynamics Investigation (GEDI) mission, a high resolution lidar system installed onboard the International Space Station (ISS). It is producing high quality 3D observations of the Earth surface structure, which are highly relevant to study forest ecosystems at a global scale (Qi et al. 2019). GEDI data is composed of 25 m diameter circular footprints for which the waveform of the received energy intensity returned by the ground is recorded. Each GEDI footprint is georeferenced and its positioning accuracy (for version 1 releases) is estimated at 15-20 m in planimetry with a systematic component of 8-10 m and a noise of the order of 8 m (1σ). A final horizontal geolocation accuracy of 8 m is expected after further processing in the final version (Dubayah et al. 2020).

Compared to most other spatial satellites the ISS is much closer to earth, causing more variations in its orientation and altitude. Therefore, geolocating data acquired by ISS sensors is more diffucult than geolocating data aquired by satellites (Dou et al. 2014). An improved geolocation of GEDI data is mandatory to evaluate their quality, by comparison with other earth observation data or field measurements, and to further facilitate their integration in ecosystem monitoring approaches. We propose a method to improve the georeferencing of GEDI footprints using a precise Digital Terrain Model (DTM).

2. Data and Methods

2.1 Data

The study site is located in south-western France and includes the Landes forest, the largest metropolitan French forest. All GEDI data of the study site has been downloaded from NASA's archive center. However, for this study, we will focus on version 1 of the level 2A product of the orbit N°3709, acquired during daytime on August 8th 2019. The area intersected by this orbit is mainly agricultural with several small tree patches. To avoid issues with ground elevation estimation, only high quality and full power data are used (Duncanson et al. 2020). The latitude, longitude and elevation of the lowest mode (i.e. ground peak) are respectively assimilated to the footprint centre coordinates and the mean ground elevation within the area covered by the footprint. The height of the highest canopy return (i.e. RH 100) is also extracted.

The reference DTM used is a 1 m resolution DTM (RGE Alti©) of the National Institute of Geographic and Forest Information (IGN) derived from both airbone lidar data and airbone stereoscopic images. The vertical accuracy (Root Mean Square Erreur, RMSE) is either 30 cm or 70 cm, depending on the data source. To allow comparison with GEDI, a moving window algorithm was applied to the DTM, by computing for each pixel the average DTM value in a 25 m circular window. The resulting 1 m resolution focal DTM was referred to as DTMref.

A photogrammetric digital surface model (DSM) derived from aerial photographs (1 m resolution) acquired in summer 2018 was also provided by IGN. As for the DTM, a DSMref is created using the same moving window algorithm and the maximum focal statistic. For each 1 m grid cell, the maximum

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height value of the surrounding 25 m diameter circle of the DSM is assigned, which is assumed to be comparable to the elevation of the highest canopy return of a GEDI footprint.

2.2 Methods

The geolocation adjustment method assumes that, 1) errors between GEDI ground elevations and DTMref are minimal when the footprints are shifted by a distance in latitude (Y) and longitude (X) corresponding to the effective geolocation of the GEDI footprints and 2) the shift remains optimal for a subset of contiguous footprints acquired within a time period and despite possible abrupt changes in ISS orientation and altitude; the maximum length of such subset needs to be defined.

The optimal shift is obtained by testing all possibilities (by 2 m steps) within a range of shifts of ±50 m in X and Y, and identifying the position which minimizes the difference between DTMref and GEDI elevations. Considering all potential shifts, leads to 2601 vectors of N elevation differences, N being the number of footprints of the considered orbit segment. For each vector, two statistic indictors were tested, the RMSE and the Mean Absolute Error (MAE), and were used to produce the corresponding error maps of the search area.

An accumulation flow algorithm is then applied to the error maps. A simple divergent flow algorithm, called FD8 (Freeman 1991), commonly used for watershed computations, is used. Thus, the lowest grid values should have the highest flow accumulation values (see Figure 1).

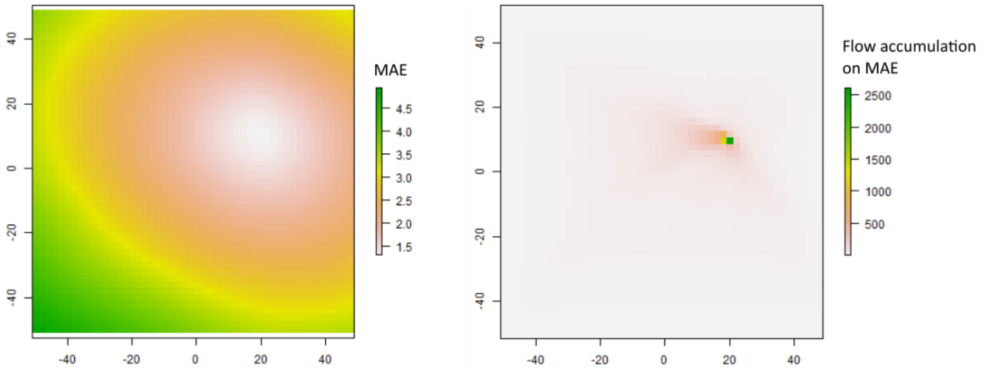

Figure 1: Example of error map showing the MAE for each tested shift (left) and the flow accumulation results applied to the error map (right).

Next, two approaches were tested. The first consists in defining the maximum value in the accumulation grid, as the optimal adjustment, i.e. the shift in Y and X that has to be applied to the GEDI footprint coordinates to improve their geolocation. The second approach is to keep the 1% of the highest accumulation values in the accumulation grid, and to calculate a weighted average of the coordinates to define the final optimal shift. This barycentre method is assumed to be less sensitive to outliers. In total, four methods were tested: maximum flow accumulation on RMSE and MAE error maps, and barycentre of maximum flow accumulation on RMSE and MAE error maps.

The number of footprints taken into account for the statistic indicator can be modulated. All footprints of an orbit that are within the study area can be used to find one global optimal shift. To take better account of ISS instability, one optimal shift can also be computed for each footprint individually, using a certain number of neighbouring footprints, which are selected based on GPS time and for a time interval centred on the single given footprint. In this study, a time interval of 0.215 seconds was chosen, resulting in about 200 neighbouring footprints, covering a zone of 3 by 2 km².

To evaluate our results the final RMSE and MAE before and after shifting are compared. An independent method is also used by applying the shifts to the DSMref and comparing the vegetation heights before and after applying the shifts.

3. Results and Discussions

When calculating a shift for each footprint individually, an important variability is observed. For the studied orbit, all shifts are positive, from 4 to 34 m for X and from 4 to 26 m for Y. The improved GEDI geolocations are oriented north-eastern from the original positions. There are gradual variations as well as abrupt changes.

As quick changes in the shift values are observed, computing only one shift for all data of an orbit seems less appropriate. Nevertheless it could be considered if a rough geolocation is sufficient.

The four methods give very similar results when looking at the overall RMSE (2.50 before and 2.10 m after adjustment) and MAE (1.45 before and 1.07 m after adjustment). Considering only ground elevation data, it is difficult to evaluate which method adjusts best the geolocation of the GEDI data.

When GEDI vegetation height (RH100) and the photogrammetric DSMref were compared with and without shifts, the MAE barycentre method was found to perform better. Before correction, the RMSE was 5.55 m and the MAE was 3.82 m. After correction, it respectively passed to 3.81 m and 2.66 m. The geolocation adjustment considerably improved the vegetation elevation estimation of GEDI (see Figure 2).

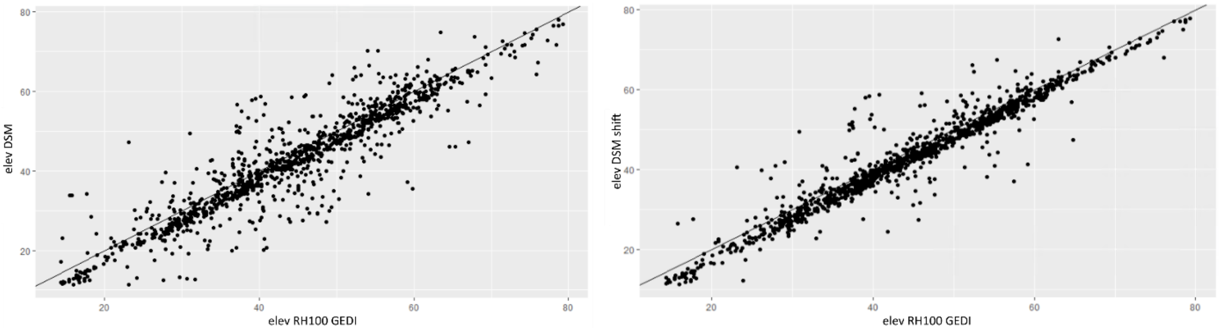

Figure 2: GEDI and DSM elevation without (left) and with the geolocation correction (right).

4. Conclusions

GEDI data provide information about forest structure at large scale and with a high sampling density, but their lack of georeferencing accuracy can be detrimental to their use in building models on forest attributes. The proposed method proved successful to improve footprint geolocation based on an orbit, but has to be further evaluated on more orbits and over more forests. Although the next generation of GEDI releases should have improved geolocation, the presented method, which can be performed in areas having high resolution DTM, could still be used to further improve footprint positioning.

Preliminary results show that the methodology provides corrections in the same direction than GEDI v2, but with lower RMSE and MAE values. The method will be applied on GEDI v2 and ICESat-2 data and in more complex environment (vegetation and topography) to assess the impact of elevation heterogeneity on lidar products and on the performance of the algorithm.

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