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Evaluation of CartoDEM with ICESat-2 and GEDI Spaceborne LiDAR datasets for parts of Plain Region in Moga District, Punjab †

Ashutosh Bhardwaj *, Hari Shanker Srivastava and Raghavendra Pratap Singh

Indian Institute of Remote Sensing; hari.isro@gmail.com (H.S.S.), rpsingh@iirs.gov.in (R.P.S.)

* Correspondence: ashutosh@iirs.gov.in; Tel.: +91-135-2524350, Dehradun, India – 248001

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Abstract: CartoDEM Version 3 Release 1 openly accessible datasets are currently the most reliable datasets for the relatively plain region in India specifically. The presented study is to evaluate the CartoDEM with respect to the two openly accessible space borne LiDAR datasets from the LiDAR sensors: Advanced Topographic Laser Altimeter System (ATLAS) on-board the Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) and Global Ecosystem Dynamics Investigation (GEDI) over the International Space Station (ISS). The difference or deviation were computed for the CartoDEM and the LiDAR footprint elevations for the two datasets namely, ICESat-2 and GEDI. The difference values were filtered for footprints with difference between 0 to 2.5 in the DEM and LiDAR elevation values. Besides this an overall estimate is also done for the elevation values obtained over the surface i.e. ground as well as the objects such as the trees or buildings. The RMSE is observed as 1.16m and 1.74m for ICESat-2 and GEDI dataset for the points/footprints on the terrain. Whereas considering similar parameters for the two datasets the RMSE is obtained as 1.78m and 5.48m for the ICESat-2 and GEDI footprints on the surface (terrain/object) respectively. The study reveals that the CartoDEM is highly accurate in the plains when validated with respect to the ICESat-2 datasets which work on the photon counting technique. Further it is observed that the ICESat-2 performance is better than the GEDI mission for the terrain height. Thus it can be observed that the spaceborne LiDAR datasets from ICESat-2 can be utilized for validation of DEMs and can be useful for applications where a input of DEM is required for engineering or modelling applications.

Keywords: RS&GIS; DGPS; GCPL; Cartosat-1; Satellite Triangulation

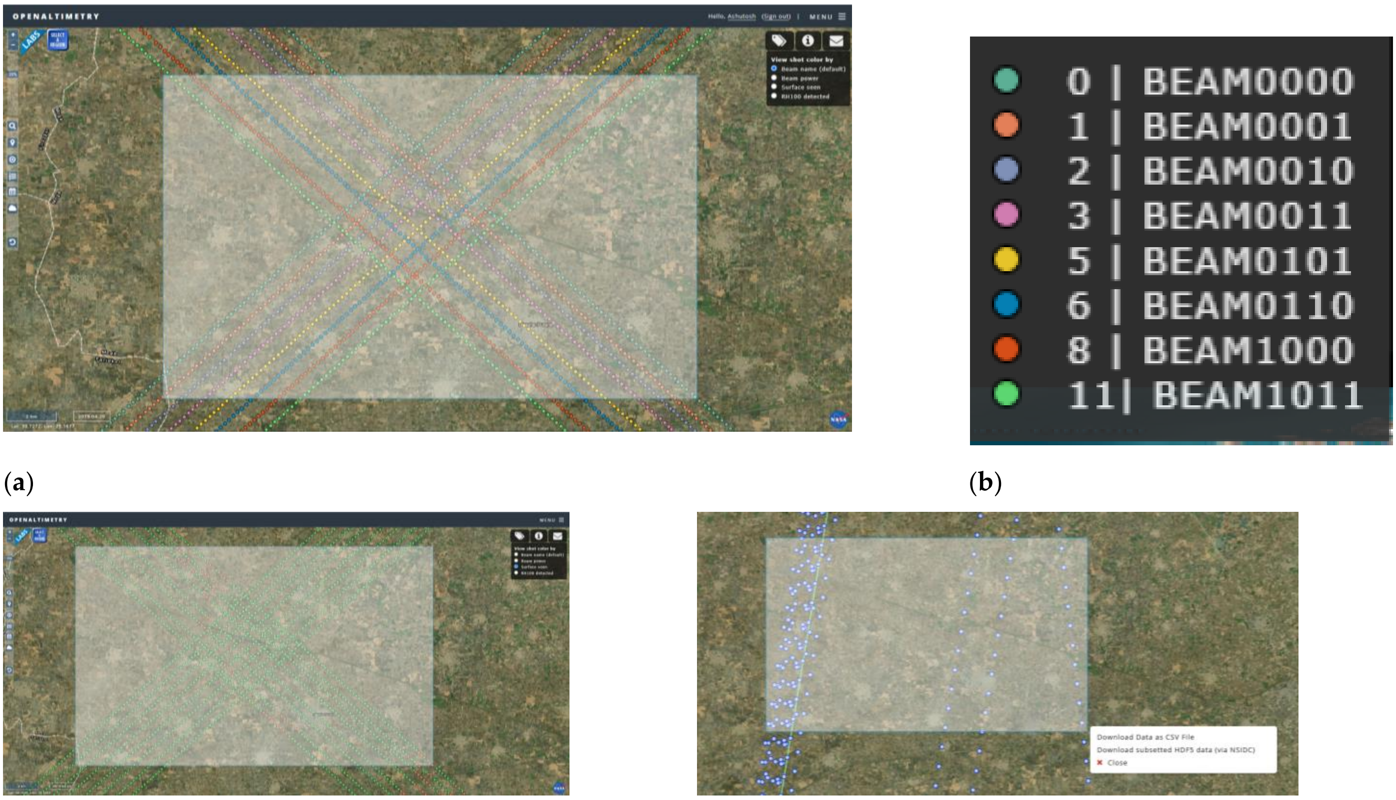
1. Introduction

Digital Elevation Model (DEM) is commonly defined as "a digital representation of the terrain". DEMs are currently being prepared and are available for Earth and other celestial bodies like Moon and Mars, so a wider set of definition is more acceptable or desirable at present. Thus DEM is now aptly defined as "a digital representation of elevations (or height) of a topographic surface in form of a geo-rectified point-based or area-based grid, covering the Earth or other solid celestial bodies" [1]. The DEMs express the topographic information digitally, providing a convenient means for terrain analysis, visualization as well as an input to models used in scientific analysis or predictions, which can further be improved by DEM fusion [2–4]. Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) elevation datasets are also being used for the improvement of DEM as well as simulation of DEM using machine learning techniques [5,6].

Studies have found that he accuracy of terrain height obtained from Global Ecosystem Dynamics Investigation (GEDI), available on International Space Station (ISS) is lower than that of Advanced Topographic Laser Altimeter System (ATLAS) sensor on ICESat-2 satellite. However, GEDI has the advantage of more intensive spatial sampling useful for the estimations of tree canopy and biomass [7]. The techniques like Random Sample Consensus (RANSAC) are used for fitting a model to the experimental scientific input datasets while smoothening it [8,9] for remote sensing and photogrammetric solutions. The Constraint Analysis and Monitoring System (CAMS) utilizes a sophisticated set of algorithms to model and predict the position (location) and attitude (pointing) of the ICESat-2 instrument providing highly accurate position of it. The four major operational components are the Attitude Predictor and Event Scheduler (APES), Long-Term Orbit Predictor (LTOP), Two-Line Element (TLE) Propagator (TLEP), and Constraint Monitor (CM) [10]. These openly available global datasets have opened a gateway for the researcher communities for utilization of these in their domains. The current study compares and evaluates the CartoDEM V3 R1 (henceforth referred as CartoDEM) elevation values with the terrain height provided by the ICESat-2 and GEDI.

2. Material and Study Area

Openly accessible datasets namely, CartoDEM, ICESat-2 and GEDI datasets were used in this study. The study area is selected in the relatively plain region around Moga District, Punjab as the GEDI has multiple passes in this region (Figure 1(a) with Beam Names and Figure 1(c) under Surface seen category), providing a good set of data for the purpose of the study with beams shown in Figure 1(b).



(**a**) (**b**) (**c**) (**d**)

Figure 1. Showcases the footprints of the laser from the two sensors: - (**a**) GEDI Beams over Moga region, (**b**) Beam Names/Types, (**c**) GEDI footprints over parts of Moga district; (**d**) ICESat-2 footprints over parts of Moga district.

CartoDEM

CartoDEM Version 3 Release 1, is an improved DEM generated from Cartosat-1 stereo datasets utilizing the ground control points (GCPs) from the GCP Library (GCPL) for satellite triangulation [11,12] as well as corrections for waterbodies [13]. The CartoDEM was downloaded from the Bhuvan web portal (Open data archieve) of National Remote Sensing Centre and shown in Figure 3 [14]. CartoDEM V3 R1 is the most dependable openly accessible DEM, since it is corrected through manual interventions, after the automatically generated DEM.

ICESat-2

ICESat-2 with Advanced Topographic Laser Altimeter System (ATLAS) instrument was launched by NASA and measures the elevation of Earth's surface using laser wavelength of 532 nm and PRF of 10 kHz producing ~70 cm footprint on the ground. This ATL08 dataset provides geolocated land-ice surface heights (WGS 84, ITRF2014), plus ancillary parameters on quality of the height estimates in the form of terrain uncertainty, that can be used to interpret or filter the values as per the requirements of an application. Figure 1(d) showcases footprints of one of the passes over the study area [15]. All the utilized ICESat-2 passes are shown in Figure 3.

GEDI

GEDI is deployed on the Japanese Experiment Module – Exposed Facility (JEM-EF), and uses 1064 nm pulses at 242 Hz. The GEDI produces high-resolution laser ranging observations of the 3D structure of the Earth including forest canopy height, canopy vertical structure, and surface elevation to characterize carbon and water cycling processes, biodiversity, and habitat. It consists of 3 lasers, among which two are full power and one is split into two, producing a total of 8 beam ground transects. This results in about 25 m to 30 m footprint samples spaced approximately every 60 m along-track. The GEDI beam transects are spaced about 600 m apart on ground with the use of Beam Dithering Units (BDUs), in the cross-track direction, for an across-track overall width of ~4.2 kilometers (km) [16,17].

3. Methodology

The figure 2 provides the Methodology used for the comparison and evaluation of the openly accessible datasets with validation of CartoDEM with ICESat-2 ATL08 dataset. The deviations were computed between the elevation values of CartoDEM and the two LiDAR datasets namely, ICESat-2 and GEDI at the footprint locations. There after the difference values were filtered for footprints with difference between 0 to 2.5 in the DEM and LiDAR elevation values to include the hanging points above the DEM, while excluding objects like single or more - storey building's. The ICESat-2 and GEDI footprints were overlaid on the CartoDEM V3 R1 dataset as shown in Figure 3 for visualization. Besides this an overall estimate is also done for the elevation values obtained over the surface i.e. ground as well as the objects such as the trees or buildings.

The root mean square error (RMSE) were calculated using equation 1 and equation 2 respectively for ICESat-2 and GEDI, to assess the variability among the elevation values. Additionally, the method of vertical accuracy assessment for DEM have been detailed in terms of linear error at 90 percentile (LE90, 90% confidence) and is used extensively for accuracy assessments of DEMs (equation 3) [18–20]. Mean error (ME) and mean absolute error (MAE) are also estimated for an assessment of overestimation and underestimations on the sampled footprint locations. Mean absolute deviation (MAD) is computed to assess the dispersion or variability in a ICESat-2 and GEDI datasets. MAD is computed using the average absolute difference between each data point and the mean of the dataset. Chi et al. (2014) and Willmott et al. (2005) has discussed the pros and cons of the MAE and RMSE based statistics, which is essential in the interpretations of datasets while constructing the inferences [21,22].

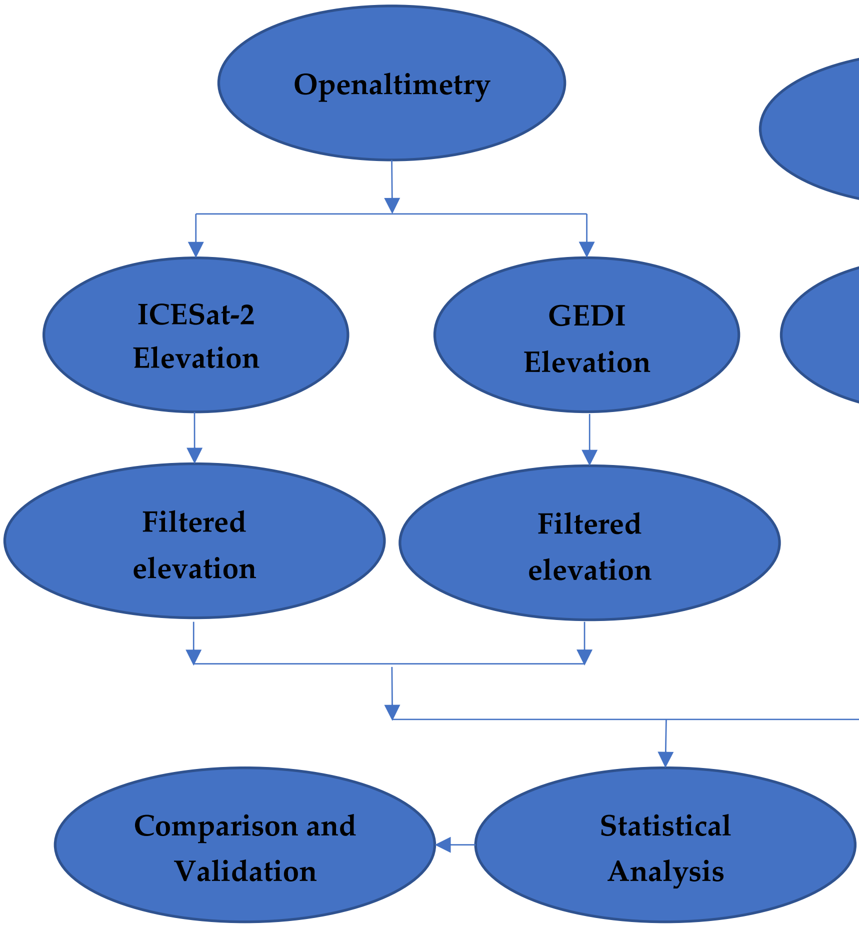


Figure 2. Flowchart for Evaluation of CartoDEM with ICESat-2 and GEDI Spaceborne Lidar datasets for parts of Plain Region in Moga District, Punjab.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Z_{i(CartoDEM)} - Z_{i(ICESat-2)})^2}{n}} \quad (1)$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Z_{i(CartoDEM)} - Z_{i(GEDI)})^2}{n}} \quad (2)$$

where $Z_{i(CartoDEM)}$ is the extracted elevation from the CartoDEM products at the ICESAT-2 / GEDI footprint locations, $Z_{i(GEDI)}$ is the extracted elevation from the GEDI product and $Z_{i(ICESat-2)}$ is the observed reference elevation with i=1 to n; where n indicates the number of observations available for the comparison and / or validation.

$$\mathrm{LE90} = 1.6449 * \mathrm{RMSE} \quad (3)$$

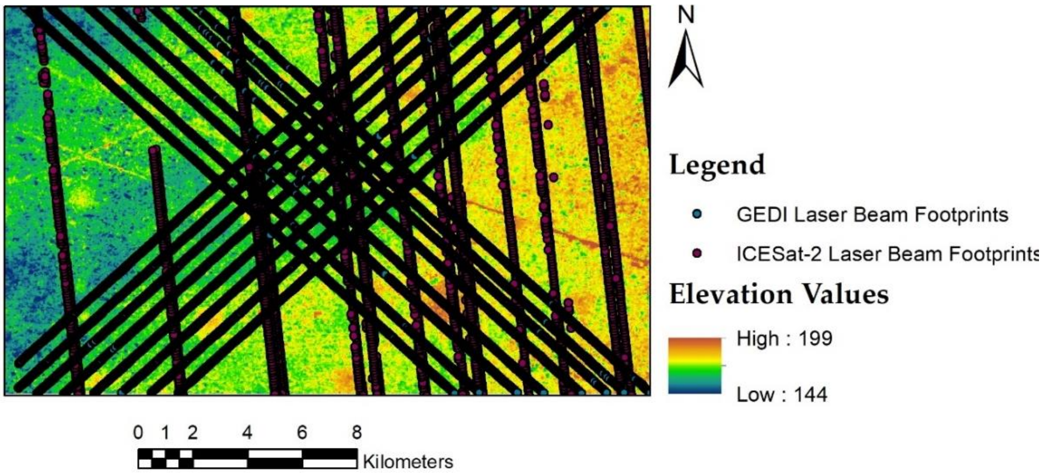


Figure 3. Depicts the ICESat-2 and GEDI footprints locations overlaid on the CartoDEM Version 3 Release 1 dataset of Moga region in Punjab.

4. Results and Discussion

Figure 3 depicts the ICESat-2 and GEDI footprints locations overlaid on the CartoDEM Version 3 Release 1 dataset of Moga region in Punjab. The RMSE is observed as 1.16m from the filtered 2802 footprints and 1.74m from the filtered 367 footprints for ICESat-2 and GEDI dataset for the locations of the footprints on the terrain as shown in Table 1 considering the deviations of less than 2.5m (Table 1). Whereas considering the values deviations of about 10m the two datasets the RMSE is obtained as 1.78m from the filtered 5203 footprints and 5.48m from the filtered 4882 footprints for the ICESat-2 and GEDI footprints on the surface (terrain/object) respectively. MAD in Table 1 depicts that the filtered samples at difference values of 2.5m has dispersion or variability in a ICESat-2 and GEDI datasets, indicating a better means for assessment of CartoDEM accuracy. The study depicts that through proper selection or filtering, ICESat-2 datasets can be used for applications requiring digital terrain models (DTM), digital surface models (DSM), and normalized digital surface models (nDSM) suitably considering the study areas and the footprint sizes. nDSM can be obtained through subtraction of DSM and DTM for specific applications, providing object (tree, building, etc.) heights [23]. The results achieved in our study are very close to those which are achieved by Pronk et al. (2023) for their latest study. Pronk et al. (2023) has also shown that for all areas and land cover classes combined, ICESat-2 achieves a bias of −0.06 m, a MAE of 0.46 m, and a RMSE of 1.39 m; whereas GEDI is observed to have less accurate with a bias of 0.45 m, a MAE of 0.98m and a RMSE of 5.66 m [24]. A utilization of difference of +/- 0.5m can also be used for filtering for more stringent studies depending on the application.

Table 1. Describes the ME, MAE, MAD, RMSE and LE90 values for on ground (considered as suitable for DTM) or on surface (considered as suitable for DSM) application suitability for the two LiDAR datasets.

Datasets	DTM/DSM Applications	No. Of footprints	ME (m)	MAE (m)	MAD (m)	RMSE (m)	LE90 (m)
ICESat-2	DTM (on ground)	2802	0.94	0.94	0.57	1.16	1.91
	DSM (on surface)	5203	-0.06	1.31	1.31	1.78	2.93
GEDI	DTM (on ground)	367	1.62	1.62	0.53	1.74	2.86
	DSM (on surface)	4882	5.15	5.15	1.47	5.48	9.01

It is observed from the Table 1 that as the filtering conditions are made more stringent for ICESat-2 datasets, the filtered values depict only overestimation of elevation values in CartoDEM, as only equal positive value remains for ME and MAE. Equal values for ME and MAE, in both cases of GEDI datasets indicate that as per the filtered parameters, only overestimations are available in CartoDEM on sampled locations. The ICESat-2 platform at a higher altitude is more stable than the GEDI over ISS, thus provide better pointing as well as accuracy for terrain height measurements. The ME of -0.06m for 5203 footprints also provides a reasonable indication of the good quality of filtered samples of ICESat-2 dataset.

5. Conclusion

The study focused on the evaluation of the quality of elevation products derived from the two sensors GEDI and ATLAS. The study concluded that ICESat-2 datasets are relatively closer to the CartoDEM V3 R1 elevation values as compared to GEDI dataset, primarily emphasizing on the more stable orbital dynamics of the ICESat-2 as compared to the GEDI on ISS platform. Further, the availability of large number of high quality filtered elevation values, qualify the filtered ICESat-2 data for validation of DEMs such as CartoDEM in the presented study for region having plain topography. Mean absolute deviation (MAD) and Mean Error (ME) are able to quantify the dispersion or variability and bias respectively for the filtered sample datasets of ICESat-2 and GEDI, depicting the superiority of ICESat-2 datasets over GEDI datasets. The study also quantifies the expected accuracy that can be achieved from the GEDI over a plain area, which is important for its utilization into any project work or development of similar sensors on the manned stations. The manned stations follow different orbital dynamics, such as the Russian Progress Spacecraft is used for the orbit raising maneuvers for the ISS, which loses about two kilometers every month.

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Conflicts of Interest: The authors declare no conflict of interest.

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