Using high-resolution ICESat-2 point clouds to evaluate 1-3 arc second global digital elevation models

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Abstract— **ICESat-2 is a new sensor which has potential to create a digital elevation model. This study measures the effectiveness of an ICESat-2 photon point cloud against other traditional DEMS. The photon point cloud does not have sufficient data to create a new DEM. ICESat-2 data does, however, show how the free global digital one arc second elevation models SRTM, ALOS, and ASTER penetrated the canopy, and the extent to which they represent a digital surface model (DSM) versus a bare earth digital terrain model (DTM). ALOS and SRTM have better canopy penetration compared to ASTER. All three show peak returns at about the midpoint of the canopy recorded by ICESat-2. For this assessment the ICESat-2 elevation data performs better than the photon data, with a significantly reduced volume of data.**

I. Introduction

A high-resolution point cloud provides a 3D elevation model of topography. Millions of data points are placed within this 3-dimensional cloud with geo-referenced to x, y, and elevation. In this study, we populated the point cloud from the photon data of NASA's ICESat-2. The launch of the ICESat-2 occurred in the fall of 2018, making it an exciting new data source [1]. The 1354 ground tracks of the satellite repeat in a 91 day orbit cycle [1]. The expected lifetime of the ATLAS laser altimeter attached to ICESat-2 is five years. [1].

We looked at data from Brazil to evaluate two things: (1) the accuracy of global 1-3 arc second DEMs which measure some surface above the ground, and (2) the possibility of using ICESat-2 to improve those models. To confirm the applicability of the results, we looked at two additional areas in California and Virginia.

II. Methods

We evaluated three near global digital models in this study: ASTER [2], AW3D30 [3], and SRTM [4]. (Table 1). These all have 1" spacing, about 30 m, and are the best free DEMs covering most of the earth. The ASTER data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer from NASA was downloaded from NASA's EarthData site [5]. The AW3D30 data from the Advanced Land Observation Satellite from JAXA was downloaded from JAXA's ALOS Global Digital Surface Model webpage [6]. The SRTM data from the Shuttle Topography Mission from NASA and NGA was downloaded from USGS' EarthExplorer [7].

We used two different forms of the ICESat-2 data, from OpenAltimetry [8]. The satellite collects data on six parallel tracks along the satellite path; all share the same trackid. Two tracks, 90 m apart, have strong and weak beams, and are 3.3 km from the next pair of beams. The ATL8 elevation data measures the ellipsoidal ground elevation and the canopy height. The ATL02 data set detects individual photons spaced approximately 0.7 m apart with an associated quality level. Away from the poles, with each 91 day cycle the data collection shifts laterally, increasing the coverage area.

For the elevation data we converted the ground elevation to the EGM2008 geoid, and added the canopy elevation to get the elevation of the top of the canopy. To this database, at the location of each ICESat-2 record, we added the interpolated elevations and slopes of the global DEMs, and the land cover category.

We converted the photon data into a point cloud with the LAS format. The beam, track identifier, confidence level, and acquisition data are all stored in the LAS file. At this stage we filtered the points to remove those with lower quality, and converted the elevations to the EGM2008 geoid to match the global DEMs. We then created a grid with the density of the ISESat-2 photons within each 1"x1" cell of the global DEM. For all cells with at least 25 photons, we create a database similar to the one with the elevation data.

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Table 1. Global DEMs used

DEM	Spacing	Source	Producer	Precision	Years Acquired	Ref	Source
SRTM (v3)	1"	Radar	NASA	Integer	2000 (11 days)	[4]	[7]
ASTER GDEM	1"	Stereo NIR imagery	NASA / JAXA	Integer	2000-2013	[2]	[5]
ALOS World 3D AW3D30	1"	Stereo pan imagery	JAXA	Integer	2006-2011	[3]	[6]

III. DISCUSSION

Table 2 summarizes the data for the three areas, for both the elevation and photon data. For all three areas, with both the elevation and photon data, there is ICESat-2 data in much fewer than 1% of the cells in the corresponding 1" global DEM.

Figure 1 displays the distribution of points from the three DEMS as well as the point cloud ground and canopy top. Though the majority of the points seem to be in a comparable range, the ASTER data is consistently above the other DEMS in elevation. Figure 2 shows the distribution of the data along a single track and beam in parallel with the ICESAT-2 elevation data.

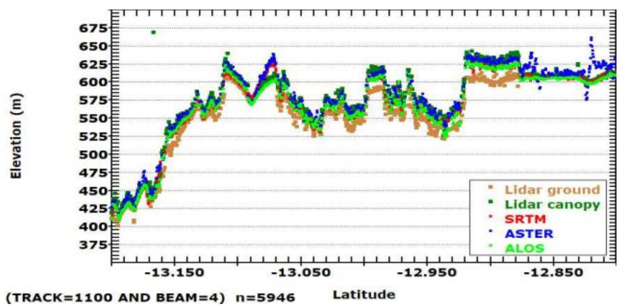

Figure 1. ICESat-2 photon data in Brazil and the three global DEMs.

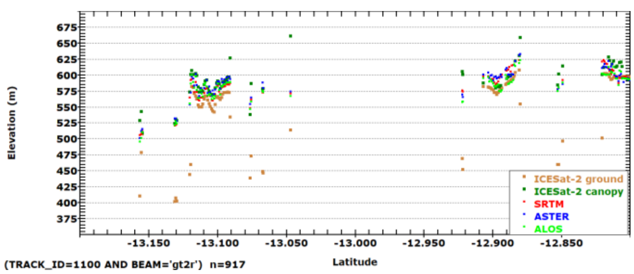

Figure 2. ICESat-2 elevation data in Brazil and the three global DEMs.

Figure 3 shows the percentage of values that falls between the ground and canopy top for each DEM for the three study areas. The California data shows the most consistency from the three DEMS in terms of percentage that falls within the point cloud. However, a good deal of data still falls both above and below the point cloud. The Brazil data shows that the ASTER data is mostly above the point cloud. The most compatible dataset to the Brazil photon point cloud is the ALOS DEM. The Virginia dataset shows that the majority of the dataset for all three DEMS falls above the point cloud.

The ICESAT-2 elevation data is also shown in Figure 3, where there are many fewer DEM elevations above the canopy top. The worst alignment occurs in Brazil and in Virginia with the ASTER DEM, a lot of the data falls above the ICESAT-2 data. In Brazil, all three DEMS have almost an equal amount of data below the dataset as inside of it. In the Virginia dataset, the ALOS DEM also has a lot of data beneath the ICESAT-2 elevation data.

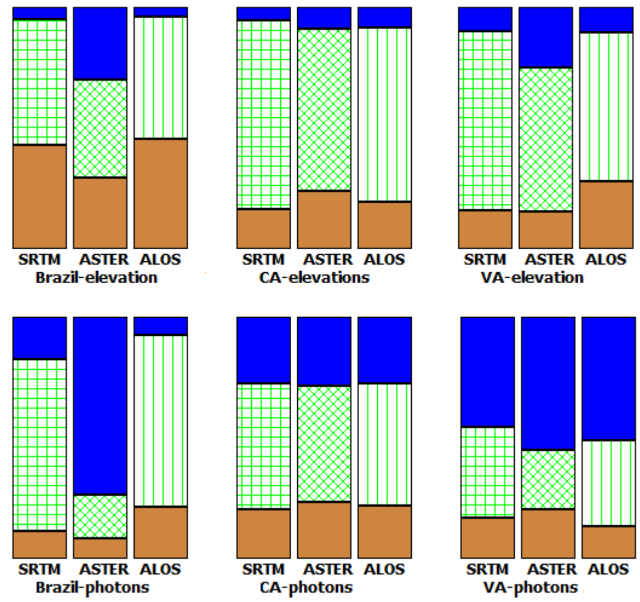

Figure 3. Proportion of data that falls within the point cloud among the three elevation models.

Figure 4 shows the distribution within the canopy of the DEM elevations. The elevations are scaled from 0 at the base of the canopy (lowest point cloud elevation in the cell) to 1 at the canopy top (highest elevation in the cell); the green shading highlights this range. A value of 2 indicates the point is twice the height of the canopy, and a value of -1 indicates the DEM elevation post was the height of the canopy below the ground level. In California, there is a division among the data with a large number of values above the point cloud and another large number of values at the ground of the point cloud data. In Virginia, it appears that SRTM has the most data in the middle of the cloud and that ALOS has a large number of points above the cloud. In Brazil, ASTER is mostly outside of the cloud, with a small number of values within the cloud. In this region of study, SRTM appears to be mostly within the recorded point cloud canopy as well.

Table 2. ICESat-2 study regions

AREA	LOCATION	1" CELLS	Points per cell	ICESat-2 elevations (m)	SRTM slope (%) and std dev	Canopy height (m) and std dev
Brazil-elevation	S13.31° W59.28°	26,717	2	182 to 713		8.78±21.52
CA-elevations	N39.86° W123.802°	75,893	2	-15 to 1764	24.50±18.42	24.31±13.97
VA-elevation	N39.17° W78.57°	4790	2	225 to 820		18.37±13.58
Brazil-photons	S14.14° W60.73°	4321	40	-76 to 1329	4.42±3.73	20.51±69.76
CA-photons	N39.86° W123.802	122,909	86	-310 to 1749	10.95±15.57	58.21±111.25
VA-photons	N38.47° W78.23°	74,250	91	15 to 1114	7.46±7.87	7.67±11.91

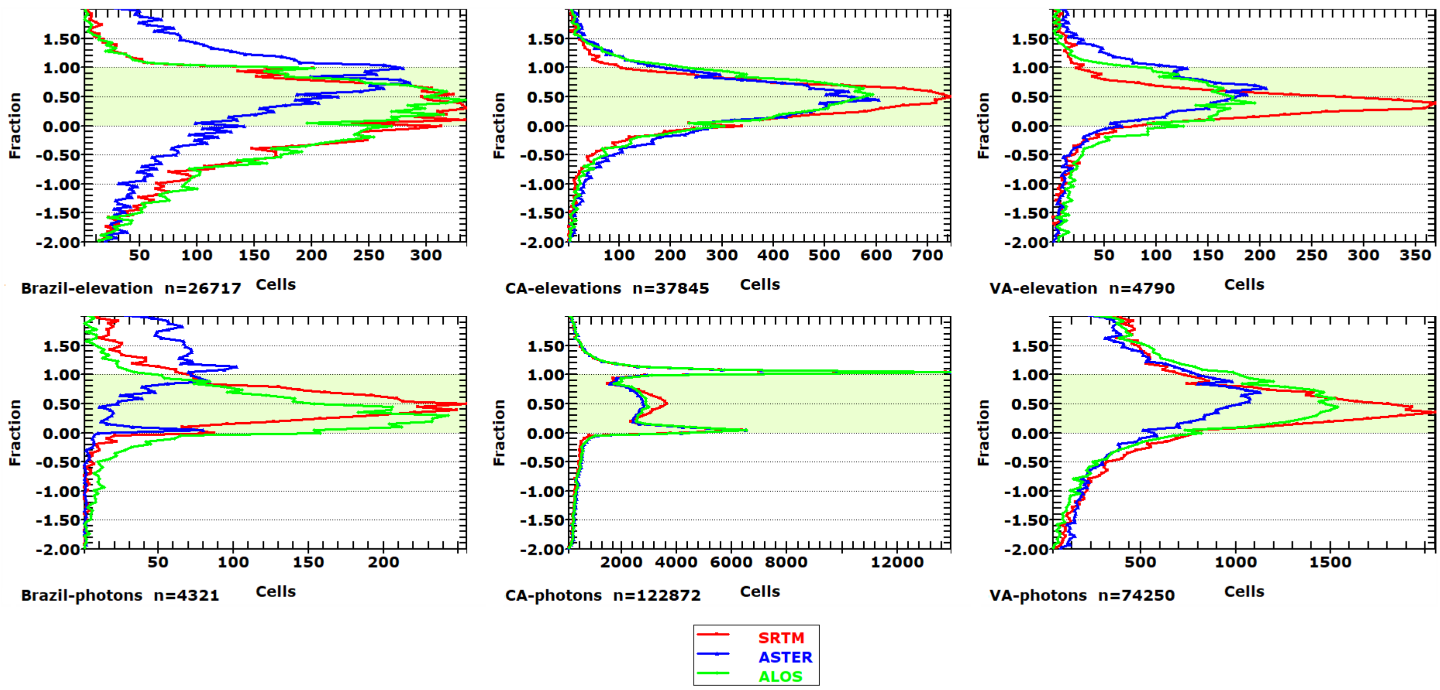

Figure 4. Fraction of data that falls within the elevation envelope and photon point cloud.

In comparison to the photon data, the elevation data appears to better correspond to the DEMs in Figure 4. The majority of the DEM data falls within the highlighted canopy region in California and Virginia. In Brazil, the DEM that disagrees most with the elevation data is ASTER. However, there are more DEM postings contained within the point cloud for ALOS and SRTM than the photon cloud counterpart.

The results of this paper are very different than the results of Guth [13] looking at lidar point clouds. The LIDAR point cloud is much more dense than the ICESat-2 point cloud , with thousands of points in each 1” cell compared to under 100, and with complete spatial coverage rather than a single altimeter track. As a result, the LIDAR point cloud provides much more coverage and provides a better assessment of the DEM .

IV. Results and Conclusion

The three global DEMS provide a good overview of the region, and are highly correlated with each other. The ICESat-2 data provides valuable ground truth to show how well the visible, infrared, and radar sensors penetrated into the canopy. This supports previous interpretations that ASTER in particular provides a lower quality DEM [10,11].In comparison, ICESat-2 data covers only a tiny fraction of the area. Data is currently available for 4-5 cycles of ICESat-2 data; if the satellite lasts for its 5 year design lifetime, even in cloud free regions it is unlikely to collect enough data to create a 1" DEM. Nevertheless, it will provide supplementary information. ICESat-2 will be useful in comparing great changes over a rapid period of time, such as glacier melt and deforestation.

In the analysis of the photon data it is apparent that in Brazil there are many low outliers. We examined these outliers with many different possibilities. We examined the land cover, that is, the ground classification of the vegetation covering the region. Figure 5 depicts the DEM data within the photon point cloud by ground classification. Compared to the entire data, the photon data is higher compared to the three DEMS for the open broadleafed deciduous forest as well as the mosaic grassland. We also analyzed the slope of the Brazil region in order to determine if high degrees of slope were responsible for problematic altimeter readings, without significant results. This indicates that the method of ICESat-2 photon data may bring inaccuracies unexplained by slope or land cover.

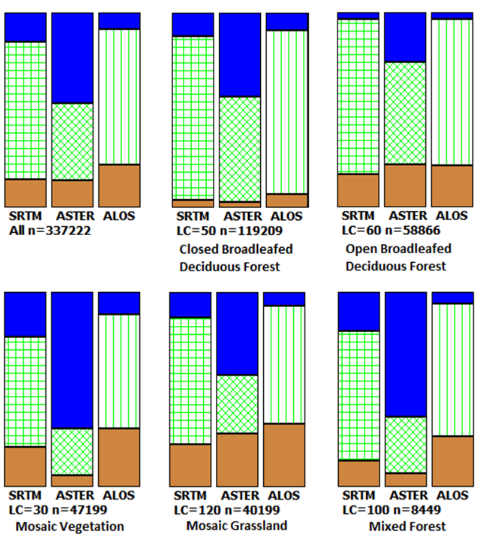

Figure 5. Fraction of DEM data within the ICESAT-2 point cloud by land cover classification

V. Acknowledgments

All analysis was done with the MICRODEM program [12], including new code to deal with the ICESat-2 data and automate the analysis steps. We thank Ian Evans for a very helpful review.

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