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Validation of ICESat-2 Surface Water Level Product ATL13 with Near Real Time Gauge Data

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Abstract: The NASA's Ice, Cloud, and land Elevation Satellite (ICESat) mission uses laser altimetry measurements to determine the elevations at point levels of Earth. ICESat-2, which is a successor to the ICESat-1 satellite mission is a continuation of this series and carries a sensor namely Advanced Topographic Laser Altimeter System (ATLAS). The key advancement of ICESat-2 is that it generates individual laser foot prints of nearly 14 m (in diameter) on the Earth's surface, with each footprint separated by only 70 cm, a much higher resolution and sampling than the earlier mission. ATLAS works under the concept of multi-beam approach containing three pairs of strong and weak beams that produce data products containing global geolocated photon data and height data from land-ice, sea-ice, land/terrain, canopy, ocean surface, and inland water-bodies. From the Level 2 master product called ATL03 numerous sub-data product are generated and are made available to the public through the National Snow and Ice Data Center. One of the products namely ATL13 is a specialized geophysical data product that gives along-track and near-shore water surface height distribution within the water masks. In this article, results after validating ATL13 data product with 46 observations made with near real-time gauged data for 15 reservoirs/water bodies have been presented. The maximum uncertainty observed for this data product is at centimeter-level. A significant observation made from this study is that the heights of surface water level computed from strong beams (gt1r, gt2r, and gt3r) and weak beams (gt1l, gt2l, and gt3l) are occasionally having a variation of 5 to 10 centimeters relatively.

Keywords: Surface Water Level, ICESat-2, ATL13, Laser Altimetry, Photon

1. Introduction

The NASA's Ice, Cloud, and land Elevation Satellite (ICESat) mission uses laser altimetry measurement to determine the elevations at point levels of Earth [1]. The recent version in this series namely ICESat-2 carries a single instrument, the Advanced Topographic Laser Altimeter System (ATLAS). The key advancement of ICESat-2 is that it generates individual laser foot print of nearly 14 m (in diameter) on the Earth's surface, with each footprint separated by only 70 cm, a much higher resolution and sampling than the earlier mission. ATLAS works under the concept of multi-beam approach that produces data products containing global geolocated photon data and height data from land-ice, sea-ice, land/terrain, canopy, ocean surface, and inland water-bodies [2]. The working mechanism and other intricate details about the advancements in ICESat-2 have been mentioned by Markus et al. [1]. Essentially, the multi-beam approach in ICESat-2 consists of a six beam of three pairs acquisition system. These beams are separated by a cross-track interval of nearly 3 km and for each beam pair, a strong and weak beam is located at a distance of 90 m.

Space-borne based measurement of terrestrial surface water level remains a challenging task but at the same time, it is of great need to model the global water and energy cycles, detect the water-level changes which in turn addresses the issues like susceptibility of life due to flood hazards. Alsdorf et al. have surveyed the space-borne methods to compute the water levels and highlighted the viability of using altimetry based methods for collecting levels of water surfaces [3].

ICESat-2 mission disseminates numerous levels of data products to the scientific fraternity and one of the geophysical products namely ATL13 is a specialized data product that gives along-track and nearshore water surface height distribution within water masks [1, 4]. Justification, goals and definition of the inland water body height data product aka ATL13 has been mentioned by Jasinki et al. in the Algorithm Theoretical Basis Document (ATBT) [4]. An ATL13 data product is available for most of the inland water bodies with an area greater than about 0.01 km^2, rivers greater than about 100 m, transitional water including estuaries and bays, and near short 7 km buffer [4]. The along-track water surface height essentially reports elevations as orthometric height above WGS84 ellipsoid in meters using an attribute namely 'ht_ortho' for six ground tracks (viz. strong tracks - gt1r, gt2r, gt3r and weak tracks - gt1l, gt2l gt3l). All these ground tracks consist of a timestamp for data acquisition.

ATL08 is one more product from ICESat-2 that contains best-fit height above a reference ellipsoid and this product too gives the height of the water surface, but one needs to convert into ortho height to compare with the gauged data of the water body. Earlier, Dandabathula et al. assessed the performance of ICESat-2 ATL08 data product by using water level changes from two dates and compared these changes with gauged data [5]. Their study shows that the accuracy of water level from ATL08 ranges from 2 to 39 cm and this uncertainty has been attributed to the inherent ripples and streaks on the water body surface.

Zhang et al. used ICESat-2 ATL13 data for observing lake level and volume changes in Tibetan Plateau (where human activities are negligible) and concluded that the water surface height from ATL13 is in excellent agreement with in situ measurements for Qinghai Lake where the uncertainty is < 0.2 m [6]. Yuan et al. have assessed the ICESat-2 ATL13 data product's accuracy in 30 reservoirs in China and their observation of mean relative errors was 0.06 m [7].

In this article, we have compared the surface water height retrieved from ATL13 strong tracks and weak tracks individually for 15 reservoirs/water bodies and compared with the near real-time gauged data that are reported in the authentic bulletins.

2. Data and Methods

2.1. Study Area

A total of 15 reservoirs/water bodies distributed across the landscape of Indian sub-continent were selected for this study. The basis for selecting these study areas is such that the time of acquisition of ICESat-2 ATL13 data product matches the availability of corresponding near real-time gauged data with a permeability of eight hours variation. Figure 1 shows the reservoirs/water bodies that are selected for this investigation. The names of the reservoirs/water bodies are mentioned in table 1.

2.2. ATL13: Inland Water Body Height Data Product of ICESat-2

Web-portal namely openaltimetry.com is a cyber-infrastructure platform for discovery, access, and visualization of data from NASA's ICESat and ICESat-2 missions [8]. Figure 2 shows the ground track and all the six beams of ATL13 on Nath Sagar reservoir formed by Jayakwadi Dam in India. In this study ATL13 data has been retrieved from openaltimetry web-portal in Comma Separated Values (.csv) format and migrated into the spatial domain. Mean elevation has been computed individually form strong beams and weak beams that are falling in the water body. Currently, version of the ATL13 data product is 3 and the same data has been used for this analysis.

2.3. Gauge Data from Central Water Commission (India) Weekly Bulletins

The Indian government is abided with the Hydro-Meteorological data dissemination policy [9, 10]. Under the aegis of this policy, Central Water Commission (CWC) releases weekly bulletins (on every Thursday) about the water storage level (gauged at 0800 Hrs.) for major reservoirs in India through the portal available at http://cwc.gov.in/reservoir-storage [11].

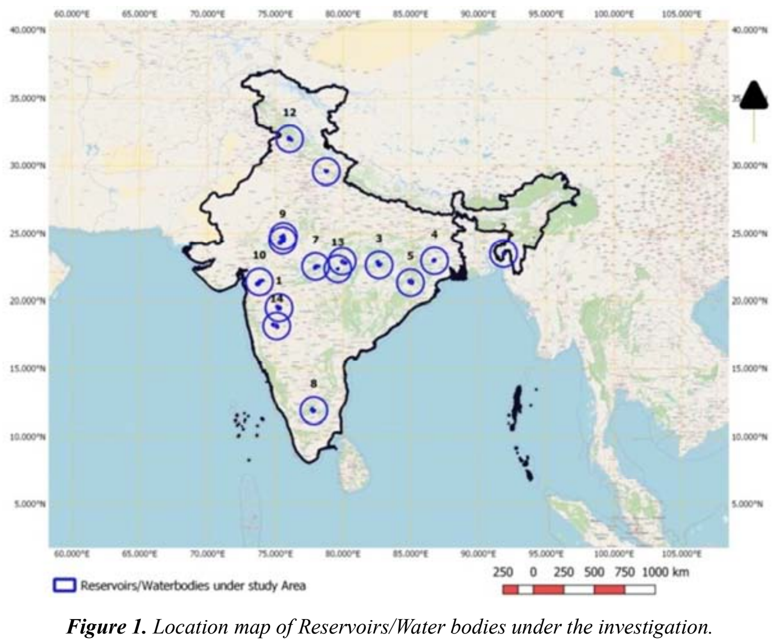

Figure 1. *Location map of Reservoirs/Water bodies under the investigation.*

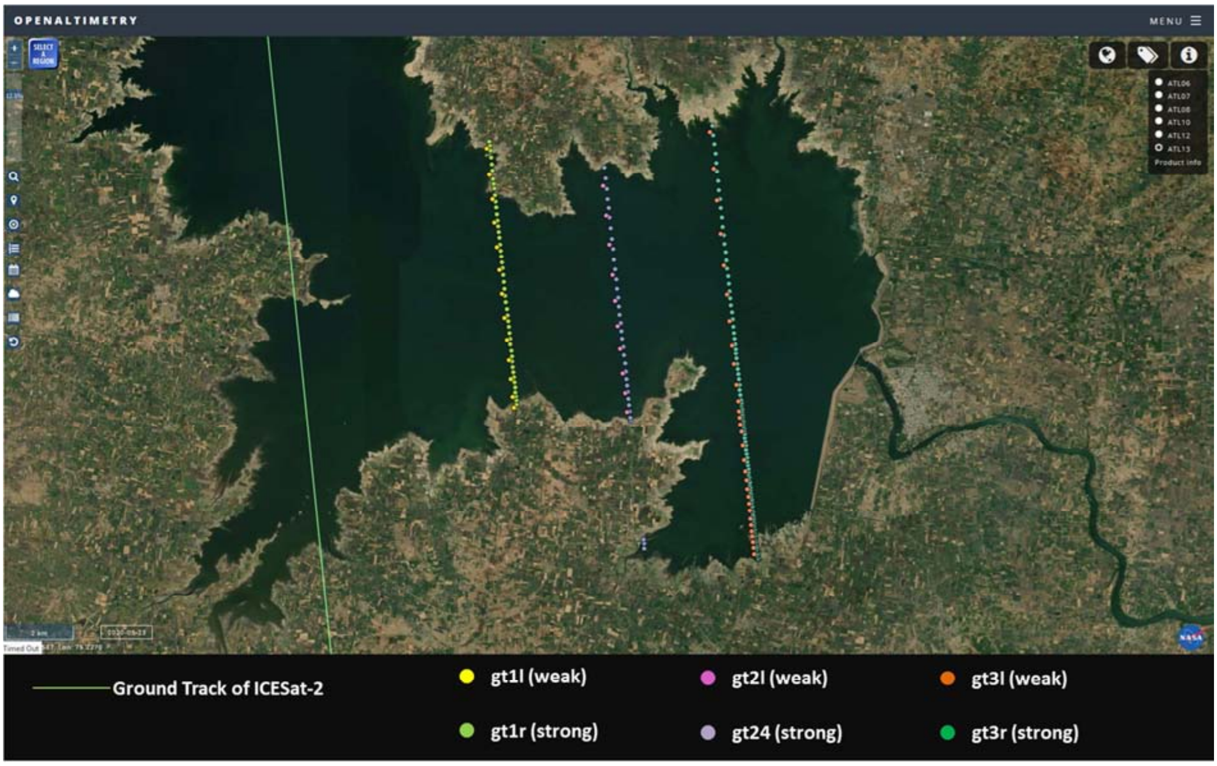

Figure 2. *Ground tracks of ATL13 data product over Nath Sagar reservoir (India).*

2.4. Methodology

Figure 3 shows the methodology that was used for this study. Initial screening of the reservoirs/water bodies has been done with the criteria that the gauged data from CWC weekly bulletins and ICESat-2 ATL13 data acquisition are closely matched in terms of time (with a permeability of +/- 8 hours).

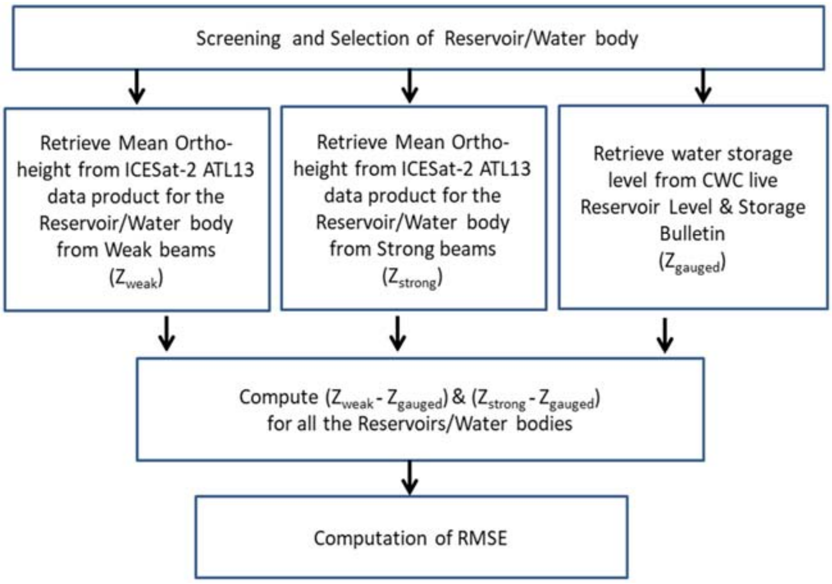

Figure 3. *Methodology used for evaluating ATL13 data product.*

A total of 15 reservoirs/water bodies have been selected which matched this criterion. Mean water level height has been estimated from all the available ground tracks individually from strong beams and weak beams. These heights have been compared with the gauged reservoir level is taken from the CWC gauged records and reported in the subsequent section. A total of 46 observations have been made for this analysis.

As a part of ATL13 data production, only those segments that are falling as a part of global lakes and reservoirs will be considered (E.g. HydroLakes database) [12], however, to ensure this we have manually checked the geolocation of segments by overlaying them in the corresponding Sentinel-2 data that is acquired on a nearby date.

3. Results

Table 1 shows the reservoir name, the track number of ICESat-2, date of data acquisition by the ICESat-2 and the observation made by gauge data, water level retrieved from strong beam and weak beam, and the respective differences with respect to the gauged data.

Table 2 represents the observations derived from table 1. Maximum uncertainties observed in the strong beams and weak beams are 52 cm and 70 cm respectively. Root mean square error (RMSE) represents quantitative model performance in total. The RMSE for the heights of surface water level from strong beams and weak beams are 29 cm and 35 cm respectively.

Table 1. *Table showing reservoir name and corresponding observations consisting heights of surface water levels.*

Obs. No.	Name of Reservoir	ICESat-2 Track No.	Dt. Of ICESat-2 Ground Track	Mean Height of Surface Water level from Strong Beam (meters) H_{strong}
1.1	Jayakwadi	950	2018-Nov-29	459.02
1.2			2019-May-30	454.59
1.3			2019-Aug-29	463.38
1.4			2020-Feb-26	463.03
1.5		508	2019-Oct-30	464.25
2.1	Gumti	614	2018-Nov-07	92.57
2.2			2019-Feb-08	90.455
2.3			2019-May-08	88.41
2.4		1384	2019-Sep-26	90.82
3.1	Minimata Bango	401	2020-Jan-21	357.68
4.1	Kangsabati	96	2020-Apr-01	129.52
4.2		538	2020-Jan-30	130.31
5.1	Rengali	104	2019-Jan-04	117.96
5.2			2019-Oct-03	124.14
5.3			2020-Apr-02	120.5
6.1	Ramganga	767	2020-Feb-14	354.51
6.2		973	2019-May-31	343.54
6.3			2019-Nov-29	357.27
7.1	Tawa	767	2020-Feb-14	349.95
7.2		1095	2019-Jun-08	337.6
7.3			2020-Mar-07	347.9
8.1	Stanley - Mettur	272	2019-Apr-16	221.05
9.1	Gandhisagar	1278	2018-Dec-12	390.76
9.2			2020-Mar-19	390.73
9.3		508	2019-Jan-30	387.33
9.4			2020-Jan-29	398.93
10.1	Ukai	630	2019-Feb-07	93.09
10.2			2019-May-09	86.63
10.3			2020-Feb-05	103.53
10.4		516	2018-Nov-01	95.77
10.5			2019-Jan-31	93.2
10.6			2019-Oct-30	105.44
11.1	Rana Pratap Sagar	1278	2020-Mar-19	348.25
11.2		508	2018-Oct-31	349.41
12.1	Pong	714	2019-Feb-13	410.91
12.2			2019-May-15	408.5
12.2		1156	2019-Mar-14	409.01
13.1	Sanjay Sarovar	654	2019-Nov-08	519.02
13.2		973	2020-FEB-28	515.17
14.1	Bhima Dam	508	2019-Oct-30	497.68
14.2			2020-Jan-29	496.89
14.3		950	2018-Nov-29	494.89
14.4			2019-Feb-28	492.5
14.5			2019-May-30	486.18
14.6			2019-Aug-29	497.59
15.1	Bargi	470	2019-Apr-29	415.86

Table 1. *Continued.*

Obs. No.	Mean Height of Surface Water level from Weak Beams (meters) H_{weak}	Water level recorded in CWC Record (meters) H	Difference of Height (meters) (H_{Strong} - H)	Difference of Height (meters) (H_{Weak} – H)
1.1	459.03	458.76	-0.26	-0.27
1.2	454.62	454.44	-0.15	-0.18
1.3	463.46	463.06	-0.32	-0.4
1.4	463.13	462.73	-0.3	-0.4
1.5	464.25	463.91	-0.34	-0.34

Obs. No.	Mean Height of Surface Water level from Weak Beams (meters) H_{weak}	Water level recorded in CWC Record (meters) H	Difference of Height (meters) (H_{Strong} - H)	Difference of Height (meters) (H_{Weak} – H)
2.1	92.61	92.15	-0.42	-0.46
2.2	90.49	90.15	-0.305	-0.34
2.3	88.42	88.2	-0.21	-0.22
2.4	90.84	90.5	-0.32	-0.34
3.1	357.72	357.38	-0.3	-0.34
4.1	129.82	129.34	-0.18	-0.48
4.2	130.37	130.68	0.37	0.31
5.1	118.01	117.77	-0.19	-0.24
5.2	124.14	124.07	-0.07	-0.07
5.3	120.6	120.52	0.02	-0.08
6.1	354.55	354.42	-0.09	-0.13
6.2	343.58	343.22	-0.32	-0.36
6.3	357.22	357	-0.27	-0.22
7.1	349.98	349.91	-0.04	-0.07
7.2	337.65	337.41	-0.19	-0.24
7.3	347.98	347.87	-0.03	-0.11
8.1	221.05	221.09	0.04	0.04
9.1	390.89	391.2	0.44	0.31
9.2	390.79	390.26	-0.47	-0.53
9.3	387.41	387.11	-0.22	-0.3
9.4	398.92	398.81	-0.12	-0.11
10.1	93.15	92.98	-0.11	-0.17
10.2	86.69	86.53	-0.1	-0.16
10.3	103.61	103.38	-0.15	-0.23
10.4	95.79	95.85	0.08	0.06
10.5	93.28	93.08	-0.12	-0.2
10.6	105.49	105.16	-0.28	-0.33
11.1	348.34	347.75	-0.5	-0.59
11.2	349.73	349.03	-0.38	-0.7
12.1	411.11	410.64	-0.27	-0.47
12.2	408.55	408.09	-0.41	-0.46
12.2	409.32	408.8	-0.21	-0.52
13.1	519.16	519.25	0.23	0.09
13.2	515.21	514.65	-0.52	-0.56
14.1	497.72	497.32	-0.36	-0.4
14.2	496.82	496.4	-0.49	-0.42
14.3	494.94	494.62	-0.27	-0.32
14.4	492.5	492.21	-0.29	-0.29
14.5	486.21	485.77	-0.41	-0.44
14.6	497.7	497.12	-0.47	-0.58
15.1	415.91	415.85	-0.01	-0.06

Table 2. *Table representing major observation from the results.*

Parameter	Remark
Total no. of observations	46
Maximum difference of Height from Strong Beam and Gauged data	44 cm
Maximum difference of Height from Weak Beam and Gauged data	52 cm
Root Mean Square Error form the observation using Strong Beam	29 cm
Root Mean Square Error form the observation using Weak Beam	34 cm

4. Discussion

As such ATL13 is a level 3B sub-product deduced from its master level 2 product ATL03 which primarily contains geolocated ellipsoidal heights for each time-tagged photon event downlinked from ATLAS sensor. Residual errors in ATL03 may have an impact on ATL13 data product at the centimeter level [4, 13]. Conversion of preliminary ellipsoidal heights (WGS84 ellipsoid) from ATL03 to orthometric heights (EGM2008 Geoid) may also contribute certain quantities of minor errors at a centimeter level. Similarly, residual errors in the water height backscatter model that used in ATL13 and related algorithms may still influence the accuracies due to specular backscatter, Lambertian backscatter, solar Lambertian backscatter light from the water surface [13-14]. Also, shallow depths of many inland and nearshore water bodies result in possible bottom backscatter component to the overall water interaction [15].

Moreover, during the along-track data acquisition process there may be water waves that are generated due to local conditions like wind, capillary and gravity waves which may vary the height computed from ATL13 data product [4, 5].

In general, the results obtained from this investigation are similar to that of works done by Zhang et al. and Yuan et al. [6, 7]. However the analysis carried out in our study using 15 reservoirs/water bodies, it appears that height retrieved from the strong beam is slightly better than that of height retrieved from the weak beams. The energy ratio between the strong beams and weak beams is approximately 1:4 and the near-surface interaction phenomenon of photons emanating from the strong beams and weak beams of ICESat-2 may influence this difference. Figure 4 and figure 5 illustrate this phenomenon where elevations from weak beams are nearly 5 cm higher than elevations from strong beams.

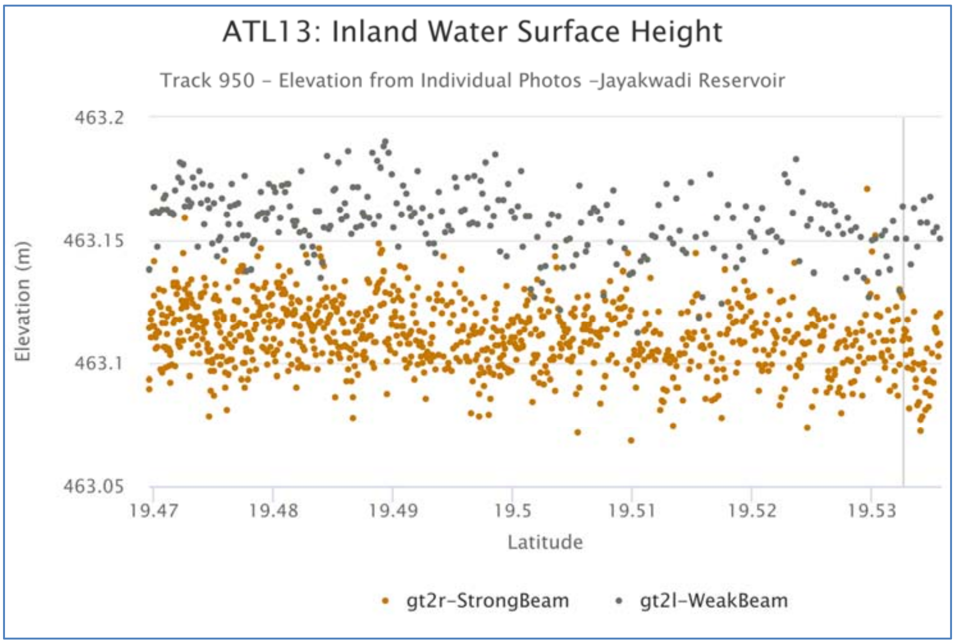

Figure 4. *Variation of water interaction mechanism by photons from strong beam (gt2r) and weak beam (gt2l) of ICESat-2.*

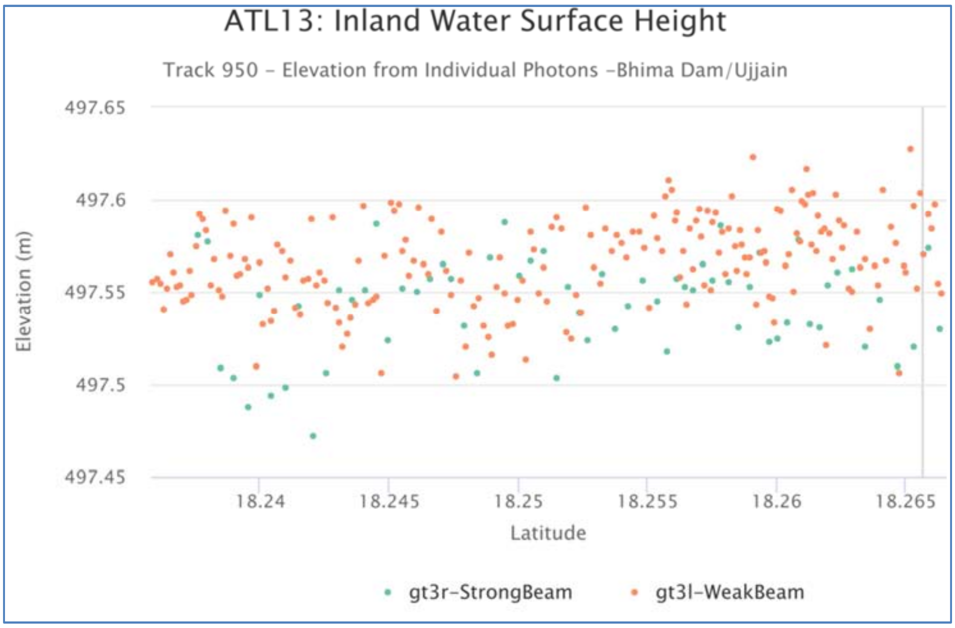

Figure 5. *Variation of water interaction mechanism by photons from strong beam (gt3r) and weak beam (gt3l) of ICESat-2.*

5. Conclusion

In this article, results after validating ICESat-2 ATL13 data product with near-real time gauged data have been presented. A total of 15 reservoirs/water bodies were investigated with 46 observations. The maximum uncertainty observed for the height of the surface water level retrieved from ICESat-2 ATL13 data product in terms of RMSE is 29 cm and 34 cm respectively for the segments of the strong beams and weak beams.

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