Evaluation of ICESat-2 ATL08 Data Product: Performance Assessment in Inland Water

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ABSTRACT

Advanced Topographic Laser System (ATLAS) instrument on-board NASA's Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) enabled the capability of detecting certain properties of the Earth's surface at a photon level. Primary applications of ICESat-2 are for cryosphere but extendable to measure and determine the changes in elevation for land terrain and canopy. ICESat-2 ATL08 data product is a level 3A product that contains the best fit height above a reference ellipsoid processed in fixed 100 m data segments, which typically uses more than 100 signal photons from level 2 product namely ATL03. In this article, ICESat-2 ATL08 has been evaluated for its accuracy. Accuracy assessment of a point ellipsoidal height can be done using known benchmarks or survey points. In the absence of known points, the performance of these points can be assessed by hydro-flattest as well as by comparing the satellite observed surface water level with gauged water table height. Both these tests have been done on 5 large reservoirs in the Indian sub-continent. Hydro-Flattest on ICESat-2's ATL08 data product determined the permissible variations that occur on the surface water body due to ripples, wavelets, and streaks at a centimeter-level. Water level from ICESat-2 data will be in ellipsoidal height and cannot be compared with gauged data as it gives the height of the water surface above an established altitude where the stage is zero, because of this we have compared the change of surface water level from different dates. The results indicate that the surface water levels from ICESat-2's ATL08 data product are in line with gauged data at centimeter-level accuracy.

Keywords: ICESat-2, ATL08 data product, Surface water level, Laser altimetry.

I. INTRODUCTION

NASA’s space based laser altimetry mission, ICESat-2 (Ice, Cloud, and Land Elevation Satellite-2) launched in September 2018 has primary scientific objectives related to cryosphere with special emphasis to measure and determine the changes in elevation for glaciers and ice sheets, as well as sea ice thickness distribution [1]-[3]. Abdalati et al. has reported the mission objectives, specification, applications, and mission duration details [1]. Markus et al. through their publication elaborated the science requirements and implementation details of ICESat-2 [2].

ICESat-2 is intended to extend the measurements that were successfully begun by its predecessor ICESat that was operated from 2003 till 2009. The measurement concept implemented in ICESat is through Geoscience Laser Altimeter System (GLAS) which was a profiling laser altimeter operated at 1064nm (infrared) to produce non-overlapping ~72 footprints every 172m along the track [4]-[5]. From each footprint, the time delay between each laser pulse from the satellite and the detected reflection from the earth’s surface was used to compute the range, and from this range the height above a reference ellipsoid was derived [6]. ICESat has only a single beam with a broad range footprint of the order 30-70m, this limited its performance when measuring the heights from the earth’s surface [7].

A new technology for laser ranging has been implemented through the Advanced Topographic Laser System (ATLAS) instrument on-board ICESat-2 that is capable of detecting sensitivities at a photon level [8]. The ATLAS instrument operates at higher repetition rates that has facilitated improved along track spatial resolution. The Algorithm Theoretical Basis Document (ATBD) mentions the processing steps of global geolocated photons from ICESat-2 Science Investigator-led Processing System (SIPS) [9]. The ATLAS instrument transmits green (532nm) laser pulses at 10 kHz and the spacecraft velocity from the ICESat-2 nominal ~500km yields one transmitted laser pulse every 0.7m along track. A sequences of operations like reformatting, unpacking, converting to engineering units, instrument correction, bias removal, Precision Orbit Determination (POD), and Precision Pointing Determination...
(PPD) will be performed to produce Level 2 product namely ATL03 which contains geolocated ellipsoidal heights for each geotagged photon downlinked from ATLAS instrument [10]. The heights in ATL03 product are classified as signal photon event or background photon event using expert algorithms. ATL03 product is the basis for generating geophysical products over various surface types such as land ice (ATL06), sea ice (ATL07), land/vegetation (ATL08), atmosphere (ATL09), and oceans (ATL12) [8].

ICESat-2 was developed with advanced multi-beam, micro-pulse laser (referred to as photon-counting) technology that provides a new set of global ecosystem applications using elevation measurements from reflected photons [1]-[2]. Large water-bodies like reservoirs can be used as a performance evaluator especially when measuring the surface heights using laser altimeters [11]-[13]. Measuring the surface water level gets the elevation of the free-water surface body relative to a datum level. Absolute water level fluctuation is change in water level of lake or reservoir caused by changes in its storage for a definite period of time [11].

In this article, the best fit height above a reference ellipsoid mentioned in ICESat-2 ATL08 product has been evaluated in 5 reservoirs that are situated in the Indian sub-continent. The following are the objectives of this study.

1) Evaluation of the best fit elevation available in ICESat-2 ATL08 data product for those data segments falling in the large reservoirs. Hydro-flatness test for LiDAR altimeter data will help us in assessing its performance. In the absence of ripples/wavelets/streaks LiDAR altimeter should produce single elevation value for entire water surface. Van Straaten in his studies mentioned that in ideal conditions water surface in reservoirs and lakes exhibits streaks, wavelets and ripples due to various reasons and because of this the surface elevation of water level varies from centimetres to meters.14 Theoretically LiDAR derived digital elevation models (DEM) should produce hydro-flatened surfaces that are similar in topographic DEMs with little post processing work.15 Through this hydro-flatness test one can assess the performance of elevation data product in the inland water bodies.

2) The second objective of the article is to evaluate the performance of ICESat-2’s ATL08 data product in inland water body by detecting the changes in water level for two different dates. Towards this the difference in water level from two dates obtained from ICESat-2’s ATL08 data product has been compared with that of authenticated gauged data reported by federal government agency. Water level from ICESat-2 data and gauged data as such cannot be compared due to the reason that satellite based LiDAR altimetry gives ellipsoidal heights whereas gauged data will give the height of the water surface above an established altitude where the stage is zero (close to streambed in case of Dam reservoirs). But the changes in difference of water levels from two different dates can be compared irrespective of datum and thus the same test has been done in this article.

II. MATERIALS AND METHODS

A. ICESat-2 ATL08 Data Product

Neumann et al. reported the ICESat-2 working principle and structure of various data products [9]. ATL03 is termed as level 2 data product that contains height above the WGS 84 ellipsoid (ITRF2014 reference frame), latitude, longitude, and time for all photons downlinked by the ATLAS instrument on board ICESat-2. The ATL03 product was designed to be a single source for all photon data, spacecraft data, instrument parameters, and ancillary information needed by higher-level ATLAS/ICESat-2 products [10].

ATL08 is termed as level3A data product that is a derived data set from ATL03 and contains along-track heights above the WGS84 ellipsoid (ITRF2014 reference frame) for the ground and canopy surfaces. The canopy and ground surfaces are processed in fixed 100 m data segments, which typically contain more than 100 signal photons [16]. ATL08 is available for scientific applications in the spatial extent of longitude 180W-180E, latitude 90N-90S and can be downloaded from the web portal maintained by National Snow & Ice Data Centre (NSIDC) in Hierarchical Data Format (HDF) [16]-[17]. Alternatively users can visualize and download various data products of ICESat-2 mission in in Comma Separated Values (CSV) format from the web portal available at OpenAltimetry.org [18]. OpenAltimetry is a cyber-infrastructure platform for discovery, access, and visualization of data from NASA’s ICESat and ICESat-2 missions. In this study the altimeter data has been taken from OpenAltimetry.org for the selected study areas that are described in next section. Fig. 1 shows land surface elevation points as visualized in OpenAltimetry.org for one of the reservoirs under investigation namely Nagarjunasagar.

B. Study Area

A total of 5 reservoirs as listed in Table 1 were selected for evaluating the ATL08 data products. All these 5 reservoirs are largest in India and there is ample scope of finding ICESat-2 data segment for these study areas because of their bigger extent. Another rationale for selecting these study areas is that they are being monitored by Central Water Commission of India (CWC) and the water level reports are made available to the public at weekly intervals. Fig. 2 shows the location of the reservoirs.
TABLE I: DETAILS OF LARGE RESERVOIRS THAT ARE PART OF INVESTIGATION FOR EVALUATING THE PERFORMANCE OF ICESAT-2 ATL08 DATA AT INLAND WATERS

| Reservoir                     | FRL (m) | Geographical extent of Reservoirs | Upper Right (Lat, Long) | Lower Left (Lat, Long) |
|------------------------------|---------|-----------------------------------|-------------------------|------------------------|
| BasavaSagar/Naraynapur       | 492.25  |                                   | 16.236420, 76.360130    | 16.141435, 76.238751   |
| Hirakund                     | 192.02  |                                   | 21.804937, 83.939932    | 21.451841, 83.5138907  |
| Indira Sagar                 | 262.13  |                                   | 22.368450, 76.841410    | 22.006895, 76.430996   |
| Nagarjunasagar               | 179.83  |                                   | 16.466711, 79.144112    | 16.596481, 79.253255   |
| Tehri dam reservoir          | 830.00  |                                   | 30.421881, 78.585949    | 30.362585, 78.4680479  |

Fig. 2. Location of 5 reservoirs which are part of the study area to investigate the performance of ICESat-2’s ATL08 data product.

C. CWC Weekly Bulletins on Reservoir Levels & Storage Data

CWC is a premier technical organization of India in the field of water resources and is presently functioning as an attached office of the Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, Government of India [19]. CWC monitors and reports the live storage of 120 reservoirs of India on weekly basis. These reports are disseminated as weekly bulletins and are made available to the public [20]. The water levels for the 5 reservoirs in this study were taken from the CWC weekly bulletins for various dates which are nearer to that of ICESat-2 ground track.

D. Methodology

Fig. 3 represents the methodology used for evaluating the ICESat-2’s ATL08 data product over inland waters. Data downloaded from the OpenAltimeter portal will be in CSV format. These CSV formatted data contains elevation values (best-fit terrain height aka ‘h_te_BestFit’) which has been imported to spatial domain to check whether the data segments are falling in the water surface or not. The data segments that are falling in the water part of the lake were only considered for evaluation.

Fig. 3. Methodology used to evaluate the performance of ICESat-2 ATL08 data product in determination of water level in reservoirs.

Two types of tests have been done to evaluate the elevation data from ICESat-2 ATL08 data product. First test verifies the hydro-flatness of the of ICESat-2 ATL08 data over the water surface of the lake. Towards this maximum, minimum and mean of the elevation values from ATL08 data segment have been retrieved and analysed. The second test computes the difference in the water-level that is observed from CWC water level bulletins and ICESat-2 ATL08 data product for various dates.

III. RESULTS AND DISCUSSION

Table 2 shows the maximum elevation, minimum elevation, and variation from the flatness (difference between maximum and minimum elevation) under hydro-flatness test for various ground tracks for all the 5 reservoirs.

From the results it is observed that the variation of hydro-flatness retrieved from ICESat-2 ATL08 data product for all the study areas is ranging from 1cm to 49cm. Fig. 4(a) shows the phenomenon of ICESat-2 photon ground track over an area containing land and water surface. Fig. 4(b) shows the zoomed version of the same ground track over water surface along with ATL08 segment with 100 m resolution.
**TABLE 2: RESULTS OF HYDROFLATNESS TEST FOR ICESAT-2’S ATL08 DATA PRODUCT OVER FIVE TEST REGIONS.**

| Reservoir Name       | ICESat-2 Track No. | Date of Pass | A    | B (m)    | C (m)    | D (m)    | E (m)   |
|----------------------|--------------------|--------------|------|----------|----------|----------|---------|
| BasavaSagar / Narayanpur | 386                | 23-Oct-18    | 7    | 410.96   | 410.86   | 410.92   | 0.1     |
|                      | 386                | 22-Jan-19    | 78   | 407.01   | 406.84   | 406.94   | 0.17    |
|                      | 1278               | 03-Mar-19    | 105  | 407.16   | 406.92   | 407.04   | 0.24    |
|                      | 386                | 23-Apr-19    | 30   | 407.25   | 407.08   | 407.14   | 0.17    |
| Hirakund             | 1110               | 18-Nov-18    | 184  | 129.99   | 129.77   | 129.89   | 0.22    |
|                      | 665                | 10-Feb-19    | 201  | 128.57   | 128.28   | 128.44   | 0.29    |
|                      | 782                | 17-Feb-19    | 238  | 128.49   | 128.09   | 128.35   | 0.4     |
|                      | 1110               | 11-Mar-19    | 442  | 127.97   | 127.48   | 127.72   | 0.49    |
|                      | 1224               | 18-Mar-19    | 104  | 127.84   | 127.50   | 127.66   | 0.34    |
| Indirasagar          | 1331               | 24-Dec-18    | 1331 | 198.94   | 198.60   | 198.76   | 0.24    |
|                      | 272                | 15-Jan-19    | 272  | 198.00   | 197.70   | 197.83   | 0.3     |
|                      | 1217               | 18-Mar-19    | 223  | 195.53   | 195.44   | 195.52   | 0.09    |
|                      | 1331               | 25-Mar-19    | 1331 | 195.14   | 194.92   | 195.04   | 0.22    |
|                      | 272                | 16-Apr-19    | 47   | 194.38   | 193.98   | 194.12   | 0.4     |
| Nagarjunasagar       | 592                | 06-Nov-19    | 425  | 91.68    | 91.35    | 91.59    | 0.33    |
|                      | 592                | 05-Feb-19    | 457  | 81.84    | 81.41    | 81.55    | 0.43    |
|                      | 1087               | 09-Mar-19    | 202  | 78.98    | 78.96    | 78.97    | 0.02    |
| Tehri                | 325                | 19-Oct-18    | 30   | 789.38   | 788.99   | 789.24   | 0.39    |
|                      | 531                | 02-Nov-18    | 31   | 788.41   | 787.93   | 788.15   | 0.08    |
|                      | 325                | 19-Apr-19    | 16   | 728.32   | 728.02   | 728.12   | 0.3     |

A - No. of ATL08 granules falling in the reservoir  
B - Maximum elevation from all the ATL08 granules falling in reservoir (Ellipsoidal)  
C - Minimum elevation from all the ATL08 granules falling in reservoir (Ellipsoidal)  
D - Mean elevation of all the ATL08 granules falling in reservoir (Ellipsoidal)  
E - Variation between maximum and minimum elevation represented by a ATL08 granules

**TABLE 3: TABLE DEPICTING THE DIFFERENCE OF WATER LEVEL COMPUTED FROM ICESAT-2 ALT08 DATA PRODUCT AND CWC LIVE BULLETIN**

| Reservoir Name       | ICESat-2 Track No. | A          | B (m)    | C         | D (m)    | E (m)    | F (m)    | G (m)/(days) |
|----------------------|--------------------|------------|----------|-----------|----------|----------|----------|-------------|
| BasavaSagar / Narayanpur | 386                | 23-Oct-18  | 410.92   | 25-Oct-18 | 491.30 [25] | --       |           |             |
|                      | 386                | 22-Jan-19  | 406.94   | 24-Jan-19 | 487.30 [26] | 3.98    | 4        | 0.02 (2)    |
|                      | 1278               | 03-Mar-19  | 407.04   | 28-Feb-19 | 487.27 [27] | 0.10    | 0.03     | 0.07 (3)    |
|                      | 386                | 23-Apr-19  | 407.14   | 25-Apr-19 | 487.59 [28] | 0.10    | 0.32     | 0.32 (2)    |
| Hirakund             | 1110               | 18-Nov-18  | 129.89   | 15-Nov-18 | 190.87 [29] | --       |           |             |
|                      | 665                | 10-Feb-19  | 128.44   | 07-Feb-19 | 189.59 [30] | 1.45    | 1.28     | 0.17 (3)    |
|                      | 782                | 17-Feb-19  | 128.35   | 14-Feb-19 | 189.37 [31] | 0.09    | 0.22     | 0.13 (3)    |
|                      | 1110               | 11-Mar-19  | 127.72   | 14-Mar-19 | 188.56 [32] | 0.63    | 0.81     | 0.18 (3)    |
|                      | 1224               | 18-Mar-19  | 127.66   | 20-Mar-19 | 188.36 [33] | 0.06    | 0.2      | 0.14 (2)    |
| Indirasagar          | 1331               | 24-Dec-18  | 198.76   | 27-Dec-18 | 258.61 [34] | --       |           |             |
|                      | 272                | 15-Jan-19  | 197.83   | 17-Jan-19 | 257.57 [35] | 0.93    | 1.04     | 0.11 (2)    |
|                      | 1217               | 18-Mar-19  | 195.52   | 20-Mar-19 | 255.61 [33] | 2.31    | 1.96     | 0.35 (2)    |
|                      | 1331               | 25-Mar-19  | 195.04   | 28-Mar-19 | 254.74 [36] | 0.48    | 0.87     | 0.39 (3)    |
|                      | 272                | 16-Apr-19  | 194.12   | 18-Apr-19 | 253.73 [37] | 0.92    | 1.01     | 0.09 (2)    |
| Nagarjunasagar       | 592                | 06-Nov-19  | 91.59    | 08-Nov-19 | 172.55 [38] |         |           |             |
|                      | 592                | 05-Feb-19  | 81.55    | 07-Feb-19 | 162.58 [30] | 10.04   | 9.97     | 0.07 (2)    |
|                      | 1087               | 09-Mar-19  | 78.97    | 07-Mar-19 | 160.39 [39] | 2.58    | 2.19     | 0.39 (2)    |

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Natural variations like ripples/wavelets/streaks due to winds (Langmuir circulation) at the water surface captured by ICESat-2 were shown in fig. 4c and in this case the variations of water level in the range of 1cm to 50cm were clearly evident. During heavy winds, water level variations may be of the orders of meters [21].

ATL08 data product gives an average elevation value computed from more than 100 signal photons for every 100 m data segment, thus each segment of ATL08 embeds the best fit of elevation from the water surface with a 1cm variation. Earlier reports from Ye et al., Zhang et al., and Li et al. while working with water levels with ICESat-1 (GLAS) data mentioned that an accuracy of better than 10cm can be achieved in normal wind conditions [12],[22],[23]. However, from this study it is observed that ICESat-2 (ATLAS) segments are able to give an accuracy of better than 1cm under normal conditions if we are using actual photons instead of level 3A product like ATL08.

In case to produce hydro flattened water surface from ATL08 data then we may have to readjust the best fit of elevation with in the minimum and maximum range of elevations. Table 3 shows the changes in the water level computed from ICESat-2 data product and gauged data reported in CWC live bulletin. It is observed that difference in change of water levels computed from ICESat-2’s ATL08 data product and from CWC live bulletins for all the study areas is ranging from 2cm to 39cm.

The limitation of this study is that the date of ICESat-2 ground track and the date of gauged data are differed from one to three days (nearest possible day of coincidence has been considered), this factor may also contribute uncertainty in the accuracy from our study. Brown et al. in their publication mentioned that ICESat-2 data can effectively use for measurements of reservoir heights.24 The results from our study demonstrate that water level changes with accuracy better than 2cm can be achieved using ICESat-2 data.

### Table 3

| Tehri | Date of Pass | ATL08 | CWC Live | Difference | Days |
|-------|-------------|-------|----------|------------|------|
| 325   | 19-Oct-18   | 789.24| 827.25 [40] | 38.01  | 0.8  |
| 531   | 02-Nov-18   | 788.15| 826.45 [41] | 38.30  | 0.8  |
| 325   | 19-Apr-19   | 728.12| 766.73 [37] | 38.61  | 0.8  |

A - Date of Pass of ICESat-2 data product  
B - Best fit elevation from ICESat-2 data product (ellipsoidal)  
C - CWC Live water level reported date (nearest date to ICESat-2 data acquisition)  
D - CWC Live water level  
E - Change of Level from Previous Reading (ICESat-2)  
F - Change of Level from Previous Reading (CWC Live)  
G - Difference of Water levels computed from CWC Live and ICESat-2 and difference of days

Fig. 4. Profile of ICESat-2 photon ground track, (a) ICESat-2 photon ground track over a part containing land and water surface, (b) Ground track over water surface along a water body, (c) Natural variations like ripples/streaks due to winds (Langmuir circulation) at the water surface captured by ICESat-2, and (d) Zoomed version of photon points on the surface of water body.

IV. CONCLUSION

This study evaluates ICESat-2 Level 3A data product namely ATL08 in inland water bodies. ATL08 contains along-track heights above the WGS84 ellipsoid for the ground and canopy surface which are processed from more than 100 signal photons for fixed 100 m data segments. Two tests were conducted for evaluating the ICESat-2’s ATL08 data product. The first test checks for the hydro-flatness with permissible variations due to ripples and streaks. The results from the hydro-flatness test for the 5 large reservoirs are ranging from 1cm to 48cm and these variations are due to ripples and streaks on the water body surface. The second test compares the change in water level from two different dates that is obtained from ICESat-2’s ATL08 data and authenticated gauged data reported by federal government agency. A difference of water level change ranging from 2cm to 39cm with actual gauged data has been observed from the second test (with a limitation of one to three days.
variability in observation). Forthcoming research will focus on further validation of these results with the same date of ICESat-2 ground track and actual gauge data. In doing so, the actual performance can be estimated. This first cut evaluation of ICESat-2’s ATL08 data product confirms that it can be used for applications related to inland water studies.

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