engineering proceedings

Proceedings

Investigating the Terrain Complexity from ATL06 ICESat-2 data for Terrain Elevation and its Use for Assessment of Openly accessible InSAR based DEMs in parts of Himalaya's

Ashutosh Bhardwaj[1,*]

[1] Photogrammetry and Remote Sensing Department, Indian Institute of Remote Sensing, Dehradun, Uttarakhand 248001, India; ashutosh@iirs.gov.in
* Correspondence: ashutosh@iirs.gov.in; +91-135-2524117
† Presented at 8th International Electronic Conference on Sensors and Applications, 1—15 November 2021; Available online: https://ecsa-8.sciforum.net.

Abstract: Spaceborne sensors are now providing invaluable datasets for the Earth's surface studies. Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) with Advanced Topographic Laser Altimeter System (ATLAS) instrument was launched by NASA on September 15, 2018, to measure the elevation of Earth's surface using laser wavelength of 532 nm and pulse repetition frequency of 10kHz giving footprint of approximately 70cm on the ground. The ICESat-2 datasets are used in this study for the visualization and investigation of the complex Himalayan terrain in the parts of the Kinnaur district and surroundings, which are prone to landslides due to the geology of the region as observed during the recent landslide events. The ICESat-2 elevation data sets were compared with the openly accessible DEM datasets namely, ALOS PALSAR RTC HR (12.5m) and TanDEM-X (90m) at ICESat-2 footprint locations. Preprocessing of datasets was done for selecting ICESat-2 footprints (Track ID: 325, 1270, 828, 386) at locations of high-quality datasets for analysis. The analysis of preprocessed 19,755 ICESat-2 footprints (out of 20,948 footprints) was done with ALOS PALSAR RTC HR (12.5m) and TanDEM-X (90m) datasets. The visualization of the region in the Google earth and OpenAltimetry 3D viewer depicts that the mountain slopes are very steep indicating rugged terrain difficult to access and challenging for construction of transport facilities. The results of Track ID: 325, show that the range of elevations in ICESat-2 elevation values in the study area is from 3409.75m to 5976.31m. The standard deviation representing terrain ruggedness using ICESat-2 elevation values is found as 432.06m. Considering higher accuracy ICESat-2 values for the difficult terrain as a reference, the mean error (ME), mean absolute error (MAE), and RMSE for TanDEM-X were found as 0.26m, 12.92m, and 17.4m respectively. Whereas the ME, MAE, and RMSE for ALOS PALSAR RTC HR DEM were found as 0.20m, 9.50m, and 13.88m respectively. Thus for the study site, using ICESat-2 ATL06 products, ALOS PALSAR RTC HR DEM is found more suitable than TanDEM-X 90m openly accessible datasets for any kind of application.

Keywords: LiDAR; ATLAS; DEM; ALOS PALSAR RTC HR; TanDEM-X

Citation: Lastname, F.; Lastname, F.; Lastname, F. Title. *Eng. Proc.* **2021**, *3*, x. https://doi.org/10.3390/xxxxx

Published: date

1. Introduction

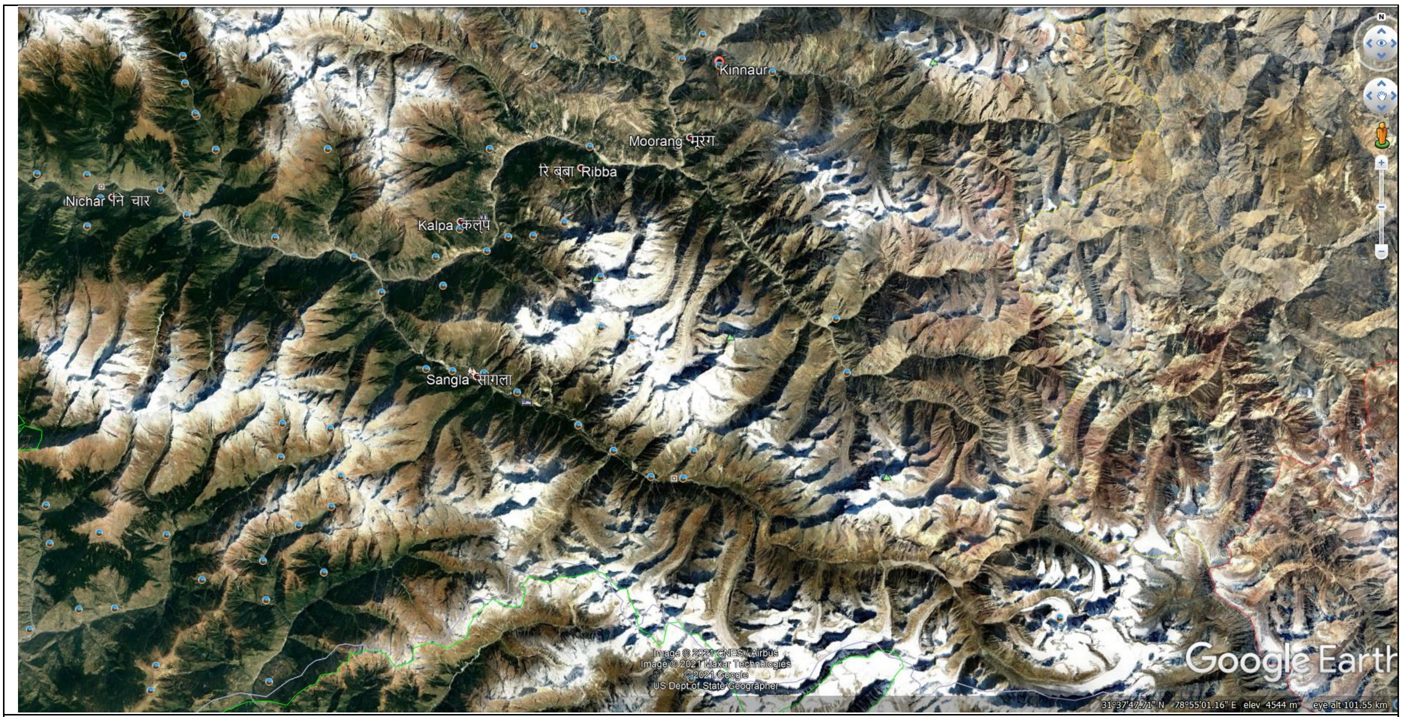
Every topographic region has its advantages and disadvantages affecting socioeconomic wellbeing in the region. Some regions are prone to flood, forest fires, earthquakes, tsunami, landslides, and so on. The mountainous regions have always been a challenge for the dwellers due to the availability of resources and infrastructure. Different mountainous regions of the world face different challenges, such as snow avalanches, rockslides, shortage of oxygen in higher reaches, health facilities, etc. The Himalayas also have similar challenges due to their ruggedness making the terrain less convenient for dwellers. However, at the same time, it has pleasant weather and a scenic atmosphere around, making many locations a choice for tourists.

The major mountain ranges of the world include the Andes, the Rockies, the Great Dividing Range, the Transantarctic Mountains, the Ural Mountains, the Atlas Mountains, the Appalachian Mountains, the Himalayas, the Altai Mountains, the Western Ghats, the Alps, the Drakensberg, and the Aravalli Range among others. Performing traditional surveys in these regions will be time taking and costly. ICESat-2 provides a good opportunity to study these mountains through its ATLAS instrument in addition to other remote sensing technologies. Landslides are common in the Alps [1], [2], Himalayas [3], [4], eastern Patagonian Andes [5], and other mountains of the world depending on the geology and weather conditions primarily. The State of Conservation Index (SCIx), which serves as an input in a Spatial Multicriteria Evaluation (SMCE), was used to study the vulnerability of 60 cultural heritage objects in Georgia from landslides and avalanches [6].

Chen et al. (2020) have evaluated the accuracy of SRTM3 DEM using ICESat/GLAS data over Jiangxi province, China [7], [8]. Zhang et al. (2021) analyzed 208 footprints of ICESat-2 ATL06 data and found that they have very high vertical and horizontal positioning accuracies. The average RMSE calculated for continuously operating reference stations (CORS) is 0.0846 m, and the corresponding RMSE for unmanned aerial vehicle (UAV) data is 0.1517 m [9]. Liu et al. (2020) found in a study over steep terrain of the south-central Chinese province of Hunan that the DEMs (SRTM-1 DEM, SRTM-3 DEM, ASTER GDEM2, AW3D30 DEM, and TanDEM-X 90-m DEM) provide the elevations higher than those of reference points [10]. A regional landslide inventory prepared with a focus on the Swiss and French Alps shows that the post-1970 portion of the database is more reliable, highlighted through an improved power-law relationship [11]. The week areas having fractured materials resting on steep slopes falls during landslides in the parts of the Appalachian Mountains, the Rocky Mountains, the Pacific Coastal Ranges, and some parts of Alaska and Hawaii [12]. Gracheva et al. (2009) studied the effects of landslides on archeological site Gruzinka (North Caucasus, Russia), including soil and minerals [13]. Wang et al. (2019) studied algorithms including the influencing factors namely, the signal-to-noise ratio (SNR), slope, vegetation height, and vegetation cover on the accuracy of ground elevation over the forest, tundra, and bare land areas in interior Alaska using airborne LiDAR data. The overall mean difference and RMSE values between the ground elevations are −0.61 m and 1.96 m, respectively. Whereas in the forest, tundra, and bare land scenarios, the mean differences are −0.64 m, −0.61 m, and −0.59 m, with RMSE values of 1.89 m, 2.05 m, and 1.76 m, respectively which are quite acceptable for difficult terrains having a large influence of slope [7]. A recent event of a rockslide in Chamoli, Uttarakhand has also been studied by researchers extensively Ronti [14]–[16]. The Copernicus DEM is found better than other openly accessible DEMs (ALOS, ASTER, NASA, and SRTM). in all eight test areas, when tested against both LiDAR and ICESat-2 data [17]. Openly accessible DEMs (TanDEM-X, SRTM, ASTER, ALOS PALSAR, CartoDEM) and Radargrammetric DEM generated using RISAT-1 (C-band) SAR stereo pair were evaluated with ICESat-2 footprints for the highly vegetated Himalayan mountainous terrain of Dehradun and surroundings in Uttrakhand state, India [18]. The presented study focuses on the evaluation of two recent high-quality InSAR-based DEMs using spaceborne LiDAR data from the ICESat-2 mission. The study on the quality of DEMs is essential as DEMs play an important role in generating correct results from geographic information system (GIS) based modeling from inputs for any phenomenon using remote sensing techniques.

2. Study Area

The study area is part of Himachal Pradesh in India, which shares its borders with the union territories of Jammu and Kashmir and Ladakh towards its north, and with the states of Haryana towards the southwest, Uttarakhand to the southeast, Uttar Pradesh to the South, and with Punjab to the west (Figure 1). The study area includes parts of the Kinnaur district and its surroundings, where some of the heavy landslides have been reported recently in the mid of the year 2021 during monsoon season. The state of Himachal Pradesh including the study area is characterized by an extremely undulating landscape having several peaks and regions with extensive drainage networks consisting of various river systems.



(**b**)

Figure 1. Study area

3. Material

3.1. Openly accessible DEMs

3.1.1. TanDEM-X 90

The TanDEM-X (90 m) DEM dataset was downloaded from the website platform provided by DLR (https://tandemx-90m.dlr.de). The detailed specifications of TanDEM-X DEM products can be seen in the data guide provided by DLR (https://geoservice.dlr.de/web/dataguide/tdm90/#introduction).

3.1.2. ALOS PALSAR RTC HR DEM

The radiometrically terrain corrected (RTC) products is a project of the Alaska Satellite Facility (ASF) that makes SAR data accessible to the user community at a high resolution (HR) of 12.5m and a resolution of 30m. The ALOS PALSAR RTC HR product (12.5m) was used for the experiment (https://asf.alaska.edu/data-sets/sar-data-sets/alos-palsar/).

3.2. Spaceborne LiDAR data (ICESat-2)

Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) with ATLAS instrument was launched by NASA and measures the elevation of Earth's surface using laser wavelength of 532 nm and PRF of 10kHz producing ~ 70cm footprint on the ground. This data set (ATL06) provides geolocated land-ice surface heights (above the WGS 84 ellipsoid, ITRF2014 reference frame), plus ancillary parameters that can be used to interpret and assess the quality of the height estimates.

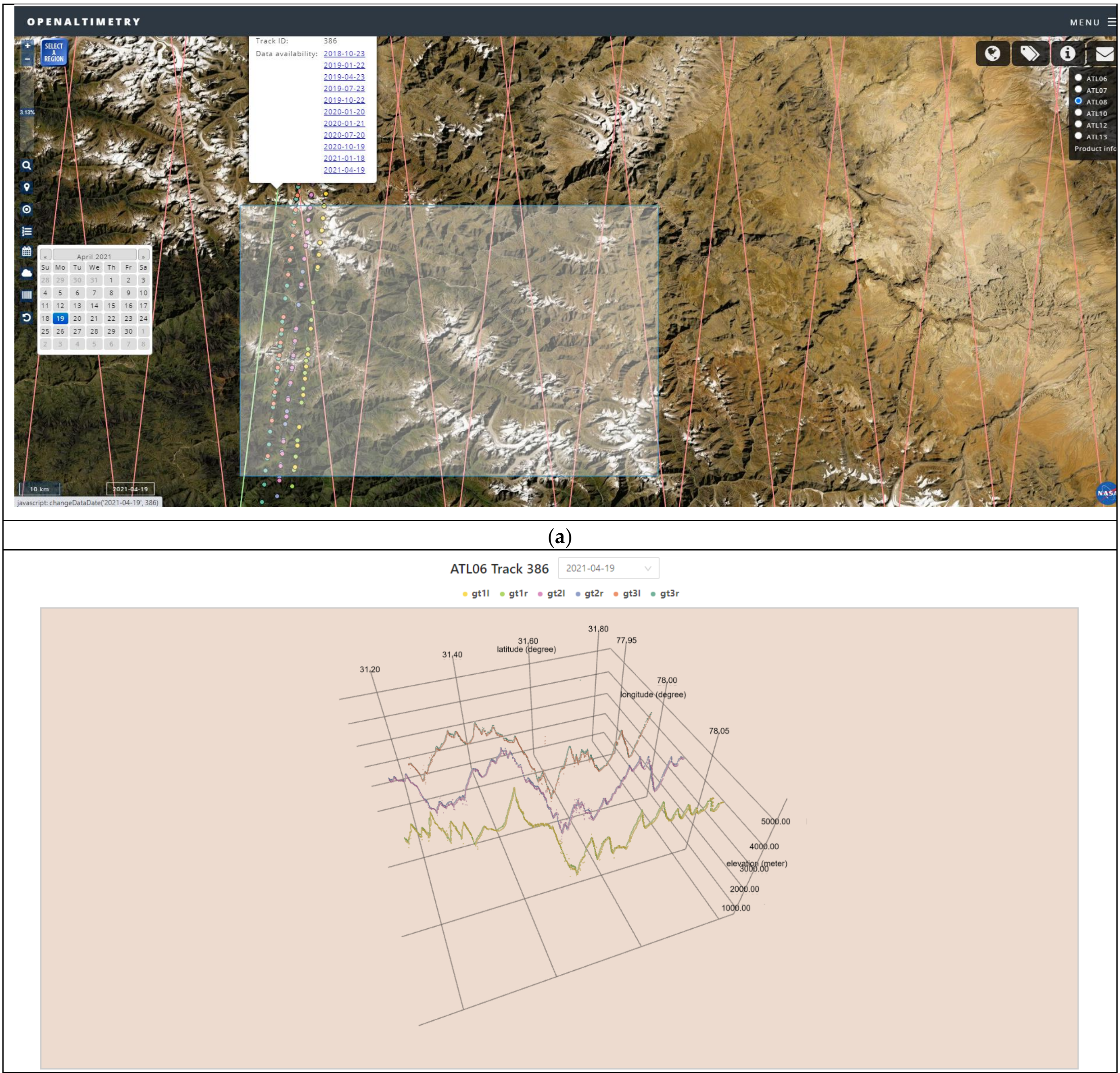
4. Method

The ICESat-2 shapefiles were generated using the ICESat-2 (ATL06) excel datasheets in ArcGIS software after preprocessing of ICESat -2 data for removal of outlier values resulting in 19,755 footprints (out of 20,948 footprints). The shapefile was used further to extract the elevation values from TanDEM-X and ALOS PALSAR RTC HR DEMs. Further, the extracted values from DEMs were tested against ICESat-2 elevation datasets in the WGS84 datum. Considering the data characteristics of openly accessible DEMs used in this study and the ICESat-2 data; the ICESat-2 elevation values after pre-processing are used as reference elevation for computation of statistical measures. Statistics comprising of the mean error (ME), mean absolute error (MAE), and RMSE were computed for both the openly accessible DEMs as detailed in [19], [20]. Besides this, the standard deviation of terrain height is computed for the terrain using ICESat-2 data for the representation of topographic ruggedness.

5. Results and Discussion

Considering the ATL06/ICESat-2 elevation values for 19,755 ICESat-2 footprints as a reference, the mean error (ME), mean absolute error (MAE), and RMSE for TanDEM-X were found as 0.26m, 12.92m, and 17.4m respectively. Similarly, the ME, MAE, and RMSE for ALOS PALSAR RTC HR DEM were found as 0.20m, 9.50m, and 13.88m respectively. Thus for the study site in the higher reaches of Himalayan terrain using ICESat-2 ATL06 products, ALOS PALSAR RTC HR DEM (L-band InSAR product) was found more suitable than TanDEM-X 90m (X-band InSAR product) openly accessible datasets for any kind of application. The range of elevations in ICESat-2 elevation values in the study area is from 3409.75m to 5976.31m alongside the ICESat-2 track ID 325 (Figure 2). Figure 3 (a, b, and c) depicts a similar undulating pattern as depicted by Figure 2 (b).

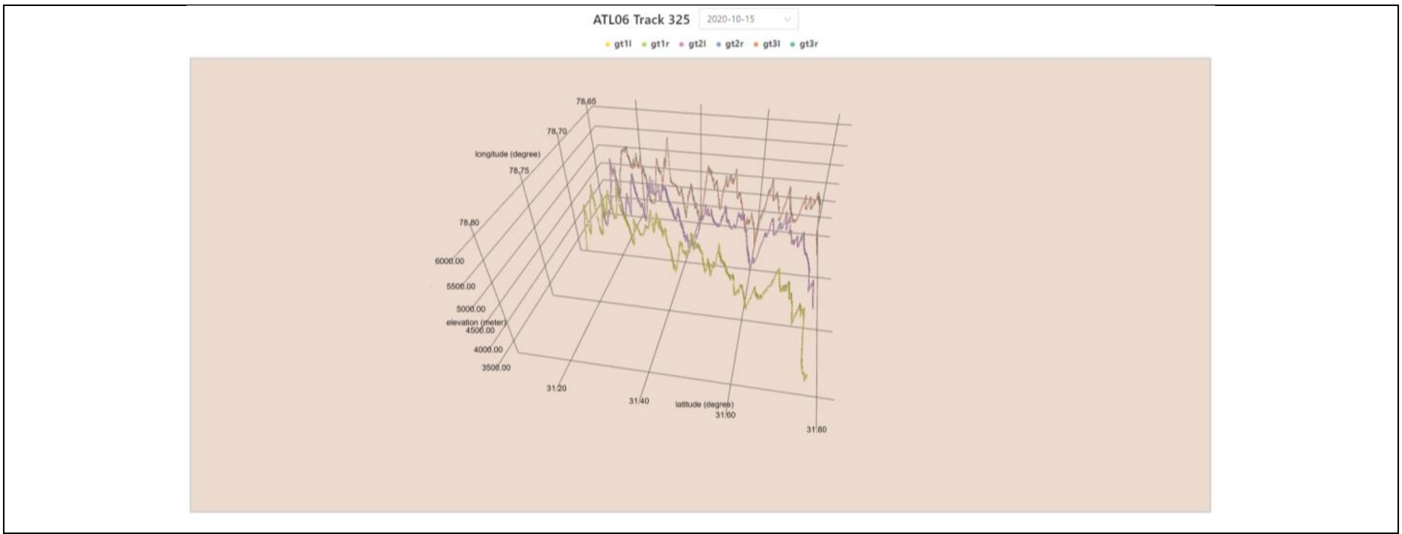
The standard deviation of terrain height values representing terrain ruggedness using ICESat-2 elevation values was found as 432.06m which is quite higher than the one reported for the younger Himalayan region such as Dehradun, and Kalka having standard deviations as 134.79m and 261.08m respectively in earlier studies [21]. The visualization of the experimental sites in the Google earth and OpenAltimetry 3D viewer depicts that the mountain slopes are steep with a large number of peaks and valleys representing the rugged terrain. The region needs more conservation measures for the stabilization of slopes, which pose challenges to the dwellers and tourists. The recent landslides at Nugulsari and Batseri villages show the danger posed by the landslides. During the recent landslides, the Batseri Bridge has collapsed due to the large boulders that tumbled down from the top of the mountains.



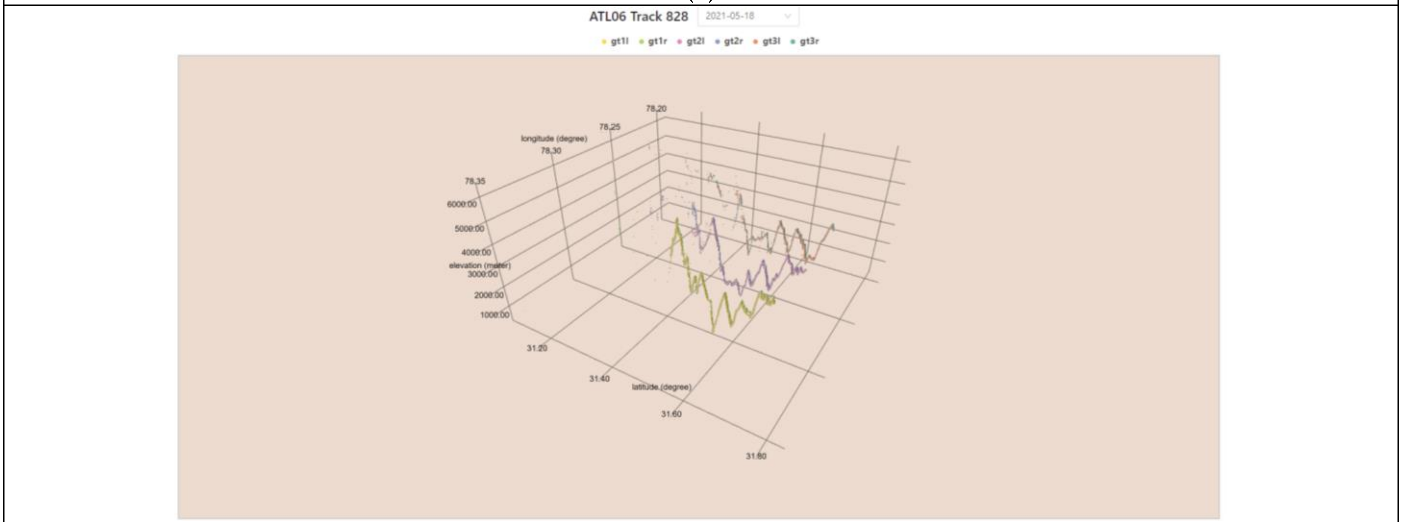
(**a**)

(**b**)

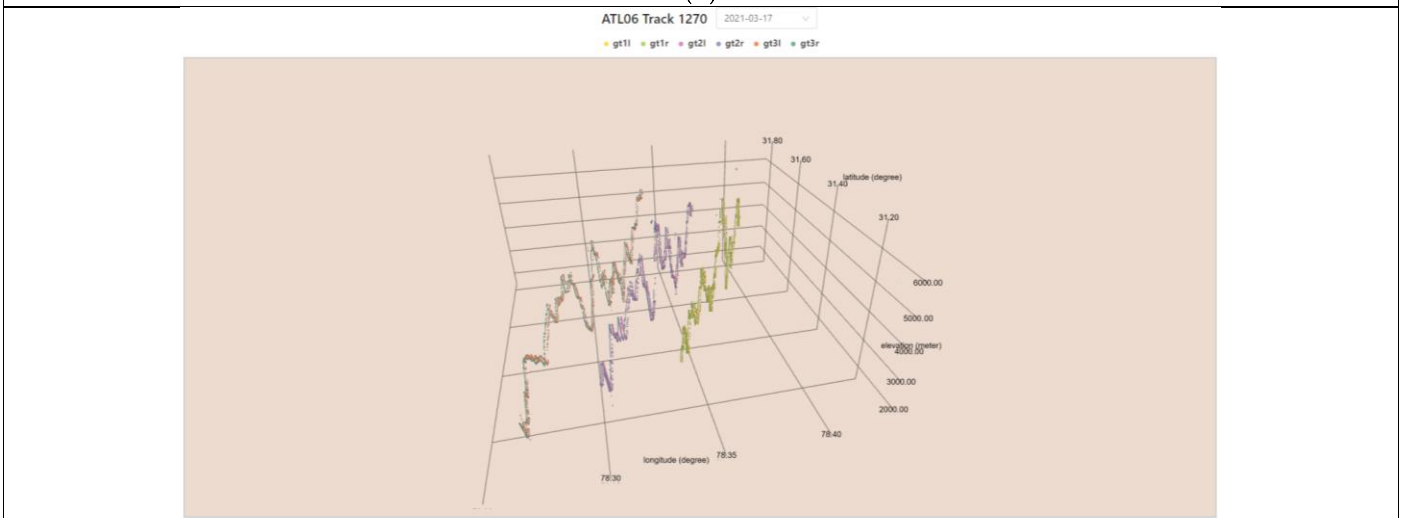
Figure 2. Depicts the study area: (**a**) Parts of Kinnaur District, Himanchal Pradesh and surroundings overlaid with ICESat-2 footprints; (**b**) Show the OpenAltimetry 3Dviewer describing the terrain cross-sections along the ICESat-2 ground track at footprint/beam locations.



(**a**)



(**b**)



(**c**)

Figure 3. Show the OpenAltimetry 3Dviewer describing the terrain cross-sections along the ICEsat-2 ground track at footprint / beam locations for: (**a**) Track 325; (**b**) Track 828; (**c**) Track 1270.

The study suggests that the locations near drainage lines shall be kept free from habitation as they have more erosion and have chances of rockslides or debris flows as experienced in the past due to high slopes. The rugged regions should be marked for such regions prone to landslides so that the commuters can avoid these routes during rains. During rains, the pore pressure increases and increase the chances of rain-induced landslides. A mechanism can be made for the stabilization of known sensitive landslide-prone areas and marking through regular monitoring of sensitive spots in the changing landscape with time. The regulated control on the movement of vehicles can also reduce pressure on the sensitive zones during monsoon season when there are higher probabilities of rainfall-triggered landslides.

6. Conclusion

L-band ALOS PALSAR RTC HR DEM is found better than the TanDEM-X 90 DEM using the ICESat-2 footprints as a reference due to its high penetration capability as well as higher resolution (point posting). The L-band ALOS PALSAR RTC HR DEM is more suitable for any application as compared to the other openly accessible InSAR-based DEMs such as the TanDEM-X 90m. Detailed investigations including geological investigations will be required for conservation practices in the region for the reduction of landslides due to high slopy mountainous terrain.

Funding: "This research received no external funding".

Institutional Review Board Statement: "Not applicable."

Informed Consent Statement: "Not applicable."

Data Availability Statement: The ICESat-2 data, TanDEM-X 90 DEM, and ALOS PALSAR RTC HR DEM datasets are available and can be downloaded from https://openaltimetry.org/, https://tandemx-90m.dlr.de, and https://www.asf.alaska.edu/sar-data/palsar/terrain-corrected-rtc/ respectively.

Acknowledgments: The author thanks the space agencies: National Aeronautics and Space Administration (NASA), German Aerospace Center (DLR), and Japan Aerospace Exploration Agency (JAXA) along with the Google Earth platform for their insights and support through data sharing platforms, which are highly valuable and critical in this study. The author is highly indebted to Director, IIRS for encouraging the research studies at the Indian Institute of Remote Sensing.

Conflicts of Interest: "The author declares no conflict of interest."

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