EVALUATIONS FOR POTENTIAL OF GLACIAL LAKE OUTBURST FLOODS (GLOFS) IN THE BHUTAN HIMALAYA USING PRISM AND AVNIR-2 ONBOARD ALOS

T. Tadono [a, *], J. Takaku [b], S. Kawamoto [b], T. Yamanokuchi [b], K. Fujita [c], K. Nishimura [c]

[a] Earth Observation Research Center, Japan Aerospace Exploration Agency, 1-2-2 Sengen, Tsukuba, Ibaraki, Japan – tadono.takeo@jaxa.jp
[b] Remote Sensing Technology Center of Japan, 1-2-2 Sengen, Tsukuba, Ibaraki, Japan – (takaku, kawamoto, tsutomuy)@restec.or.jp
[c] Nagoya University, F3-1, Furo-cho, Chikusa, Nagoya, Aichi, Japan – (cozy, knishi)@nagoya-u.jp

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ABSTRACT:

The objectives of this study are to validate generated Digital Surface Models (DSMs) by PRISM onboard the Advanced Land Observing Satellite (ALOS, nicknamed "Daichi") in snow and glacier regions to contribute to the evaluation of potential Glacial Lake Outburst Floods (GLOFs) and their mitigation in the Bhutan Himalaya. Glacial lake inventory will also be generated to investigate the expansion process of glacial lakes using historical satellite imageries, including those by ALOS, as current conditions. Failures of glacial lake dams terminated by natural moraines can cause outburst floods and represent a serious hazard to downstream regions. The development and expansion of glacial lakes is sometimes said to be due to recent global warming, while other researchers say no correlation between them exists. The fact is, people living in such regions are exposed to the risk of GLOFs. To mitigate the damage of GLOFs, investigation into the melting process of glaciers and the development and expansion processes of it and evaluations of outburst potential of glacial lakes and triggers of GLOF are necessary. Preparations for risk management, such as operational monitoring of glaciers and glacial lakes, hazard maps, early warning systems, etc., are equally as important. Earth observation satellites have the potential to investigate existing conditions and operational monitoring of glaciers and glacial lakes.
This paper introduces a study to validate generated PRISM DSMs in general terrains without snow as well as those covered by snow in mountainous areas. Airborne Lidar data and field-based GPS measurements have been used to validate PRISM DSMs as reference data. The height accuracies of PRISM DSMs have achieved 2.88 m (RMS) at the Alaska test site, and 6.31 m (RMS) at Mt. Tateyama, Japan. Both sites were covered by snow. These results are sufficient to analyze glaciers and glacial lakes in the Bhutan Himalaya. The three-dimensional glacial lake inventory is currently being generated by PRISM and AVNIR-2 as the latest condition.

1. INTRODUCTION

Glacial lake dam failures terminated by natural moraines can cause outburst floods and represent a serious hazard to downstream regions. The development and expansion of glacial lakes is sometimes said to be due to recent global warming, while other researchers are saying no correlation between them exists. The fact is, people living in such regions are exposed to the risk of Glacial Lake Outburst Floods (GLOFs). Failure of the moraine at Lugge glacial lake in the Lunana region, Bhutan, for example, caused a GLOF on October 7, 1994 (Fujita et al., 2008). The flood damaged local government facilities at Punaka and killed more than 20 people. To mitigate the damage of GLOFs, investigation into the melting process of glaciers and the development and expansion processes of glacial lakes and evaluations of outburst potential of glacial lakes and triggers of GLOF are necessary. Preparations for risk management, such as operational monitoring of glaciers and glacial lakes, hazard maps, early warning systems, etc., are equally as important. However, these areas are generally located in high mountainous regions and are difficult to access for ground surveys. In addition, precise or current geographical maps are not available yet, especially in the Himalayan regions. Earth observing satellites have the potential to investigate existing conditions and operational monitoring of glaciers and glacial lakes and historical satellite data are available to analyze the past conditions.

The Advanced Land Observing Satellite (ALOS, nicknamed "Daichi") was successfully launched on January 24, 2006, and it has continued to operate very well for more than 4 years (Shimada et al., 2010). The Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) onboard ALOS has 2.5-m spatial resolution, and performs along-track stereo observation by a forward-, nadir-, and backward-looking radiometer to extract precise Digital Surface Models (DSMs) or Digital Elevation Models (DEMs). Such terrain information is important when measuring current conditions of glaciers, glacial lakes, and the surrounding areas, as well as runoff and flooding analysis to make hazard maps.

The objective of this study is to validate generated PRISM DSMs in snow regions of mountainous areas. Airborne Lidar data and field-based GPS measurements have been used to validate the DSMs as reference data. The validation results of the DSMs will contribute to analyzing the glaciers and glacial lakes in the Bhutan Himalaya. This work is partially supported by the Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA) under the "Science and Technology Research Partnership for Sustainable Development (SATREPS)".

* Corresponding author

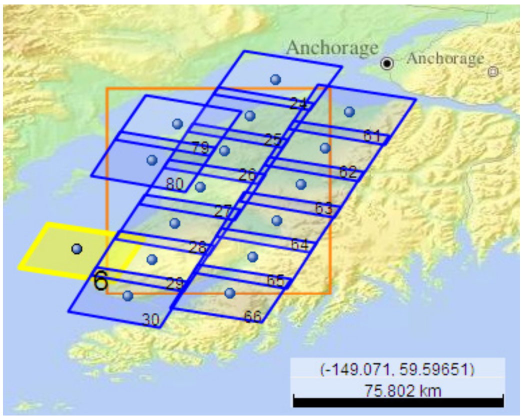

Figure 1. PRISM location and image coverage (blue and yellow rectangles) of the Kenai Peninsula, Alaska, US

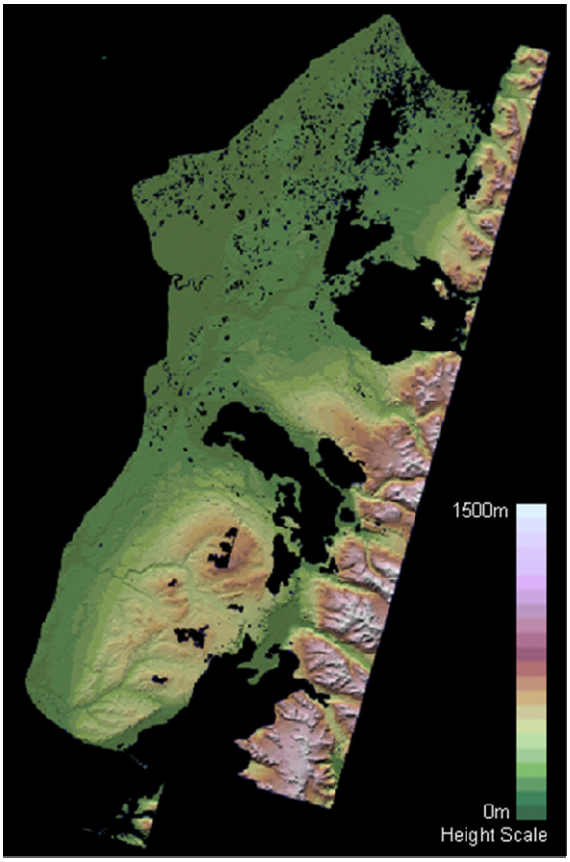

Figure 2. Mosaic of generated PRISM DSM of the Kenai Peninsula, Alaska (black: masked out areas)

2. OPERATION STATUS OF ALOS

ALOS is in good health, and has been in continuous operation for more than 4 years. It has three mission instruments: two optical instruments, PRISM and the Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2), and the Phased Array type L-band Synthetic Aperture Radar (PALSAR). Global images are being acquired by each instrument, and the number of archived images is more than 1,642,215 scenes by PALSAR, 2,230,825 scenes by PRISM, the nadir-looking radiometer, and 974,133 scenes by AVNIR-2 as of May 2010. The images are being used to help achieve the mission objective as well as to aid in global environmental issues.

Figure 3. Height difference between generated PRISM DSM and airborne Lidar (black and sky blue: masked out areas)

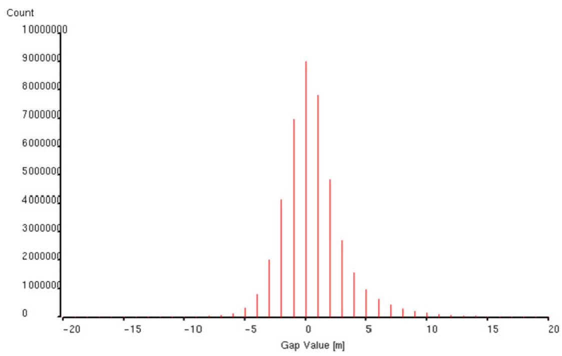

Figure 4. Histogram of height difference between generated PRISM DSM and airborne Lidar

Sensor calibrations and accuracy evaluations are very important in any application field because they directly affect the accuracy of results in the applications. The interim calibration results of PRISM and AVNIR-2 and the validation result of DSMs generated by PRISM have been published (Tadono et al., 2009; Takaku and Tadono, 2009). We are continually performing calibrations and accuracy evaluations of each instrument as operational calibration.

3. VALIDATIONS OF PRISM DSM

We are developing DSM generation software using PRISM stereo pair images, called DSM and Ortho-rectified image Generation Software for ALOS PRISM (DOGS-AP). It is also able to perform sensor calibration through interior and exterior orientations (Takaku et al., 2005; 2008). In this section, the updated validation results of generated DSMs by PRISM are described using a new reference dataset.

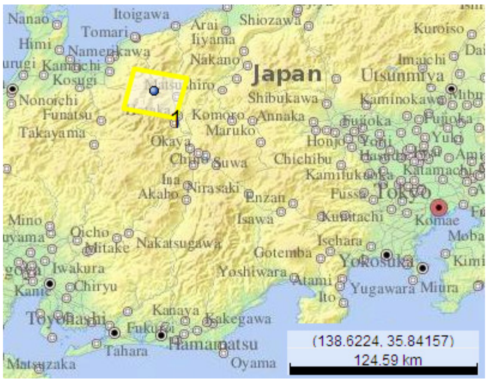

Figure 5. PRISM location and the scene coverage (yellow rectangle) of Mt. Tateyama, Japan

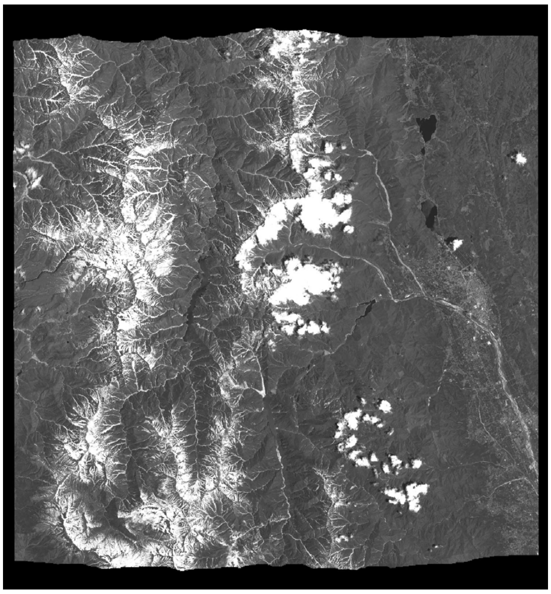

Figure 6. Generated ortho-rectified PRISM image of Mt. Tateyama, Japan (35 km x 35 km area)

3.1 The Kenai Peninsula, Alaska, US

As a new test site of PRISM DSM validations, the reference DSM acquired by an airborne Lidar instrument is available in the Kenai Peninsula, Alaska, US, which covers an area of more than 60 km x 150 km. This dataset is actually very useful in validating derived DSMs by satellite imageries. Figure 1 shows the PRISM location and image coverage of the Kenai Peninsula. A total of 16 stereo-pair images of triplet observing mode were used to process the DSMs. This area contains an altitude variation of 0 m to 1,500 m, general terrain in the western part of the test site, and mountainous regions with snow and glaciers in the eastern part. Figure 2 shows the generated PRISM DSM mosaic of 16-scene DSMs of the test site, which were acquired between October 3, 2007 and June 9, 2009. The black indicates masked out areas due to clouds, ocean, and land water areas. Figure 3 shows a height difference image between a generated DSM and a Lidar DSM as reference. The white areas indicate a height difference of around 0 m, and red and blue areas show height differences of +/-30 m. Sky blue and black indicate masked areas due to clouds and land waters. Basically, this shows the good accuracy of the generated DSM because it is colored mostly white. Figure 4 shows a histogram of height difference between the generated DSM and the Lidar DSM.

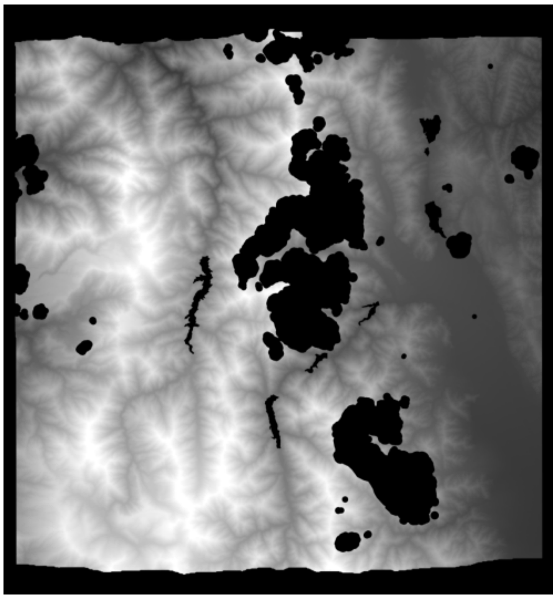

Figure 7. Generated DSM by PRISM (black: masked out)

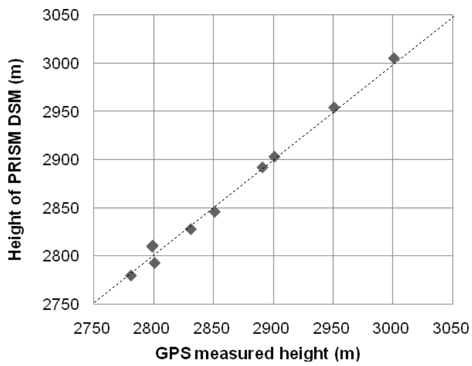

Figure 8. Validation of PRISM DSM compared with ground-based GPS height measurements

Statistically, the generated PRISM DSM has accuracies of 2.88 m (RMS), 0.60 m (bias), and 2.82 m (standard deviation) at 43,669,079 Lidar DSM reference points.

3.2 Mt. Tateyama, Japan

As another new validation test site of PRISM DSM, Mt. Tateyama, Japan, was used for testing DSM generation in snow-covered regions. The altitude of Mt. Tateyama is 3,015 m, and the top of the mountain was covered by snow. Figure 5 shows the PRISM location and scene coverage of Mt. Tateyama, which was used in this evaluation. The ground-based GPS measurement data were available for the validation. Figure 6 shows the generated Ortho-Rectified Image (ORI) of PRISM acquired on June 23, 2007. The ORI was simultaneously processed with the DSM in the DOGS-AP software. The western region is mountainous, including Mt. Tateyama. Unfortunately, the middle parts of that area were covered by clouds. Figure 7 shows a generated DSM by PRISM. The black indicate masked out areas due to clouds and land water areas. Figure 8 shows height comparisons between ground-based GPS measurements and the generated PRISM DSM. We randomly selected 10 reference points in snow regions and compared both heights. Statistically, the generated DSM has accuracies of 6.31 m (RMS), 1.72 m (bias), and 6.40 m (standard deviation).

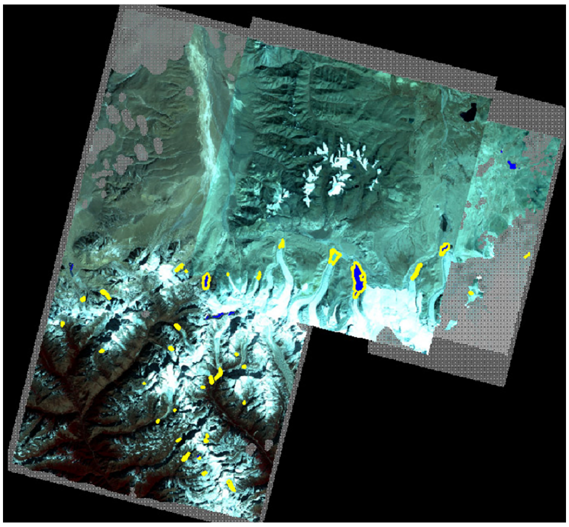

Figure 9. Mosaic of pan-sharpened ORIs by PRISM and AVNIR-2, and digitized glacial lakes (yellow polygons)

4. PREPARATIONS FOR THE INVENTORIES

Based on the validation results in Section 3, a PRISM DSM can be sufficient to generate precise glacial lake and glacier inventories with terrain height information. Therefore, we are currently processing glacial lake inventory of the Bhutan Himalaya using PRISM and AVNIR-2. The processing procedure is as follows:

1) ORIs are processed for both PRISM and AVNIR-2 to compare the past and future satellite data,
2) Pan-sharpened images that have 2.5-m spatial resolution with color information are generated,
3) Digitizing is conducted manually to extract glacial lakes from the pan-sharpened images, and
4) The glacial lakes inventory is prepared as the current condition.

Figure 9 shows an example of the result of this procedure in the western area of Bhutan. The yellow polygons show digitized glacial lakes, which contain shape files. A PRISM DSM is also available in the same geometry. Based on the pan-sharpened ORI, the DSM, and the shape files, three-dimensional inventories will be produced as the current state of glacial lakes and glaciers. Furthermore, this ALOS dataset will be used for assessing runoff and flood analysis, making hazard maps, explaining the hazard risks to local governments and residents, and landslide evaluation using stereo pair images.

In addition, we are collecting and processing past satellite data, such as that of CORONA/KH-9, SPOT, LANDSAT, JERS-1/OPS, and ASTER, to investigate expansion of glacial lakes and GLOF events. They are basically processed by ortho-rectification. For example, Figure 10 shows a browse mosaic of JERS-1 OPS between 1992 and 1996. The past satellite imageries may contribute to revealing the temporal changes of glacial lakes and glaciers in the Bhutan Himalaya.

5. CONCLUSIONS

This study described validation results of PRISM DSMs using new reference data, which mainly focus on snow-covered regions to contribute to glacial lake and glacier monitoring in the Bhutan Himalaya. The height accuracies of the Alaska test site DSM and the Mt. Tateyama DSM have achieved 2.88 m (RMS) and 6.31 m (RMS), respectively. These results basically

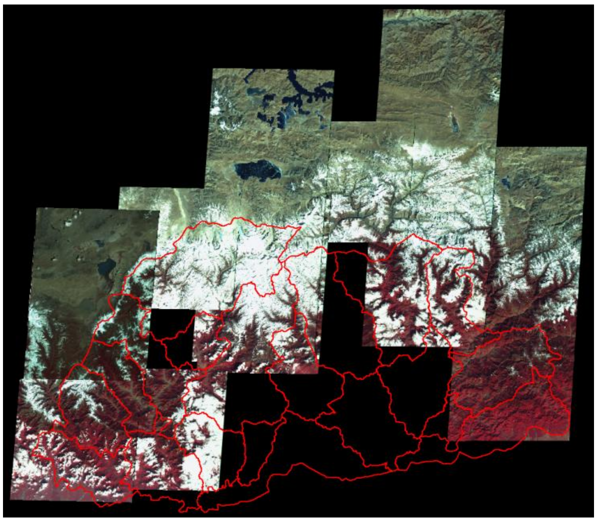

Figure 10. Mosaic of ORIs of JERS-1 OPS in 1992 to 1996

coincide with previous validation results. Based on the results, glacial lake inventory is currently being developed by PRISM and AVNIR-2 of the Bhutan Himalayan under a project scheduled for 3 years from 2009. We expect the updated glacial lake inventory to be open to the public in the near feature.

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References:

Fujita, K., Suzuki, R., Nuimura, T., and Sakai, A., 2008. Performance of ASTER and SRTM DEMs, and their potential for assessing glacial lakes in the Lunana region, Bhutan Himalaya. *Journal of Glaciology*, 54(185), pp. 220-228.

Shimada, M., Tadono, T., and Rosenqvist, A., 2010. Advanced Land Observing Satellite (ALOS) and Monitoring Global Environmental Change. *Proc. the IEEE,* 98(5), pp.780-799.

Tadono, T., Shimada, M., Murakami, H., and Takaku, J., 2009. Calibration of PRISM and AVNIR-2 Onboard ALOS "Daichi". *IEEE Trans. Geoscience and Remote Sensing,* 47(12), pp.4042-4050.

Takaku, J., Futamura, N., Iijima, T., Tadono, T., Shimada, M., and Shibasaki, R., 2005. High Resolution DSM Generation from ALOS PRISM Data –Pre-launch Simulation and Assessment Plans-. *Proc. IGARSS,* IEEE, Seoul, CD-ROM.

Takaku, J., Tadono, T., and Shimada, M., 2008. High Resolution DSM Generation from ALOS PRISM –Calibration Updates-. *Proc. IGARSS,* IEEE, Boston, CD-ROM.

Takaku, J., and Tadono, T., 2009. PRISM On-Orbit Geometric Calibration and DSM Performance, *IEEE Trans. Geoscience and Remote Sensing,* 47(12), pp.4060-4073.