Development of Glacier Lake Inventory in the Bhutan Himalayas Using PRISM and AVNIR-2 Onboard ALOS "DAICHI"

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Abstract - This study is describe to development of glacial lake inventory in the Bhutan Himalayas using the Panchromatic Remote Sensing Instrument for Stereo Mapping (PRISM) and the Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2) onboard the Advanced Land Observing Satellite (ALOS, nicknamed "Daichi") to contribute to the evaluation of potential Glacial Lake Outburst Floods (GLOFs) and their mitigation. 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. This paper introduces to develop new glacial lake inventory using ALOS. PRISM can be generated precise digital surface model (DSM) using stereo capability. Based on the validation of PRISM DSMs in snow and ice region, the three-dimensional glacial lake inventory is generating with pan-sharpened ortho images by PRISM and AVNIR-2.

Keywords: ALOS, Daichi, PRISM, AVNIR-2, DSM, Glacial Lake, Glacier, Cryosphere

1. INTRODUCTION

Failures of glacial lake dams terminated by natural moraines can cause outburst floods and represents a serious hazard damages in downstream regions. The development and expansion of glacial lakes is sometime saying due to the recent global warming, on the other hand other researchers are saying no correlation between them. The fact is peoples living in such regions are exposing to a risk by 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 peoples. To mitigate damages of GLOFs, investigations for melting process of glaciers and development and/or expansion processes of glacier lakes, evaluations of potential of outburst of glacial lakes and triggers of GLOF, as well as preparations for risk management such as operational monitoring, hazard map, early warning systems etc. are necessary.

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 five 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 Model (DSM) or Digital Elevation Model (DEM). 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 Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2) has 10-m resolution with cross-track pointing capability.

The objective of this study is to develop existing glacial lake inventory to understand expansion history using PRISM and AVNIR-2. In this study, updated validation results of generated DSM by PRISM are summarized to consider its capability. The procedure of image processing to make the inventory is also developed, which is introducing pan-sharpened and ortho-rectified images by PRISM and AVNIR-2, and glacial lakes are extracted manually using them. In addition, terrain information i.e. location (lat, long), elevation, slope, etc. will be introduced in the inventory. The field surveys have been conducted in Bhutan in 2010, and validation of developed the inventory is also described compared with an extract glacial lake and ground-based GPS measurement.

2. ALOS OPERATION STATUS

ALOS is in good health, and has been in continuous operation for more than five years. It has three mission instruments: two optical instruments, PRISM and 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 1,867,925 scenes by PALSAR, 2,722,143 scenes by PRISM nadir, and 1,174,184 scenes by AVNIR-2 as of November 2010. The images are being used to help achieve the mission objective as well as to aid in global environmental issues.

The 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, 2009a). We are continually performing calibrations and accuracy evaluations of each instrument as operational calibration. If we find accuracy degradations of instruments, tuning of processing parameters and software will be done to keep and improve accuracies. The latest evaluation result can be found (JAXA EORC, 1997).

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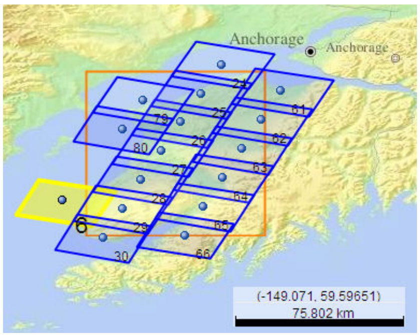

Figure 1. Location and image coverage of PRISM (blue and yellow rectangles) in the Kenai Peninsula, Alaska, US.

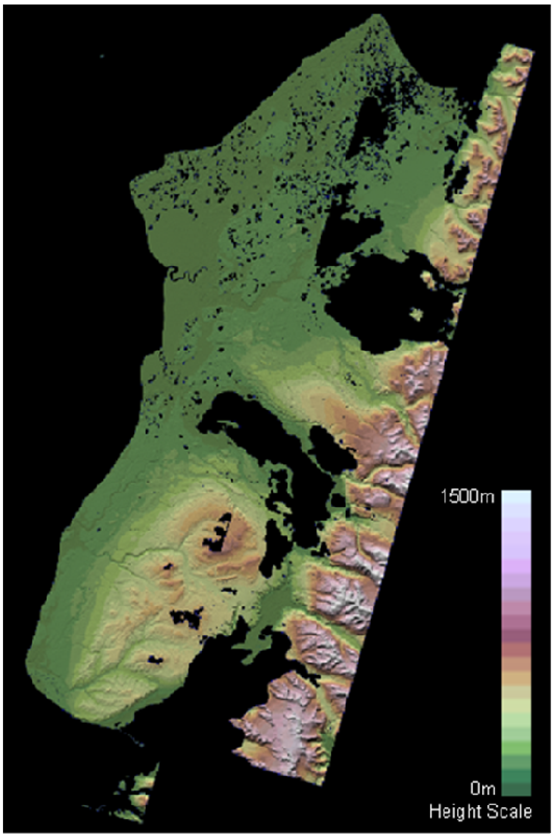

Figure 2. The generated PRISM DSM mosaic of the Kenai Peninsula, Alaska (black: masked out areas).

3. PRISM DSM VALIDATIONS UPDATE

We are developing and maintaining PRISM DSM generation software called the "DSM and Ortho-rectified image (ORI) Generation Software for ALOS PRISM (DOGS-AP)" for calibration and validation purposes. It is also able to perform sensor calibration through interior and exterior orientations (Takaku et al., 2008). In past years, we have been validated the generated PRISM DSM using reference data i.e. airborne Lidar and ground control points (GCPs) (Takaku and Tadono, 2009b). In this section, the updated validation results of generated DSMs by PRISM are described using a new reference dataset.

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

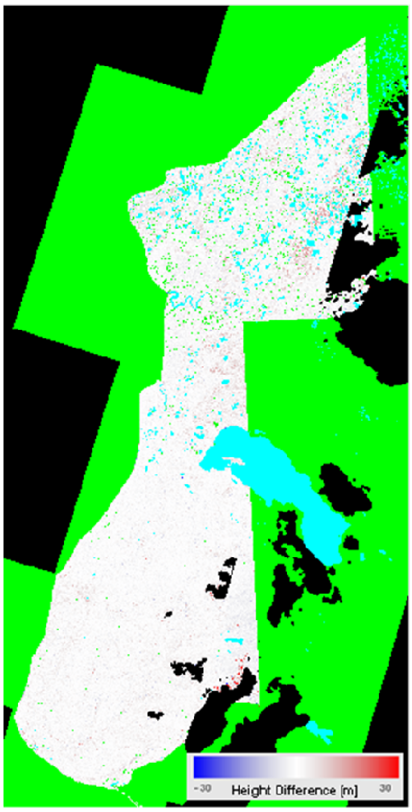

Figure 3. Height difference between generated PRISM DSM and airborne Lidar (black and sky blue: masked out areas).

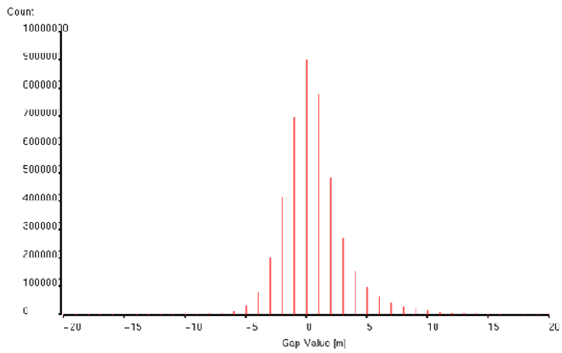

Figure 4. Histogram of height difference between generated PRISM DSM and airborne Lidar.

the PRISM location and image coverage of the Kenai Peninsula. 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, Toyama Pref., 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

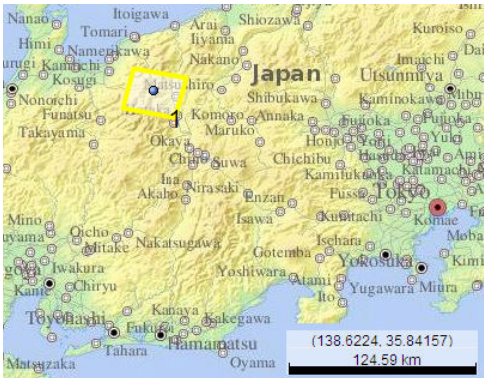

Figure 5. Location and the scene coverage of PRISM (yellow rectangle) in Mt. Tateyama, Toyama, Japan.

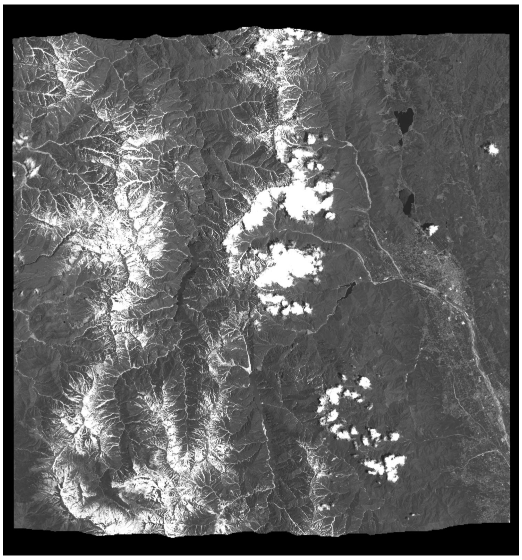
Figure 6. Generated ortho-rectified PRISM image of Mt. Tateyama, Japan (35 km x 35 km area).

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).

4. DEVELOPMENT OF GLACIAL LAKE INVENTORY

4.1 Image Processing

Based on the validation result in Section 3, PRISM DSM can be sufficient to generate precise glacial lake inventory 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 manually conducted to extract glacial lakes from the pan-sharpened images, and
4) The glacial lakes inventory is prepared as the current condition.

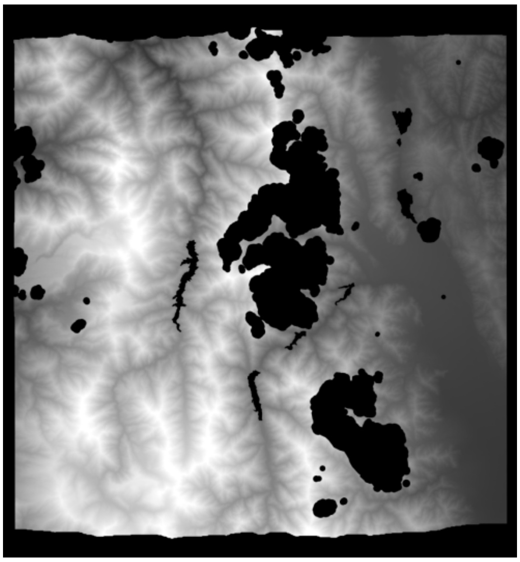
Figure 7. Generated DSM by PRISM (black: masked out).

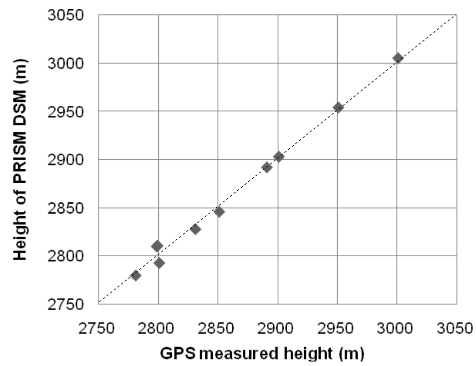

Figure 8. Validation of PRISM DSM compared with ground-based GPS height measurements.

Figure 9 shows an example of the result of this procedure in the northern region of Bhutan. The yellow polygons show digitized glacial lakes, which contain as shape files. Based on the pan-sharpened ORI, the DSM, and the shape files, three-dimensional inventory will be produced as the current state of glacial lakes.

4.2 Validation of the Inventory

According to a report by the International Centre for Integrated Mountain Development (ICIMOD), there are approximately 15,000 glaciers and 9,000 glacial lakes in the Himalayas (Mool et al., 2005). The ICIMOD reported Metatshota Lake indicated by red square in Fig. 2, located in the Mangde Chu sub-basin, as one of 24 potentially dangerous glacial lakes in risk of GLOFs in Bhutan (Mool et al., 2001). In September and October 2010, we conducted a field survey in the Metatshota area taking GPS measurements. Figure 10 shows Metatshota Lake by AVNIR-2 image acquired on Feb. 27, 2010 overlaid three polygons: ALOS-based our inventory (yellow), ground-based GPS measurement (green), and existing glacial lake inventory reported by ICIMOD (Mool et al., 2001). The GPS measurement was made along the Shore of Metatshota Lake. To cope with this limited amount of validation data we first chose 40 points out of about 4,500 GPS points with a nearly equal spacing. Then given each chosen point we computed a distance from the point to the nearest neighbor of the ALOS polygon. The mean value of this quantity turned out to be 9.5 m with the

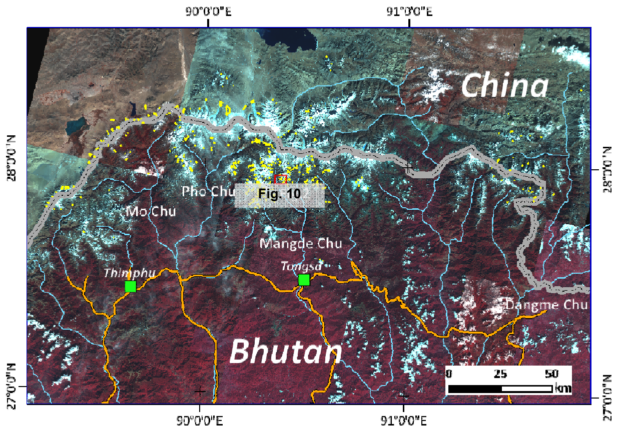

Figure 9. A mosaic image of the northern region of Bhutan by ORIs of AVNIR-2, and the glacial lakes inventory (yellow polygons). The Metatshota Lake area is denoted by a red square.

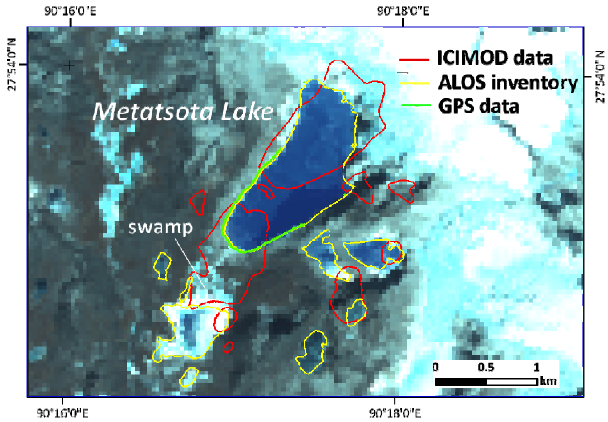

Figure 10. AVNIR-2 image taken over the Metatshota Lake area on Feb. 27, 2010 overlaid polygons of our inventory (yellow), ground-based GPS measurement (green) and ICIMOD data (red) (Mool et al., 2001).

RMS of 6.9 m. If you compare the ICIMOD report (red) with green polygon, the ICIMOD polygon is significantly offset. The ICIMOD polygons were made based on a series of topographic maps published in the 1950s to 1970s by Survey of India. Thus, a part of the difference in the lake size can be attributed to different observation times. However, the fact that the ICIMOD data show the location as significantly offset suggests.

5. CONCLUSIONS

This study described validation result of PRISM DSMs using new reference data, which was focus on snow-covered regions. The height accuracies of generated PRISM DSM have achieved 2.88 m (RMS) in the Kenai Peninsula, US test site compared with 43,669,079 Lidar reference points, and 6.31 m (RMS) in Mt. Tateyama test site compared with 8 ground-based GPS reference points. Based on the results, glacial lake inventory is currently being developed by PRISM and AVNIR-2 in the Bhutan Himalayan. The preliminary validation result of glacial lake inventory for Metatshota Lake was showed compared with the field survey, and it has sufficient accuracy. We expect the updated glacial lake inventory to be open to the public in the near feature.

REFERENCES

K. Fujita, R. Suzuki, T. Nuimura, and A. Sakai, "Performance of ASTER and SRTM DEMs, and their potential for assessing glacial lakes in the Lunana region, Bhutan Himalaya," Journal of Glaciology, vol.54, no.185, pp. 220-228, 2008.

JAXA EORC, 1997. ALOS Research and Application Project, "Calibration and Validation," http://www.eorc.jaxa.jp/ALOS/en/calval/calval_index.htm

P.K. Mool, D. Wangda, S.R. Bajracharya, K. Kuzang, D.R. Gurung, and S.P. Joshi. "Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods: Monitoring and Early Warning Systems in the Hindu Kush–Himalayan Region, Bhutan," International Centre for Integrated Mountain Development, Kathmandu, Nepal, 2001.

P.K. Mool, S.R. Bajracharya, and B.R. Shrestha. "Glaciers, Glacial Lakes and Glacial Lake Outburst Floods in the Hindu Kush-Himalaya," Proc. of the International Karakorum Conference, Pakistan Academy of Geological Sciences & Ev-K^2-CNR Committee of Italy, pp.80-82, April 2005.

M. Shimada, T. Tadono, and A. Rosenqvist, "Advanced Land Observing Satellite (ALOS) and Monitoring Global Environmental Change," Proc. the IEEE, vol.98, no.5, pp.780-799, May 2010.

T. Tadono, M. Shimada, H. Murakami, and J. Takaku, "Calibration of PRISM and AVNIR-2 Onboard ALOS "Daichi"," IEEE Trans. Geoscience and Remote Sensing, vol.47, no.12, pp.4042-4050, Dec. 2009.

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

J. Takaku and T. Tadono, "PRISM On-Orbit Geometric Calibration and DSM Performance," Trans. Geoscience and Remote Sensing, IEEE, vol.47, no. 12, pp.4060-4073, Dec. 2009a.

J. Takaku and T. Tadono, "High Resolution DSM Generation from ALOS PRISM - Status Updates on Over Three Year Operations -," Proc. IGARSS 2009, IEEE, Cape Town, South Africa, 2009b (CD-ROM).

J. Takaku and T. Tadono, "High Resolution DSM Generation from ALOS PRISM - Processing Status and Influence of Attitude Fluctuation -," Proc. IGARSS 2010, IEEE, Honolulu, US, 2010 (CD-ROM).

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