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Japan Aerospace Exploration Agency (JAXA)
Earth Research Observation Center

Description of Glacier and Glacial Lake Inventory of Bhutan using ALOS (Daichi) Data (Version 16.11)

Abstract
This document aim to develop and publish the glacier and glacial lake inventory in the Bhutan Himalayas using optical instruments onboard the Advanced Land Observing Satellite (ALOS, nicknamed "Daichi"), which was operated from January 2006 to April 2011. The Glacial Lake Outburst Flood (GLOF) is exposing to a risk for peoples living in downstream regions. A glacial lake inventory was developed using ALOS data under "Study on GLOFs in the Bhutan Himalayas"*1 project supported by Japan Science and Technology Agency (JST) and Japan International Cooperation Agency (JICA) under the "Science and Technology Research Partnership for Sustainable Development (SATREPS)" (Fujita et al., 2012). The field survey has been conducted in 2010 and 2011, and the location accuracy of 9.5 m (average) and 11.9 m (RMS) has been achieved at a lake in the inventory. In addition, a glacier inventory was generated using the same ALOS images to integrate with the lake inventory (Nagai et al. 2016). Integrating them, we are cordially announcing public release of "Glacier and Glacial Lake Inventory of Bhutan using ALOS Data (Version 16.11)".

Keywords: Glacial lake inventory, Glacier inventory, ALOS, PRISM, AVNIR-2, DSM

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). According to a study coordinated by the International Centre for Integrated Mountain Development (ICIMOD) there are 44 potentially dangerous glacial lakes in risk of GLOFs in Nepal and Bhutan (Mool et al., 2001). However, it may relatively be old and should be update to monitor existing conditions and re-evaluate a potential of GLOF objectively.
This study aim to develop and publish of new glacier and glacial lake inventory 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"). ALOS was operated from January 2006 to April 2011 (Shimada et al., 2010).

2. Data processing and status

PRISM 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). AVNIR-2 has 10 m resolution by four radiometric bands from visible to near infrared. Firstly, ortho-rectified image is processed for both of them using own developed software (Takaku and Tadono, 2009). The PRISM DSM can be simultaneously generated with ortho image. Secondly, pan-sharpened image is generated using them to obtain 2.5 m resolution with color composite image. Thirdly, water bodies are extracted manually using pan-sharpened image. If it is not available yet due to cloud covers in the image, the ortho-rectified AVNIR-2 image is used for this processing instead of it. Finally, glacial lakes are screened from extracted water bodies based on the following definitions: Glacial lakes in our definition are bodies of water that lay between the terminus of the mother glacier and the Little Ice Age moraine. Lakes located within 2 km of the Little Ice Age moraine down-valley are also included to take into account a possible flooding event with multiple lakes being involved. In addition, supraglacial lakes on debris- covered glaciers are included. We also set 0.01 km^2 as the minimum lake size considering small lakes contribute a less amount of GLOFs' risk. More detail of methodology is given by Ukita et al. (2011) and Tadono et al. (2012).

Figure 1 show a pan-sharpened mosaic image for the Bhutan Himalayas as of July 2011 with bands 3, 2, and 1 assigned as red, green, and blue, respectively, and overlaid boundaries of river basins with a red line. The color dots show extracted glacial lakes. The image covers almost the entire state of Bhutan, except for some cloudy areas. Hence, it can be used not only as a base image for the ALOS period but also as a reference to other satellite imageries from fine resolution and precise geolocation. Figure 2 shows enlarged image around upper stream of Mangde Chu basin as example.

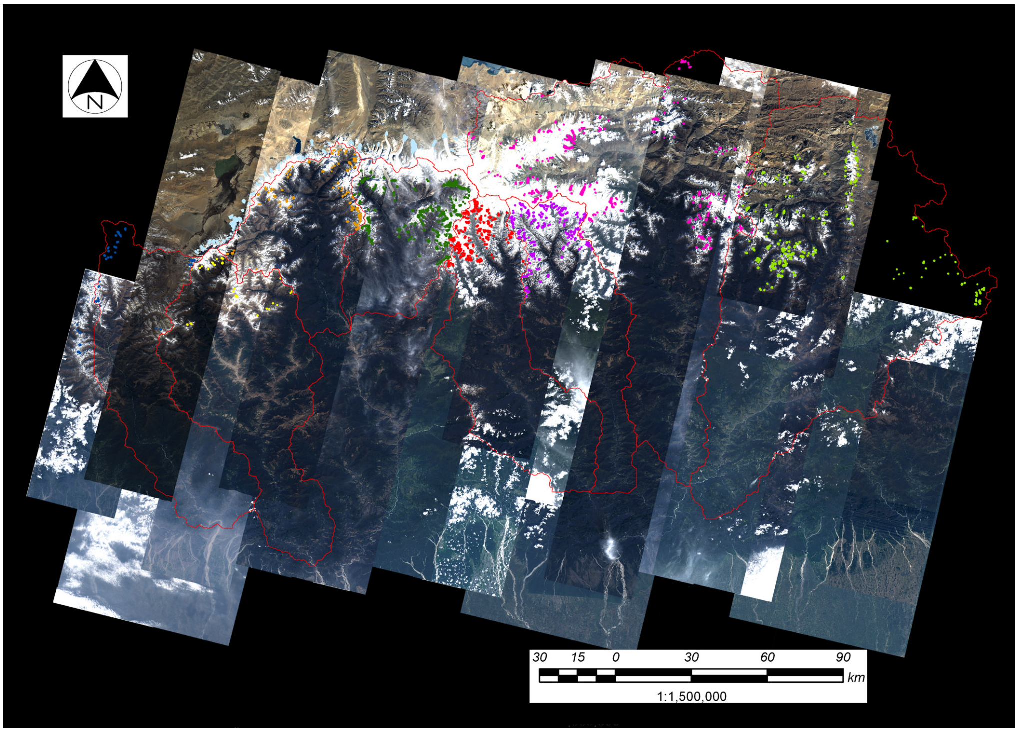

Figure 1: Pan-sharpened mosaic image by PRISM and AVNIR-2 in the Bhutan Himalayas as of July 2011 (R, G, B = Band 3, 2, 1 as true color composite). The red lines show boundaries of river basin and the color dots show extracted glacial lakes in this study.

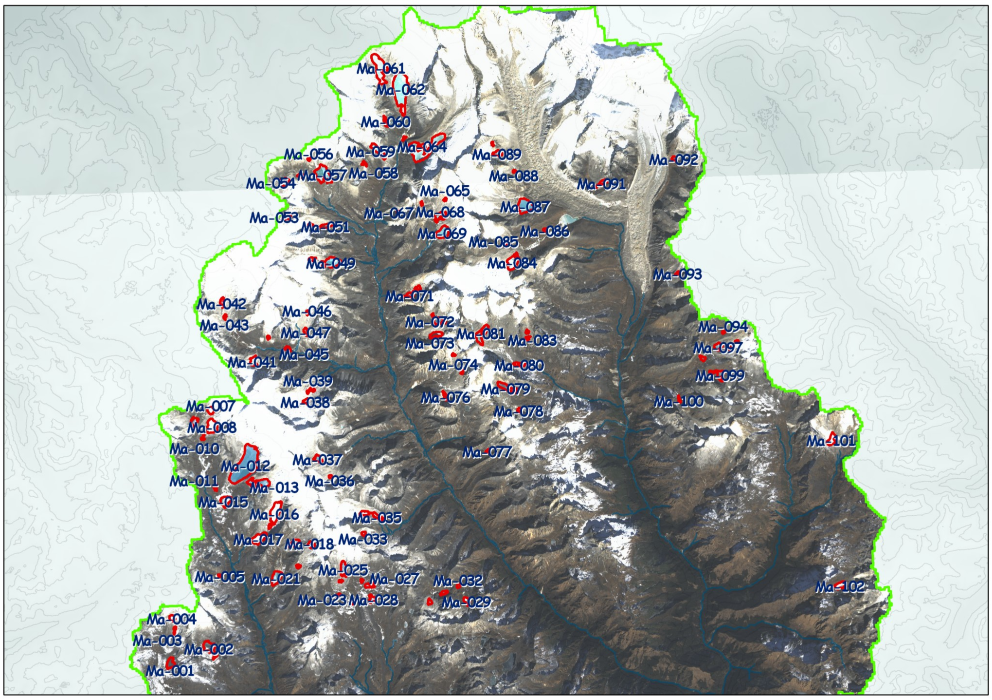

Figure 2: Enlarged image around upper stream of Mangde Chu basin with glacial lake inventory (red polygons).

3. Glacial lake inventory

ALOS-based glacial lake inventory in the Bhutan Himalayas consists of shape file, which includes mostly follow the ICIMOD convention, ID, coordinates in terms of latitude and longitude of the lake center, area, and elevation. Each lake has its own ID based on the name of the river basin and latitude and longitude of the lake center. In addition we provide a cross-reference with respect to the ICIMOD code whenever available.

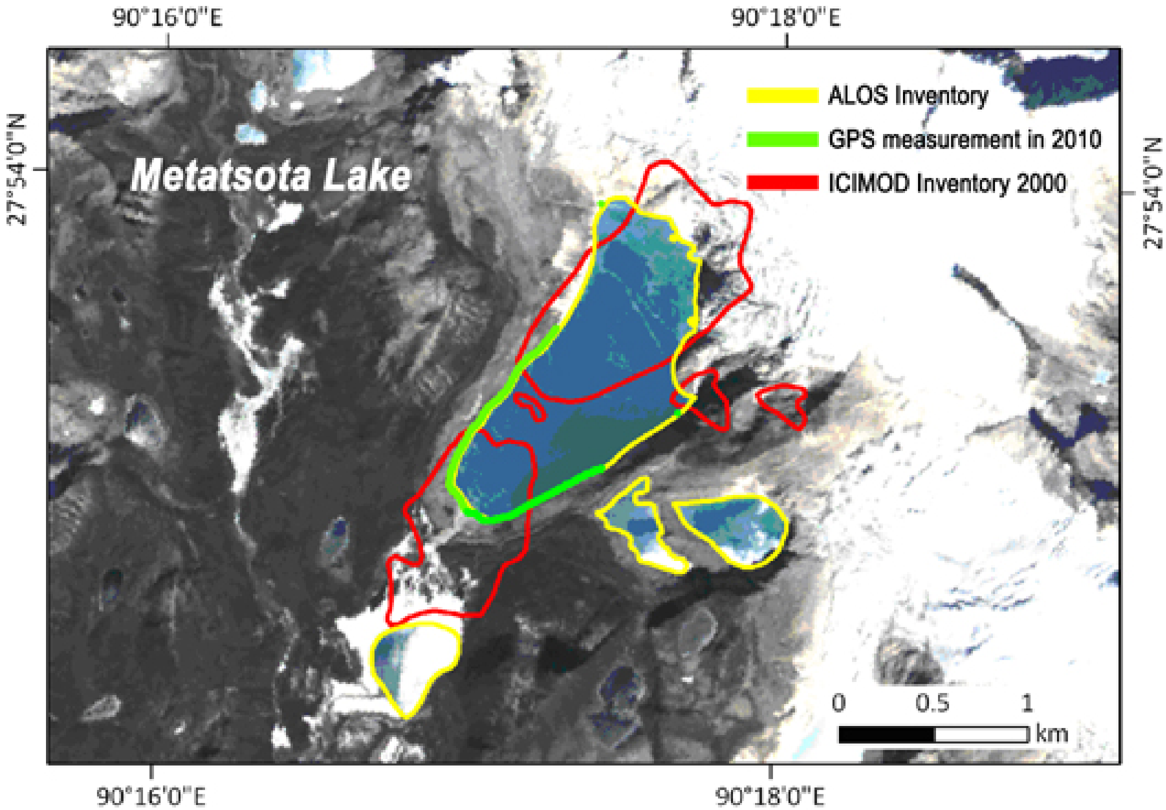

Figure 3: Comparison of polygons among our inventory (yellows), ground-based measurement (green) and ICIMOD inventory (reds) at Metatshota Lake.

As the validation of our inventory, we conducted the ground-based GPS measurements on Sep. to Oct. 2010 at Metatshota Lake in Mangde Chu basin. Figure 3 shows comparison of polygons among ALOS-based inventory (yellows), ground-based GPS measurement (green), and ICIMOD inventory (reds) overlaid AVNIR-2 image. Unfortunately, there has not been a synchronous set of clear PRISM and AVNIR-2 images covering the area. Therefore, ALOS-based inventory was used here on AVNIR-2 image. In statistically, we confirmed that ALOS-based inventory has 9.5m of averaged error, and 11.9m of root mean square (RMS) error compared with ground-based GPS measurement, which was applied post processing with base station GPS data and selected 40 points out of about 4,500 points with a nearly equal spacing (Ukita et al., 2011).

4. Glacier inventory

We manually delineated glaciers and debris-covered areas in PRISM and other satellite imagery (Fig. 4) (Nagai et al. 2016). Our Bhutanese study follows the definition of a glacier proposed by Global Land Ice Measurements from Space (GLIMS) (Raup and Khalsa, 2007), with the sole exception that we excluded adjacent snow-covered slopes on which glacier flow is not expected. Glacier outlines were generated as vector-format polygons traced onto the PRISM images, over which ASTER GDEM2-derived contour lines (20-m interval) were laid using GIS software. Having delineated the outer line, internal bedrock and nunataks were removed from the polygon domain. PRISM data were unavailable for 32 glaciers located in the northernmost part of the study site, for which AVNIR-2 imagery alone was used.

Delineated outlines smaller than 0.01 km^2 in area were removed to minimize the risk of including snow patches. This study does not delineate rock glaciers because they are not defined as a type of glacier (Raup and Khalsa, 2007). Snow-covered rock walls adjacent to the ice surface were also excluded. Any detached ice masses located just above a glacier were included in the delineation if ice redistribution was expected. Shapes for these features are recorded and registered in the inventory as a single row in the attribute table with contains used ALOS-scene IDs, longitude and latitude of glacier centroids, glacier area, debris-covered area, and glacier ID. Upon delineation of glacier outlines and debris-covered areas, outlines were corrected by review of exported glacier polygons into Google Earth, which includes three dimensional high-resolution satellite images.

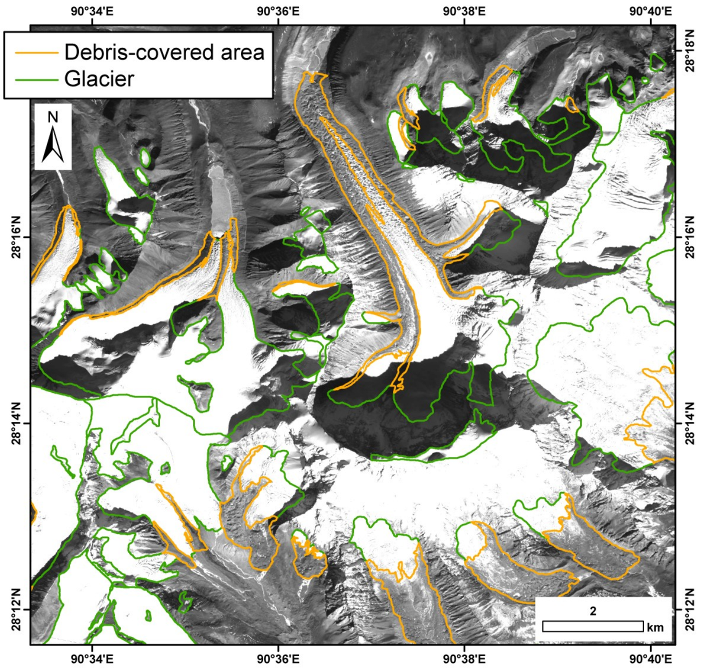

Figure 4: Example of manually delineated outlines of glacier and debris-covered area (an edited figure from Nagai et al., 2016).

5. Public release of "Glacier and Glacial Lake Inventory of Bhutan using ALOS Data"

We are cordially releasing "Glacier and Glacial Lake Inventory of Bhutan using ALOS Data" with free of charge only for research and education purposes and not in commercial purpose. The motivation for this release is to support the research community and various domestic and international projects.

When the inventory is used in any publications, please indicate that *"The ALOS-based glacial lake inventory was prepared under the international project 'Study on Glacial Lake Outburst Floods in the Bhutan Himalayas' supported by the Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA)"* and send copy of the publication to Z-GLOFST@jaxa.jp by e-mail. It is also welcome your valuable comments.

References

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