OUTFLOW ESTIMATION FOR SHIRASE GLACIER USING ASTER AND PALSAR DATA

Kazuki Nakamura (1), Tsutomu Yamanokuchi (2), Koichiro Doi (3) and Kazuo Shibuya (3)

(1) National Institute of Advanced Industrial Science and Technology
(2) Remote Sensing Technology Center of Japan
(3) National Institute of Polar Research

1. INTRODUCTION

Antarctica preserves about 70% of inland waters on the earth surface as an ice sheet. The mass of ice discharged by glaciers plays an essential role in the mass balance of the Antarctic ice sheet. Antarctic contains a great number of crevasses and inclement weather conditions, making it prohibitively dangerous to carry out local observations, consequently, remote sensing is effective for the objectives of these observations. To understand fluctuations of the ice sheet and glacier, we need to get precise information of the ice flow velocity, ice thickness (surface height of the ice sheet) and the boundary between the land ice sheet and the sea ice shelf (called grounding line). The grounding line lies on the boundary of the Antarctic ice sheet adjoining the land base terrain and the sea ice shelves surrounding the ice sheet. The determination of the grounding line is difficult by the interpretation of satellite imagery alone.

The Antarctic Digital Database (ADD) [1] compiled from global Antarctic observations and edited by the British Antarctic Survey (BAS), which provides an estimate of grounding lines. However, the positions and shapes of these grounding lines have been reported as inaccurate, depending on areas [2]. The grounding line could be identified through an analytical technique called interferometry synthetic aperture radar (InSAR). The sea ice shelf area floats on the ocean and oscillates vertically due to ocean tides, while the Antarctic ice sheet can be considered static over the short term (one to several days). InSAR image, vertical movements of the ice shelf caused by ocean tides appear as a dense fringe pattern at the boundary with the static ice sheet, caused by changes in the vertical distance of the ice shelf from the satellite as shown by [3]. The grounding line can be extracted by tracing the inland boundary of the dense fringe area [2],[4],[5].

Because complex SAR data decorrelate rapidly (within 10 days) over the ice sheet and glacier area, application of the InSAR technique is limited to images acquired over short time periods of around 3 days. This means that phase correlation cannot be achieved without data from the European Remote Sensing Satellite (ERS) tandem mission (1-day repeat cycle) or the ERS-1 ice mode operation (3-day repeat cycle). Given that both missions are limited in their operational schedule, the current fluctuation of the glacier and the ice sheet in Antarctica cannot be detected using these archived ERS SAR data and data derived from currently operated SARs. The advanced spaceborne thermal emission and reflection radiometer (ASTER) is installed onboard TERRA satellite. ASTER has the stereoscopic image sensor views nadir and backward in the same orbit, which allows us to generate digital elevation model (DEM) in a single path observation. The ASTER DEM is useful for detecting the grounding line without a decorrelation or such as an InSAR incoherence over the ice sheet and glacier area.

This paper describes that detects and estimates of the grounding line and ice thickness for Shirase Glacier obtained using the ASTER DEM, and also detailed estimates of ice flow vectors obtained using the SAR amplitude image correlation [6],[7]. This method can be applied to a long repeat cycle (46 days) for the phased array type L-band SAR (PALSAR) data obtained by Advanced Land Observing Satellite (ALOS).

2. ASTER AND PALSAR DATA

2.1. ASTER data

ASTER is an advanced optical sensor comprised of 14 spectral channels ranging from the visible to thermal infrared region. This study used the Visible and Near Infrared (VNIR) high resolution radiometer, which has the stereoscopic image sensor views nadir and 27.6º backward of the Band 3N and 3B sensors in the same orbit. This can be applied the grounding line detection to a long observation span of 2000 to 2009 in the present study and we chose ASTER data with as little cloud as possible each year.

2.2. PALSAR data

The repeat cycle of the ALOS satellite is 46 days and it carries on the observations of JERS-1 with an L-band SAR (λ = 23.5 cm), called PALSAR. The PALSAR intensively observed Shirase Glacier and its surrounding region from 2007. It is possible to estimate the displacement of a given point upon Shirase Glacier at 46 days intervals. We used a total of 6 PALSAR images pairs, which were obtained from signal data (raw data) provided by the Earth Remote Sensing Data Analysis Center (ERSDAC).

3. DATA ANALYSIS

3.1. Flow velocity estimation

We first generated SLC (single-look complex) images from the raw PALSAR data using the common routine of the GAMMA SAR Processor. Next, we precisely estimated the range and azimuth offsets to sub-pixel accuracy and accurately co-registered the master and slave scenes. We then generated a multi-look amplitude image with 2 looks in range and 5 looks in azimuth. This multi-look processing was necessary to suppress speckle noises in the SLC images. For each PALSAR scene, pixel size was 16.4 m in the azimuth direction and 15.0 m in the range direction.

The image correlation detects similarities in a pair of co-registered images by examining a matched point between the matching window of the master image and that in the slave image. In the search procedure, the matching window was taken as 64 pixels (about 1 km^2) in both azimuth and range, which are established and are considered to be matched when the correlation coefficient is maximized. In the case that the mismatch attains the decorrelation limit of ±1 pixel unit, the error of the ice flow becomes ±18.6 m/46 days (±0.15 km/a) as the mean value between the minimum (1 pixel distance in range) and maximum (diagonal between a distance in range and azimuth). Given that the details of the image correlation are described in [7].

3.2. Grounding line and surface height detection

The grounding line detection and ice thickness estimation for Shirase Glacier used the ASTER DEM derived from ASTER data β, which was generated by the global earth observation grid (GEO Grid) in National Institute of Advanced Industrial Science and Technology (AIST) [8]. The ASTER DEM derived from the GEO Grid is characterized by the Universal Transverse Mercator (UTM) coordinates in the World Geodetic System 1984 (WGS-84) reference system and the spatial resolution is 15 m. We used the pixel coordinates transformed into the RADARSAT Antarctic Mapping Project (RAMP) [9], which is characterized by polar stereo graphic coordinates in the same reference system. Since the geodetic heights of the ASTER DEM is WGS-84 ellipsoidal height, the height was a calculated geoid height of each pixel based on EGM96 [10] 15' grid subtracted from the ellipsoidal height. The ASTER DEM is with an error of ±7.8 m and that vertical offset as -9.1 m is known [11].

The ice sheet flows to the drainage basin, i.e. the grounding line, and the surface height decreases along with that flow. Thus, the grounding line can be identified as the elevation of innermost ice sheet when the elevation of ice sheet is similar to that of ice shelves. Ice thickness is deduced from hydrostatic equilibrium extracts the elevation H near the grounding line across the central streamline of Shirase Glacier and a conversion factor taking account of different ice and seawater densities. If the densities of ice and seawater (ρ_{ice} and ρ_{sea}) are respective values of 917 kg/m^3 and 1023 kg/m^3, the ice thickness is calculated by a following equation; $H\rho_{sea} / (\rho_{sea} - \rho_{ice})$.

4. RESULTS AND DISCUSSION

Shirase Glacier accelerates in the upstream area with the moving distance, reaching a flow velocity at the grounding line. This trend has continued largely unchanged, judging from the flow velocity profiles gathered in the JERS-1 SAR observations 11 years ago in 1996 - 1997 [7]. There is a clear acceleration upstream of the grounding line and a slight but definite deceleration downstream of the grounding line. The ice velocity is approximately constant up to 10 km downstream from the grounding line, where the glacier accelerates again and continues to do so towards the ice front. A velocity derived from the ERS-1 SAR observations in 1996 was also reported, which was 2.3 km/a at the grounding line [12]. The mean velocity was estimated from PALSAR observations as 2.26 km/a. This cannot be considered a significant change considering the estimated error.

The grounding line was detected from ASTER observations in 2000 - 2009. The annual variations of the grounding line position are little change, but the slight variations were shown in periphery of the central streamline. The flow of ice sheet converges on the center of grounding line, and the ice partly tumbles down to the grounding line. Since the DEM is generated with the error of stereo matching as the surface becomes a rough, the slight variations can be considered in the central grounding line position.

The annual ice outflow of Shirase Glacier was estimated using the flow velocity estimated from the PALSAR image correlation and the grounding line, its thickness and width detected from the ASTER DEM. The inferred ice loss of 18.25±2.16 km3/a is comparable with an ice loss of 15.1±2 km^3/a estimated from the InSAR technique [12]. From the comparison of these results, the out flow of Shirase Glacier might have been increased last decade.

For the future, the grounding line detection and ice flow estimation will be applied to other glaciers. We will also try to make an improvement in the Antarctic mass balance through comparisons the ASTER DEM with another DEM from GRACE, ICESat or ALOS PRISM.

5. ACKNOWLEDGEMENT

This research used ASTER data beta processed by the AIST GEO Grid from ASTER data owned by the Ministry of Economy, Trade and Industry (METI). METI and Japan Aerospace Exploration Agency retain ownership of the original ALOS PALSAR data, which were distributed by ERSDAC.

6. REFERENCES

[1] ADD Consortium, "Antarctic Digital Database, Version 3.0. Database, manual and bibliography," Scientific Committee on Antarctic Research, Cambridge, pp. 93, 2000.

[2] T. Yamanokuchi, K. Doi, and K. Shibuya, "Validation of grounding line of the East Antarctic Ice Sheet derived by ERS-1/2 interferometric SAR data," *Polar Geosci.*, vol. 18, pp 1-14, 2005.

[3] R. M. Goldstein, H. Engelhardt, B. Kamb, and R.M. Frolich, "Satellite radar interferometry for monitoring ice sheet motion: application to an Antarctic ice stream," *Science*, vol. 262, pp. 1525-1530, 1993.

[4] E. Rignot, "Tidal motion, ice velocity and melt rate of Petermann Gletscher, Greenland, measured from radar interferometry," *J. Glaciol.*, vol. 42, pp. 476-485, 1996.

[5] T. Ozawa, K. Shibuya, K. Doi, and S. Aoki, "Detection of grounding line and vertical displacement of ice shelf by SAR interferometry -A case study for the Stanjukovicha Ice Shelf, East Antarctica, using ERS tandem SAR data," *Polar Geosci.*, vol. 15, pp. 112-122, 2002.

[6] K. Nakamura, K. Doi, and K. Shibuya, "Why is Shirase Glacier turning its flow direction eastward?" *Polar Sci*. vol.1, no.2-4, pp.63-71, 2007.

[7] K. Nakamura, K. Doi, and K. Shibuya, "Estimation for seasonal change of Shirase Glacier flow by using JERS-1/SAR image correlation," *Polar Sci.* vol.1, no.2-4, pp.73-83, 2007.

[8] S. Sekiguchi, Y. Tanaka, I. Kojima, N. Yamamoto, S. Yokoyama, Y. Tanimura, R. Nakamura, K. Iwao and S. Tsuchida, "Design Principles and IT Overviews of the GEO Grid," *IEEE Sys. J.*, vol. 2, no. 3, pp. 374-389, 2008.

[9] K. Jezek, and RAMP Product Team, "RAMP AMM-1 SAR Image Mosaic of Antarctica," Alaska Satellite Facility, Fairbanks, AK, in association with the National Snow and Ice Data Center, Boulder, CO, 2002.

[10] F. G. Lemoine, S. C. Kenyon, J. K. Factor, R.G. Trimmer, N. K. Pavlis, D. S. Chinn, C. M. Cox, S. M. Klosko, S. B. Luthcke, M. H. Torrence, Y. M. Wang, R. G. Williamson, E. C. Pavlis, R. H. Rapp and T. R. Olson, "The Development of the Joint NASA GSFC and NIMA Geopotential Model EGM96," NASA/TP-1998-206861, NASA Goddard Space Flight Center, Greenbelt, MD, 20771 USA, 1998.

[11] S. Kodama, M. Arioka, A. Mio, R. Nakamura, and K. Iwao, "Geometric accuracy of ASTER DEM," *Proc. 43rd Autumn Conf. Remote Sens. Soc Jpn*., pp. 241-242, 2007.

[12] E. Rignot, "Mass balance of East Antarctic glaciers and ice shelves from satellite data," *Ann. Glaciol*. vol. 34, pp. 217-227, 2002.