Determination of the Antarctic coastal line by InSAR, and variation estimate of Shirase Glacier flow by a SAR image correlation method

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Summary We applied InSAR analysis to the ERS-1/ERS-2 SAR data mostly obtained between November 1995 and March 1997, and obtained the grounding lines for parts of East Antarctica (25˚W-40˚E) and West Antarctica (85˚W-165˚W). The InSAR detected grounding lines delineated more precise (7000 m depending on location) and more detailed coastline features than the ADD coastlines. We also applied SAR image correlation method to the JERS-1 SAR data over the Shirase Glacier region to estimate seasonal and spatial variations of the ice flow velocities. From the grounding line towards 30 km downstream into Lützow-Holm Bay, seasonal and annual variations of the ice flow velocities were detected. It is significant that the western streamline has systematically larger ice flow velocity than the eastern streamline, and therefore Shirase Glacier deflects toward east by 38˚. This may partly be related with 50 m (10 %) systematic deepening of bedrock topography in the eastern side, and inflow of tributary ice streams from west.

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Detection of Antarctic coastline by InSAR

We applied Interferometric Synthetic Aperture Radar (InSAR) analysis to detect the grounding lines along the East Antarctic coast (25˚W-40˚E) and those along the West Antarctic coast (85˚W-165˚W), as steep fringe patterns appear at the boundary between ocean ice shelf and land ice sheet. The ERS-1/ERS-2 SAR data were processed to derive "interferograms", and the geographic coordinates were given to the interferograms through the superposition of the intensity scenes to the RAMP (Radarsat Antarctic Mapping Project; Jezek and RAMP Product Team, 2002) whole Antarctic mosaic image which already has the WGS84 coordinates. Details of the detection method are described in Yamanokuchi et al. (2005).

Figure 1 indicates outline of the InSAR-derived grounding line for East Antarctica (25˚W-40˚E), while Figure 2 shows similar result for West Antarctica (85˚W-165˚E). As compared with the ADD (Antarctic Digital Database) grounding line compiled by BAS (British Antarctic Survey), InSAR derived grounding lines delineate more precise (for location) and more detailed (for coast feature) ocean-continent boundary. The location difference between InSAR and ADD grounding lines attained 5000m in Riiser-Larsenhalvoya (60˚00'S, 34˚00'E), 1200m in Padda (69˚39'S, 38˚20'E), and Skallen (69˚40'S, 39˚25'E). On the other hand, there was good consistency around Neumayer Station (70˚36'S, 08˚22'W). The amount of discrepancy changed from region to region; it attained 6000m at westward of Siple Island (73˚39'S, 125˚00'W), 7100m at eastward of King Peninsula along with Pine Island coast (73˚10'S, 102˚30'W).

ADD grounding line is basically based on interpretation of Landsat optical sensor images and it usually has unavoidable ambiguities. In contrast, InSAR grounding line is based on tidal motion of ice shelf and follows precise ocean-continent boundary. Although Lazarevisen (13˚E-16˚E) looks like a peninsula in the ADD, it actually is a group of snow-covered islands or ice rises. Similarly Bear Peninsula (74˚35'S, 111˚00'W) is an independent stand-alone Island, not a peninsula. However, InSAR grounding line does not necessarily gives accurate features all the time. For example, Robertskollen (71˚30'S, 3˚15'W) showed erroneous fringe patterns, reflecting insufficient tidal amplitude (9.4 cm) from the NAO99b ocean tide model (Matsumoto et al., 2000).

InSAR DEM evaluation by ICESAT GLAS

ICESAT (Ice, Cloud, and land Elevation Satellite) / GLAS (Geoscience Laser Altimeter System) is the newest spaceborne laser altimeter in operation; it can measure the Earth's surface topography with an accuracy of ±14cm. Together with InSAR Digital Elevation Model (DEM) of high spatial resolution, accurate GLAS altimeter height can be integrated to correct for heights of DEM. This integration was tested at southern area of Breivika (71˚15'S, 24˚10'E). Before the height correction, rms height difference between InSAR DEM and GLAS data was ±284m. After the correction, height difference reduced to ±33m, and comparison with JARE-28 (28th Japanese Antarctic Research Expedition) ground truth GPS measurement heights (Shibuya and Fukuda, 1988) along the Breivika traverse route resulted in height difference of ±39m. This shows that GLAS height can be used as the Ground Control Point (GCP), instead of in-situ GPS height.

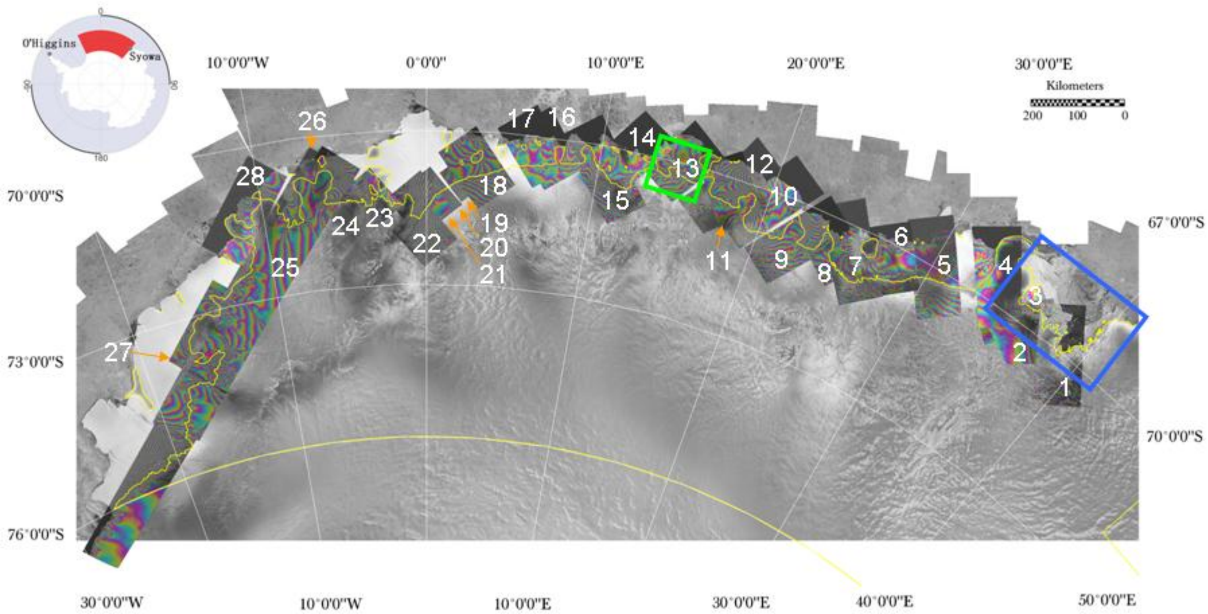

Figure 1. The number on each interferogram corresponds to the data pair for ERS-1/ERS-2 interferometry. The observation date ranges from 1995/11/07-08 to 1997/03/14-15 and 1999/11/14-15 of Tandem mission, except for ice mode pair of 1991/12/06-09. Receiving station was Syowa (11-17, 24, 25, 27) and O'Higgins (18-23, 26). GCPs range from 7 to 22. GLAS height comparison with the in-situ GPS height was made in the Breivika area in pair 8. Pair 1 covers the Shirase Glacier area whose dynamics were studied by using the image correlation method.

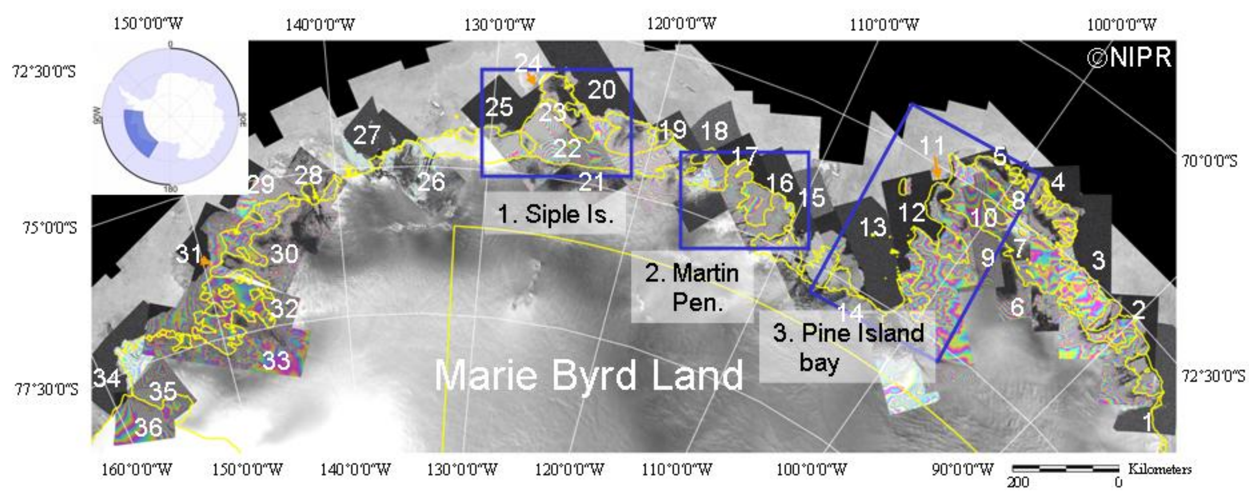

Figure 2. The number on each interferogram corresponds to data pair for ERS-1/ERS-2 SAR interferometry. The observation date ranges from 1995/10/16-17 to 1996/03/22-23 of Tandem mission. Receiving station was O'Higgins (1-24) and McMurdo (25-36). Number of GCPs range from 7 (pair 9, 10, 15, 18, 27, 35) to 22 (pair 4), except 4 for pair 14, 22, 25 and 26. The grounding line was manually detected by tracing the most landward fringe band (several km wide) between the ocean and the continent, and it is archived by the Arc-info format.

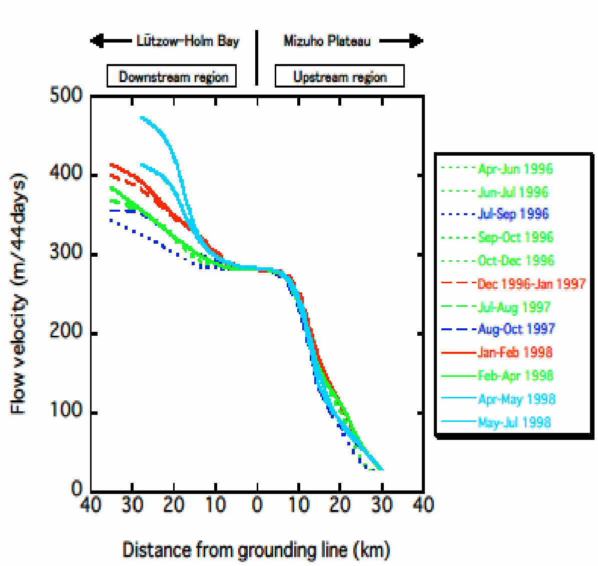

Figure 3. Flow velocities (m/44 days) on the central streamline of Shirase Glacier. Dotted, dashed, and solid lines are those in 1996, 1997, and 1998 respectively.

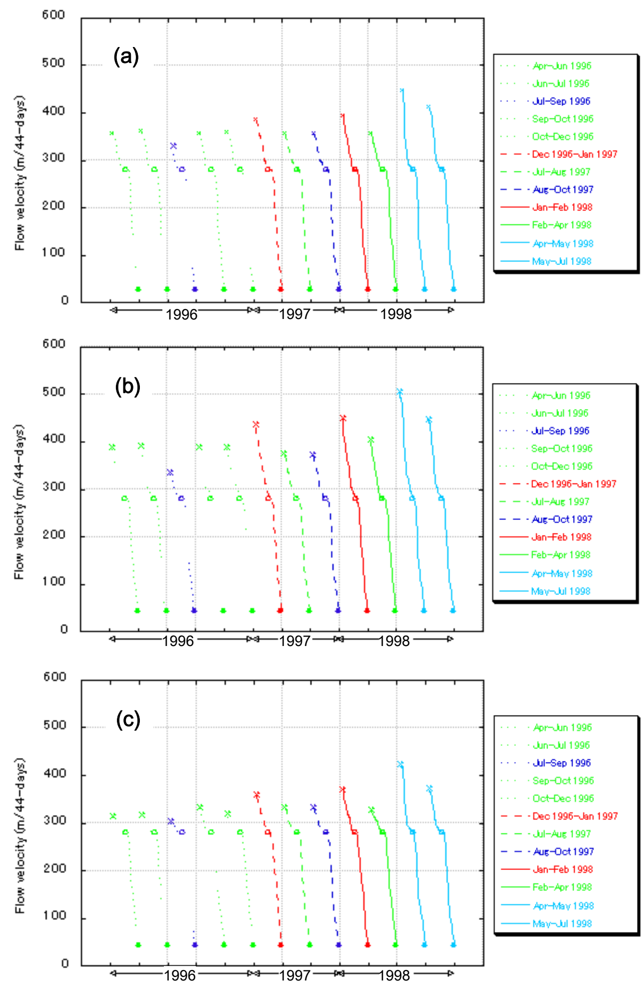

Figure 4. Time series of ice flow velocity are plotted for (a) central streamline, (b) western streamline, and (c) eastern streamline of Shirase Glacier.

Shirase Glacier flow by a SAR image correlation

Seasonal variation

Using the Japanese Earth Resources Satellite-1 (JERS-1) SAR data, we investigated seasonal ice flow velocity variation of Shirase Glacier. We used 12 pairs of 44 days' repeat cycle over the time span from 30 April 1996 to 1 July 1998 to estimate ice flow fields by an image correlation method (Nakamura et al., 2007a). The geometric registration is taken by referring to the RAMP image dataset (Jezek and RAMP Product Team, 2002) and error analysis by feature mismatch indicated the absolute error of ±0.30 km/a, and relative error of ±0.04 km/a in the estimated flow velocity. As shown in Figure 3, the obtained ice flow velocity increases rapidly from the upstream region (1.18 km/a) towards the grounding line and stagnant there (2.33 km/a), accelerates gradually to 2.70 km/a in the downstream region, then becomes further faster to 3.05-3.50 km/a in the terminus of the floating ice tongue. The ice flow velocities in the downstream region are highly variable, depending on both the distance from the grounding line and the observed epoch (season). As for seasonal variation at the floating ice tongue, most of the obtained variations are within the discrepancy of the associated error, but the year-to-year difference between 1997 (3.11 km/a) and 1998 (3.50 km/a) is significant, reflecting possible accelerated motion in relation to disappearance of floating ice tongue between April and May of 1998. As for difference of the sea ice thickness in Lützow-Holm Bay between the summertime and the wintertime, thicker difference (44.2 cm) in 1997 than thinner difference (33.9 cm) in 1996 corresponds to slower ice flow velocity (about 0.20 km/a) in 1997 than faster ice flow velocity (about 0.30 km/a) in 1996, indicating air-sea ice-glacier flow interactions in Lützow-Holm Bay.

Unbalanced flow velocity between western and eastern flow lines and turning towards east

Together with seasonal variation of ice flow velocities in the downstream region (from grounding line towards 30 km downstream), it is significant that the ice flow velocity was systematically larger on the western streamline than on the eastern streamline (Nakamura et al., 2007b). The differences on both sides were 0.28 km/a in 1996 and 0.33 km/a in 1998, which were significantly larger than the error estimate of 0.03 km/a. The ice flow direction was about 312˚ at the grounding line and changed to 327˚ at 10 km, 346˚ at 20 km and 2˚ at 30 km downstream from the grounding line. The total deflection attained 38˚ towards east. Under the assumption of ice mass conservation across the cross section of Shirase Glacier, the reason of eastward turning in the transition zone can be explained by asymmetric deepening of bedrock topography in the eastern side. Further turning in the downstream region must be related with inflow of tributary ice streams from west.

Conclusions

We applied InSAR analysis to the ERS-1/ERS-2 SAR data mostly obtained between November 1995 and March 1997, and obtained the grounding lines for parts of East Antarctica (25˚W-40˚E) and West Antarctica (85˚W-165˚W). The InSAR grounding lines delineated more precise (7000 m offset correction depending on location) and more detailed coastline features than the ADD coastlines. We also applied SAR image correlation method to the JERS-1 SAR data over the Shirase Glacier region to estimate seasonal and spatial variations of the ice flow velocities. From the grounding line towards 30 km downstream, seasonal and year-to-year variations of the ice flow velocities were detected. It is significant that the western streamline has systematically larger ice flow velocity than the eastern streamline, and therefore Shirase Glacier deflects toward east by 38˚. This may be related with asymmetric bedrock topography (eastward deepening) and inflow of tributary ice streams from west.

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