PRECISE EXTRACTION OF ICE SHEET TOPOGRAPHY AND GROUNDING LINE IN ANTARCTICA USING ALOS / PALSAR DATA

PI No. 371

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1. INTRODUCTION

The global warming may affect the cryospheric environment and many reports showed the retreat of glaciers, thinning of ice shelves and ice sheet at West Antarctica. On the contrary, East Antarctica seems to be calm state than West Antarctica.

Usually, it is necessary to know three geophysical parameters, which are ice thickness, flow velocity of ice and position of grounding line for estimating ice mass balance.

This paper describes the potential ability for estimating ice flow velocity and grounding line by ALOS / PALSAR data, and then we show several application examples at East Antarctica.

2. FLOW VELOCITY ANALYSIS AT ANTARCTIC GLACIERS

Flow velocity is one of the most important parameters to understand the ice mass balance at Antarctica and there is quite difficult to know except for satellite data analysis because it is almost impossible to measure by in-situ observations to cover whole glacial regions due to hard geographical and weather conditions of Antarctica. Therefore, the use of satellite data is maximized for these kinds of applications.

There are two ways for estimating flow velocity, one is InSAR analysis [2] and the other is offset tracking [3]. InSAR analysis is applied for the area which has slow velocity and it is impossible to estimate fast flowing glacier due to the decorrelation between InSAR image pairs. On the other hand, it is able to estimate the flow velocity at glacier region from offset tracking analysis. Offset Tracking detects the horizontal movement by using spatial correlations between images. Therefore, the image features need to be fixed (no movement) except for the target area. Fig.1 (a)[1] clearly explain the principle of offset tracking.

For flow velocity analysis, we focus on Shirase Glacier at Lützow-Holm bay (70.1°S, 38.75°E).

Fig.2 shows the ALOS / PALSAR image and flow velocity map of Shirase glacier by offset tracking analysis. Left image show descending image pair acquired at 21, Apr., 2009 and 6, Jun., 2009. Right image show ascending image pair acquired at 16, May, 2009 and 1, Jul., 2009. The spatial distribution of alternative velocity field between them is consistent. However, descending velocity map is slightly slower than ascending one. One considerable reason is that the difference of ice shelf area size on the image. Ice sheet and bare rocks can be treated as fixed, while ice shelf along with coast line is sometimes flow away due to ocean current. At the upper-right part of descending image, there is wider ice shelf area than ascending image and the slight movement of this part may affect the estimation of flow velocity of glacier (See Fig.1 (b)).

Fig.3 shows the expanded view around grounding line. The flow velocity are 1974.2m/a, 2104.3m/a, 2253.5m/a at position 1, 2 and 3 respectively. These velocity values are consistent with Nakamura et, al [4] and other results.

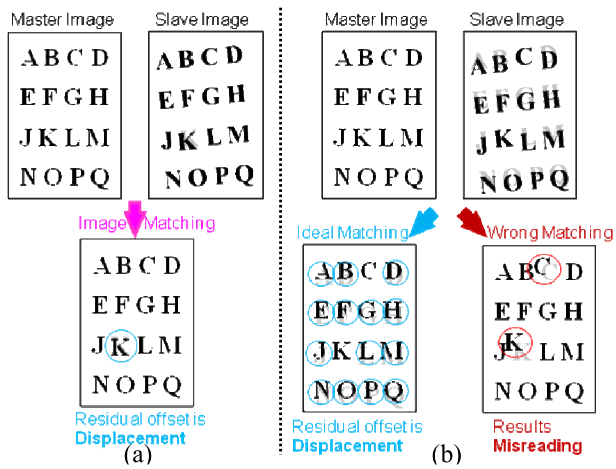


Fig. 1 (a) A schematic drawing of the image matching. After overall image matching, a residual offset is represented by "K" (From Tobita et al, [1]). (b) Misdetection by wrong matching on the constant ice shelf flowing area.

3. MONITORING OF ICE SHELF AT LÜTZOW-HOLM BAY

Lützow-Holm bay (69.5°S, 37.5°E) is located between Riiser-Larsen Peninsula and Soya coast at East Antarctica. Japanese Antarctic expedition base namely

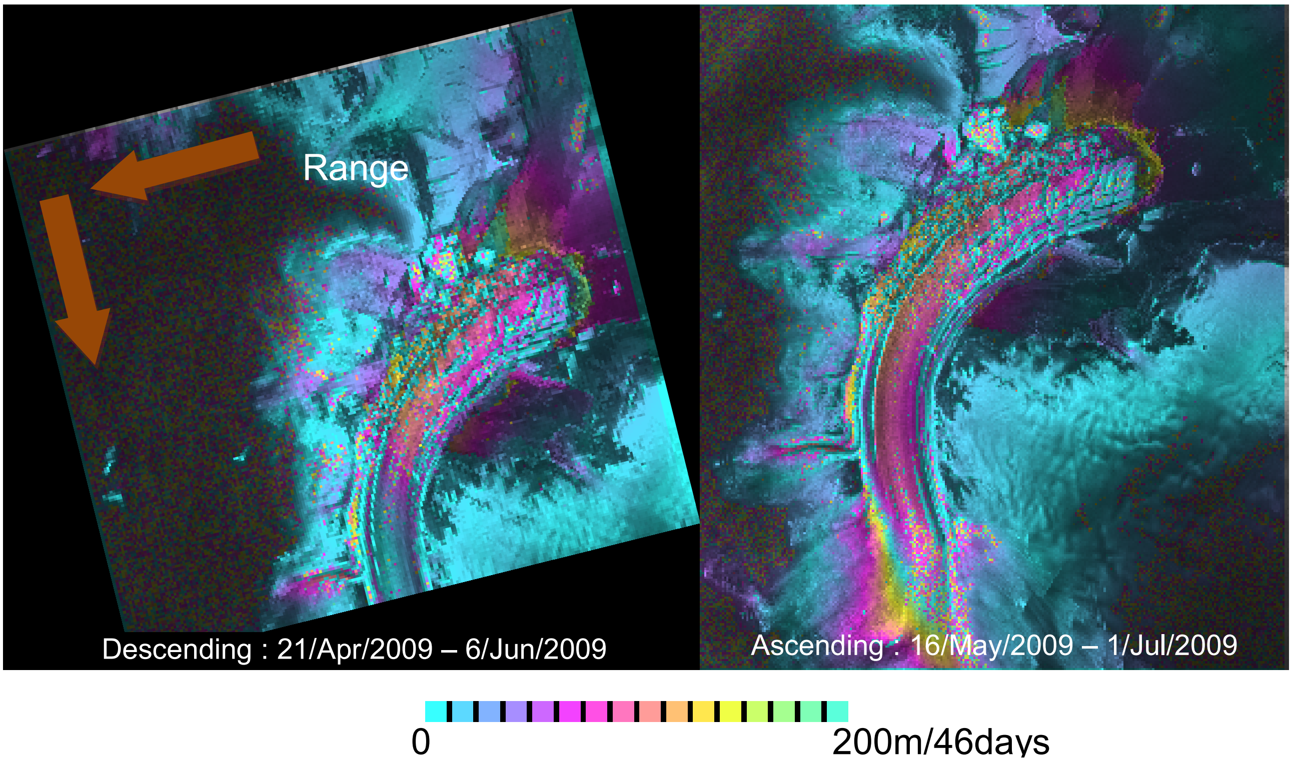


Fig. 2 Offset tracking result of Shirase Glacier by PALSAR data. Left image was made from the image pair of 21, Apr., 2009 and 6, Jun., 2009. Right image was made from the pair of 16, May, 2009 and 1, Jul., 2009.

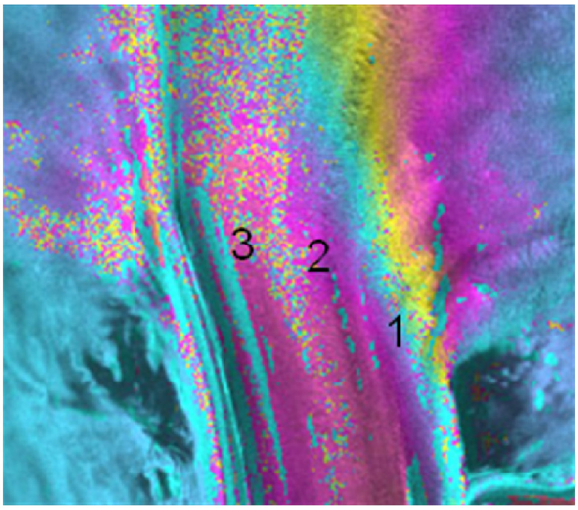


Fig. 3 Expanded image around grounding line

Syowa Station (69.5°S, 37.5°E) is faced on this bay at East Ongle Island. .Syowa Station was opened at 1958 and many kinds of scientific data are acquired and archived. Especially, SAR data archives of JERS-1 / SAR and ERS-1/2 AMI data since 1991 is quite useful. Therefore, this area is suitable for monitoring the state of East Antarctic ice shelf and ice sheet. Here we focus on the changes of ice shelf which are change of area size and variation of flow velocity.

3.1 Monitoring of ice shelf area size

Retreat or advance of ice shelf is a fundamental issue for mass balance research and this issue is the most suitable application for satellite data, while it always faced with the problem of cloud cover in case of optical sensor. However, it is able to avoid this problem using SAR data. Here we employed the JERS-1 / SAR data acquired in 1995 and ALOS / PALSAR WB1 image acquired in 2008. Fig. 4 shows the results of ice shelf area extraction. Image (a) to (d) in Fig.4 show the intensity image of JERS-1 (a) , PALSAR (b), ice shelf extraction results by JERS-1 (c) and PALSAR (d), respectively. The extraction method is, at first roughly divided to water and ice/land area by applying intensity threshold and after applying threshold, manual image interpretation was applied for precise determination of ice shelf-water boundary.

Boundary between land and ice shelf is defined by grounding line extracted by InSAR extracted from ERS-1/2 tandem data [5]. By the visual interpretation from Fig.4, the huge iceberg seems to calve at yellow circle on Fig.4 (b) and ice shelf area has the expanding trend. The area size of ice shelf is 8848.88km^2 in 1995 JERS-1 and 7999.53km^2 in 2008.

From above result, ice shelf area size was expanded in this region and the ice mass state of this area is inferred as calm by this result. However, it is necessary to

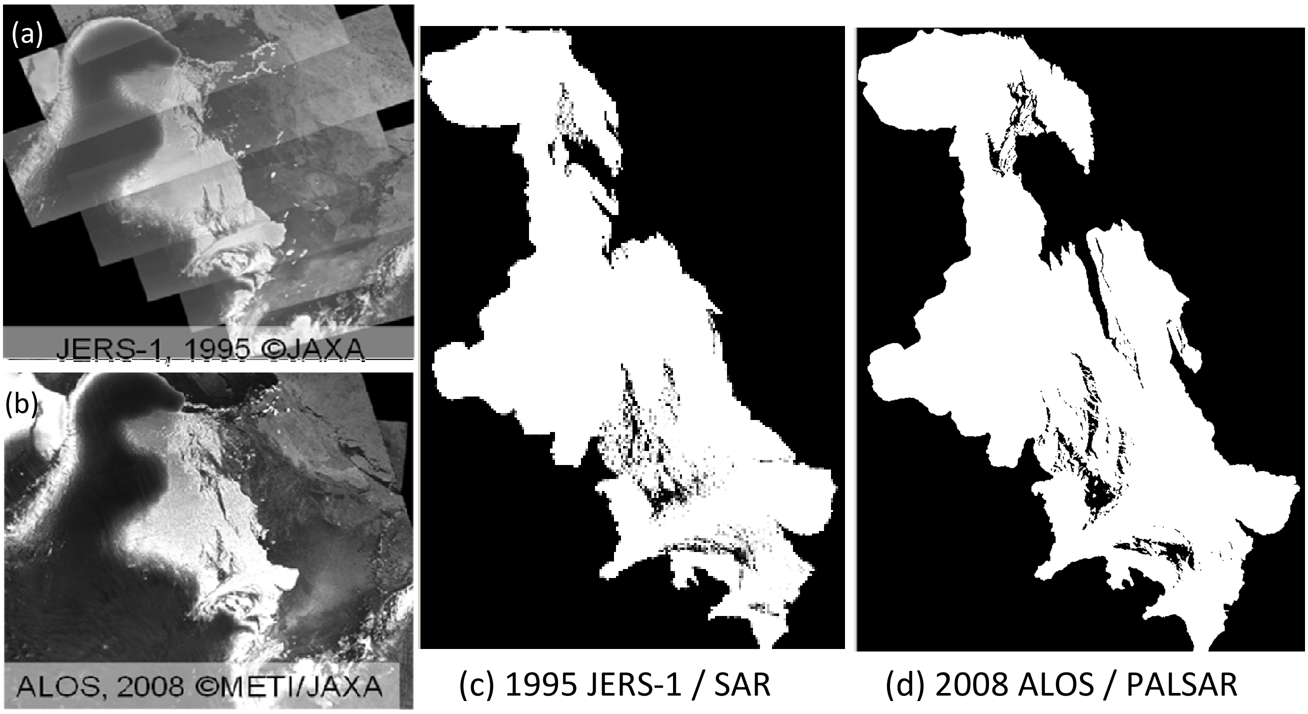


Fig. 4 Ice shelf area size analysis result. Left image is original SAR image (a) and (b). (c) is ice shelf area extracted by JERS-1/SAR and (d) is same result as (c) from ALOS /PALSAR data.

measure the ice thickness between 1995 and 2008 for actual mass volume analysis.

The remote sensing analysis point of view, ALOS/PALSAR WB1 image is quite useful for this kind of research because PALSAR has the high geometric and radiometric accuracy even in the Antarctic continent.

3.2 Ice shelf flow velocity analysis over three decades

Ice shelf at western part of Lützow-Holm Bay shows the robust feature which has over 50m ice thickness above sea level, so it might be quite stable. Therefore, we focused on this region to evaluate the stability of ice shelf by measurement of ice shelf flow velocity using ALOS/PALSAR and other satellite data.

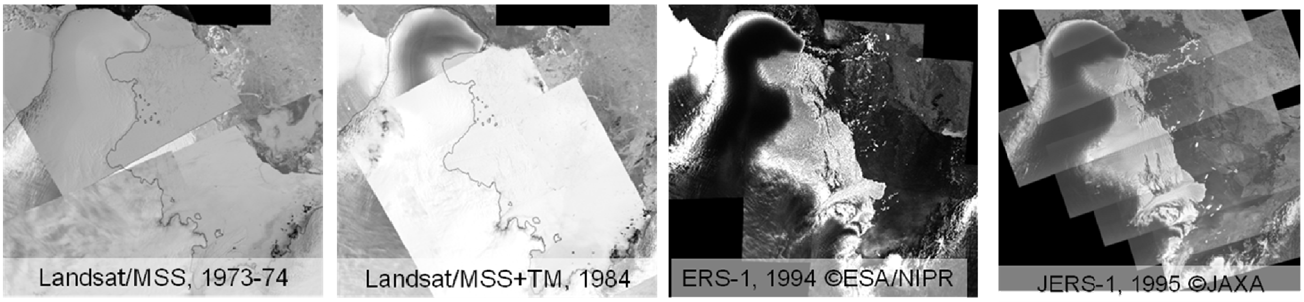
We took two ways of approach for velocity measurement. One is to measure the trajectory of iceberg by interpretation of satellite image and the other is offset tracking method. Satellite data used for first approach is shown in Table.1. Available data exist from 1973 Landsat image. ERS-1/2, JERS-1 data were received at Syowa Station. RAMP is the mosaicked image dataset of Antarctica by Jezek et, al [6]. All data were mosaicked and geocoded to Polar Stereographic projection with standard parallel 71°S. The old data were necessary to apply geometric correction with GCP and mosaicking manually. On the contrary, ALOS/PALSAR data is quite easy to handle because it has quite high geometric accuracy to skip geometric correction and no necessity

Table 1. Satellite data used for iceberg trajectory analysis.

Satellite	Sensor	Obs. Period	Num. of Scenes
Landsat 1	MSS	Dec., 1973 -Jan., 1974	5
Landsat 4	MSS TM	Dec, 1984	TMx1,MSSx1
ERS-1	AMI	Aug., 1994	10
JERS-1	SAR	Jan-Feb, 1995	19
RADARSAT	RAMP	Oct., 1997	-
ERS-2	AMI	Jan.-Mar., 2000	14
PALSAR	PALSAR (WB1)	Aug., 2008	1

for mosaicking. For geometric correction, PALSAR data was used for geometric reference and overlay all the other data onto it. The all geometrically-corrected and mosaicked time series images are shown in Fig. 5. Optical sensor image is more difficult than SAR image for interpretation of boundary between ice shelf and open water area.

Point A to E on ALOS image in Fig.5 is the position measurement point of iceberg or ice shelf feature for



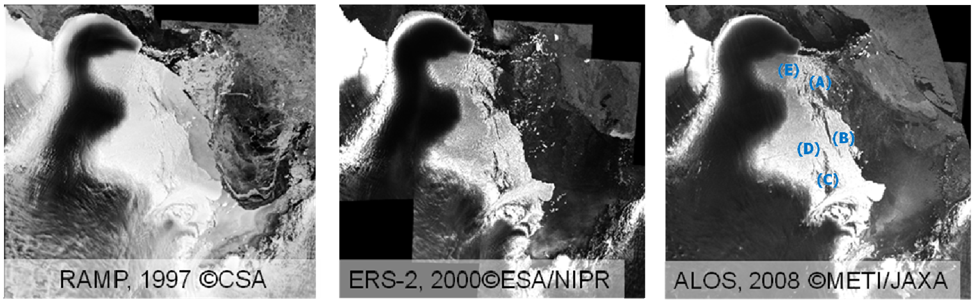


Fig. 5 Temporal satellite image dataset at Lützow-Holm Bay. The acquisition data period is longer than years.

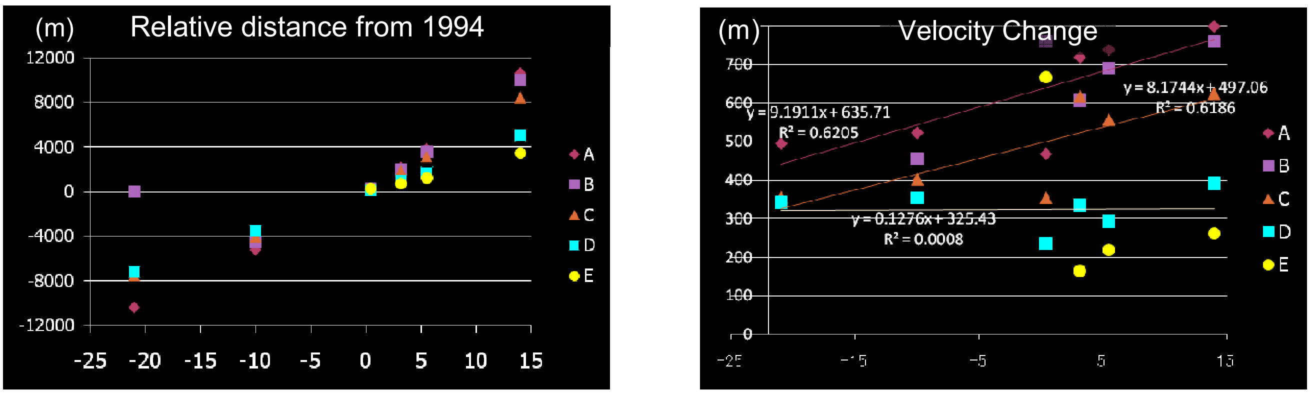


Fig.6 Manual interpretation result of ice shelf flowing features. Vertical axis shows the distance in meters and horizontal axis show the relative year which origin is set to 1994. Left graph shows the relative distance from 1994 and right graph show the velocity change.

trajectory tracking. Point A is where the active calving has been going on continuously. Point B is the place where the huge ice shelf is about to separate and C is close to the open water area inside the ice shelf. Point D and E are located on relatively stable ice shelf. We measured these typical points for velocity measurements by visual interpretation.

Fig.6 shows the result of temporal movement of ice shelf from visual interpretation using time series satellite data from 1974 to 2008. Legend A-E is the velocity measurement points described above. This result shows that the flow velocities of ice shelves are quite stable in 35years and it implies the stability of this ice shelf. The relative distance show the first order linear relationship in all points and velocity change to faster in point A to C, where located to marginal area of ice shelf, while the velocity of point D and E has little velocity changes. The reason for this phenomenon is that in point A-C, these points are located to relatively fast flow velocity area because ice shelf itself has the velocity gradient to go to the downstream. Therefore, each point accelerates flow velocity with the movement of positions to downstream year by year. This result represent that velocity change is not caused by the global warming but spatial velocity distribution of ice shelf. This reason gives to the reasonable explanation to the velocity change of point D and E. Point D and E is located to the upstream or stable region of ice shelf and the flow velocity is relatively slow. Therefore, velocity acceleration is difficult to detect in time scale of 34 years. The actual flow velocity at each points are shown in Table.2.

3.3 Velocity comparison with offset tracking results

As shown in section 2, offset tracking is another effective method to estimate flow velocity. This section describe the comparison results of flow velocity between offset tracking and velocity estimation results shown in previous section, and discuss the some issues to apply offset tracking at ice shelf region.

Table.2 show the comparison results of ice shelf / iceberg flow velocity. First column correspond to the point A to E. Column "TS" mean the flow velocity estimated by image interpretation by "TimeSeries" satellite data. Column "OT" shows the "Offset Tracking" results. The word "Winter" and "Summer" correspond to the satellite data used were observed in that season. PALSAR data used for offset tracking are 1, Nov., 2008 and 17, Dec., 2008 for summer season data and 14, Jun., 2006 and 30, Jul., 2006 for winter season data.

Table.2 Comparison of flow velocity (unit=m/year)

	TS	OT (Winter)	OT/TS	OT (Summer)	OT/TS
(A)	681	408	0.6	468	0.69
(B)	693	434	0.63	401	0.58
(C)	539	527	0.98	465	0.86
(D)	314	453	1.44	463	1.47
(E)	215	303	1.41	—	—

As a result, flow velocity of manual interpretation (TS) estimate faster than offset tracking (OT) results at point A – C, the fast flowing region and it attains 1.5 times faster. On the contrary, TS was slower than OT at point C-E, where has slow flow velocity and stable ice shelf region. The reason why such phenomenon occurred has not been cleared yet. One possibility is that misdetection of OT due to ice shelf area as shown in Fig.1 (b).

4. GROUNDING LINE ANALYSIS

Grounding line is also quite important parameter for ice mass flux estimation. ERS-1/2 tandem data is the most suitable data for grounding line analysis because of the less temporal decorrelation (revisit cycle is only 24 hours) and well-controlled orbit to narrow baseline, which is less than 200m between orbits. However, tandem operation was held at 1996, is old and recent condition of grounding line is necessary to estimate for understanding present behavior of ice mass movement. Therefore, we try to analyze the extraction of grounding line by ALOS / PALSAR data. Orbit control of ALOS / PALSAR is very good (less than 500m) [7] and L-band has more tolerance against temporal decorrelation than C-band. For these two points of view, PALSAR is suitable for grounding line analysis. However, revisit cycle of PALSAR is 46days and this is too long for grounding line analysis because temporal decorrelation due to ice flow has a serious effect on fringe generation.

Based on the above facts, target area is carefully set to Lazarevisen because this area has relatively slow ice flow velocity, therefore, it is able to suppress the effect of decorrelation due to ice flow.

Interferogram of ALOS / PALSAR 3pass pairs and ERS tandem pair are shown above (a) and below (b) of Fig.8,

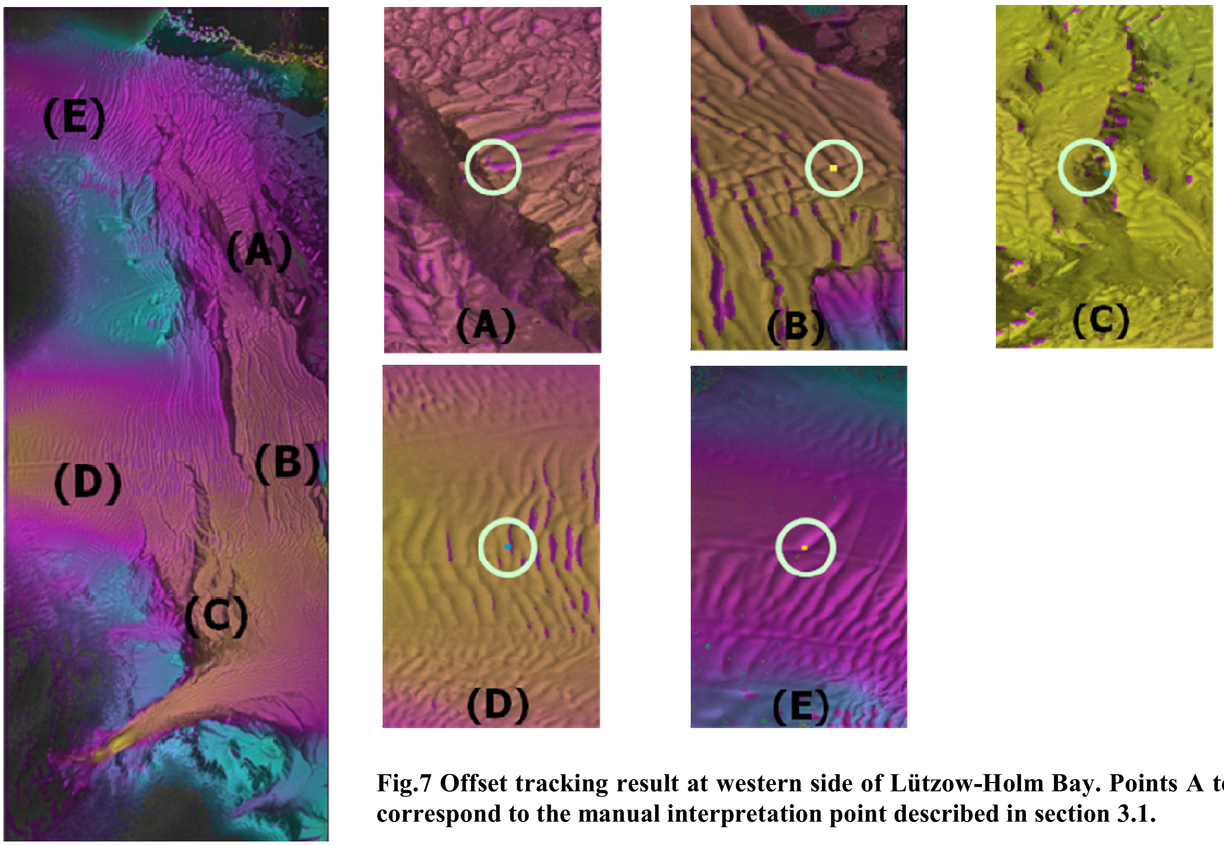


Fig.7 Offset tracking result at western side of Lützow-Holm Bay. Points A to E correspond to the manual interpretation point described in section 3.1.

respectively. ALOS / PALSAR data used here are 22, Oct., 2010, 7, Dec., 2010 and 11, Jan., 2011. ERS-1/2 tandem data were observed on 5 and 6, Apr., 1996. Basically, fringes are represented by the sum of topographic fringe, fringe due to flow of ice, tidal movement of ice shelf and noise. In case of ERS-1/2 tandem pair, fringe due to flow of ice is able to treat as zero because revisit cycle is short enough to neglect the movement of ice. Therefore, grounding line can be interpreted by the concentration of fringe between ice sheet and ice shelf clearly in Fig.8 (b).

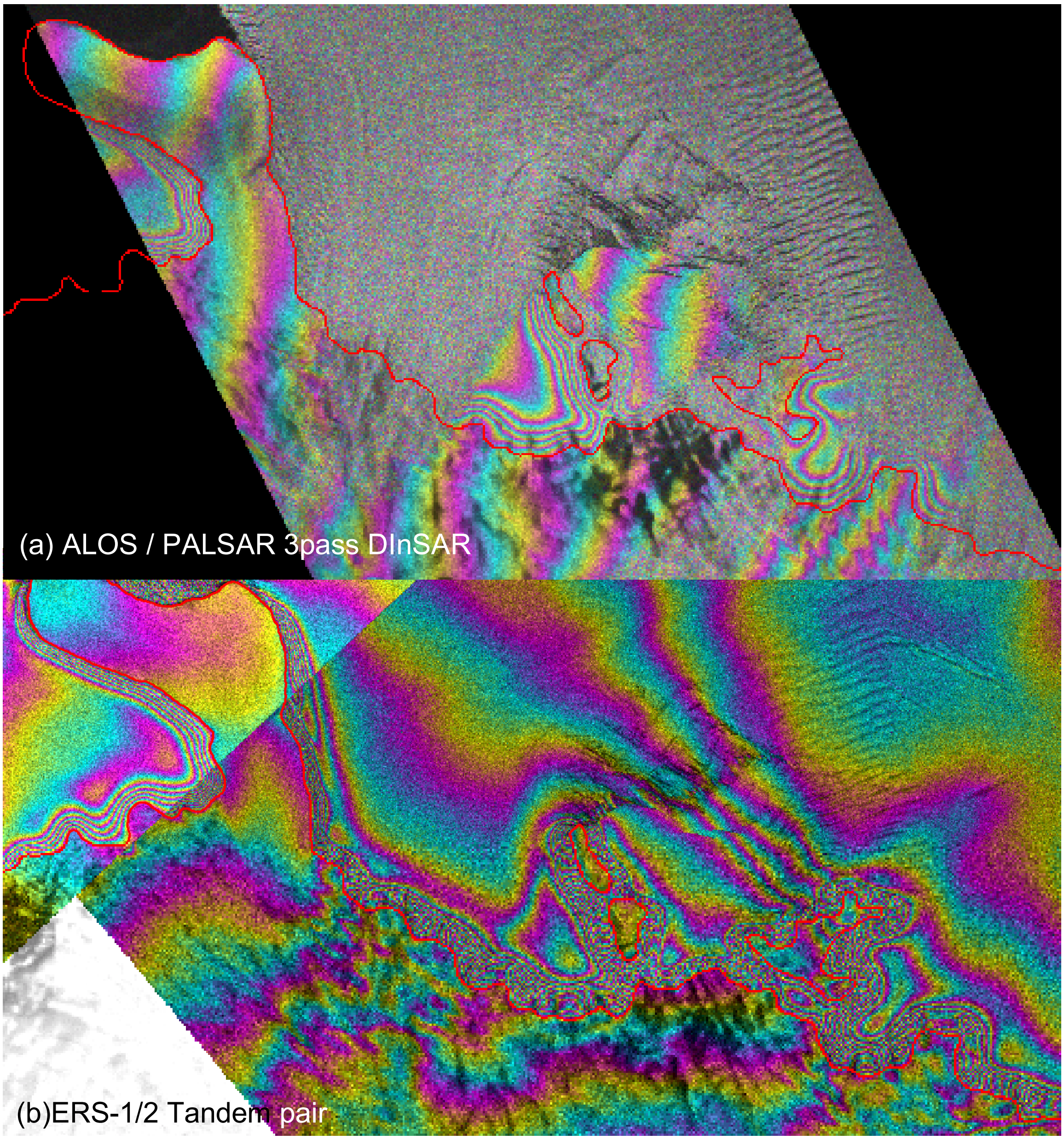


Fig.8 Interferogram at Lazarevisen, east Antarctica. Above interferogram was made from 3pass DInSAR and lower interferogram was made from ERS-1/2 tandem data. Red lines represent the grounding line interpreted from fringe. Shapes of grounding line are completely coincide with ERS-1/2 tandem interferogram and PALSAR 3pass interferogram

On the other hand, revisit cycle of PALSAR is 46 days and it is long enough to create the fringe caused by flow of ice (Fig.9). Then, fringe pattern is more complex than in case of ERS-1/2 and it is quite difficult to determine grounding line from 2pass interferogram of PALSAR data. 2pass DInSAR using DEM is also difficult to apply because there are no texture on ice surface and it prevent tie-point collection between simulated SAR image and actual PALSAR image. 3pass InSAR is the method to avoid these problem because the effect of fringe due to ice flow was cancelled when second pair was subtracted from first pair under the condition of ice sheet flow is stable

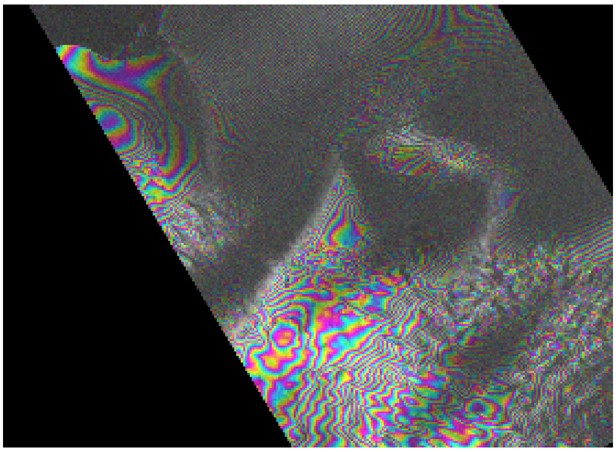


Fig.9 2pass interferogram from PALSAR data at same region as Fig.8.

5. SUMMARY AND FUTURE PLANS FOR ALOS-2

This study show the stability of East Antarctic ice sheet environments and the potential ability of ALOS / PALSAR data for application of Antarctic ice marginal zone monitoring in several different points of view. One is estimation of ice shelf flow velocity using offset tracking method. At Antarctica, there are usually under the bad weather condition and it is difficult to observe image from optical sensor. Therefore, it is a very strong point to estimate flow velocity from SAR data because it can be estimated constantly unless the satellite stop operation. Second one is the estimation of ice shelf area size and time series analysis of ice shelf flow velocity. The results show that ice shelf area size increases approximately 10%. Flow velocity change analysis over three decades show that there is quite stable ice shelf flow. This result is harmonic with other research. At the technical point of view, high geometric accuracy made analysis easier because it is not necessary to process geometric correction and PALSAR image can be used as geometric reference image data for applying geometric correction to the old data. Third result represents the ability to extract grounding line from PALSAR data. At first, from the experience of author, it seems quite difficult because long revisit cycle create complex fringe pattern caused by flow of ice. However, it is able to extract fringe correspond to grounding line applying 3pass InSAR technique. It might be able to be the standard analytical technique for grounding line extraction for ALOS-2data. Also, ALOS-2 has shorter revisit cycle, 14 days. Therefore, it is expected that quite high coherent interferogram will be able to obtain from ALOS-2 in combination with precise orbit information and L-band feature.

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