Observation of ice sheet and glacier movement in the Antarctica by JERS-1 SAR interferometry

Hiroshi Kimura[1], Takashi Kanamori[1], Hiroyuki Wakabayashi[2] and Fumihiko Nishio[3]
1 Dept.of Electrical & Electronic Engineering, Gifu University
E-mail: hkimura@cc.gifu-u.ac.jp and h3135006@guedu.cc.gifu-u.ac.jp
2 Japan Aerospace Exploration Agency
3 Center for Environmental Remote Sensing, Chiba University
E-mail: fnishio@cr.chiba-u.ac.jp

Abstract
From a series of three JERS-1 SAR interferograms over the Yamato mountains area in the Antarctica, ice surface movement and change of motion speed are detected. In spite of less accurate orbit information, baselines are estimated using 1 km global DEM and referring phases over bare rock areas. Results suggest that movement is not constant over the study are, and variations of ice motion speed and acceleration exit around bare rocks.

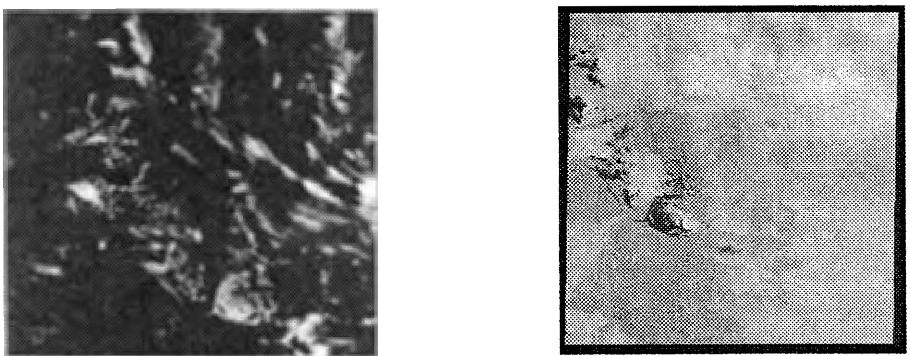
1. Introduction

In order to interpret changes in the Antarctic ice sheet as indication of global change on climate, it is necessary to observe the local changes in a regional context. This requires a comprehensive monitoring effort that addresses both the inland ice and changes in the ice margin. Objective of our study is regional observation of the Antarctic ice sheet using the interferometric SAR technique for detection of changes in the ice sheet margin. Spaceborne imaging SAR presents the opportunity for measuring surface displacement fields interferometrically by use of the radar beam. Application to the glacial flow and sea ice, interferometric phases contain the combined effects of the baseline separation, motion of ice sheet or glacier over the period of the repeated cycle of satellite between two images, and the surface topography. Goldstein et al. [1] and Kwok et al. [2] demonstrated measurements of ice sheet movements using ERS-1 InSAR. Accurate baselines of ERS-1 InSAR allow these measurements. JERS-1 satellite SAR has also a large potential for monitoring ice sheet and glacier movement [3]. The radar wavelength is 24 cm, so a fringe of phases appears every 12 cm displacement. However, the JERS-1 orbit information is not so good to extract only phase due to surface movement and topography. Ozawa et al. [4] assumed seacoast lines as 0-m height reference to generate a DEM of the Soya coast area, Antarctica from JERS-1 InSAR. This approach can be applicable for coastal regions. This situation prevents us from global monitoring of Antarctic ice movements by JERS-1 SAR. However, we can expect some conditions over the Antarctica, and they allow us to measure only ice movements inland of the Antarctica. In this study, we succeeded to extract surface movements in the Yamato mountains area, and detect change of motion speed from a series of three JERS-1 SAR interferograms.

2. Method

2.1 Study area and used interferograms

Our study area is the Yamato mountains area. One of JERS-1 SAR images (D187-422) and an optical image from JERS-1 are shown in Fig. 1. The area is located inland of the Antarctica, and bright features in the SAR image and dark features in the optical image are bare rocks. We use three interferograms from data takes of March, April, June and July 1996. Surface height changes from about 1700 m to 2400 m in the study area.



(a) JERS-1 SAR image (b) OPS image

Fig. 1. JERS-1 SAR and OPS images of the study area.

2.2 Anticipated conditions

SAR interferogram phase is given as a sum of three components as follows,

$$\phi = \phi_f + \phi_t + \phi_m \tag{1}$$

where ϕ_f is flat Earth phase, ϕ_t is topographic phase and ϕ_m is movement phase. In this study, we anticipate three conditions over the Antarctica to apply interferometric technique to JERS-1 SAR data,

Condition 1: Short baseline,

Condition 2: Existence of stable bare rock areas,

Condition 3: Gentle undulating surface terrain.

Condition 1 comes from the fact that satellite orbits cross in the polar region, and means topographic phase has much less sensitivity to topographic height variations. Condition 2 means that these exists areas with only flat earth phase and topographic phase. Under condition 1 and 2, bare rock areas are expected to have only flat earth phase, and can be used to estimate an initial value of baseline (flat earth phase). Condition 3 comes from the fact that most of the Antarctica is covered with ice and snow, and height variations are dominated very low spatial frequency. This means that even low-resolution digital elevation model (DEM) is useful, and such 1 km Global DEM can be used to improved baseline estimation (flat earth phase and topographic phase).

2.3 Processing flow

Fig 2 shows the processing flow of our approach. Even from a unwrapped interferogram, only a relative phase is derived. In our approach, initial relative flat earth phase is expressed as,

$$\phi_{f\text{-}ref} = \phi_f - \phi_o = ax + by \tag{2}$$

where ϕ_o is an offset phase from absolute phase at (0,0), (x,y) is the coordinate of (range, azimuth). Constants a and b are flat earth change rate in range and azimuth respectively, and derived from the phase over bare rock areas under the condition 1 and 2. Fig. 3 shows the interferometric phase ϕ_2 (April and June pair) over the largest bare rock, and indicates allowance of a linear function expressed in (2).

Processing steps are as follows,

Step 1: Using initial relative flat earth phase of (2) and orbit information of used JERS-1 data, baseline is estimated by the least square method.

Step 2: Using estimated baseline and 1 km global DEM, flat earth phase (ϕ_f) and topographic phase (ϕ_t) are generated.

Step 3: Movement phase is calculated ($\phi_m = \phi - \phi_f - \phi_t$).

Step 4: Standard deviation of movement phase over bare rock areas are calculated ($\sigma_{\phi m}$).

Step 5: If baseline is correct, should be 0, so if is more than 0.1 cycle, go to step 6, otherwise finish iteration.

Step 6: Update constants of flat earth phase function expressed in (2), using flat earth phase and movement phase over bare rock areas, and then go to step 2.

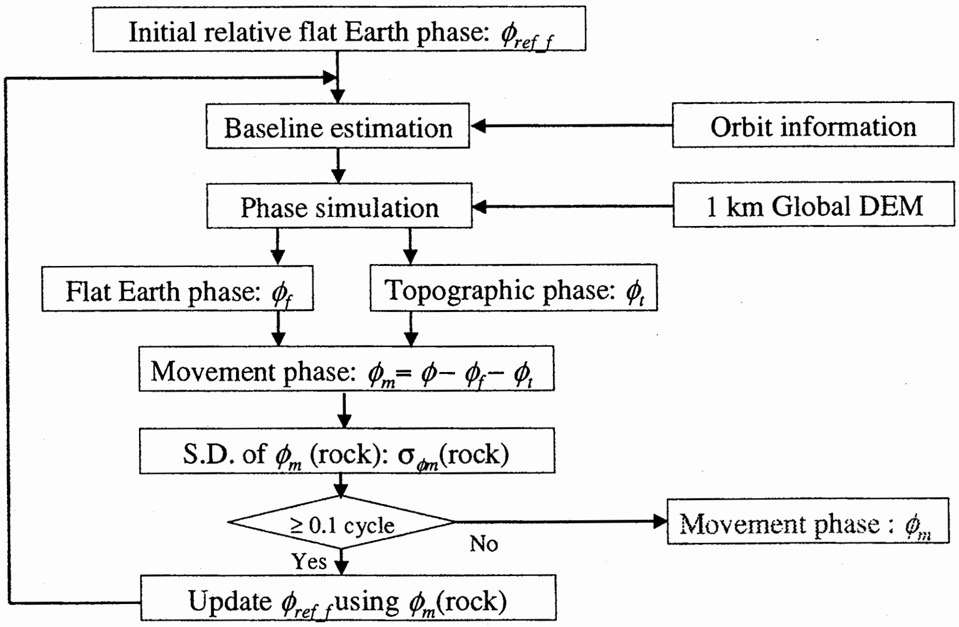


Fig. 2. Processing flow.

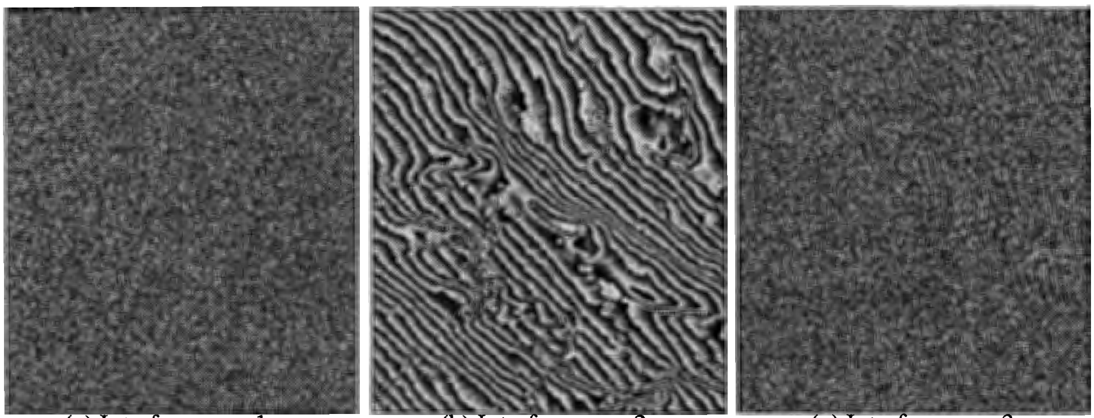
3. Results

3.1 Motion field

The interferogram from a pair of April and June is estimated to have the smallest baseline among three interferograms, because phase fringes are the sparsest. Therefore, it (ϕ_2) is firstly processed. The initial and three decomposed phases after processing described in 2.3 is shown in Fig. 3. Movement phase converged after only two times iteration. Calculated baseline, ranges of flat earth and topographic phases and Standard deviation of movement phase over bare rock areas are shown in Table 1. As anticipated, the estimated baseline is small (33 m), so topographic phase changes only 0.4 cycles. Fig. 4 shows histograms of movement phase over bare rock areas at first and second iterations. Table 1 and Fig. 4 shows a small improvement after iterations, but this is due to a small baseline. Criteria of convergence of movement phase over bare rock areas is 0.1 cycle, and this is based on the fact that 0.1 cycle corresponds to only 1 cm movement.

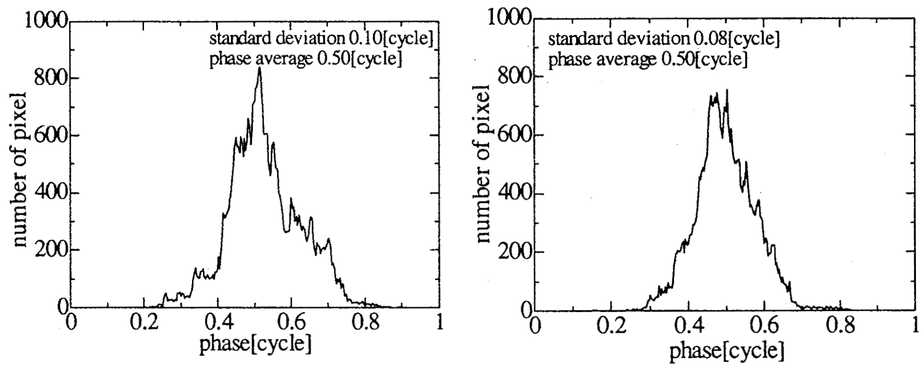
3.2 Decomposition of 3 elements

Based on an assumption of the movement parallel to slope, measured movement in line-of-sight direction is decomposed into three components. Fig. 5 shows the result. Each component is scaled to the range from each minimum to maximum. Fig 5 shows that the dominant movement is the range direction (x) and that high speed parts exist between bare rocks A and B, at the center from bottom-right to top-left direction, and at the top-right.



(a) Interferogram-1 (b) Interferogram-2 (c) Interferogram-3

Fig. 3. Initial interferograms.

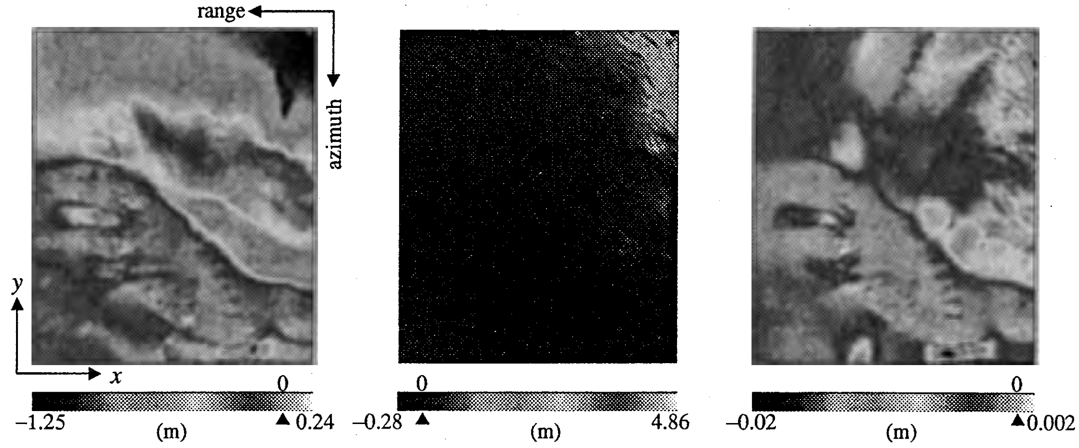


(a) Iteration 1 (b) Iteration 2

Fig. 4 Histograms of movement phase over bare rock areas from interferogram-2.

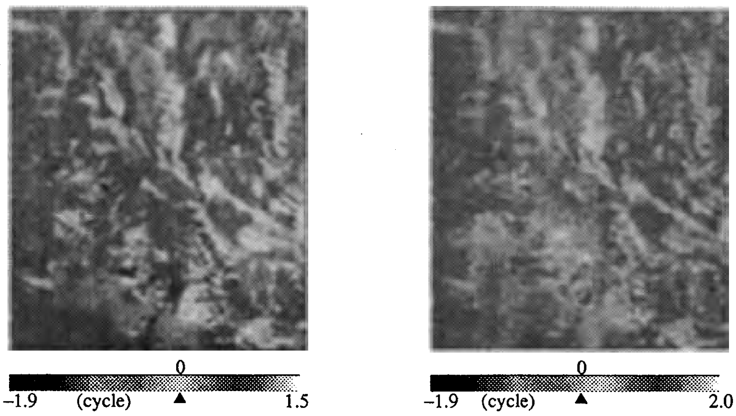
Table 1 Estimated baseline and phases from interferogram-2

iteration	$B_\perp$(m) [height change]	ϕ_f(cycle) min/max	ϕ_t(cycle) min/max	$\sigma_{\phi m}$(cycle) over rock
1	32.1 [2010m]	−18.7/23.3	1.0/1.4	0.10
2	33.0 [2070m]	−19.4/23.8	1.0/1.4	0.08



(a) x component (b) y component (c) z component

Fig. 5 Decomposition of derived movements from interferogram-2.



(a) Interferogram-1 (b) Interferogram-2

Fig. 6 Differentials of movement phase from the interfergram-2.

3.3 Change of motion speed

The same approach was applied to other two interferograms shown in Fig. 3, and then movement phases were derived. Fig. 6 shows differential phases of movement phase from the middle interferogram (ϕ_{2m}). These phases mean deviation from a constant velocity or acceleration of ice movement. We can find negative areas in $\phi_{1m}-\phi_{2m}$ around bare rocks, and those areas are positive in $\phi_{3m}-\phi_{2m}$. This shows that a constant movement is invalid over this area and some acceleration exits around bare rocks.

3. Conclusion

We succeeded to extract surface movements in the Yamato mountains area, and detect change of motion speed from a series of three JERS-1 SAR interferograms. Results suggest that movement is not constant over the study are, and variations of ice motion speed and acceleration exit around bare rocks. Further discussion based on hydrodynamics will clarify details of this phenomenon. This approach is expected to expand JERS-1 InSAR applications in the Antarctica.

References

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