Motion of Arctic glaciers derived from PALSAR DATA

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Abstract
Offset fields between pairs of JERS-1 SAR and ALOS PALSAR data acquired in winter with 44 respectively 46 days time interval were employed for the estimation of glacier motion over Novaya Zemlya in the Russian Arctic. The displacement maps show a number of clearly defined fast-flowing units with displacement larger than about 50 m/year. The estimated error of the offset tracking derived displacement is on the order of 20 m/year. Comparison of JERS-1 SAR and ALOS PALSAR results obtained in 1998 and 2007 allows us to investigate past and recent behavior of Polar Regions and possibly detect changes in the velocity of the glaciers.

Keywords: ALOS PALSAR, offset tracking, glacier motion.

1. INTRODUCTION

Many studies on Arctic and Antarctic glaciers and ice streams have demonstrated the invaluable potential of satellite Synthetic Aperture Radar (SAR) interferometry and offset tracking to map ice surface velocity fields without the expense of in-situ measurements [1-6]. Most of these studies used data from the European Remote-Sensing Satellites ERS-1 and ERS-2 and from Canada's Earth observation satellite RADARSAT-1 at C-band (5.6 cm wavelength λ) with 1, 3 or 24 days acquisition time intervals. The experience with L-band (λ = 23.5) SAR data with longer acquisition time intervals is, however, limited.

Recently, the capability of satellite L-band SAR data to derive the motion of Arctic glaciers with offset tracking has been demonstrated using JERS-1 over Svalbard, Novaya Zemlya and Franz-Josef Land [7]. One of the findings of this study was that the larger wavelength and the greater penetration of the radar signals into the snow and firn at L-band compared to C-band results in a reduced signal decorrelation. The smooth motion maps derived from offset tracking of JERS-1 SAR images suggested that after 44 days the speckle at L-band is retained.

In this contribution we present and compare the motion of Arctic glaciers at Novaya Zemlya derived with offset tracking of L-band SAR data acquired by the JERS-1 and ALOS satellites in winter with 44 respectively 46 days acquisition time interval.

2. DATA AND METHODS

For this study two winter JERS-1 SAR scenes from descending orbits covering Novaya Zemlya were exploited (see Figure 1). The images were taken under favorable weather conditions and were selected in order to compute an interferogram with an acquisition time interval of 44 days and a perpendicular baseline of 390 m. The JERS SAR data were obtained from the ESRIN archive as long stripes Level-0 raw data and were processed to full resolution Single-Look Complex (SLC) images.

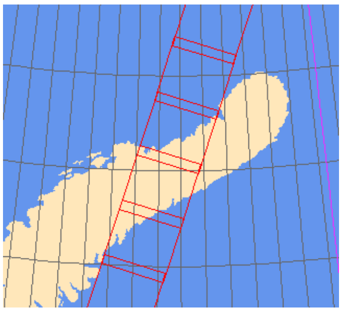

Figure 1. JERS-1 SAR frame over Novaya Zemlya in the Russian Arctic. Acquisition dates of the interferometric pair are January 28 and March 13, 1998.

A winter ALOS PALASAR interferometric pair of the ascending orbit with an acquisition time interval of 46 days and a perpendicular baseline of -25 m in Fine Beam Single Polarization (HH) mode was selected from the ALOS AUIG catalogue (see Figure 2). The two ALOS PALSAR images were obtained in raw format and processed to full resolution SLC images.

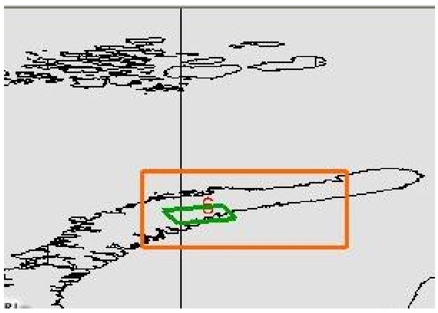

Figure 2. ALOS PALSAR frame over Novaya Zemlya in the Russian Arctic. Acquisition dates of the interferometric pair are December 6, 2006 and January 21, 2007.

With offset tracking the registration offsets of two SAR images in both slant-range (i.e. in the line-of-sight of the satellite) and azimuth (i.e. along the orbit of the satellite) directions are generated and used to estimate the displacement of glaciers [8-9]. Offset tracking is a robust and direct alternative technique to SAR interferometry for the estimation of glacier motion in the case of rapid flow and large acquisition time intervals. The estimated errors of JERS-1 offset tracking derived displacements are on the order of 20 m/year [7]. Occasionally, azimuth streaks related to auroral zone ionospheric disturbances are detected and dedicated processing steps applied to minimize their influence on the estimated motion pattern [10].

3. RESULTS

3.1. SAR Interferometry

The JERS-1 SAR and ALOS PALSAR image pairs were first interfere in order to investigate the L-band coherence over glaciated areas after one satellite cycle. Interferometric processing was done to 6 azimuth and 2 range looks with common-band filtering after co-registration of the SLC images. The baseline was first estimated from the orbit data and subsequently refined based on the fringe rate in range and azimuth directions. Our SAR interferometric results indicate a very good coherence in both cases, with well preserved fringes over the slow moving glaciers (see Figures 3 and 4). Decorrelation is mainly observed over the areas with excessive strain rates, in particular along the margins of the glacier. On the other hand, the effects on the interferometric coherence of snow and ice melting, snow accumulation or wind drift, and volume decorrelation because of microwave penetration in the dry snow cover and ice are limited.

3.1. Offset-tracking

For presentation and interpretation of the offset-tracking results, slant-range and azimuth displacements were combined to provide a 2-dimensional ground displacement field and these maps were superimposed to Moderate Resolution Imaging Spectroradiometer (MODIS) imagery and a schematic map of ice divides and outlet glaciers from the catalogue of the glaciers of the USSR [11]. The results for the area covered by both satellite images are presented in Figures 5 and 6. It can be observed that the boundaries of outlet glaciers from the catalogue are generally consistent with JERS-1 and ALOS offset-tracking results in the lower parts, but the satellite-based ice-surface motion maps show a significantly larger glacier feeding zone in the upper parts. Thus, we expect that the mapping of glaciers with ice-surface velocities larger than 20 m/year can significantly benefit from SAR offset tracking. For both JERS-1 SAR and ALOS PALSAR image pairs the azimuth streaks were very limited.

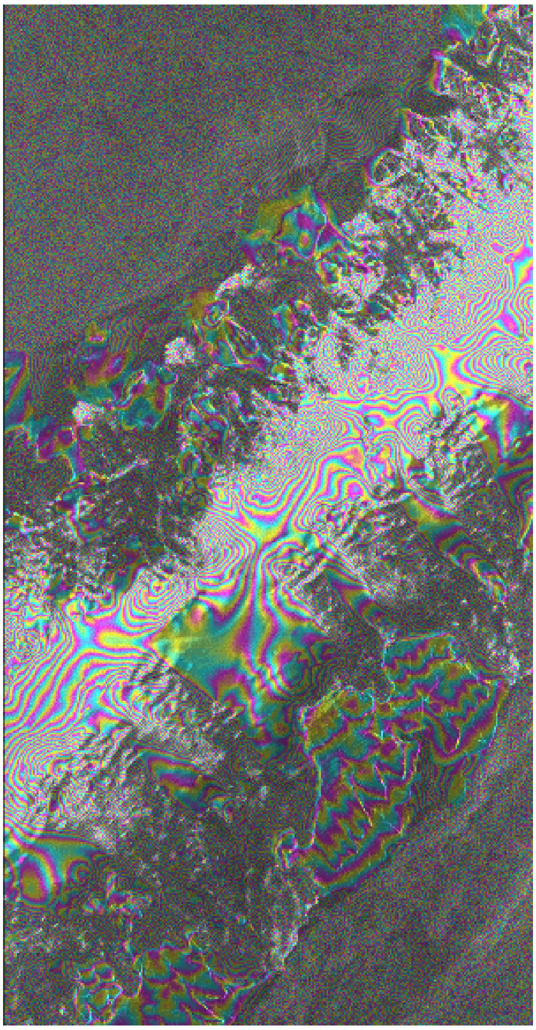

Figure 3. JERS-1 SAR interferogram of January 28 and March 13, 1998 in SAR geometry over Novaya Zemlya. Image width is ~70 km.

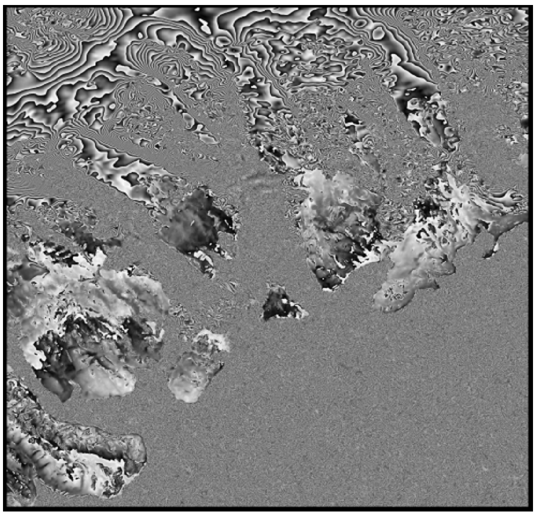

Figure 4. ALOS PALSAR interferogram of December 6, 2006 and January 21, 2007 in SAR geometry over Novaya Zemlya. Image width is ~70 km.

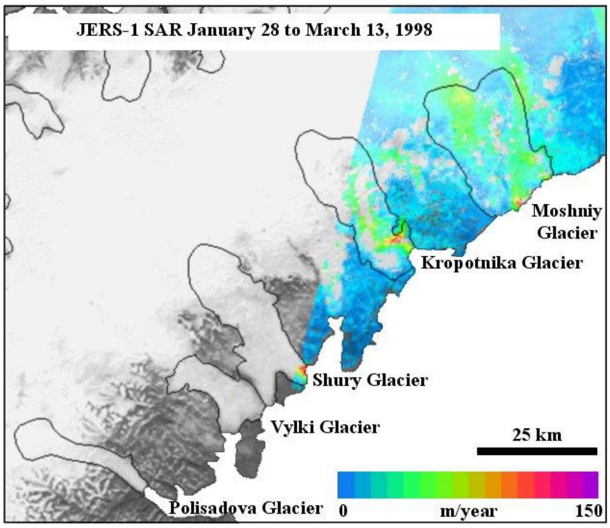

Figure 5. Horizontal displacement for Novaya Zemlya from JERS-1 offset tracking between SAR images of January 28 and March 13, 1998. Background is MODIS imagery from July 29, 2003. Ice divides and outlet glaciers boundaries are after [11]. Glacier names are after World Glacier Inventory (National Snow and Ice Data Center, 1999).

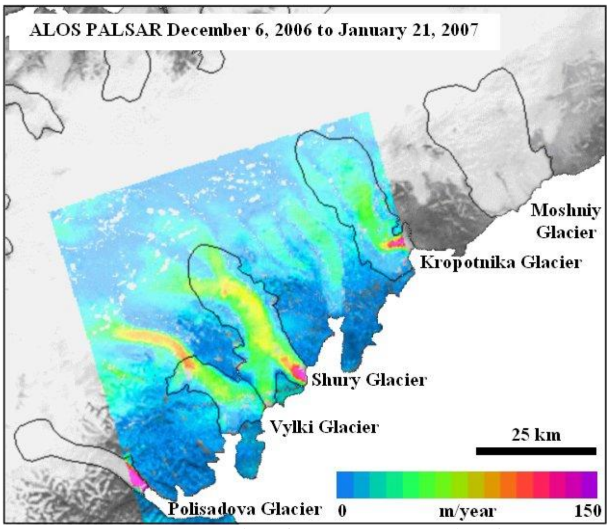

Figure 6. As Figure 5 but for Novaya Zemlya from ALOS offset tracking between PALSAR images of December 6, 2006 and January 21, 2007.

In the area covered by both satellite images, the ice-surface velocities of Kropotnika Glacier measured with JERS-1 SAR in 1998 and ALOS PALSAR in 2007 are similar (see Figure 7). In the marginal part of the glacier, where no JERS-1 estimates were determined, highest velocity estimates in 46 days ALOS data are about 160 m/year with expected errors of about ±20 m/year. Frontal velocity estimates in 44 days JERS-1 data are about 80 m/year. Unfortunately, the ALOS PALSAR image is missing the frontal part of Kropotnika Glacier. The marginal part of Shury Glacier shows a slight increase in ice-surface velocities from 1998 (about 120 m/year measured with JERS-1 SAR) to 2007 (about 160 m/year measured with ALOS PALSAR). In general, the ALOS PALSAR estimates appear less noisy than the JERS-1 SAR measurements.

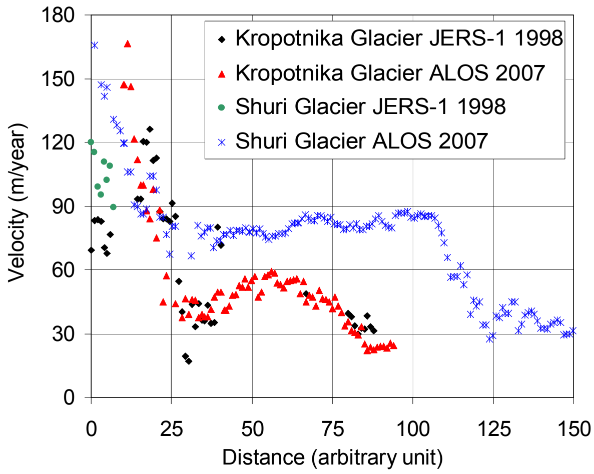

Figure 7. Horizontal displacement along the approximate main flow lines of Kropotnika glacier and Shury glacier from JERS-1 SAR and ALOS PALSAR offset tracking.

5. CONCLUSIONS

Our results demonstrates that offset tracking of L-band SAR images is a robust and direct estimation technique of glacier motion. The method is particularly useful when differential SAR interferometry is limited by loss of coherence, i.e. for rapid and incoherent flow and large acquisition time intervals between the two SAR images. Archived JERS-1 SAR and ALOS PALSAR data are available for whole Novaya Zemlya. Comparison of motion estimates from 1998 and 2007 allows us to investigate past and recent behavior of Polar Regions and possibly detect changes in the velocity of the glaciers.

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References

[1] R. Goldstein, R. Engelhard, B. Kamb and R. Frolich, Satellite radar interferometry for monitoring ice sheet motion: application to an Antarctic ice stream, Science, 262: 1525-1530, 1993.
[2] M. Fahnestock, R. Bindschadler, R. Kwok and K. Jezek, Greenland ice sheet surface properties and ice dynamics from ERS-1 SAR imagery, Science, 262: 1530-1534, 1993.
[3] E. Rignot and P. Kanagaratnam, Changes in the Velocity Structure of the Greenland Ice Sheet,

Science, 311(5763), 986-990, 2006.
[4] E. Rignot, S. Gogineni, W. Krabill and S. Ekholm, North and Northeast Greenland ice discharge from satellite radar interferometry, Science, 276(5314): 934-937, 1997.
[5] J. J. Mohr, N. Reeh and S. Madsen, Three-dimensional glacial flow and surface elevation measured with radar interferometry, Nature, 391(6664): 273-276, 1998.
[6] A. Luckman, T. Murray and T. Strozzi, Three-dimensional surface flow evolution throughout a glacier surge measured by satellite radar interferometry, Geophysical Research Letters, 29(23), 2002.
[7] T. Strozzi, A. Kouraev, A. Wiesmann, U. Wegmüller, A. Sharov and C. Werner, Estimation of Arctic glacier motion with satellite L-band SAR data, Remote Sensing of Environment, In Press, Corrected Proof, Available online 2 August 2007, doi:10.1016/j.rse.2007.06.007.
[8] L. Gray, K. Mattar and P. Vachon, InSAR results from the RADARSAT Antarctic mapping mission: estimation of glacier motion using a simple registration procedure, Proc. IGARSS'98, Seattle, USA, 6-10 July 1998.
[9] C. Werner, U. Wegmüller, T. Strozzi and A. Wiesmann, Precision estimation of local offsets between SAR SLCs and detected SAR images, Proc. IGARSS'05, Seoul, Korea, 25-29 July 2005.
[10] U. Wegmüller, C. Werner, T. Strozzi and A. Wiesmann, Ionospheric electron concentration effects on SAR and INSAR, Proc. IGARSS'06, Denver, USA, 31 July - 4 August 2006.
[11] G.M. Varnakova and V.S. Koryakin, The catalogue of the USSR glaciers (Katalog lednikov SSSR). Resources of the USSR surface waters (Resoursy poverkhnostnyh vod SSSR), Vol. 3 (Northern Territories), part 2 (Novaya Zemlya), Leningrad, Hydrometeoizdat publishing, USSR, 112 pp., in Russian, 1978.