Conference Proceedings Paper

Estimation of Velocity of the Polar Record Glacier, Antarctica Using SAR

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Published:

Abstract: The ice flow velocity is a critical variable in understanding the glacier dynamics. The Synthetic Aperture Radar Interferometry (InSAR) is a robust technique to monitor Earth's surface mainly to measure its topography and deformation. The phase information from two or more interferogram further helps to extract information about height and displacement of the surface. We used this technique to derive glacier velocity for Polar Record Glacier (PRG), East Antarctica, using Sentinel-1 Single Look Complex images captured in Interferometric Wide mode. For velocity estimation, Persistent Scatterer interferometry (PS-InSAR) method was applied, which uses time coherent of permanent pixel of master images and correlates to same pixel of the slave image to get displacement by tracking the intensity of that pixels. C-band sensor of European Space Agency, Sentinel-1A and 1B data were used in this study. Estimated average velocity of the PRG is found to be approximately ≈400 ma^{-1} which varied from ≈100 to ≈700 ma^{-1}. We also found that PRG moves at ≈700 and 200 ma^{-1} in lower part and the upper inland area, respectively.

Keywords: PS-Interferometry, Velocity, Sentinel-1, Polar Record Glacier, Microwave Remote Sensing.

1. Introduction

Synthetic Aperture Radar interferometry (InSAR) is the common practice for the measurement of topography and deformation of the earth surface. It is an active microwave radar imaging system based on Doppler motion principle, wherein two Synthetic Aperture Radar (SAR) images are used to generate an interferogram. It uses InSAR acquiring great capabilities to measure and detect ground surface deformation up to sub-centimeter level on a wide scale. Several studies based on InSAR have quantified earth surface deformation caused by processes like ice motion, subsidence phenomena, earthquake, volcanism, etc. While Radio Detection and Ranging (RADAR) is a one of the primary tools that measures distance of object, SAR records phase and amplitude information; the phase of the radar represents the number of cycles of oscillation of waves between radar and the surface. If phase is not provided it is singular image, for which more than one image is required for processing, however by the convention the amplitude or intensity of images are usually delivered to the end user.

The application of the SAR techniques for cryosphere is increasingly day by day for different purposes such as measurement of the flow of glacier and ice sheet, generation of high resolution topographic maps, calculation of surface displacement associated with crustal deformation [1]. Rapid movement of the flowing ice creates spectacular fringes pattern in interferogram, which increases with increase in the surface velocity which sometime exceeds more than 1m/day. Monitoring such high motion by satellite radar interferometry needs small orbital and temporal separation between consecutive passes [2]. Sequence of differential interferogram such as Differential SAR interferometry (DInSAR or DiffSAR) is an effective technique to explore the properties of InSAR for monitoring temporal behavior for the change detection which leads to generation of the time series for monitoring deformation [3]. The temporal gap of repeat-pass interferometry with marginal repetition of days, months, or even years can be used to monitor long-term geodynamic phenomenon. DInSAR measures displacements with centimeter accuracy provided higher coherence is available. Persistent or Permanent Scatterer Interferometry (PS Interferometry) allows monitoring subsidence effect with millimeter accuracy. The processing system of PSI was developed to cope with a single dominant point scattered within a resolution cell; when the number of interferogram increases the PS density also improves.

The recognition and quantification of the glacier surface deformation using SAR interferometry technique have great impact on the accuracy of results. Phase difference between two SAR images taken with some temporal gap with different view angle has been used to measure the velocity of ice sheets and movement of glacier in polar region as well as Himalayan cryosphere. InSAR phase is sensitive to both coherent displacement and surface topography along the SAR look vector derived from the acquisitions of the InSAR image pair [4]. Coherence tracking and intensity tracking are two cross-correlation techniques applied to SAR data to produce 2D vector field datasets with InSAR. If two or more radar images with good correlation and orbital, topographic, tropospheric contributions are modelled, the precision of InSAR of the order of millimeter can be achieved; however, other errors may arise while resolving the phase ambiguity through the unwrapping process [5]. The coherence over the glacier surface is affected by flow condition and meteorological forcing, which diminishes with increasing time interval between SAR images used to generate interferogram. Meteorological parameters, which create decorrelation, include surface melt of snow and ice due to rise in surface temperature, precipitation in the form of snowfall and sometimes winds redistribute snow and ice. Decorrelation caused by the glacier motion are incoherent displacements of adjacent scatterers and rapid flow if local deviations from the overall images registration function are not considered [6].

2. Experiments

2.1. Study Area and Data Used

The Polar Record Glacier (PRG) is located 69.5°S, 75.4°E on Princess Elizabeth land. It is one of the largest outlet glacier flow situated near Larsemann Hills in East Antarctica. It is one of outlet glacier besides the Ingrid Christensen coast bounded by Dodd Island and Meknattane Nuntaks [7]. The Indian Antarctic Research station Bharati is located to the northeast, about 50 km from this glacier. Using satellite data from 1937 to 1947, Roscoe, a geographer in US detected an ice tongue extending ~ 70 km into the open sea and he predicted that the tongue would calve when it encounters Amery Ice Shelf (AIS) which was confirmed that a large ice piece broke away into the sea between 1980-1990. Further monitoring has revealed that the total area is decreasing every year: from 450 km^2 it decreased to 300 km^2 after several calving events. [8] claimed that the surface velocity of the tongue enhanced by 19% from 140 to 580 ma^{-1} in winter to 720 ma^{-1} in the summer.

In this study we used Sentinel-1 SAR interferometric single look complex data (SLC) level-1 product. More specification of data set used in this study is mentioned in Table-1 and Table-2.

Table 1 Specification of Sentinel-1 product used in this study

Parameters Specification	Parameters Specification
Polarization	HH
Incidence angle	31° – 46°
Azimuth Resolution	20m
Ground range resolution	5m
Azimuth and Rang look	Single
Swath	250km
Phase Error	5°

Figure 1: Location of PRG East Antarctica.

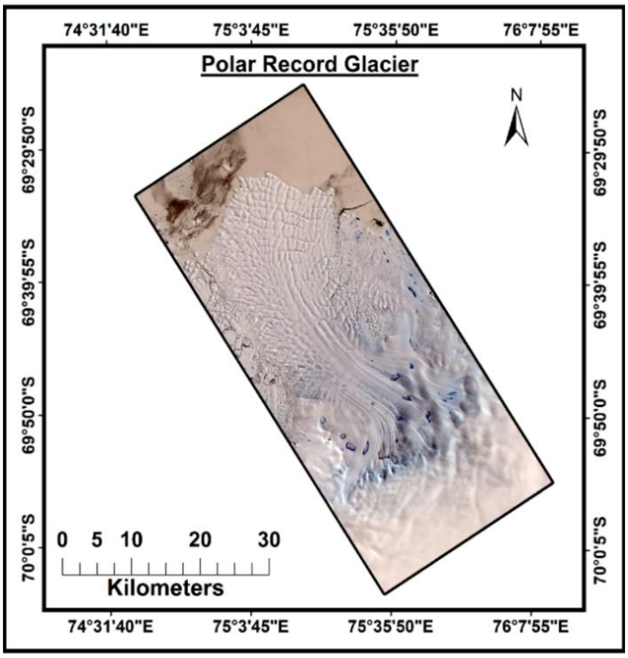

Figure 2: FCC Map for PRG.

Table 2 Data used in study of PRG glacier

Mission	Acquisition date	Orbit number	Id	Unique identifier	Flight Direction
S1A	07-08-2016	012500	0138DA	DA1D	Descending
S1A	19-08-2016	012675	013E9C	7FB2	Descending
S1A	31-08-2016	012850	01448E	27DE	Descending
S1A	12-09-2016	013025	014A22	2258	Descending
S1A	18-10-2016	013550	015B08	93BF	Descending
S1A	11-11-2016	013900	0165F4	9EDC	Descending
S1A	05-12-2016	014250	0170BC	4526	Descending
S1A	29-12-2016	14600	017BB9	C3E0	Descending
S1A	22-01-2017	014950	018671	6B79	Descending
S1B	30-09-2016	002304	003E57	540C	Descending
S1B	24-10-2016	002654	0047CC	A1F8	Descending
S1B	05-11-2016	002829	004CA8	F585	Descending
S1B	17-11-2016	003004	0051B4	7BAB	Descending
S1B	11-12-2016	003354	005BA9	C91B	Descending
S1B	04-01-2017	003704	0065D5	6C7B	Descending
S1B	21-02-2016	004404	007A9F	C99D	Descending

2.2. Methodology

Interferometric processing of SAR data for DEM generation as well as velocity calculation involves common steps: Image Co-registration, Interferogram Generation, Interferogram flattening and topographical phase removal, Phase Unwrapping, Height or velocity conversion and Geocoding [9][10][11][12][13].

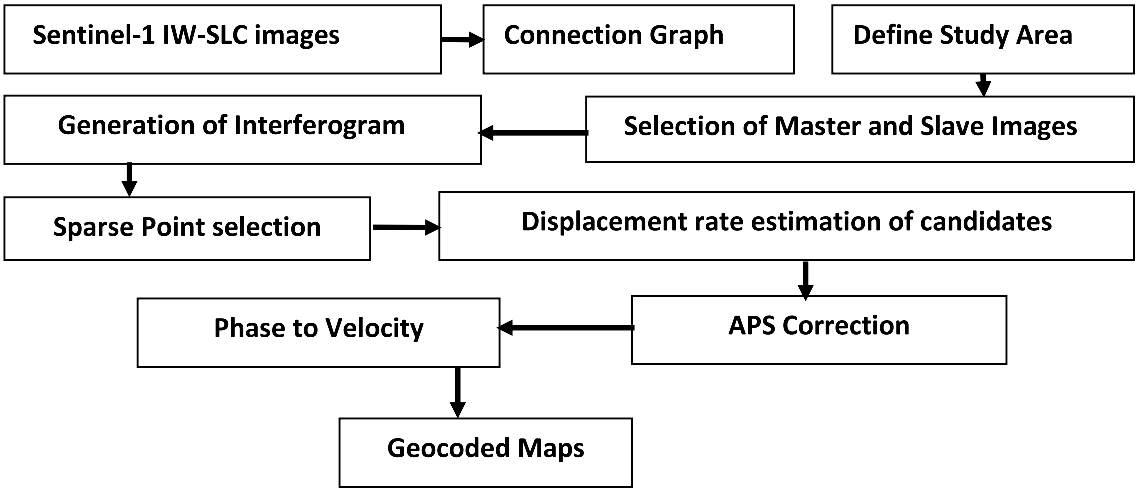

Figure 3. General steps for PS Interferometric process

2.2.1. Processing steps for velocity calculation:

For velocity calculation of study area, we used PSInSAR method where all SAR single look complex (SLC) images were involved for co-registration. As mentioned earlier, in the PSI method the number of images affects the accuracy of the results because the co-registration depends upon the amplitude of the signal [14]. The SARPROZ software that was used to generate velocity map from the SAR data, has its own inbuilt module to handle every step of the functions and the function is further parted in sub-function as shown in figure 3.

First, SLC images were co-registered by Terrain Observation by Progressive Scans (TOPS). which is a Sentinel-1 image capturing mode. At the time of registration of images, we also used DEM (for terrain correction) and Precise orbit information. In second step, selection of Master and Slave images was incorporated depending on the need and availability. Before performing the third step, sparse point selection based on amplitude stability and reflective maps was carried. These all sub-processes along with synthetic GCP generation was performed using RAMP DEM which were uploaded with the software. In final step of data processing, geocoding process was processed.

3. Results and Discussion

The velocity of Polar Record glacier is calculated with the help of sixteen SAR images using PSInSAR process. All the 16 images are alternatively used as master and slave, if one image is master rest of other images behave as slave. In this study, we found similar behavior from image, if the coherence of master and slave is higher, then accuracy was higher. We also found that PRG is one of the very fast-moving glacier in eastern part of Antarctic with annual velocity of ≈700 m for lower part and ≈200 m for the upper inland area. The western part of the glacier is moving faster in comparison with the eastern part. The rate of glacier movement in summer was found to be more than 4 $mday^{-1}$ whereas some inland region exhibited 2 $mday^{-1}$.

4. Conclusion

It is possible to find velocity of the glacier using C-band sensor satellite with accurate result. Polar Record glacier is very fast flowing glacier. The velocity of PRG was estimated to be around 2 $mday^{-1}$ for the tongue portion and nearly 1 $mday^{-1}$ at upper inland area. The results showed that at lower altitude the velocity was 700-750 ma^{-1} whereas at higher altitude toward eastern side of the glacier flow it was 300-400 ma^{-1}. In the PSInSAR method on Interferometric SAR data for estimating glacier velocity, the accuracy of the results varied according to the coherence level of the SAR images; those having higher coherence (>0.92) yielded accurate results. As the coherence decreased, it was not feasible to proceed with the SAR images.

Table 3. Velocity output estimated using different images

Date of Image	Average Coherence (0 to 1)	Estimated average velocity (ma^{-1})
07-08-2016	0.76	432
19-08-2016	0.78	441
31-08-2016	0.81	442
12-09-2016	0.65	465
30-09-2016	0.82	476
18-10-2016	0.92	513
24-10-2016	0.90	528
05-11-2016	0.92	576
11-11-2016	0.94	580
17-11-2016	0.93	586
05-12-2016	0.88	580
11-12-2016	0.68	580
29-12-2016	0.79	582
04-01-2017	0.79	583
22-01-2017	0.78	524
21-02-2017	0.68	520

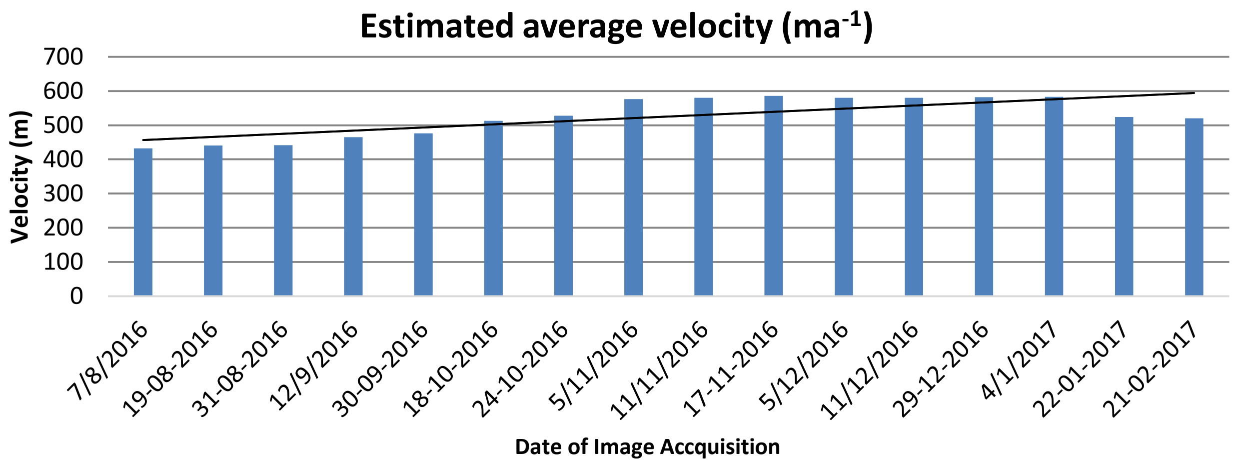

Figure 1. Estimated average velocity (ma^{-1})

Acknowledgments: The authors would like to thank Dr. Daniele Perissin, Assistant Professor at Purdue University for providing the software assistance. We are very thankful to the European Space Agency for making availability Sentinel-1 data for free. We also acknowledge Dr. M. Ravichandran, Director, ESSO-NCAOR, for his encouragement and motivation for this research.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

PRG: Polar Record Glacier
SAR: Synthetic Aperture Radar
SLC: Single Look Complex

DInSAR or DiffSAR: Differential SAR interferometry
PSI or PSInSAR : Persistent scatterer interferometry.

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