ICE VELOCITY ESTIMATION OF NARSSAP SERMIA IN GREENLAND USING MULTI-TEMPORAL X-BAND SAR OBSERVATIONS

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ABSTRACT: Glaciers has been paid an attention as important indicator related to climate change and sea level rises from global warming. In this study, we use multi-temporal X-band synthetic aperture radar (SAR) observations to analysis dramatic changes of ice velocity in glacier over Greenland. Differential radar interferometry (DInSAR) can measure glacier movement with high accuracy of from cm to mm scale, but it is often limited by degraded loss of coherence due to significant temporal and volume decorrelation. Thus, we adopted intensity offset tracking to estimate the displacement of the different part of glacier. Since offset tracking is determined by the cross-correlation of the amplitude between two SAR images, it can be applied to large displacements regardless of temporal decorrelation. In this study, a time series of ice velocity of Narssap sermia and Qamanaarsuup Sermia was estimated by using TerraSAR-X/TanDEM-X X-band SAR images. We processed 95 SAR images, which were collected with mostly the 11-day temporal baseline in the stripmap mode at ascending direction, VV polarization, and incidence angle of 21.4 degree, acquired from July 22, 2013 to February 09, 2017. The multi-temporal observations of the ice velocity changes using available SAR data collected over about three and a half years will be presented. Estimated ice velocity time series would present seasonal and spatial velocity variations.

1. INTRODUCTION

It is well known that the glacier melting is closely related to climate change and global warming. Significant ice loss in glacier in the Greenland and Antarctica contributes to sea level risings which threaten coastal area over the world. Researches on glacier suggest that glacier move faster than past (Rignot and Kanagaratnam, 2006; Joughin et al., 2010), therefore it is important to monitor the glacier continuously and carefully. Because, however, it is difficult to reach the glacier for terrestrial frequent observation, space-based remote sensing measurement has been preferred. A terrestrial measurement using Global Positioning System (GPS) can provide ice velocity with very high temporal resolution. However, it costs and cannot generate a two-dimensional displacement map of the glacier with high spatial resolution. A synthetic aperture radar (SAR) is a technology that obtains earth surfaces' information by transmitting and receiving microwave electromagnetic signals with a radar antenna installed on moving objects such as satellites or airplane. It is relatively independent to either weather or day-and-night condition and can be periodically observed at high-resolution over a wide range (Moreira et al., 2013). The monitoring using SAR observations can be cost effective compared with any other in-situ measurements.
Differential radar interferometry (DInSAR) provides a displacement map with high spatial resolution on earth surfaces like an earthquake, volcano, and water level change in mm to cm accuracy (Strozzi et al., 2003). However, the DInSAR application is often limited due to decorrelation effect caused by significantly larger displacement than the radar wavelength, large temporal baseline which is time span between two SAR observations, volume decorrelation from snow melting or accumulation, etc (Strozzi et al., 2006; Riveros et al., 2013). Therefore the DInSAR technique is more appropriate when applying to relatively slow-moving areas like solid earth surfaces (Sánchez-Gámez and Navarro, 2017). On the other hand, offset tracking does not rely on coherence of interferometric phase, it can be applied for fast-moving areas such as glacier surface (Chunxia et al., 2011). There are two approaches to apply offset tracking: one is the intensity tracking based on the amplitude cross-correlation which relies on the same feature between the two images in a window patch, and the other is coherence offset tracking based on interferometric phase coherence which can be used in areas which have no features (Strozzi et al., 2002). However, the latter has a limitation where significant interferometric coherence loss is discovered.
In this study, we employed intensity tracking using multi-temporal SAR observations because the large displacement of ice flow in the glacier was expected. We present a preliminary result of a time series of ice velocity in the Narssap sermia at Greenland and also evaluate variation of the ice velocity with regard to time and season.

2. STUDY SITE AND DATASETS

Greenland is the largest island in the world occupied about 82% by the ice sheet which enables to raise the sea level about 7 m (Cuffey and Marshall, 2000). There are several types of the glacier in Greenland, according to its behavior, shape and geographical features. Glaciers can be categorized into two groups: one is continental glacier and the other is valley or alpine glacier. These two main groups can be divided into different sub-types, such as cirque glacier, valley glacier, tidewater glacier, piedmont glacier, ice sheet, etc (Molnia, 2004). We chose Narssap sermia as the study area which is located at tidal outlet glacier in the southwest Greenland (Weidick et al., 1995) and Qamanaarsuup Sermia which is the land-terminating glacier. The Narssap sermia is located near the Nuuk where is influenced by the warm West Greenland current (Holland et al., 2008; Rignot et al., 2010). This glacier is characterized by flowing directly and terminating to the sea its terminus calves to form iceberg (Van Der Veen, 1996) and the land-terminating glacier is characterized by forming surface melt ponds. According to the previous research, it started to retreat rapidly from 2006, and the retreat occurred about 500 m from 2000 to 2010 and 3.3 km from 2010 to 2013, respectively (Rignot and Kanagaratnam, 2006; Howat and Eddy, 2011). Recently, the Narssap sermia is retreating at 150 m/year and the velocity of glacier at the terminus is about 5,500 m/year (Motyka et al., 2017).
We collected 95 TerraSAR-X/TanDEM-X X-band SAR observations with mostly 11-day revisit cycle. The acquisition date ranges from July 22, 2013 to February 09, 2017. The collected images were acquired with the stripmap mode image with an ascending direction, VV polarization, incidence angle of 21.4 degree, and high spatial resolution of 0.9 m in range direction and 1.9 m in azimuth direction.

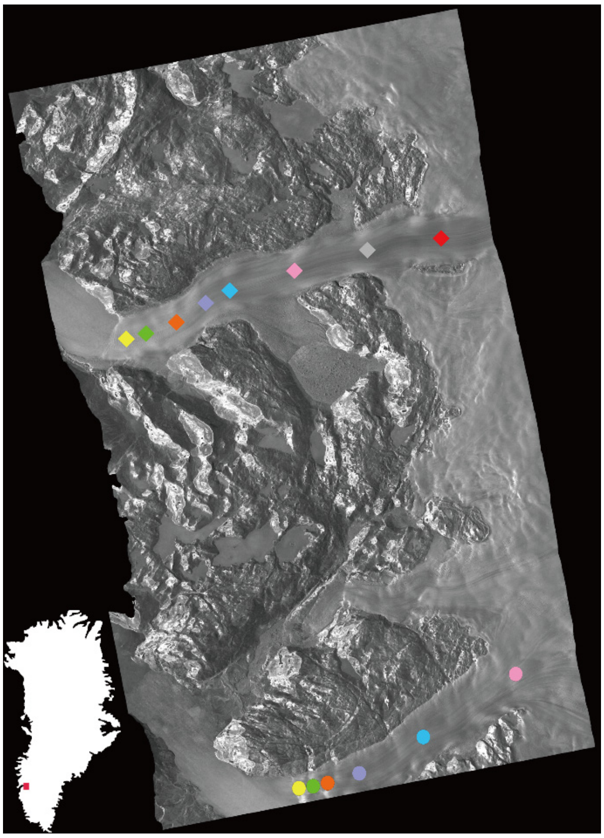

Figure 1. The average geocoded amplitude image of TerraSAR-X (Image courtesy of DLR). Selected points for time-series analysis of ice velocity were marked with different color scheme. The glacier located at the upper part of the image is Narssap sermia and the lower is Qamanaarsuup sermia.

3. METHOD

The intensity offset tracking has been applied to measure the displacement by finding patterns and features matching between two images by amplitude cross-correlation as follow (Strozzi et al., 2002; Baek et al., 2017; Chae et al., 2017; Baek et al., 2018). The offset tracking method using multi-temporal SAR observations has been used widely to measure the ice velocity in the cryosphere. At first, two or more SLC images with respect to a master image were coregistered using the satellite orbit information and amplitude cross-correlation. Next, we examined suitable window patch size varying according to ice velocity in the glacier. The appropriate window patch size, which is critical parameters to estimate the offset between two SAR images, is necessary to find the identical feature. We used sub–window patch sizes of from 32 x 32 to 512 x 512 pixels at the range and azimuth directions. When the small patch size is applied, we can get a high spatial resolution surface displacement map, the offset cannot be estimated where the glacier is fast moving. In order to remove the systematic artifact or linear trend between two images, the polynomial of the offset was estimated. The offset in the range and azimuth direction is estimated using the amplitude cross-correlation and the estimated offset has been converted into displacement. Finally, the displacement was calculated into ice velocity with temporal baseline and pixel spacing of the SAR images

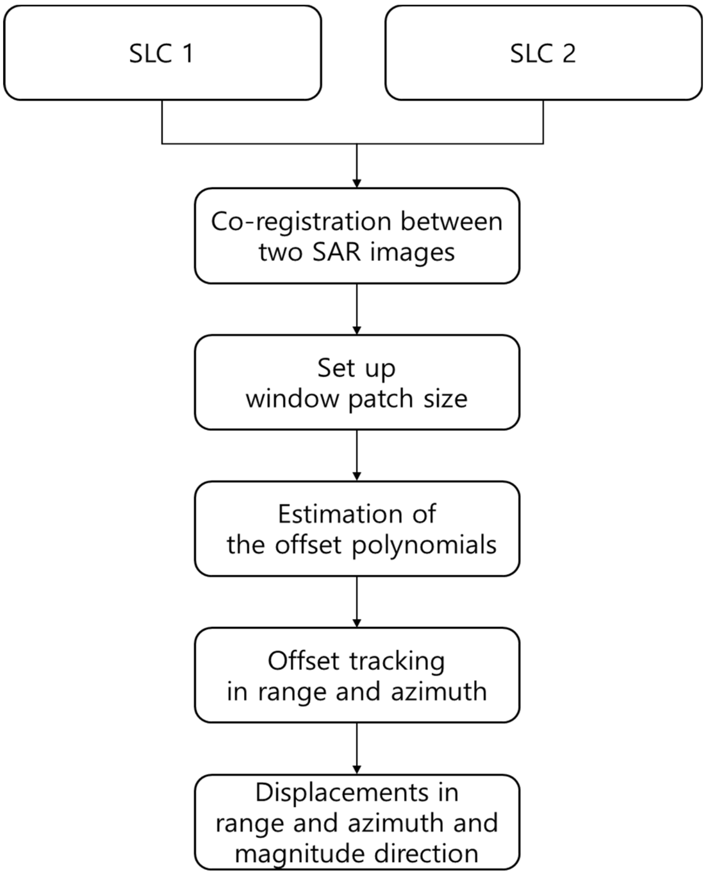

Figure. 2. Flowchart of offset tracking for estimation of ice velocity.

4. RESULT

We obtained 94 ice velocity maps using offset tracking with 95 consecutive SAR observations over Narssap sermia and Qamanaarsuup sermia. Fig. 3(a, c) represents average ice velocity maps processed by the offset tracking. Each color cycle presents a surface displacement marked at the scale bar. The areas of having constant blue color are bedrock, compared with a flowing glacier. The estimated ice velocity maps have been evaluated by considering the effect of time and season. The Narssap sermia shows a more significant change of glacier movement compared to Qamanaarsuup sermia over time. It might be related to that the Narssap sermia is closely located nearby the ocean as the glacier terminus at the west coast of Greenland. The glacier flows from right to left and has the velocity difference. We found that the ice velocity was faster at the terminus than elsewhere. To examine the spatial and temporal effects in the ice velocity, we extracted profiles by stacking the results from the multi-temporal observations. Fig. 3(b, d) shows more possible significant changes at the terminus of the glacier compared with the ice velocity at the middle or the front part of the glacier (Motyka et al., 2003). The regression analysis indicates that ice velocity was increased from August to July of the following year in overall. The ice velocity from July 2014 to March 2015 is slightly slower than that of previous year, but the gradient of the velocity is a bit higher. And from August 2015 to July 2016, the ice velocity and the gradient of the Narssap sermia were increased. Qamanaarsuup sermia shows a different trend with regard to Narssap sermia, which decreases over time. The ice velocity of the Qamanaarsuup sermia was also increased from July to August of the following year, but the average velocity was decreasing over time. The gradient of the velocity from July 2014 to March 2015 is a bit higher than that of previous and following year. Further research related to annual variation will be performed through additional data analysis

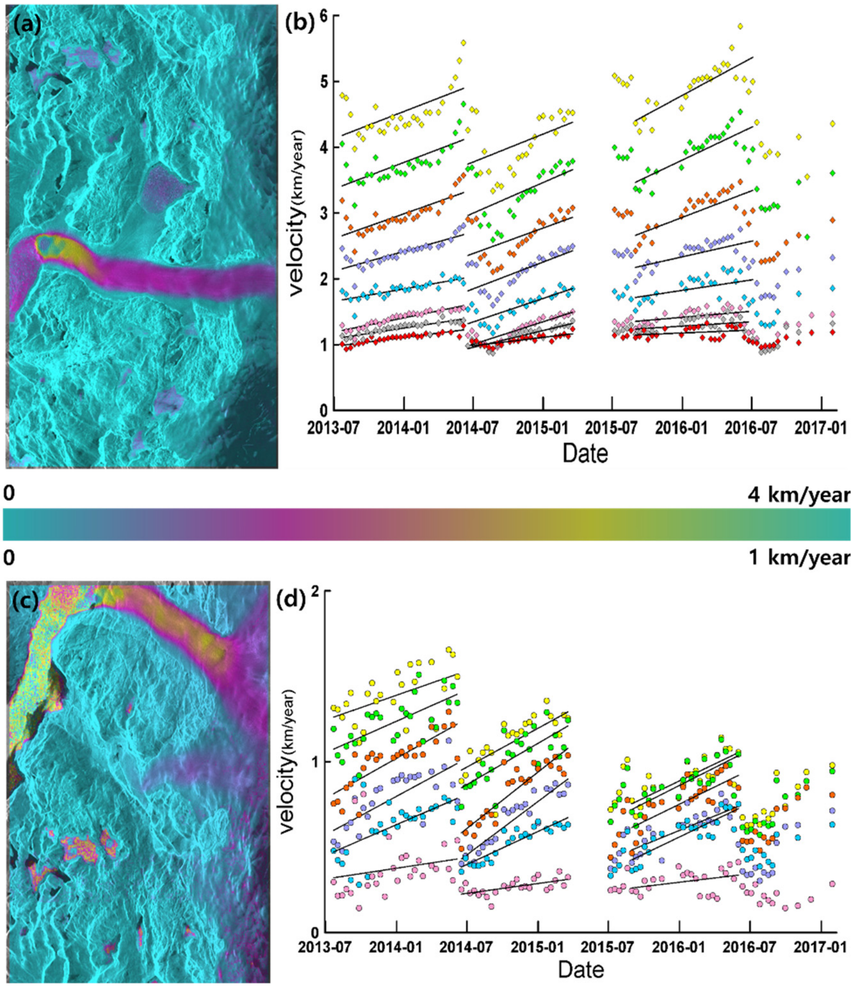

Figure 3. Average ice velocity map from July 2013 to February 2017 over (a) Narssap Sermia and (c) Qamanaarsuup Sermia. The plot of ice velocity time-series over about almost three and a half years period for (b) Narssap Sermia and (d) Qamanaarsuup Sermia. The location of the selected points could be found in Figure 1.

5. CONCLUSION

In this study, the ice velocity of Narssap sermia and Qamanaarsuup Sermia was estimated by intensity offset tracking from a total of 95 SAR images collected from July 2013 to February 2017. The ice velocity of glacier movement shows seasonal changes from the preliminary result. As expected, the ice velocity at the terminus is much faster than at the middle or the front part of the mainstream. Also, the overall pattern of the ice velocity of the Narssap sermia is increased over time and decreased in the Qamanaarsuup Sermia. We will further investigate with more SAR observations such as Sentinel-1A/B and temperature data like sea surface temperature product from Moderate Resolution Imaging Spectroradiometer (MODIS) sensor or Nuuk sea temperature data to find interesting ice velocity trend with respect to time.

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