Evaluating the TanDEM-X Digital Elevation Model in Differential Interferometric topographic phase removal process for glacier velocity estimation

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ABSTRACT: Glacier movement is an important parameter for understanding the climate change, glacier dynamics, ice thickness and mass balance studies. The movement can be measured using field based (Global Positioning System) or remote sensing (Interferometry or offset tracking) based technique. GPS gives spatially limited information and it is very difficult on rugged terrains. Remote sensing techniques give velocity measurements in inaccessible areas and also overcome the spatial limitation problem. Interferometric Synthetic Aperture Radar (InSAR) is a remote sensing technique for measuring the glacier velocity with centimeter accuracy. Topographic phase removal is one of the important steps in the 2-pass Differential InSAR (DInSAR) technique and also it is one of the major error sources in this process. An external Digital Elevation Model (DEM) is required for this step and using an optimizing DEM increases the accuracy level of glacier movement. The time period of SAR image pair is also considerable for the selecting of external DEM due to the changes in elevation (in the process of glacier mass loss/gain). The main objectives of this study are to estimate the Eidembreen glacier movement and evaluating the TanDEM-X 90m DEM with ArcticDEM in DInSAR topographic phase removal step. The ArcticDEM is selected due to the accuracy and resolution. The majority of ArcticDEM data was generated by using optical stereo high-resolution imagery. For this study, Eidembreen glacier is selected and it is located in the Svalbard. Sentinel 1 A/B sensor SAR images selected for the interferometric process with a perpendicular baseline of 12.89 m and the mean coherence value is 0.67. We used both TanDEM-X and ArcticDEM as external DEM to remove topographic phase information and compared the both generated line-of-sight (LOS) velocity maps along the central flow line of Eidembreen glacier. We observed the mean difference value as 0.35 mm/day and it represents approximately 12.7 cm/year. So, this value is almost negligible with the annual glacier velocity range values.

INTRODUCTION

Glaciers are a key indicator of climate and its movement is an important parameter to understand glacier health and dynamics (Bhutiyani et al., 2010). Glacier velocity mainly depends on ice thickness, bed topography and local weather conditions. The velocity component additionally useful to derive ice thickness and mass balance and recent studies are observed disintegrating behavior through the velocity of a glacier (Singh et al., 2020). But direct or field measurements of glaciers are very difficult and spatially limited (Nela, Singh, et al., 2019). Remotely sensed data is very useful especially for inaccessible areas like glaciers. In this study we used Differential Interferometric SAR (DInSAR) measures displacement/velocity in the line of sight (LOS) direction. This technique can be used for different application like monitor Earth Quakes (Massonnet, D.; Rossi, M.; Carmona, C.; Adragna, F.; Peltzer, G.; Feigl, K.; Rabaute, 1993), Volcanoes (Massonnet et al., 1995) and glacier movement (Joughin et al., 2000; Kwok & Fahnestock, 1996; Rignot et al., 1995; Rigont et al., 1996; Sánchez-gámez & Navarro, 2017). Goldstein et al., (1993) (Goldstein et al., 1993) first time used satellite radar interferometry (SRI) technique to monitor the velocity of the ice sheet. In DInSAR process, the interferometric phase component consists of displacement, elevation and atmospheric error information. It is compulsory to remove topographic phase information (elevation) from the phase to obtain glacier movement. The study is mainly focusing on evaluation of the TanDEM-X DEM in topographic phase process with the ArcticDEM. The vertical precision of ArcticDEM is 0.5 m (Morin et al., 2016) and we are assuming it gives accurate velocity results.

STUDY AREA & DATASET

The Eidembreen glacier is located in the Svalbard region (Fig. 1). It is one of the glaciers giving a good coherence in the Svalbard archipelago and it is the main reason for selecting this glcier. Coherence is one of the main factors in the interferometry process and selection of a pair depends on the coherence. So, we selected Sentinel C-band pair with the temporal baseline of 6 days in the month of November 2017 (Table. 1).

Table 1. Interferometry details of selected SAR datasets for the DInSAR technique

Interferometry Pair	Dates	Satellite	Perpendicular baseline (met)	Temporal baseline (days)
Master	01 November 2017	Sentinel 1A	0	0
Slave	07 November 2017	Sentinel 1B	12.89	6

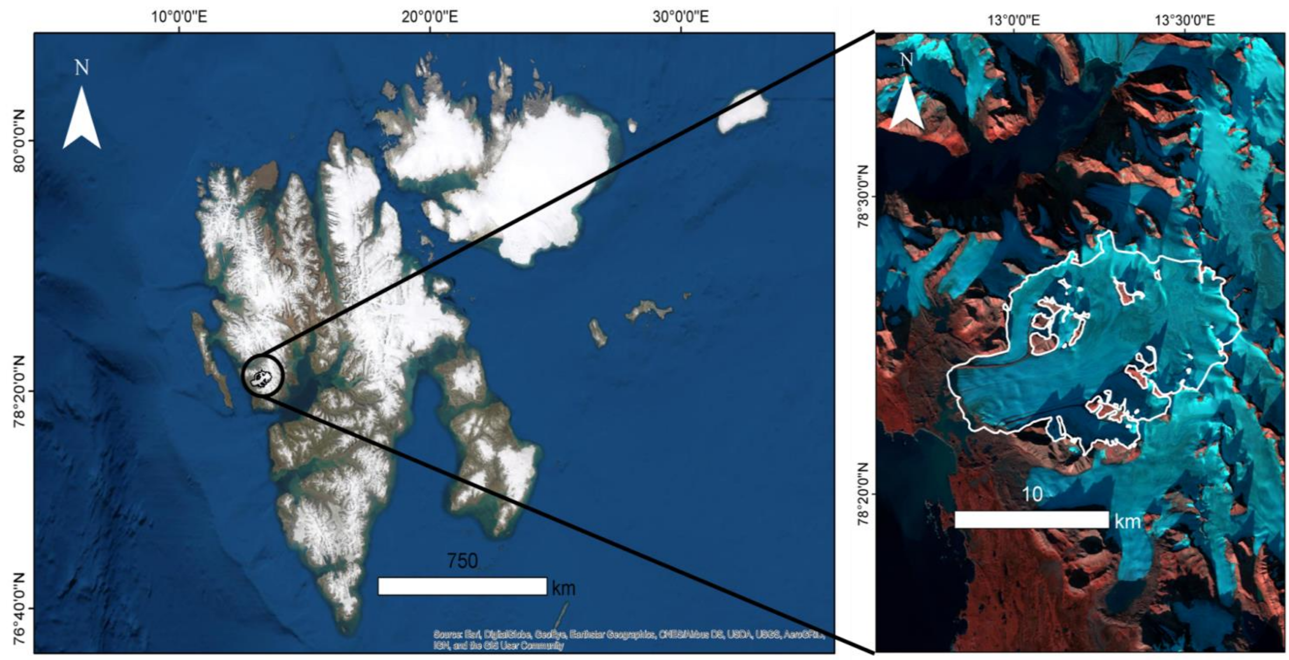
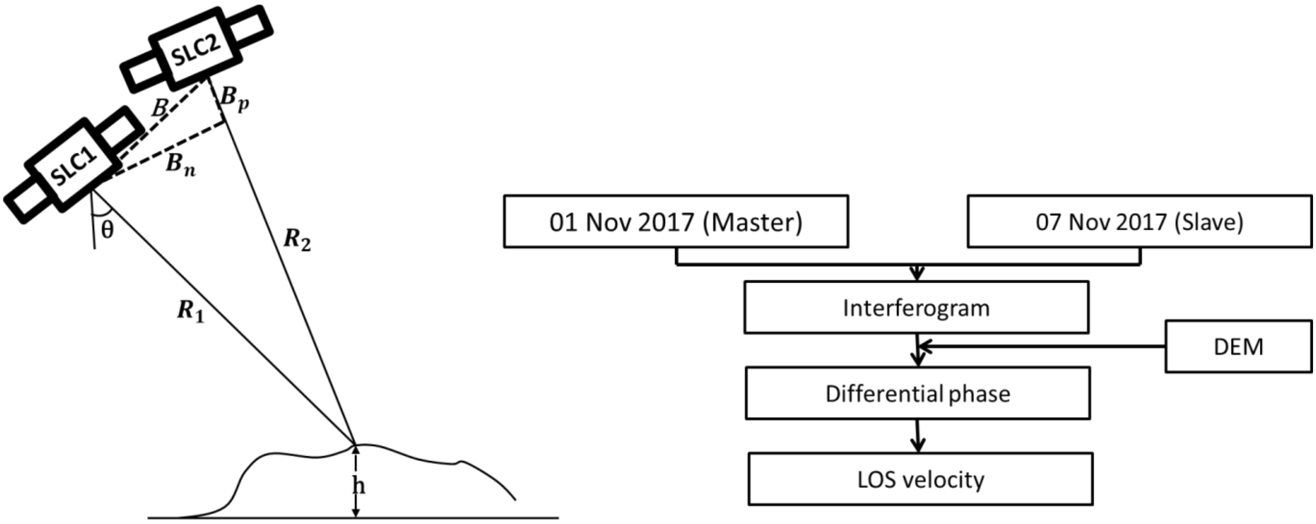


Figure 1. The study area of the Eidembreen glacier (right) using Landsat-8 natural FCC image located in the Svalbard archipelago (left)

METHODOLOGY

Eidembreen glacier movement was estimated using the DInSAR technique. DInSAR is the microwave remote sensing technique used to measure the displacement in line of sight (LOS) direction by subtracting the phase information (interferogram) of two radar back-scattered signals (Master and Slave), acquired at two different time periods. For this application, it requires two SAR side looking complex (SLC) images, collected in the same track and look angle with some temporal difference. This temporal baseline should be minimum for glacier movement estimation to minimize the effect of decorrelation. Initially, these two SAR images should be coregistered to perform sub-pixel level operations then interferogram can be generated by subtracting the phase of two coregistered SAR images. The interferogram consists of the information of movement and elevation. Therefore, topographic phase (DEM) is subtracted from interferogram to get the glacier movement information only and it is called differential interferogram. But, this phase information of this differential interferogram is wrapped in between $-\pi$ to π. Phase unwrapping used to recover the original phase and this unwrapped differential interferogram provides the LOS velocity information of that ground point.



(a) (b)

Figure 2. (a) Interferometry imaging geometry (B_n: normal/perpendicular baseline, B_p: parallel baseline, h: elevation, B: distance between two scenes, θ: inclination angle) and (b) basic methodology of 2-pass DInSAR technique

RESULTS & DISCUSSION

The glacier LOS velocity was estimated using DInSAR technique in November 2017. In the interferometry process coherence (varies between 0 and 1) is one of the important quality check parameter in order to have reliable results (Nela et al., 2018; Nela et al., 2019) and here in this study the value of coherence is 0.67. Glacier velocity varies seasonally and the velocity was estimated during the ablation season. The SAR data was acquired in the ascending pass, positive sign in LOS velocity map (Fig. 3, using ArcticDEM) is indicating that the glacier movement is towards the satellite, i.e., east to west. The high velocity rate observed along the main trunk of the glacier (Fig. 3) and it is 1.3 to 1.6 cm/day. Compared to other most of glaciers in the Svalbard region, Eidembreen is moving with a low velocity rate. This is another reason for selecting Eidembreen glacier in this study. If the glacier move with a rate of meters or few centimeters in a day, then the DEM induced errors can be ignored, since this uncertainty value is negligible with the flow rate. Velocity of the glacier mainly depends on its slope, ice thickness and local temperature. The area of the glacier is 114 km^2 and its mean thickness value is 211 m (Farinotti et al., 2019) and the slope of the glacier is also gentle. We generated the velocity maps by removing the topographic phase with the two different DEMs: ArcticDEM and TanDEM-X DEM and compared their velocity along the centerline. Both the velocity maps are following the same trend with the mean difference of 0.035 cm/day and it is equivalent to 0.127 m/yr. The uncertainty due to TanDEM-X DEM error is very low and the flow rate of Eidembreen glacier is also low. Hence, we need to consider this uncertainty value for the generated velocity with the TanDEM-X DEM. But for the fast moving glaciers, we can neglect the uncertainty value.

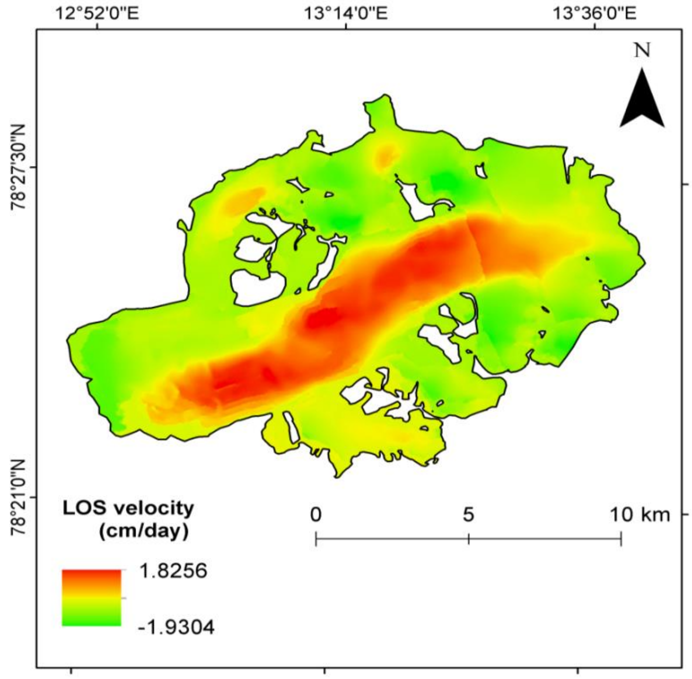


Figure 3. Glacier movement in LOS direction of Eidembreen glacier using 2-pass DInSAR with ArcticDEM

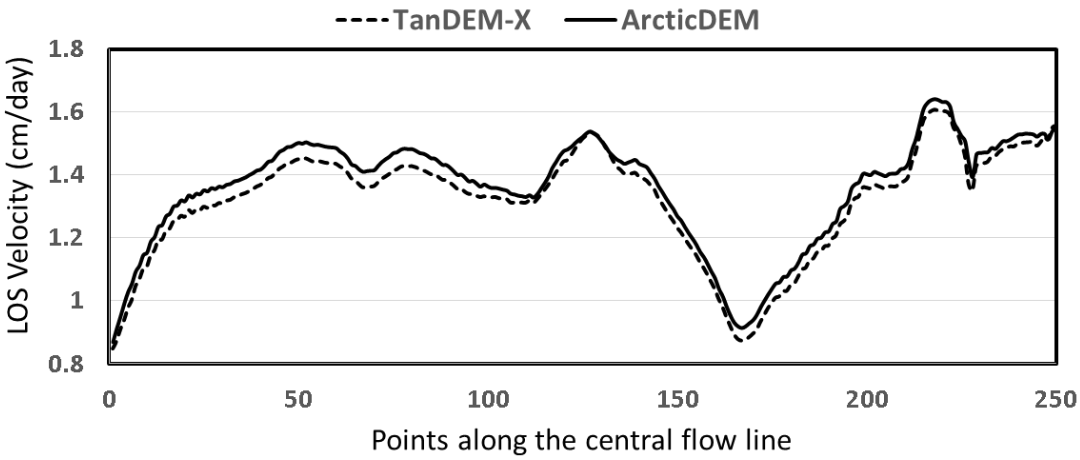


Figure 4. Comparison of glacier LOS velocity profiles along the centreline by using ArcticDEM and TanDEM-X DEM data in the topographic phase removal process.

CONCLUSION

The main two objectives of this study are estimating Eidembreen glacier velocity and evaluating the TanDEM-X DEM in the topographic phase removal process. The DInsAR technique was selected for the study. The observed mean LOS velocity along the main trunk of Eidembreen glacier is 1.4 cm/day. The evaluation of TanDEM-X DEM in Differential Interferometric topographic phase removal process accomplished with ArcticDEM. We assumed ArcticDEM is precise data to use in the topographic phase removal process to give accurate velocity results. The observed mean difference value of two generated velocity maps with different DEMs is 0.35 mm/day. The uncertainty value may increase if there is a large difference in time gap between SAR data and DEM due to change in ice thickness. But these error values need not to be considered if the glacier moves with a high velocity rate.

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