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Evaluation of Geospatial Tools for Generating Accurate Glacier Velocity Maps from Optical Remote Sensing Data †

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Abstract: Changes in the dynamics of glaciers must be assessed, as they are important for sea level changes. Glacier velocity is the most important parameter used in glacier dynamics studies. Various image matching techniques, which are implemented in different domains, have been utilized to estimate the surface velocity of glaciers, since the first use of remote sensing technology. In this study, we derived the precise velocity of the Polar Record Glacier (PRG), east Antarctica, in recent years, using optical remote sensing. The secondary objective of the study was to comparatively test the accurate geospatial tools for velocity estimation. The study was first conducted on a single image pair, and four different tools were used for the estimation of the glacier velocity, which are the COSI-Corr (Co-registration of Optically Sensed Images and Correlation) tool in ENVI (Exelis Visual Information Solutions), the IMGRAFT (Image GeoRectification and Feature Tracking) in MATLAB, the IMCORR (Image correlation) feature tracking tool in SAGA-GIS, and the image correlation software CIAS. After evaluation of the four feature tracking tools, COSI-Corr yielded a pixel-level velocity with both magnitude and directions, while IMGRAFT provided the glacier speed without the directions. On the other hand, IMCORR yielded good results with respect to magnitude and directions of the glacier velocity, but the pixel-wise magnitude was not produced. CIAS also provided closely bundled velocity products without pixel-wise velocity. COSI-Corr and IMGRAFT were found to be the best of the four tools, and COSI-Corr is recommended for further studies to estimate the velocity of the PRG.

Keywords: optical remote sensing; image matching; COSI-Corr; glacier velocity

1. Introduction

The location of glaciers in remote areas like Anatarctic and Himalaysa makes remote sensing the exclusive technique to monitor the velocity of the glaciers [1–3]. The availability of optical remote sensing data makes it convenient to estimate different glacier parameters. The estimation of glacier surface velocity using optical satellite datasets is an efficient and low-cost method and has been in use for more than three decades [4]. Glacier displacement is an important indicator that requires

temporal monitoring to understand its dynamics. The monitoring of glacier displacement is a key to quantify a glacier mass balance, which is a crucial component of the climate change [5] of the region. This study intended to obtain the accurate velocity of the PRG by using four different geospatial tools on optical remote sensing data and compare their performance.

2. Experiments

2.1. Study Area

The study was conducted on the PRG (69°45′ S, 75°30′ E) located in the Prydz Bay area on the eastern side of the Amery Ice Shelf (Figure 1). It is the largest outlet glacier along the Ingrid Christensen Coast, bounded by Meknattane Nunataks and Dodd Island. The Polar Record Glacier was first surveyed in 1947. Later in 1952, it was found that the glacier possesses an ice tongue [6].

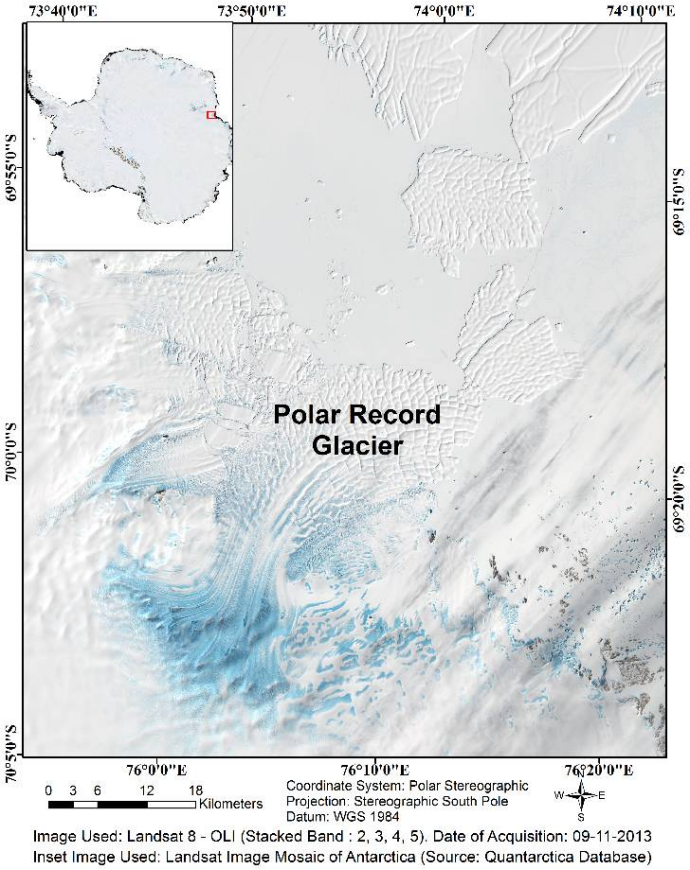

Figure 1. Image showing the location of the study area. (Image used: Landsat- 8 OLI, Date of Acquisition: 9 November 2013; Inset Image: Landsat Image Mosaic of Antarctica (Source: Quantarctica Database).

2.2. Materials Used

Landsat 8 OLI (Operational Land Imager) images (panchromatic band) (Table 1) were used for the estimation of velocity using different geospatial tools.

Table 1. Satellite data used in the study.

S. No.	Sensor	Path	Row	Date of Acquisition	Source
1.	Landsat 8-OLI	126	109	9 November 2013	Earthexplorer [1]
2.	Landsat 8-OLI	126	109	27 November 2013	Earthexplorer [1]

[1] earthexplorer.usgs.gov.

2.3. Method Adopted

The comparison to obtain the velocity was done using four different tools and techniques, namely, ImGRAFT, COSI-Corr, IMCORR, and the image correlation software CIAS. All four techniques were used initially to obtain the velocity on a smaller area on the glacier for comparative analysis. This enabled the selection of the best tool to derive the precise velocity (Figure 2a).

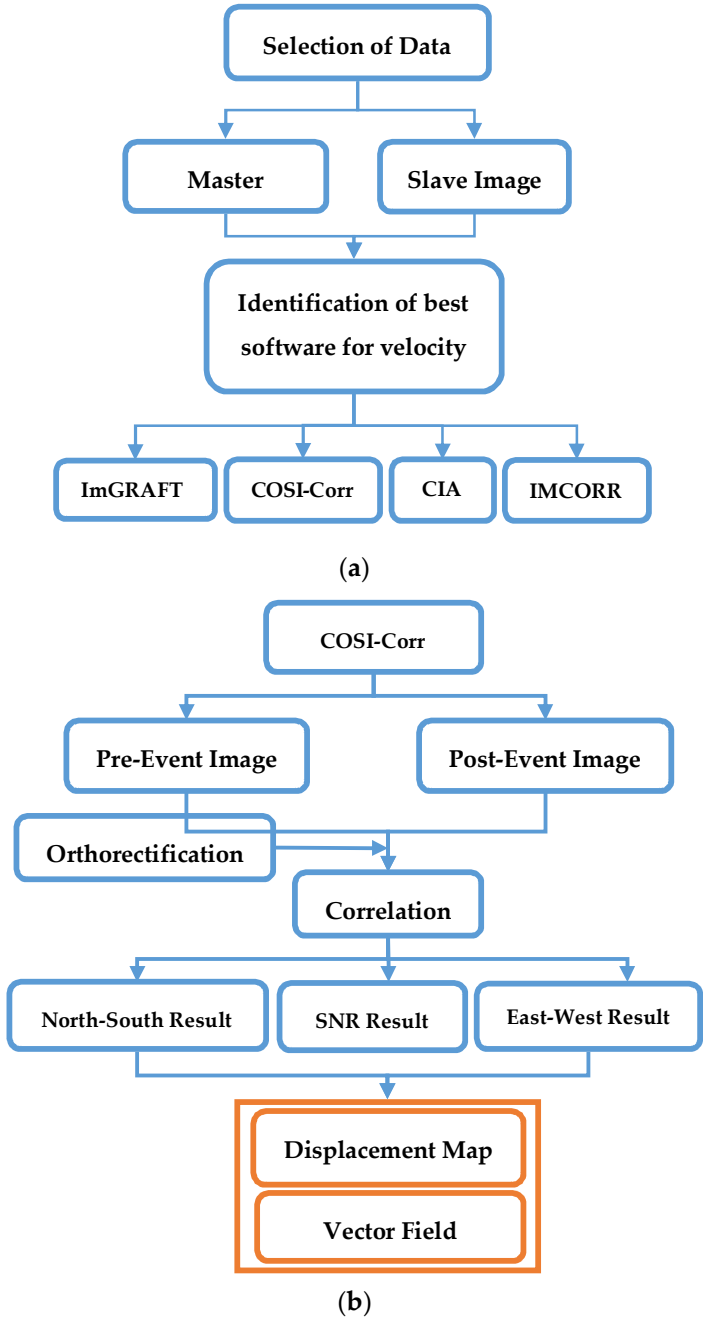

Figure 2. (**a**) Methodology adopted for the selection of the suitable software for the estimation of the glacier velocity; (**b**) Steps used for deriving the glacier velocity using the COSI-Corr software.

- ImGRAFT: This is a toolbox in the MATLAB for feature tracking, using template matching to map displacement and satellite images [7].
- COSI-Corr: This is a software package developed under IDL (Interactive Data Language) and integrated under the ENVI software. It is a method of detection of sub-pixel changes using a pair of ortho images [8].

- IMCORR: This takes two images and a series of input parameters and attempts to match small subscenes (called 'chips') from the two images. The program uses a fast Fourier transform-based version of a normalized cross-covariance method [9].
- Image correlation software CIAS: The software is based on Normalized Cross-Correlation (NCC). It uses the NCC and NCC-O (Normalized Cross Correlation and Orientation in Fourier domain) algorithms [10].

After the analysis of the outputs of the aforementioned tools, the COSI-Corr tool was selected for estimating the precise flow speed and direction of the PRG. The displacement map and the vector fields were both obtained using the geospatial tool (Figure 2b).

Pre-event and post-event images were selected and orthorectified. The images were then correlated with each other using search window of 256 × 256 pixels (max value) to 8 × 8 pixels (min value), with a step size of 8 pixels and a mask threshold of 0.9, using the frequency correlator option. The flow direction vector file was then created using the East–West movement and North–South movement with the help of the vector field tool in the COSI-Corr menu. The output contains Signal-to-Noise ratio (SNR) that was used to remove noise from the result. The images were converted into an ArcGIS readable format (.img) for displacement image and .shp for flow direction vector.

3. Results

A comparison between the different tools and techniques helped to ascertain the best technique to obtain the velocity. In other studies, different tools have led to various kinds of results in terms of magnitude and direction of the flow of glaciers. The analysis for the most efficient tool was done on the basis of these parameters.

3.1. Analysis of Different Geospatial Tools for Velocity Estimation

- ImGRAFT: ImGRAFT provided good displacement measurements, but the direction of the glacier flow was not provided. The speed of the glacier obtained by ImGRAFT agreed with the velocities derived by the other techniques, but this tool was unable to trace the direction of the flow.
- COSI-Corr: the COSI-Corr software package gave precise flow speed along with the direction of the flow of the glacier at the pixel level. The velocity obtained using this technique was well defined, along with the vectors in the direction of the flow of the glacier.
- IMCORR: The results of IMCORR feature tracking yielded a pixel-level direction of the flow, but the its magnitude was not estimated at the pixel level, rather, the values were bundled. The output could not provide numerical values of the highest and lowest flow speeds.
- Image correlation software CIAS: The velocities derived using the CIAS software also gave a bundled velocity, and the flow direction was also not identified.

The velocities were estimated using the four different geospatial tools and techniques. The ability to derive pixel-level magnitude and flow direction of the glacier was the basis of the selection of COSI-Corr for further study.

3.2. Calculation of the Velocity of the PRG

The study was extended to estimate the glacier velocity using the COSI-Corr tool in ENVI 5.3. The velocity and direction obtained using the COSI-Corr software matched well with previously derived velocities [11,12]. The velocity of the PRG was observed to be in the range of 1–2 m/day. Figure 3 depicts the velocity of the glacier in meters per day (shade), and the vectors indicate the direction and speed of the glacier.

Extremely high values occurred in places with loss of the correlation parameters and are indicated by enhanced movement. The length of the vectors shows the magnitude of the flow and is directly proportional to the speed. The vectors respresent the areas with higher and lower flow where the longer vectors denote areas with higher magnitude and shorter vectors denote areas with lower magnitude.

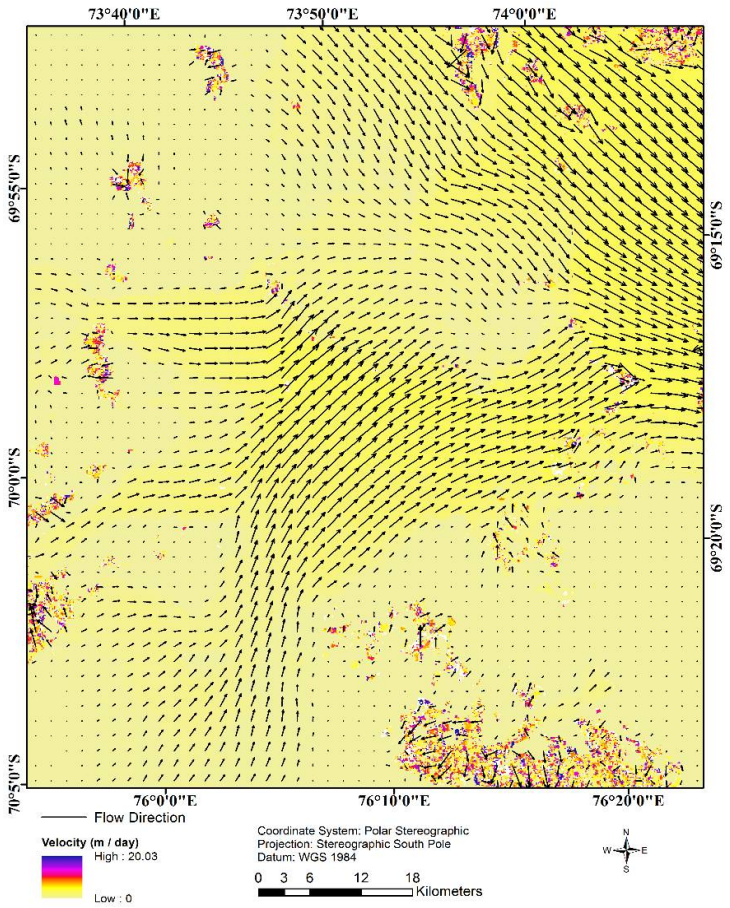

Figure 3. The velocity of the PRG in meters per day. The vectors show the direction of the flow; the length of the vectors is directly proportional to the speed.

4. Discussion

The assessment of the four tools and techniques used in the derivation of velocities showed that COSI-Corr was the most effective. The results obtained by the COSI-Corr tool were precise and matched to the results of previous studies, with respect to both magnitude and direction. The velocities ranged between 1 and 2 m/day in most of the areas. The study was conducted for only a single period, and further work should include time-series analyses of the PRG using optical images.

5. Conclusions

The COSI-Corr technique was observed to be the most appropriate technique among four different tools and techniques for the estimation of velocity (magnitude and direction) using temporal optical imagery. The results of the estimated flow velocity are accurate as compared to other studies of the PRG. The different window size option was useful to estimate the displacement at different levels and could be useful for estimating the displacement of the fast flowing glaciers in the Antarctica, whose flow could be mapped using the COSI-Corr technique.

Author Contributions: S.D.J. and A.J.L. conceived and designed the experiments; S.K., M.B., and S.T. performed the experiments; S.D.J. and S.K. analyzed the data; A.J.L. and A.C.P. contributed in revising the manuscript; S.D.J. and S.K. wrote the paper.

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

Abbreviations

The following abbreviations are used in this manuscript:

ImGRAFT	Image GeoRectification and Feature Tracking
COSI-Corr	Co-registration of Optically Sensed Images and Correlation
IMCORR	Image correlation
ENVI	Exelis Visual Information Solutions
IDL	Interactive Data Language
OLI	Operational Land Imager
PRG	Polar Record Glacier
NCC-O	Normalized Cross Correlation and Orientation in Fourier domain

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