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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 the glacier must be assessed as they are important for the sea level changes. Glacier velocity is the most important parameter used in the glacier dynamics studies. Various image matching techniques which are implemented on different domains have been utilized to estimate the surface velocity of the glaciers, since the first use of remote sensing technology. In this study we derive precise velocity of the Polar Record Glacier, east Antarctica, in the recent years using optical remote sensing. The secondary objective of the study is to comparatively test the accurate geospatial tool for the velocity estimation. The study was first conducted on a single image pair and four different tools were used for estimation of glacier velocity, which are COSI-Corr tool in ENVI, IMGRAFT in MATLAB, IMCORR feature tracking tool in SAGA-GIS and image correlation software CIAS. After evaluation of all the four feature tracking tools, COSI-Corr yielded 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 magnitude and directions of the glacier velocity, but pixel-wise magnitude was not produced. CIAS also provided closely bundled velocity products without pixel-wise velocity. COSI-Corr and IMGRAFT were found out to be the best of four tools in which COSI-Corr is recommended for further studies to estimate velocity of Polar Record Glacier.

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. Estimation of glacier surface velocity using optical satellite datasets is one of the efficient and low cost method and has been in use for the 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 the glacier mass balance, which is a crucial component of the climate change [5] of the region. This study intents on obtaining accurate velocity of the Polar Record glacier (PRG), East Antarctica, by using four different geospatial tools on using optical remote sensing data and compare their performance.

2. Experiments

2.1. Study Area

The study was conducted on Polar Record Glacier, East Antarctica (69°45′S, 75°30′E) located in the Prydz Bay area on the eastern side of the Amery Ice Shelf (0). It is the largest outlet glacier along the Ingrid Christensen Coast, bounded by Meknattane Nunataks and Dodd Island. Polar record Glacier was first surveyed in 1947. Later in 1952, the studies approved that the glacier possesses an ice tongue [6].

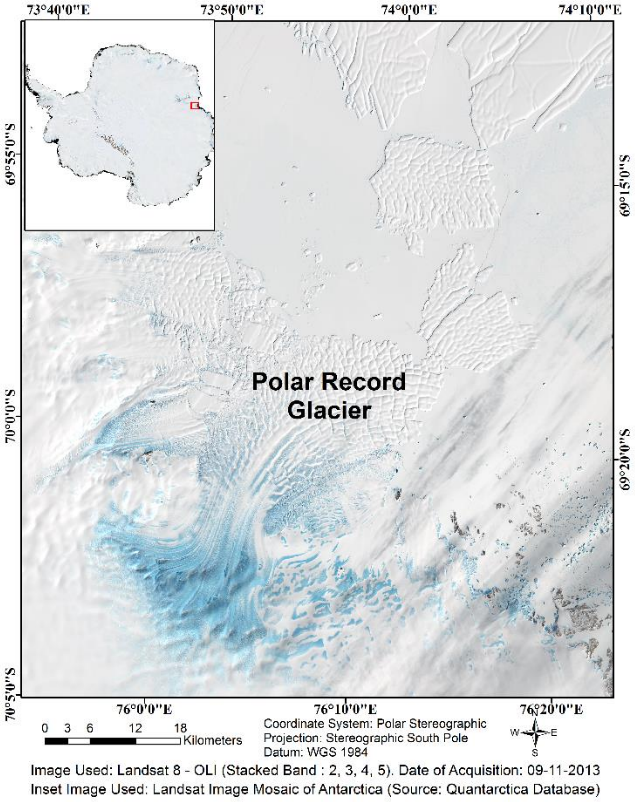


Figure1. Image showing the location of the study area. (Image used: Landsat – 8 OLI, Date of Acquisition: 09-11-2013; Inset Image: Landsat Image Mosaic of Antarctica (Source: Quantarctica Database).

2.2. Materials Used

Landsat 8 OLI images (panchromatic band) (0) were used for the estimation of velocity using different geospatial tools.

Table1.: Table showing the satellite data used in the study.

S. No.	Sensor	Path	Row	Date of Acquisition	Source
1.	Landsat 8 - OLI	126	109	09-11-13	Earthexplorer[1] [1]
2.	Landsat 8 - OLI	126	109	27-12-13	Earthexplorer [1]

[1] earthexplorer.usgs.gov

2.3. Method Adopted

The comparison to obtain the velocity was done using four different tools and techniques viz. ImGRAFT, COSI-Corr, IMCORR and image correlation software CIAS. All four techniques were used initially to obtain velocity on a smaller area on the glacier for comparative analysis. This enabled the selection of the best tool to derive precise velocity (0a).

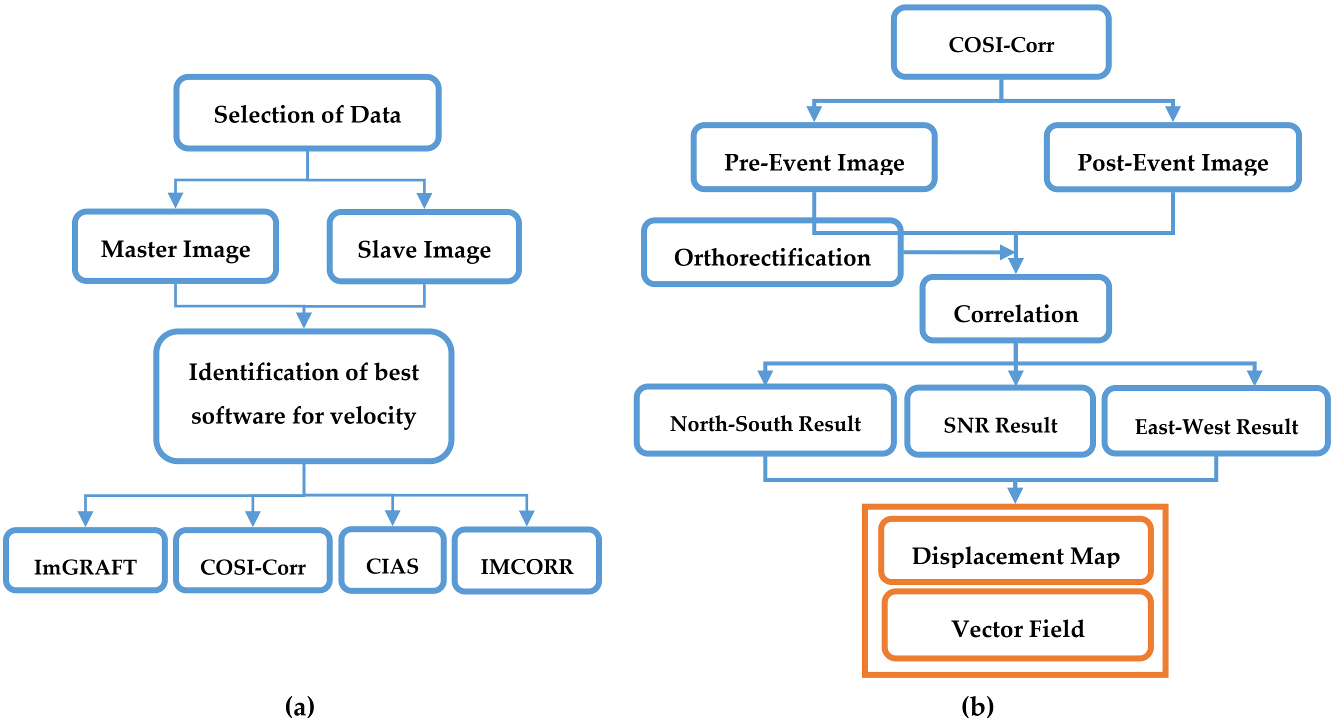


Figure2.: (a) Methodology adopted for the selection of suitable software for estimation of glacier velocity, and **(b)** Steps used for deriving glacier velocity using COSI-Corr software.

- ImGRAFT: This is a toolbox in the MATLAB for feature tracking using template matching to map displacement using satellite images [7].
- COSI-Corr: This is a software package developed under IDL and integrated under ENVI software. It is a method of detection of sub-pixel change using a pair of ortho images [8].
- IMCORR: IMCORR 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 NCC and NCC-O algorithms [10].

After 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 (0b).

The pre-event and post-event images were selected and the then orthorectified. The images were then correlated with each other with a search window size of 256 x 256 pixels (max value) to 8 x 8 pixels (min value) with the step size of 8 pixels and 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 images were converted into 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. Different tools led to various kinds of results in terms of magnitude and direction of the flow of glaciers. The analysis for 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 measurement 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 was unable to trace the direction of the flow.

- COSI-Corr: COSI-Corr software package gave precise flow speed along with the direction of the flow of glaciers 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.

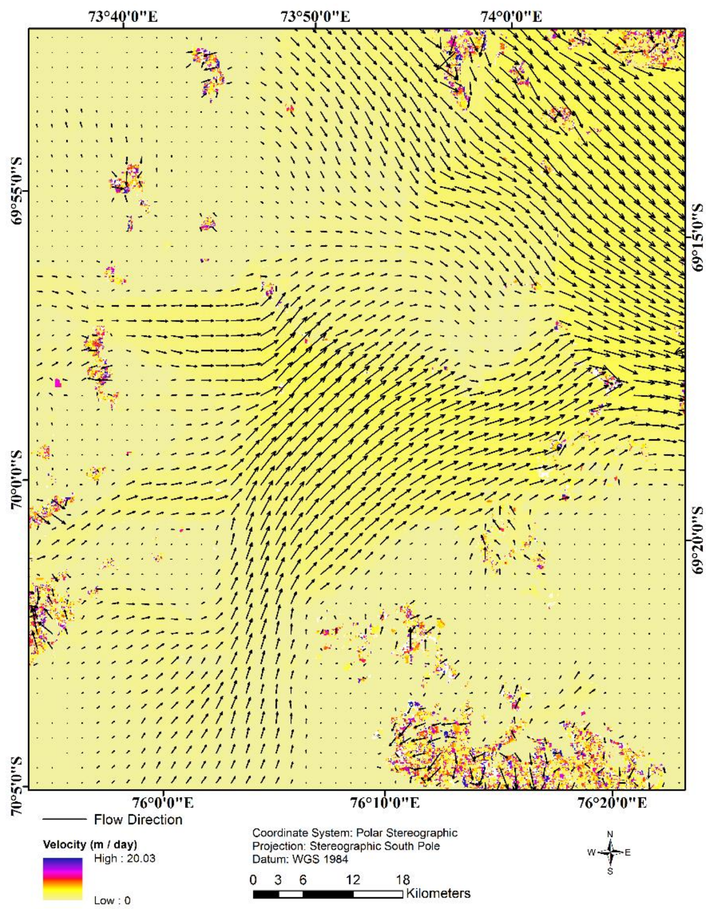
- IMCORR: The results of IMCORR feature tracking yielded pixel-level direction of the flow but the its magnitude was not estimated at pixel level rather the values were bundled. The output could not provide numerical value of the highest and lowest flow speed.

- Image correlation software CIAS: The velocities derived using CIAS software also gave bundled velocity and the flow direction was also not identified using the CIAS tool.

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

3.2. Calculation of velocity of 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 is observed to be in the range of 1 - 2 m/day. 0 depicts the velocity of the glacier in meters per day (shade) and vectors indicate the direction and speed of the glacier.



Fugure3.: The velocity of the PRG in meters per day. The vector shows the direction of flow along with the length of vectors directly proportional to the speed.

Extreme higher values occur in the places with loss of correlation parameters and are indicated by enhanced movement. The length of the vectors show the magnitude of flow velocity but are not proportional to the speed. The vectors only respresent the areas with higher and lower flow. Longer vectors denote areas with higher magnitude and shorter ones denote areas with low magnitude.

4. Discussion

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

5. Conclusions

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

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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
NCCO: Normalized Cross Correlation and Orientation in Fourier domain

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