RETRIEVING ICE VELOCITY OF HIMALAYAN GLACIERS USING INDIAN REMOTE SENSING DATA

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ABSTRACT: Ice velocity of glaciers is an important parameter in glacier studies. Temporal variation of Ice velocity is connected to the changes in mass balance of the glacier. It can be seen as health indicator for a glacier.
In remote sensing, Differential Interferometric Synthetic Aperture Radar (D-InSAR) and Image Correlation are the two techniques that are used to retrieve ice velocity. Feature tracking using optical images is based on the image correlation techniques. Phase coherence loss and availability of data on large temporal scale make D-InSAR difficult to use for highly terrain Himalayan region. Feature tracking is effective for estimating ice velocity for Himalayan. Feature tracking using SAR imagery can be done in two ways- Intensity Offset Tracking and Coherence Offset Tracking. There are some advantages of using SAR over optical imagery. One is that it can be used even for cloudy regions and second is that due to higher penetration of microwave in-depth features can also be tracked. SAR Intensity Tracking is based on the cross correlation of SAR intensity images.
In this study, a latest image correlation technique based on normalized cross-correlation of orientation images is used to retrieve ice velocity. LISS-3 data (24 m resolution) from Indian satellite Resourcesat-2, PAN data from IRS C1 and MRS data from RISAT-1 are used to retrieve ice velocities for the three important glaciers of Indian Himalayas- Gangotri, Bara Shighri and Siachen Glacier. The velocity varies from 10-20 m/year at lower ablation region to 40-45 m/year in the upper ablation region for Gangotri glacier. The velocity in the upper ablation region is found to be 55-65 m/year for Bara Shighri Glacier and 130-160 m/year for Siachen Glacier.

1. INTRODUCTION

Glaciers, especially in mountain area are sensitive indicators of climate fluctuations and also contribute to present rates of sea level rise. In Central Asia, these glaciers are the primary resource for fresh water. They periodically retreat and advance depending on the amount of snow accumulation or evaporation or melt that occurs. As long as a glacier accumulates more snow and ice than it melts or calves, it will advance. Glacial ice is largest reservoir of fresh water on earth.

Himalayan glaciers are distributed from West in Kashmir to East in Arunachal Pradesh covering entire stretch of Himachal Pradesh, Uttarakhand, Nepal and Sikkim Bhutan. The distribution and intensity of glaciation is governed by latitude and altitude of the mountains. Because of importance of Himalayan cryosphere in global climate change studies, in regulating the supply of fresh water to all the major Indian rivers, the scientific studies of Himalayan glaciers are important. Since glaciers of Himalaya constitutes the largest concentration of freshwater reserve outside the polar region, these natural resources are the source of fresh water to almost all minor and major rivers of northern India and sustain the civilization for irrigation, hydroelectricity and drinking water. Concentration of glaciers in Himalaya varies from northwest to northeast according to the variation in altitude and latitude of the region. Siachen glacier in Kashmir, Gangotri glacier in Uttaranchal, Bara Shigri glacier in Himachal, Baltoro glacier in Karakoram and Zemu glacier in Sikkim are a few major glaciers of Himalayas.

The mass movement of a glacier is mainly due to ice deformation, basal sliding or bed deformation. Ice velocity of glaciers is an important parameter in glacier studies. Temporal variation of Ice velocity is connected to the changes in mass balance of the glacier (Paterson, 1994) and can be seen as health indicator for a glacier.

In-situ, ice velocity is estimated by installing stacks on the glaciers. The movement of the stacks is measured using GPS or DGPS every year to estimate the average annual movement of the point. But the limitation and challenging part is to install the stacks in upper ablation regions or in accumulation region of the glacier. Also most of the Himalayan glaciers are in-accessible and have highly challenging terrain and so in-situ observation of the velocity is only limited to small and accessible glacier and that too in the lower ablation regions only for some glaciers.

Retrieving the velocity using remote sensing techniques is thus effective for the Himalayan glaciers. In remote sensing, there are mainly two techniques that is used to retrieve ice velocity, Differential Interferometric Synthetic Aperture Radar (D-InSAR) and Feature tracking based on Image Correlation techniques. In D-InSAR technique, a differential interferogram is generated from the interferogram of two SAR images acquired at two different time of the same location. The phase difference between two SAR images is a function of elevation and displacement in the line of sight direction. The elevation part is removed by using a DEM and thus the surface displacement can be obtained. In-SAR technique has higher accuracy as compared to the image correlation techniques but the loss of coherence between the two images limits the use of D-InSAR for Himalayan glaciers. Generally, for D-InSAR the timescale between the two images should be days to weeks to minimize the phase coherence loss but for Feature tracking the timescale can be months to years provided that the displacement is greater than the spatial resolution of the images.

Bindschalder and Scambos (1991) have developed and demonstrated a method of numerical cross-correlation for measuring velocities of crevasses and related features on repeat satellite imagery. Gantayat and Kulkarni (2014) estimated the velocity for Gangotri glacier using sub-pixel correlation of optical images. Satyabala (2016) studied the temporal variations in the velocity for Gangotri glacier using image correlation on SAR images.

Feature tracking using SAR imagery has been frequently used to obtain ice velocity (e.g. Michel and Rignot, 1999; Joughin, 2002; Murray et al., 2002; Giles et al., 2009). In Intensity tracking, the image correlation is performed on the SAR intensity images. Coherence offset tracking uses the correlation of coherence images obtained from the complex SAR images. Speckle Tracking uses the correlation of complex SAR image.

Feature tracking is best suited to retrieve the average annual velocity for Himalayan glaciers because the temporal availability of the data is generally months to years.

2. STUDY AREA AND DATA USED

Presently, three glaciers of Himalayan regions, Gangotri glacier, Bara Shighri glacier and Siachen glacier, are chosen as study area to estimate ice velocity. Gangotri glacier, the primary source of the river Ganges, is one of the largest and important glaciers of Himalayas. The glacier is about 30 km in length, has an average width of about 1.5 km and the elevation ranges from 4000 m to 7000 m (Jain, 2008). The Bara Shighri glacier, located in chandra basin of Himalayas, is about 28 km long and on average 1 km wide. The glacier’s altitude varies from 3,950 m to 4,570 m and it feeds Chenab River. The Siachen glacier, about 70 km long, is the longest glacier in the Karakoram Range of Himalayas. The glacier’s melt water flows to Nubra River which drains into Shyok River. The Shyok River joins Indus River. Thus, Siachen Glacier is a major source for Indus River and hence feeds largest irrigation system in the world.

Both Optical and SAR data from Indian Satellites are used to retrieve the ice velocity for the three glaciers. The details of the satellite data used are given in the table. For Gangotri Glacier, NIR band (Band 4) of LiSS-3 is used because glacier features appear to be more enhanced and hence image correlation is good. There are some limitations of using optical imagery for image correlation. The presence of clouds over glacier and acquisition during daytime will limit the data availability. Also the image pairs to be correlated should be acquired at same time of the year and also at same time of the day. Generally, images from post monsoon seasons are preferred for data selection as they have minimum cloud cover over the region. The glacier features in the imagery should be exposed thus ablation months are preferred. Images acquired at different times of the day can lead to the correlation of shadows. Feature tracking using SAR imagery doesn’t have these limitations. The cloud penetration capability of microwave and active remote sensing of SAR, give more freedom for data selection for feature tracking using SAR imagery. Also due to penetration capability of SAR, the in-depth glacier features can also be tracked.

Table 1 Details of Indian Satellite Data used in the study

SATELLITE/SENSOR	GLACIER	LOCATION	RESOLUTION	ACQUISITION DATE
IRS P-6 LiSS III (Band 4)	Gangotri	30° 50′ 0″ N 79° 07′ 0″ E	24 metres	Image 1: 31 Oct 2012 Image 2: 9 Oct 2014
IRS 1C PAN	Bara Shighri	32° 10′ 0″ N 77° 41′ 0″ E	6.5 metres	Image 1: 5 Sep 1998 Image 2: 13 Sep 2001
RISAT-1 MRS (HH pol)	Siachen	35° 30′ 0″ N 77° 00′ 0″ E	18 metres	Image 1: 14 Sep 2012 Image 2: 14 Oct 2015

3. METHODOLOGY

Feature tracking uses two images acquired at different time of the same area to obtain the displacement. The images are pre-processed and co-registered at subpixel level. Then the images are matched using Image Cross-Correlation technique. The displacement of a point in reference image is estimated by defining a square template window of some size at the point (Figure 1). A search window is also defined at the point being tracked. The displacement of the point should be within that search window. Then the reference template is matched using cross-correlation with the search template at all the points within the search window in the search image. The search template, having the highest correlation, is the best match template. Then the displacement is obtained by the difference in the positions of the reference template and the best matched template.

Orientation image correlation is performed in this study to obtain displacement. Orientation image correlation is cross-correlation of orientation images which is generated based on the orientation of intensity gradient of the images to be matched. This correlation technique generally gives better results compared to Normalized cross correlation technique. (Fitch et al., 2002)

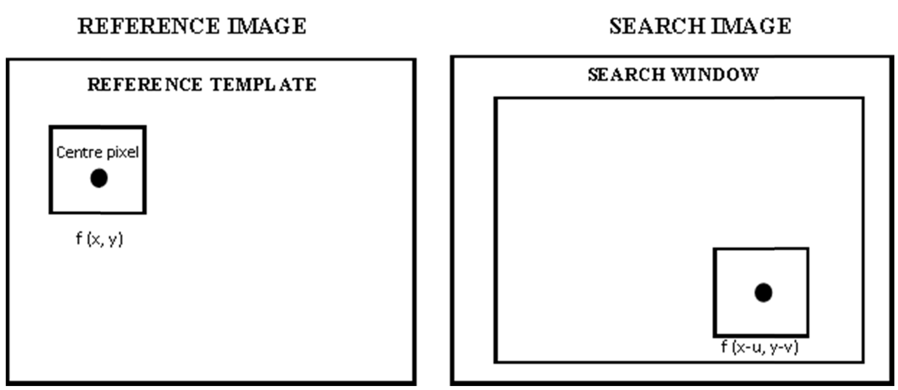

Figure 1: Template matching using Image Correlation technique

3.1 Pre-processing

Before performing the image cross-correlation, the input image pairs is pre-processed to enhance the wanted surface features on the glacier. For optical imagery, glacier features are more enhanced in Near Infrared Band. The clouds over the glacier are masked out, if present in any pair image.

The most crucial pre-processing step is the co-registration of pair images. The images are transformed to same co-ordinate system, orthorectified and co-registered at sub-pixel accuracy using the stable points in the image. A region of interest (ROI) of stable areas is chosen and sub-pixel level shift is calculated based on that ROI using correlation technique.

3.2 Post-processing

The low correlation points are filtered out based on the SNR parameter. SNR is the ratio of correlation coefficient of best match template to the mean correlation coefficient of all points in the search window. Thus higher SNR values indicate good correlation. The SNR value also depend on the search window size. Higher search window size will decrease the mean correlation coefficient and hence the increase in SNR. Points having SNR < 4 are flagged as bad correlation points and filtered out. The points having improper flow direction is also filtered out. The 3D correction for velocity is performed using the slope generated from CartoDEM.

3.3 Template size

One of the important parameter in image correlation is the template size. Different template sizes give different velocities. The best template size depends on the size of the glacier and surface features that is being tracked. The template size can be different for different glaciers and even within a glacier it can be different for different areas. To study the template size dependency on velocity obtained, the variation of few parameters is observed with the template size. A small region of interest (ROI), about 20 closely located points, is taken on the glacier where the flow vectors are highly expected to be same. Variations of three parameters are studied with template size, the mean velocity, standard deviation of flow vectors and mean SNR.

4 RESULTS AND DISCUSSION

Orientation correlation (OC) is giving better results compared to Normalized Cross Correlation (NCC). Velocity is estimated using both the techniques with the same correlation parameters. The correlation is better using OC over NCC. NCC is unable to get the movement of features in upper ablation area while OC detects the movement. Thus in orientation images, features are more enhanced and correlation is better.

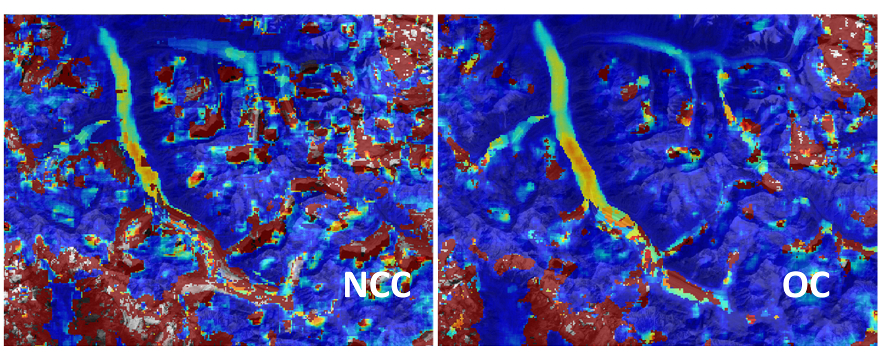

Figure 2: A comparison of displacement obtained by normalized cross correlation and orientation correlation using the same correlation parameters.

Template size study shows that there is specific range of template width for which velocity can be obtained with high correlation or SNR values. The flow vectors seem to be highly random if the template size is too low or too high. Tracking using high template size decreases the obtained velocity. This is obvious because large scale features may deform as ice flows and appear to be moving slowly. Analysis for Gangotri glacier shows the template width of 25-45 pixels is good to get better correlation and flow vectors. The mean velocity parameter is nearly constant in this range and the standard deviation of flow direction is also low.

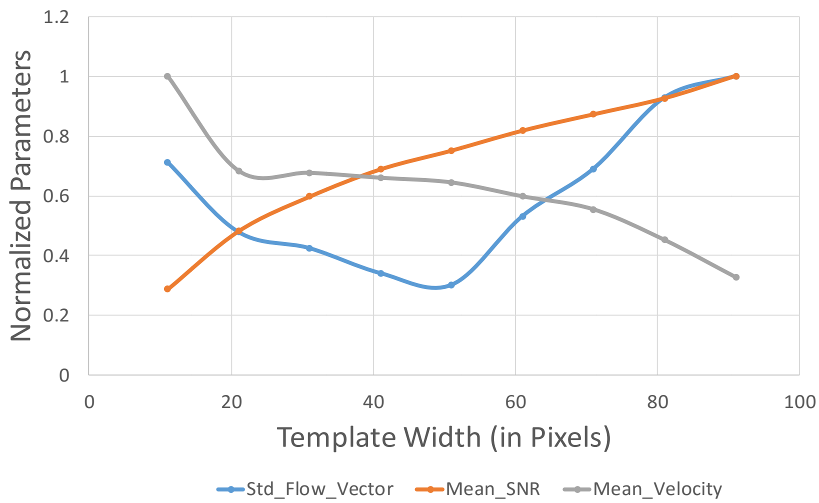

Figure 3: Variation of three study parameters with the template size. Axis Y is normalized for each parameters.

The velocity for Gangotri glacier is estimated to be 40-45 m/year in the upper ablation area and 25-30 m /year in lower ablation region. Due to snow in the accumulation area, surface features are less enhanced and very low correlation is obtained. However, some good correlation points in the accumulation region show velocity up to 100 m/year.

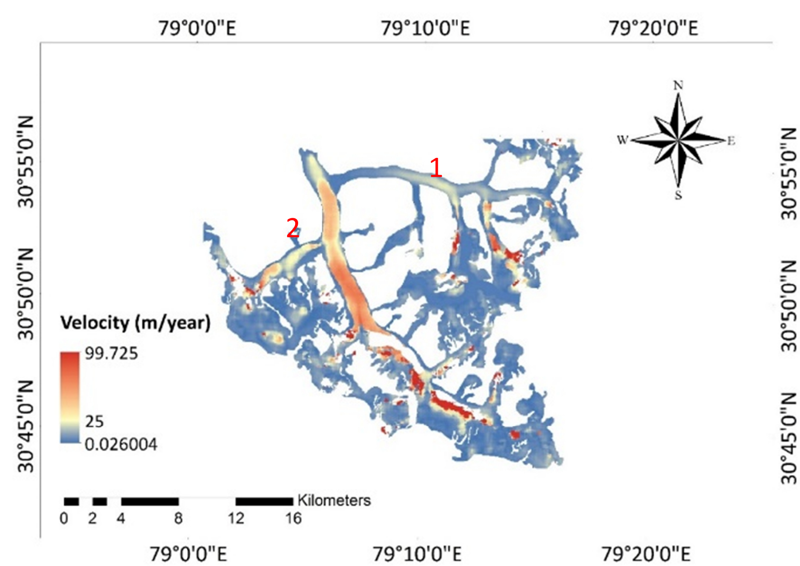

Figure 4: Velocity Estimated for Gangotri Glacier using moderate resolution LiSS 3 data from Indian satellite ResourceSat-2. The velocity vectors are shown in the next figure for marked locations.

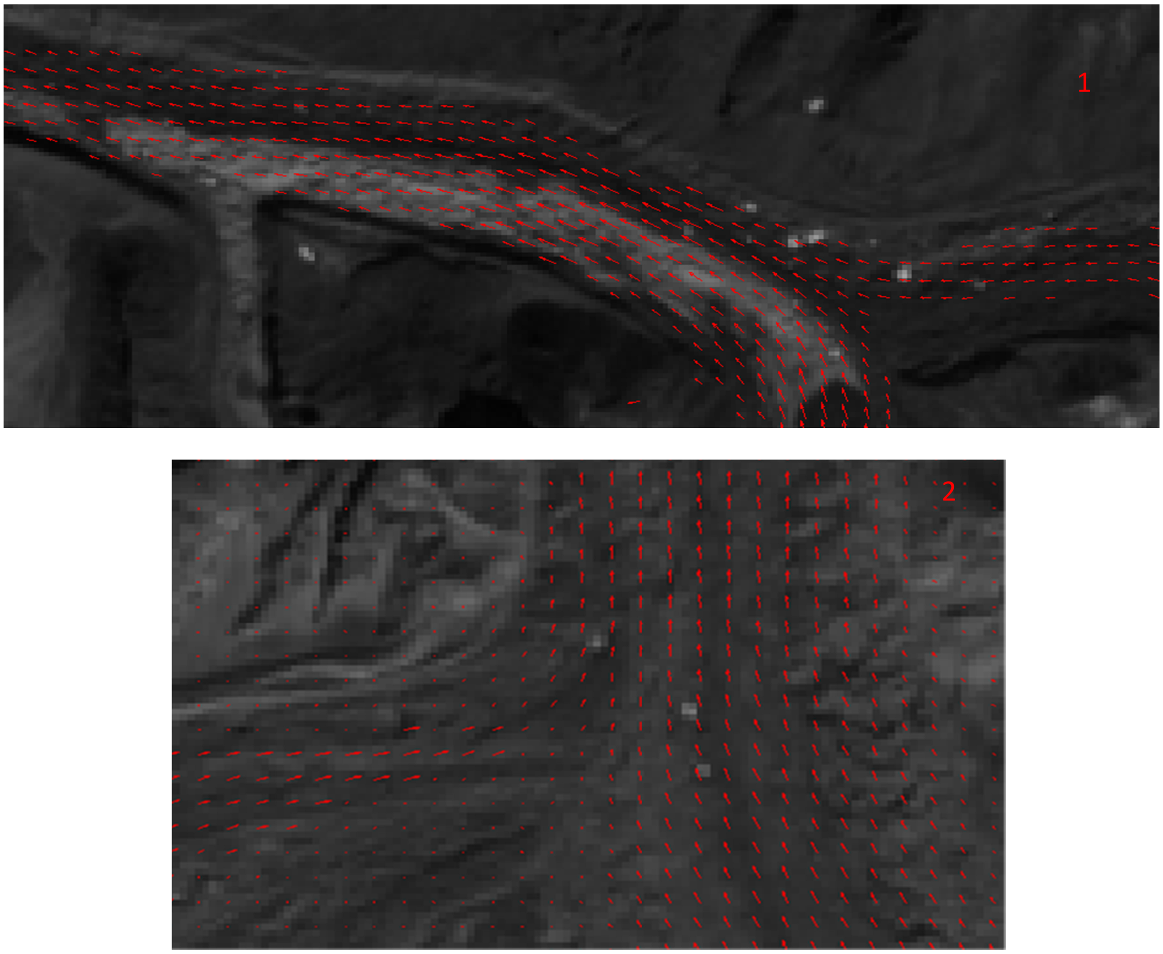

Figure 5: Velocity vectors at locations marked in Figure 4. No. 1 is Chaturangi tributary. No. 2 is the conjunction of Kirti Bhamak tributary to Gangotri Glacier. NIR band image is displayed as background.

The tributary Chaturangi marked as 1 in figure 5 shows velocity of about 20-25 m/year. The velocity vectors are appearing to be in good agreement with the expected flow direction, along the moraines.

For Bara Shighri Glacier, the velocity decreases from 65-70 m/year in upper ablation region to 20 m/year in lower ablation region. The velocity estimated is three-year average velocity. Thus, having the 6.5 m resolution, the accuracy would be around 2.2 m for single pixel level correlation error. Here also, due to snow no correlation is obtained in accumulation area.

For Siachen Glacier, correlation is obtained in only in middle ablation area where the average velocity retrieved is about 150 m/year.

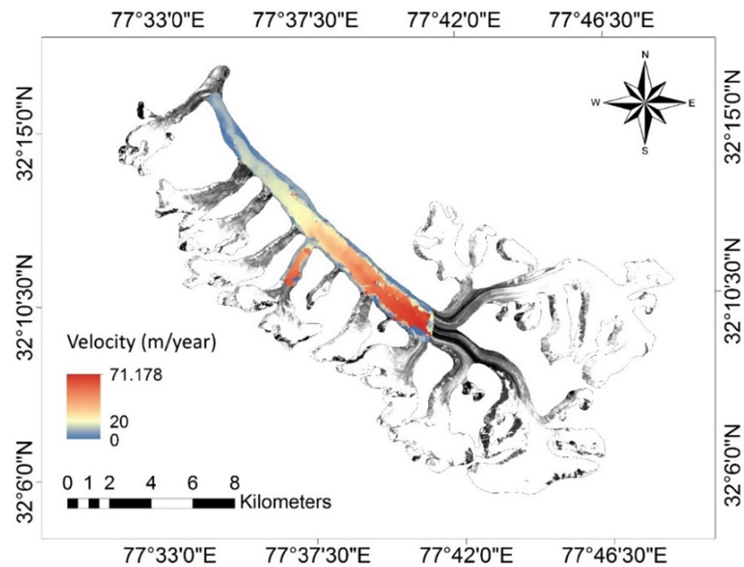

Figure 6: Velocity Estimated for Bara Shighri Glacier using high resolution Panchromatic data from Indian satellite IRS C1. PAN image is shown as background.

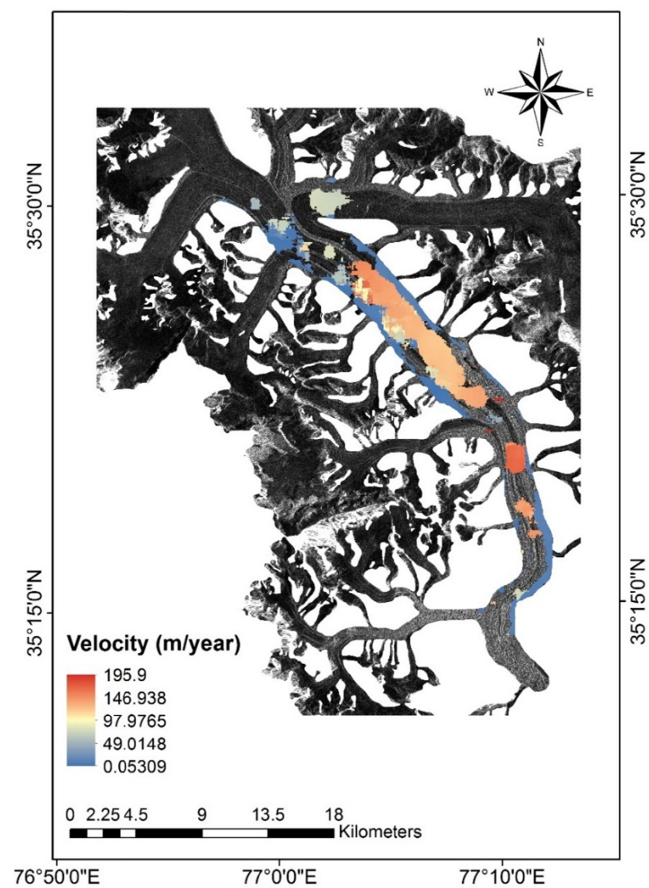

Figure 7: Velocity Estimated for Siachen Glacier using moderate resolution MRS data from Indian SAR Satellite RISAT-1. MRS HH-pol image is shown in background

5 CONCLUSION

Feature tracking using Orientation correlation is an effective method to estimate the velocity of Himalayan Glaciers. Normalized Cross-Correlation (NCC), which is commonly used to derive glacier displacements, does not perform well compared to Orientation Image Correlation (OC). Template size is one of the important parameter to decide for image correlation.

Ice velocity for the glacier depends upon the several factors, such as ice thickness/mass of the glacier, slope of the glacier surface, bed topography, glacier shape and size etc. Indian remote sensing data, both optical and SAR, can be used to map the velocities of Himalayan glaciers. LiSS-3 data having moderate resolution can be used to derive the velocities for moderate to large sized glaciers. But for small sized glaciers, high resolution optical data (Liss-4 or PAN from ResourceSat satellite), can be used to retrieve velocity. Using SAR in Feature tracking is an alternative to cloudy regions and where optical data availability is limited. Also the seasonal variations in velocity can be estimated using SAR data.

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