Estimation of Glacier Ice Velocity Using Sentinel-1A SAR Data– Application to Sathopanth and Bhagirathi -Kharak Glacier in Himalayas

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Abstract— Glacier movement has a major impact on the environment and ecological system. Movement in the surface ice plays significant role on the health of any glacier. The Estimation for glacier-ice flow velocity is calculated from two image-to-image offset tracking technique with 8 SAR imagery of Sentinal-1A SAR data for year 2017. The elevation information of the area was extracted from Shuttle Radar Topography Mission (SRTM) data which has a spatial resolution of 90m. The study approach is to produce time-series of the surface velocity for Sathopanth and Bhagirathi-kharak glacier. Study area dynamics across its entire surface, changes throughout the annual period where the maximum flow rate of 16.5 cm/day has been recorded in the months of September and October, in high accumulation areas.

Keywords: SAR, InSAR, SRTM-DEM

I. INTRODUCTION

Glacier ice flow velocity is one of the important parameter to understanding the glacier dynamics which plays an important role in the Global climate research. Glaciers are more sensitive to climatic variations, such as temperature and precipitation. Variation in any one can impacts on the snow accumulation and ablation on the snow packs. (Snehmani et al. 2015). Various studies show that glaciers in Himalayan region have various retreat rate during last century in response to climatic warming (Bhambri and Bolch 2009), (Kulkarni, A., & Bahuguna, I. (2002). Due to increasing temperature in the Himalayan glaciers such as Gangotri (19m/year) (Bhambri, et al. 2012), Dokriani (17m/year) (Dobhal, et al. 2004), (Dobhal D P and Mehta Manish 2010), Chorabari glacier (6.8m/year) (Manish Mehta, et al. 2012), & Sathopanth and Bhagirathi kharak are experiencing a severe retreat in the recent years. Thus the accumulation area of snow in glaciers region is moving downward to the ablation area due to excessive climatical disorders, gravitational force and snow melt process. Global and regionally these glaciers increased the serious risk of avalanches, intensity of floods and other environmental problems in low lying areas. The combination effect of melting glaciers, increased the serious risk of avalanches, intensity of flood and other environmental problems in low lying areas. (Singh, et al. 2018). In order to understand the glacier velocity is relevant to understanding the glacier dynamics. The present study with the use of high resolution SAR images has focused on effective measurement of glacier velocity in the years 2017. Study using microwave imaging satellites such as sentinel 1, 2, and 3, due to its high sensitivity to displacement over the earth surface, a wide range of glacier observations can be performed. Recentlylaunched sensors ALOS-2, TanDEM-X & TerraSAR –X, and Sentinel–1 are not only provide high resolution image but also have with low repeat periods, thereby increasing the feasibility of SAR imagery for timely monitoring of glacier velocity.

The data acquired from Synthetic Aperture Radar (SAR), which contains intensity and phase information can be used in any weather conditions. SAR images can be used for glacier monitoring such as Snowline, Surface flow velocity (retreation and advancement), mass balance study (positive or negative), and volume change. Systematic studies for glaciers change assessment and trend analysis can be generated from the archived satellite datasets over time periods of several decades.

Velocity measurement with SAR data can be divided into two approaches viz. interferometric approach and offset tracking approach. The interferometric measurements are very sensitive to level displacements in the glacier with coherent imagery. But due to 12 days acquisition timebetween the images and fast movement of glacier, it is observed that viability of Interferometric Synthetic Aperture Radar (InSAR) due to coherence loss is often limited. Offset Tracking is a technique that measures feature displacement between two images using patch intensity cross-correlation optimization (Strozzi et al., 2002). It is widely used in glacier motion estimation.

The Synthetic Aperture Radar (SAR)-offset tracking method has been successfully applied on study area for glacier velocity estimation. Offset tracking technique in SAR imagery is similar to cross correlation of optical satellite imagery (Bindschadler & Scambos, 1991). It is reported that Gangotri glacier in Uttarakhand-Garhwal Himalaya retreation rate is 5.9 ±4.2 m year-1 from 1965 to 1968 and 26.9±1.8m year-1 from 1968 to 1980, and it retreated 21.0 ±1.2m year-1 between 1980 and 2000. During 2001-2006 the retreat rate of Gangotri has declined to 7.0±4.0 m year-1 (Bhambri, et al. 2012).

II. STUDY AREA

Sathopanth and Bhagirathi-kharak glacier is located in the North-Eastern part of Chamoli district of Uttarakhand state. It covers an Area of 46.3Km2. Topographical elevation ranges from 6548-3587 Mtr (Max-Min). The adverse topographic and climatic conditions of this region makes it difficult to access and do not supports the favourable conditions for in-situ data collection such as Net-snow accumulation, Glacier-ice flow velocity and meteorological stations (Rainfall data) in the region for half of the annual seasons.

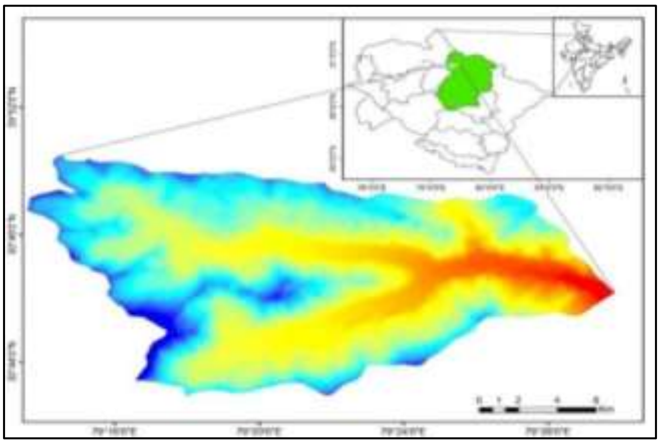

Fig. 1: Study area map

III. DATASET & PROCESSING

The Setinal-1A data-Scenes/imagery acquired year 2017 is used in order to measure Glacier-ice flow velocity. The dataset listed below in Table1 downloaded from https://ssoidp.copernicus.eu. 8 SAR images of 12 days interval was derived from remote sensing data of European Space Agency (ESA), Sentinal-1A, with 10m ground- range data in both Range and Azimuth directions and SRTM-DEM. These images acquired in descending orbit, IW mode with VH and VV polarization. For Geocoding and Co-registration of two imagery (Master& Slave) SRTM-DEM spatial resolution 30 Mtr was used.

Observation date	Product	Polarisation	Orbit	Methodology
3 January 2017	S1A-IW-GRDH-1SDV	VH and VV	Descending	Offset Tracking
15 January 2017	S1A-IW-GRDH-1SDV	VH and VV	Descending	Offset Tracking
28 March 2017	S1A-IW-GRDH-1SDV	VH and VV	Descending	Offset Tracking
9 April 2017	S1A-IW-GRDH-1SDV	VH and VV	Descending	Offset Tracking
7 August 2017	S1A-IW-GRDH-1SDV	VH and VV	Descending	Offset Tracking
19 August 2017	S1A-IW-GRDH-1SDV	VH and VV	Descending	Offset Tracking
28 September 2017	S1A-IW-GRDH-1SDV	VH and VV	Descending	Offset Tracking
10 October 2017	S1A-IW-GRDH-1SDV	VH and VV	Descending	Offset Tracking

Table 1: Dataset description

IV. METHODOLOGY

Sentinel-1A, 8 SAR imagery with 12-day interval, corresponding to descending pass are taken for Offset tracking analysis. The entire processing was executed in SNAP Toolbox software. The two images are first co-registered with each other to ensure that the same area is being observed. The co-registered images are resampled to same size by using SRTM DEM. DEM-assisted co-registration of the SAR images are used for minimize stereoscopic artifacts in offset-tracking displacements due to high topography (Kobayashi et al. 2009). The objective of this study is to explore the high resolution SAR image for measuring Glacier-ice movement velocity within glaciers.

It is important to done orthorectification before feature tracking for image matching. Before two image are used for feature tracking, we need them to be ortho-rectified or also say that original images without ortho-rectification cannot be used for image matching. In the offset tracking technique, the orthorectification process depends upon generating ground control points (GCPs) automatically. A precise set of GCPs is generated from a raw image (slave), with respect to an already orthorectified image (master), by iteratively refining an initial rough selection of manually defined tie points. Image patches from the raw slave image are orthorectified and their mis-registrations with the master image are estimated from correlation.

In this study we used Offset Tracking technique that estimates the ice movement velocity on glacier surfaces between master and slave images in both slant-range and azimuth direction. It performs cross-correlation on selected Ground Control Point (GCP) in master and slave images. Then the ice movement velocity on the selected GCPs are computed and finally, the ice movement velocity map is obtained through interpolation of the velocities computed on the GCP grid.

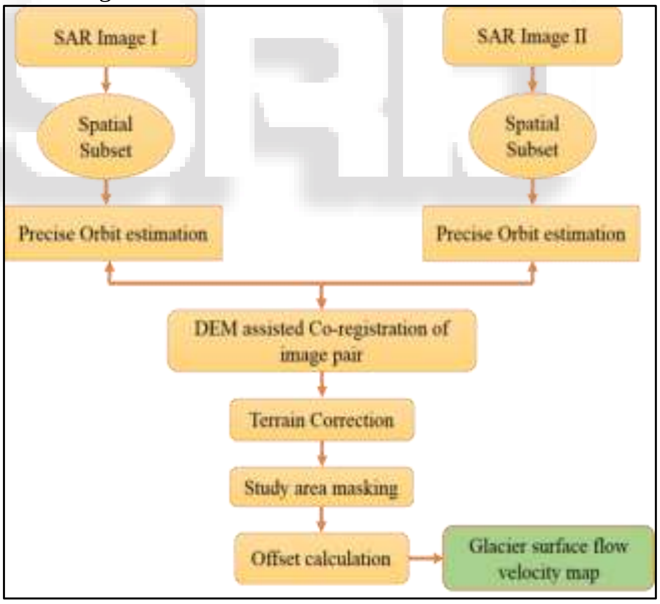

Fig. 2: Methodology

V. RESULT AND DISCUSSION

A. Analysis of glacier ice velocity

Sathopanth-Bhagirathi kharak glacier ice movement velocity maps generated from Sentinel 1A SAR image pairs for the year 2017. The maximum and minimum ice movement velocity range for the Glacier show in the months of January, March-April, August, September-October months for year 2017, depending on the satellite image acquisition dates mentioned above in Table 1.

The maximum four profile mapped from glacier surface velocity maps which shows glacier ice flow at higher accumulation areas are 0.117 md-1 (2017/01/03-2017/01/15), 0.146 md-1 (2017/03/28-2017/04/09), 0.108md-1 (2017/08/07-2017/08/19) and 0.165md-1(2017/09/28-2017/10/10 shown below in Figure 3 & Table 2. During the study time period of SAR imageries, we observed that the average ice movement velocity from September to October is maximum than others time period but on the other hand we found that during winter season flow of velocity decreasing. Also we found that higher the slope, the maximum the ice movement velocity. For the images acquired in September-October 2017, the maximum velocity is 0.165 m d-1 at higher accumulation zone and minimum velocity is 0.038 md-1 toward snout.

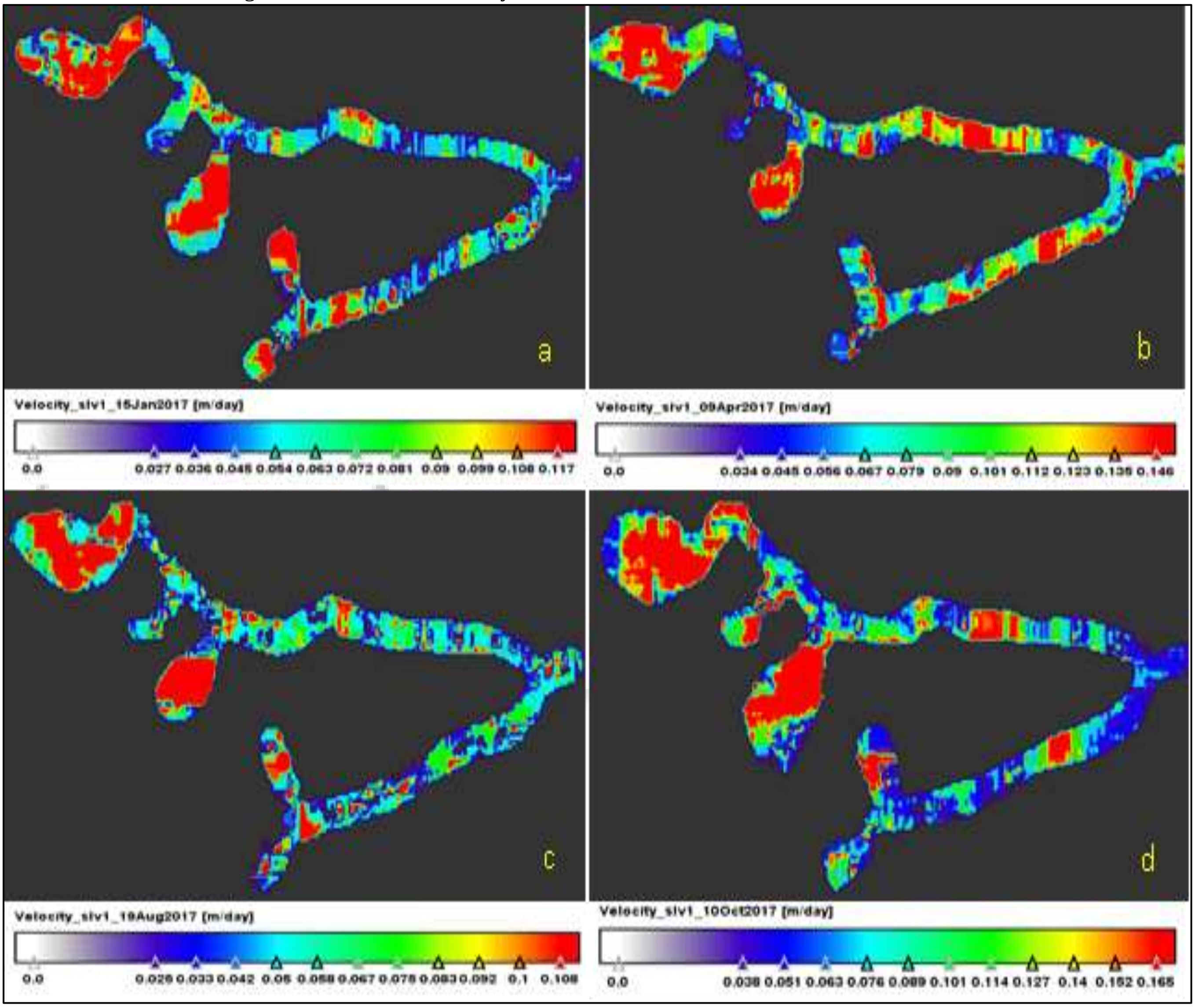

Fig. 1: Ice velocity field computed by Offset Tracking from sentinel-1A descending pairs of year 2017.
(a) 3Jan-15 Jan (b) 28Mar-09Apr. (c) 07Aug-19Aug. (d) 28Sept-10Oct

Observation date	Methodology	Velocity (cm/day)	
		Max (Accumulation area)	Min (Terminus/snout)
03-15 Jan	Offset tracking	11.7	2.7
28Mar-09Apr	Offset tracking	14.6	3.4
07Aug-19Aug	Offset tracking	10.8	2.5
28Sept-10Oct	Offset tracking	16.5	3.8

Table 2: Sentinal-1A data output for observation dates

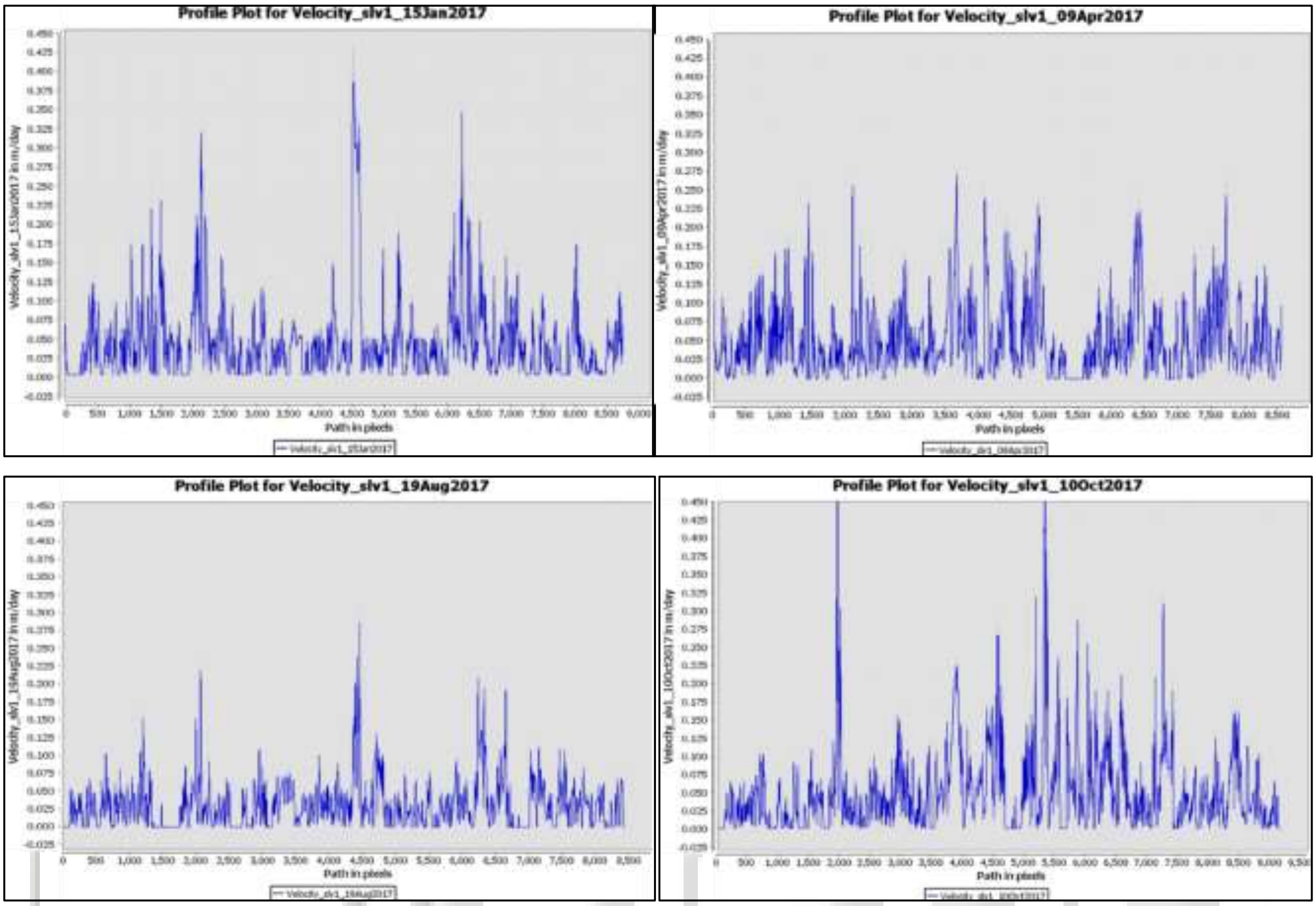

Fig. 2: Profile Plot for Velocity (a) 3Jan-15 Jan (b) 28Mar-09Apr. (c) 07Aug-19Aug. (d) 28Sept-10Oct

VI. CONCLUSIONS

In order to achieve the primary objective 'Glacier ice flow velocity' has been successfully employed using Sentinal-1A SAR imagery over study area for year 2017. Surface Ice velocity has been measured for each image pair using an effective offset tracking method. The maximum flow rate of 16.5cm/day has been observed in high accumulation area whereas, 3.8 cm/day calculated towards the terminus for months September-October. Hypsometric curve (figure 5) also shows that glacier dynamics of Sathopanth and Bhagirathi kharak glacier is a strong controlled by topography in the region. It is important that such glacier should regularly monitored using above mentioned techniques.

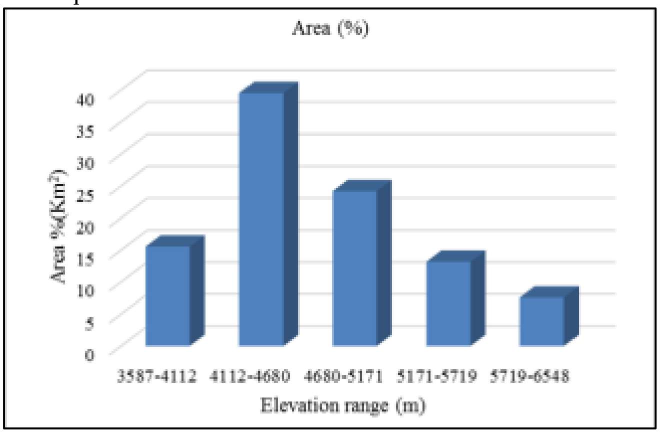

Fig. 5. Elevation profile with respect to Area

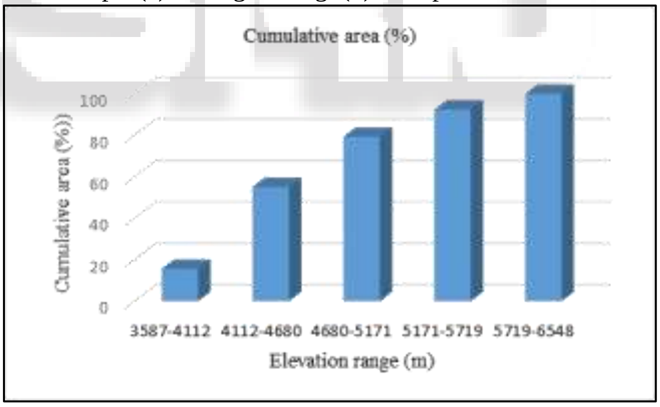

Fig. 6. Hypsometry of area

VII. REFERENCES

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