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Glacier dynamic study using C-band SAR data for Jety-Oguz area of Eastern Kyrgyzstan

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Abstract

A glacier dynamic change for entire Jety-Oguz area, which covers a large part of the Central Tien-Shan, is always interesting and important for purpose of research. The water discharge from this heavily glaciered Jety-Oguz area (Eastern Kyrgyzstan) is of high importance for the very arid area of Tarim Basin, located in Xinjiang (north-western China). In Kyrgyzstan, 1310 glaciers (>0.1 km2), which covered 2055 ± 41.1 km2 (~18% of the entire basin) in 1990. In general, debris-covered glaciers shrink significantly less than clean-ice if compare and this can be seen from Landsat TM images. We analyzed and identified in the Jety-Oguz area Debris-covered is less than 10%. Glacier velocity was analyzed by using two images which is at 6 day to annual time interval to find movement of the glaciers, using Sentinel 1 (SAR) and Landsat-8 images. SAR images are also used for classification purposes using time series composite approach, where various glacier radar zones such as debris covered zone, bare ice zone, percolation-refreeze zone, wet snow zone etc. were identified and mapped. In this study glacier velocity was analyzed using Optical and Microwave SAR data, maximum and minimum glacier velocity were estimated annual 0.01m to 20m respectively.

1. Introduction

Most of the glacier all over the world is under the overall recessional regime since 1850s with intermittent phases of glacier advancement. Glaciers are the most illustrative examples of climatic changes and their advancement and retreat are linked with the cold and warm periods. Response of the glaciers characterizes the long-term changes in the climate and provides valuable insight on the water resources management challenges. Glaciers are sensitive to temperature and precipitation in the mountain system or mountain hydrological system, both these variables are interdependent. Glaciers play vital role in mountain hydrological systems and influence the quantity and quality of headwater river flows. Apart from providing fresh water, glaciers produce large quantities of sediment that flushes into the streams and critically effects the life span of hydropower stations in the mountains. The remote sensing plays an important role of regular mapping and monitoring of these glaciers, as they can be easily mapped with optical and microwave based sensors [1-3].

2. Study area

The Kyrgyz Republic (Kyrgyzstan) is located in center of Asian continent, in the north-east Central Asia between 39^0 and 43^{0}C north latitude and 69^0 and 80^0 east longitude [4]. On north and south Kyrgyzstan borders on Kazakhstan, with Uzbekistan on the west, Tajikistan on the southwest and with China on the southeast. The study area as shown in an image it is located 28 kilometers to the south-west of the town of Karakol. Jety-Oguz the name is translated from Kyrgyz language means "Seven bulls".

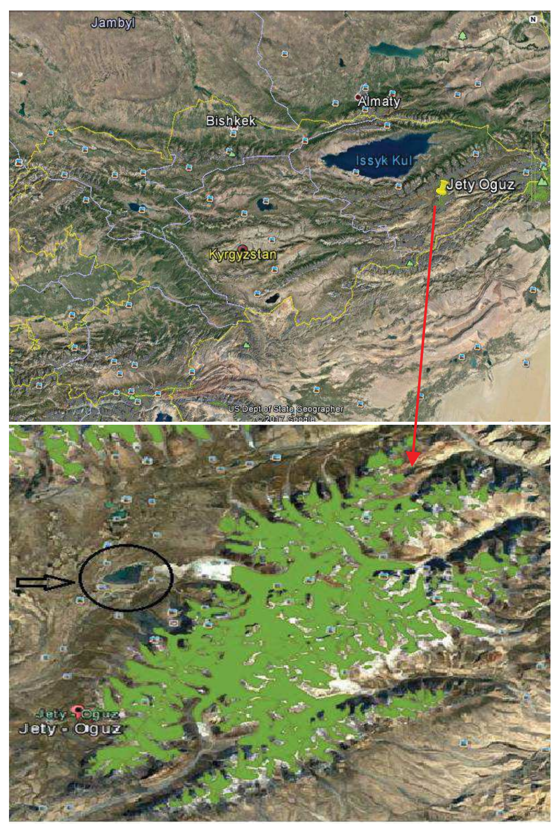


Figure 1 Study area of Kyrgyzstan with Glaciers in a Jety-Oguz region (Source: Google Earth).

The climate of study area is considered to be a local steppe climate. During the year, there is little rainfall in Jety-Oguz. With the averages temperature of 5.3^{0}C. July is the warmest month of the year. The temperature in July average 18.8^{0}C. In January, the average temperature is -10.6^{0}C, so it is the lowest average temperature of the whole year. The annual mean rainfall is only 378mm. It is shown in figure 1 that some of glaciers could be impacted from Gold Mining Factory which is located on the downhill of Jety-Oguz glacier (black circle in figure 1). Some of the major glacier of this region are Bordu south, Sary-Tor South, Davidov, Petrov, Sary-Tor north, Besimjanich, Djamansuu, Kaindy, Kara-Say North [4]. Due to the climate and economic sensitivity of this region, and role of glacier melt water for hydro power and irrigation needs of this area, following main objective are framed for this work. Estimation of glacial area and snout change using remote sensing, glacier ice velocity estimation using optical and differential Interferometric SAR (DInSAR) and glacier facies classification using SAR data.

3. Material and methods

This work is done using multiple data sets such Sentinel 1, SAR (Synthetic Aperture Radar) satellite data, Landsat 8 OLI (Operational Land Image) satellite data, RGI (Randolph Glacier Inventory) database of glacier boundary. These datasets are processed in ArcGIS 10.1, QGIS version (2.18.4), Semi-Automatic plugin and SNAP (Sentinel Application Platform) tools [4].

4.1 Methods

The figure 2 show the main methodology flow chart used in this work. Sentinel 1 SAR images were used for glacier facies classification purposes. The derived glacier are elevation dependent percolation refreeze zones, clean ice zones, debris ice, and wet and dry snow zones. This was done using the time series color composite approach [2], with SAR data from 8th January, 31st May, 11th August in 2016 and 26th January, 14th May, 18th August in 2017 were used. SNAP software was used to do all pre-processing for SAR images [4]. The classified glacier map was also used for finding the location of firn line, which is the line between clean ice and percolation-refreeze zone.

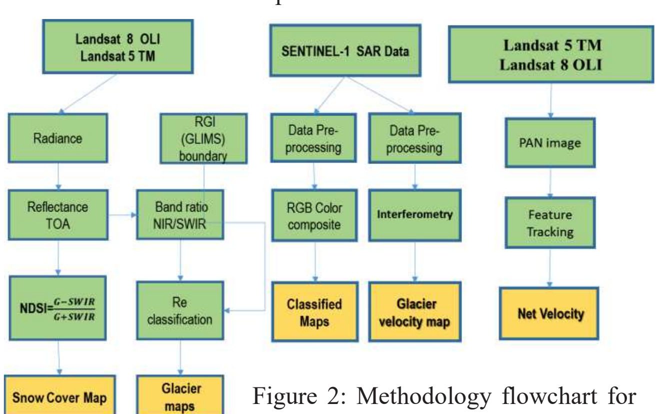


Figure 2: Methodology flowchart for glacier dynamics

Band Ratio method (NIR/SWIR) was used for generating the band ratio maps, using Landsat TM time series images of 11th of August in 1994, 22nd of August in 1998, 12th of August 2006 and 11th of September in 2011. Band Ratio is a more appropriate method for clean glacier ice than NDSI (Normalized Differentiate Snow Index) [4-5]. These maps are also used to estimate change in the glacier area and snout position over time.

The glacier velocity was estimated using DInSAR methods as described in [2] [6], with InSAR data pairs from C-band sentinel-1 data from 07 Feb-19 Feb 2017, at 12 day interval. The two year glacier velocity was estimated using feature tracking (FT) methods [7], with input data from ortho-rectified Landat-8 data from 21 August 2015 to 10 August 2017.

5. Results and discussions

This section gives the main results of this study. First the glacier classification using band ratio method and change in area of glacier with respect to RGI inventory is presented (figure 3a to d).

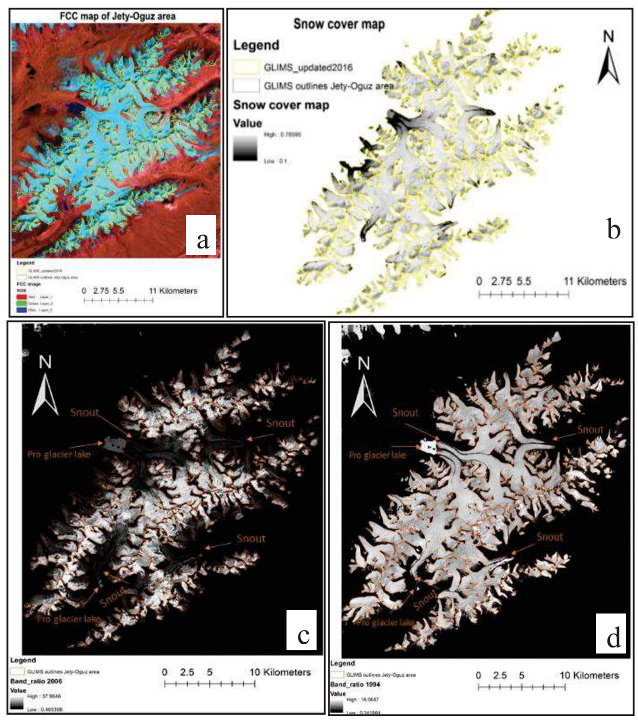


Figure 3a: The FCC of study area; 3b: Snow cover with 2016 updated and original RGI glacier boundary; 3c: band ratio for 12 August 2006; and 3d: 11 August 1994 TM data.

The band ratio, NDSI and updated RGI maps showed that total glacier area change from 1999-2002 to 2016 time period is 352.581 km^2 to 350.25 km^2, with major area changes occurring near Petrov pro-glacier lake and Kumtor mining area. The snout change varied from 281 to 582 m for the few main glaciers during this time, i.e., 2000-2016 time period [4].

The glacier facies classification is done using method as given in section 4.1, with overall accuracy of 84.66% and kappa coefficient of 0.798 [4]. This classification was used to find the location of firn line and clean ice-firn line, which can be used as an approximation of equilibrium altitude elevation (ELA) [2-3] [8] and finally this ELA can be used for glacier mass balance estimation.

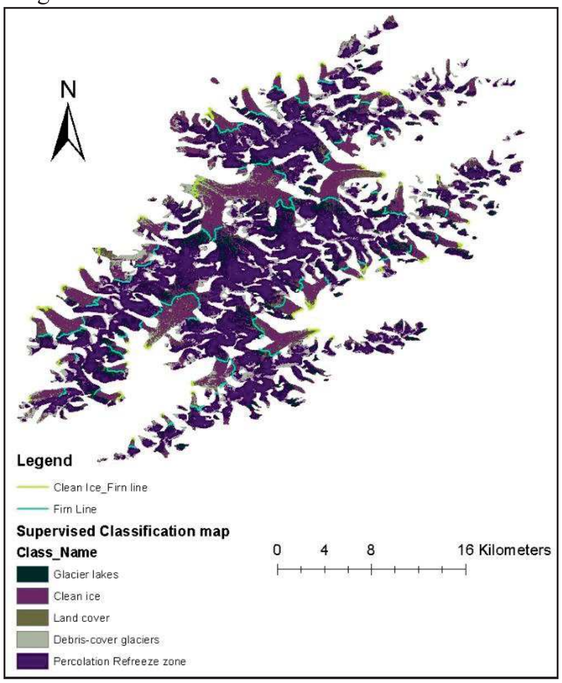


Figure 4: Jetuy Oguz glacier classification for SAR based color composite of the year 2016, with overlay of mapped firn line and clean ice firn line.

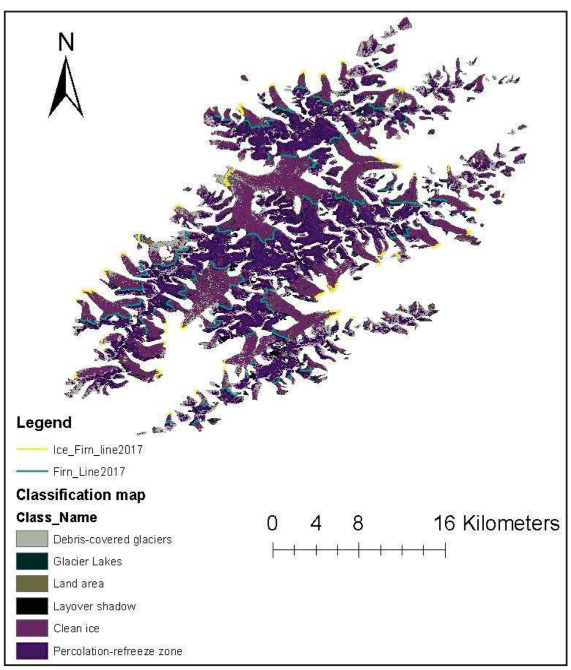
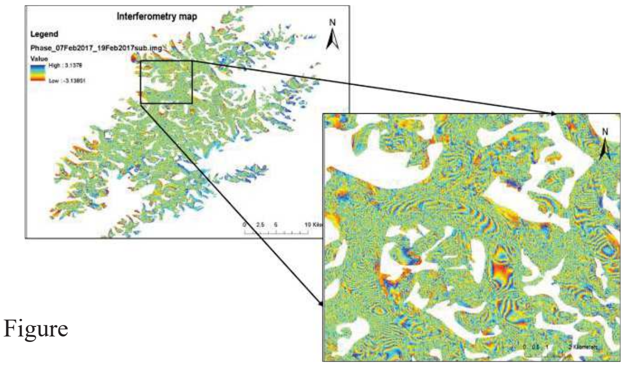


Figure 5: Jetuy Oguz glacier classification for SAR based color composite of the year 2017, with overlay of mapped firn line and clean ice firn line.

Next the glacier velocity results using the DInSAR and feature tracking based methods are presented. The figure 6 shows the main results of DInSAR based data processing and final line of slight (LoS) glacier velocity for Jetuy Oguz glaciers. Most of the area showed high coherence and good quality interferogram (figure 6), which resulted in accurate glacier velocity map.



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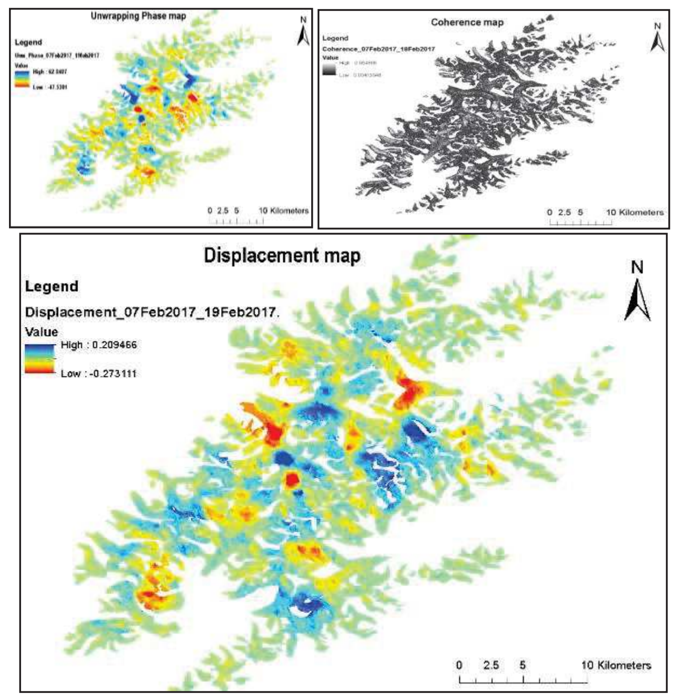

6: Sentinel-1 DinSAR based interferogram, unwrapped phase, coherence and final LoS glacier displacement or velocity map for the Jetuy Oguz glaciers.

The LoS velocity varied from -0.273 m to +0.2095 m during 12 day interval of 07-19 Feb 2017. The plus sighn shows velocity component is towards the satellite and –ve value shows velocity component is away from the satellite [6], [9]. The mean net velocity from DInSAR comes as 6.30 to 8.30 m/year, but more work is needed to convert this LoS velocity into glacier flow direction velocity using digital elevation model and other methods [10].

The feature tracking based glace velocity results are shown in figure 7. This method was implemented in Cosi-Corr extension of ENVI software [7].

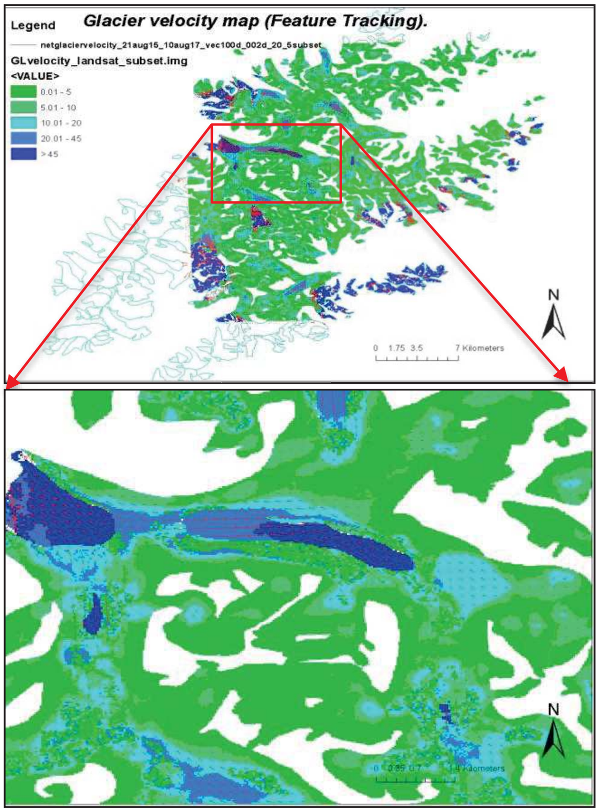

Figure 7: Optical image and FT based glacier velocity map of Jetuy Oguz glaciers overlaid with velocity vectors.

The feature tracking based results gave total velocity between 21st August 2015 and 10th August 2017, with range from 0.01 to > 45 m for two years. The mean surface glacier velocity was high for central part of glacier, as compared to other area, and it decreases from center to edges, as expected due to U-shape of glacier ice stream, which causes less thickness at edges and gives more resistance to movement of glaciers. The validation with ground based glacier velocity and comparison with global land ice velocity products [11] is also being done for this area.

6. Acknowledgements

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7. References

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