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Estimation of changes in ice thickness of Chhota Shigri glacier, Himachal Pradesh using DGPS and SRTM derived elevation profiles

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Abstract: Himalayan glaciers are animportant source of water and sensitive indicator of climate change, however, sufficient field based scientific database is lacking due toinaccessible and harsh climatic conditions. Field measurements on Himalayan glaciers are vital to understand glaciation-deglaciation processes, apart from validating satellite based analysis. This study has attempted to estimate changes in ice thickness of Chhota Shigri glacier, Himachal Pradesh using DGPS and SRTM derived elevation profiles. DGPS measurements were madeduring an expedition carried out in 2014. Around 1100 elevation observation points were collected in the non- glaciated region and 4800 on the glacier surface. Elevation profile generated over the glacier surface was compared with the corresponding profile extracted from DEM of SRTM data of the year 2000. SRTM DEM bias was estimated using non glaciated elevation points collected using DGPS. It observed that during14 years' period, there has been a loss in glacier ice thickness of around 6.7m (~0.5m per year). Rate of volume loss is estimated as0.002 km^{3}per year.The study suggests periodic DGPS observations over same elevation profile in subsequent field expeditions for improving accuracy of estimated changes in glacier ice thickness, which can be utilised for validating results derived from DEM differencing technique.

Keywords: DGPS, Chhota Shigri, Glacier, Elevation Profile

1. Introduction

Global warming is causing an apparent rapid retreat of many glaciers worldwide. Estimation of total glacial ice volume and ice-thickness distribution periodically are crucial for understanding the complex interactions between climate and the glacial system.Himalayan glaciers are not only important source of water, but are also sensitive indicator of climate change. It is extremely difficult to collect fieldbased observations due to inaccessible and harsh climatic conditions prevailing in Himalayan region. Limited field based scientific database is available. This database is general collected during various field expeditions for validating satellite based interpretations and analysis.

Changes in glaciers and ice caps are good indicators of climatic fluctuations (Zemp et. al., 2008) and the current trend shows that majority of the world glaciers have undergone a reduction in glacier mass at an accelerating rate. Monitoring changes in total ice-volume is significant for studies related to climate change and its consequences on global sea level rise (Jevrejeva et. al., 2008). UNESCO initiated the International Hydrological Decade (1965–74) to estimate the total volume of stored water worldwide. Many studies carried out regarding mass balance of mountain glaciers on global level are showing negative mass balance (Cogley, 2009; Zemp et. al., 2009), which may be due to global warming(Yadav et. al., 2004; Roy and Balling, 2005). Temperate glaciers are sensitive indicator of climate change as indicated by their changes in mass balance patterns (Vincent et. al., 2004; Ohmura et. al., 2007). Limited mass balance data in the Himalayan region is a major constrain to explain impact due to climatechange. Field based mass balance study was initiated for Gara glacier, Himachal Pradesh in September 1974 (Raina et. al., 1977). Mass balance were estimated for eight glaciers at least for one year during 1980s (Dyurgerov and Meier, 2005). These studies are scanty and insufficient and carried out for short period, not exceeding one decade (Dobhal et. al., 2008).

Mass balance of a glacier referred as the total loss or gain in mass at the end of the hydrological year. It estimated by measuring total accumulation and ablation of snow and ice during a specific year. Empirical relations were developed between field mass balance and Accumulation Area Ratio (AAR) by Kulkarni, 1992; Kulkarni et al., 2004, Kulkarni et. al., 2007 and Singh et al., 2013.

There are wide variations in glacier mass changes from time to time and place to place due to various factors such as elevation, latitude, orientation, precipitation, size, debris covered or debris free etc. Generally mass balance studies are carried out by using geodetic, glaciological, hydrological or AAR method (Benn and Evans, 2010; Bhambri et. al., 2011; Cuffey and Paterson, 2010; Gardelle et al., 2012).

Field based glacier mass balance estimations require large amount of efforts in terms of resources, logistics and accuracy in measurements. Remote sensing based methods have become an important alternative to conventional methods of mass balance estimation. These methods include monitoring of snow line at the end of ablation season and adopting AAR approach, DEM differencing, LIDAR techniques (Bahuguna et al., 2007; Berthier et al., 2007; SAC, 2011; SAC, 2016).This study has attempted to estimate changes in ice thickness of Chhota Shigri glacier, Himachal Pradesh using DGPS and SRTM derived elevation profiles.

2. Study area

The ChhotaShigri is typical valley type glacier located in the Chenab basin, Lahaul and Spiti Valley, PirPanjal Range, Western Himalaya in Himachal Pradesh. The glacier is located in the altitude range of 6263 m to ~4050 m a.s.l., is ~9 km long and covers 15.7 km^2 of area. The main glacier is a north facing, whereas trunk glaciers areeither east or west facing (Figure 1). Due to orographic position, this glacier is influenced by the monsoon-arid transition zone and two atmospheric circulation systems, viz., the Indian monsoon during summer (July–September) for wet precipitation and the northern-hemisphere mid-latitude westerlies during winter (January–April) (Singh et. al 1997; Bookhagen and Burbank, 2006; Gardelle et. al 2011) for dry precipitation.

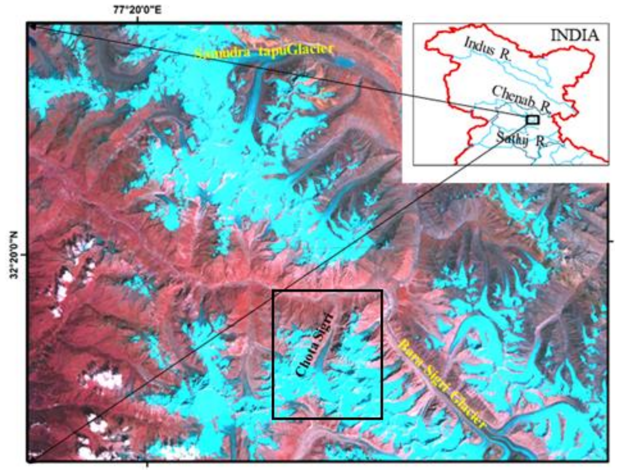

Figure 1: Location Map of study area (Chhota Shigri glacier)

3. DGPS measurements

The geodetic measurements were carried out with the help of GPS instrument. The dual frequency GPS instrument is equipped with Leica GPS500 instrument with SR520 receiver. The dual frequency instrument measures the GPS observable in dual (L1 and L2) frequency mode, which is utilized for the ionospheric correction. The GPS based observation were taken during the period 13th - 16th September 2014. Two base stations were established i.e., one in glaciated and other in non-glaciated region. These were used as reference points for collection of kinematic profiles over the glaciated and non-glaciated regions.

3.1. Elevation profile measurements

The kinematic observations using DGPS were made in two steps. In the first step, the kinematic observation was collected in the non-glaciated region while in the second step, measurements were collected in the glaciated region. In the non-glaciated region, the observations were made along the main stream of the Chandra River as well along a stream originating from snout of the glacier. The elevation profile was collected at an interval of 15 seconds. Over the glaciated surface, measurements were madeat a higher interval rate of 3 seconds. DGPS measurements were made from snout to accumulation zone of the ChhotaShigri glacier. In addition to elevation profile,locations of glacier features such as maulin, crevasses and erratics over ablation/accumulation zonewere also obtained using DGPS (Figure 2).

Figure 2: DGPS measurements over different glacier features of Chota Shigri glacier

4. Data analysis and results

The static GPS observations of the base stations were processed using six IGS stations namely (CHUM, COCO, LHAZ, HYDE, KIT3 and PBR2) and precise ephemeris using Gamit software developed by MIT. The established precise base station was used for the computation of the elevation profile using differential data processing with the help of the Track module developed by MIT. The total 1104 elevation observation points were collected in the non- glaciated region and 4878 elevation observation collected on the glacier surface are shown as blue and yellow color respectively in figure 3.

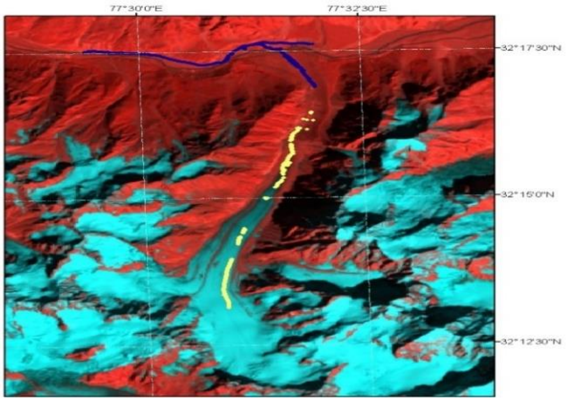

Figure 3: Location of DGPS measurements (Blue dots are over non-glaciated region and yellow dots are over glaciated surface)

The DGPS measurements are observed in the WGS84 ellipsoid whereas the SRTM DEM is in the Orthometric heights. In order to estimate changes in elevation of the glacier surface with respect to SRTM 30m DEM, the SRTM DEM was corrected to get the elevation information in the same GPS reference plane. The corrections were made by estimating the geoid height using EGM96 (Earth Gravity Model 1996). The EGM96 geoid height is used for the conversion of SRTM Orthometric height into ellipsoidal height according to the following formula

$h = H + N$

Where,
h = WGS84 Ellipsoid height
H = Orthometric height
N = EGM96 Geoid height

The non-glaciated elevation values between SRTM DEM and DGPS measurements were compared and used for the estimation of the Biases present in the SRTM DEM. Figure 4 shows that there is a strong correlation between elevation of SRTM and DGPS and there is an elevation offset of -2.5 m.

The elevation of the glaciated surface was further corrected by applying a computed offset value in the non-glaciated region. The elevation range measured over the glacier varies in the range of 3950 to 4850 m. DGPS based observations were taken both in the accumulation and ablation zone of the glacier.

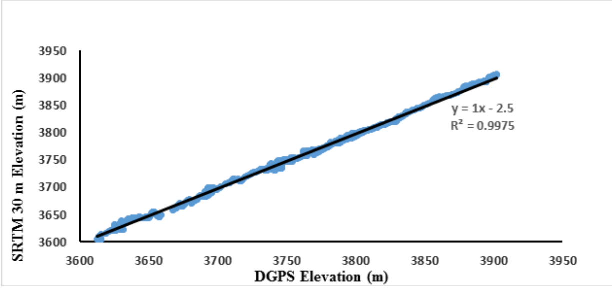

Figure 4: Correlation of DGPS and SRTM 30m DEM shows vertical offset of -2.5 m in non-glaciated region

While comparing DGPS and SRTM derived profiles over same transect, it is observed that change in ice thickness is about 6.7m for 14 years which is -0.5m per year (Figure 5). Total volume loss per year is estimatedas ~0.002 km^3 using standard method. These results are comparable with studies carried out by Azam et. al., 2012 and Engelhards et. al., 2016 who have estimated a negative mass balance of –0.67 ±0.40 m w e a^{-1}during the period 2002/2010 and -0.59±0.12 m w e a^{-1}during 2002-2013 of Chhota Shigri glacier using glaciological methods respectively.

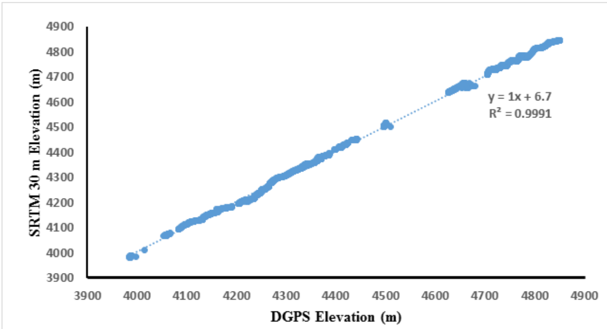

Figure 5: Correlation of DGPS and SRTM 30m DEM with vertical offset of -6.7 m in glaciated region of ChhotaShigri

5. Conclusions

The study has demonstrated potentials of DGPS measurements over glaciated region to derive elevation profile and its utility in estimating changes in glacier ice thickness, in conjunction with SRTM DEM derived elevation profile. The study shows that there has been a loss in glacier ice thickness of around 6.7m (~0.5m per year) over Chhota Shigri glacier during time frame 2000 - 2014.Rate of volume loss is estimated as 0.002 km^3per year. The study suggests periodic DGPS observations over same elevation profile in subsequent field expeditions for improving accuracy of estimated changes in glacier ice thickness, which can be utilised for validating results derived from DEM differencing technique.

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