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Impact of accumulation area ratio on glacial change: A few examples of Jammu and Kashmir

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Abstract: Glaciers are an important natural resource to human kind because they are fresh water in frozen state and sensitive indicator of climate change. Therefore, continuous monitoring of glaciers is one of the most essential tasks to be performed. The glaciers considered for this study are debris free and are located in Chenab basin of Western Himalaya. These glaciers are not only debris free but also small in size. One of the advantages of taking up debris free glaciers is that the signatures of these glaciers on the image are so distinct that no ambiguity can occur in the interpretation. The main objective was to monitor the changes in glacial extent since 2001 followed by estimation of accumulation area ratio (AAR) of each glacier. Thus, multi-temporal IRS LISS III and IRS P6 AWiFS images were used to estimate change in glacial area and accumulation area ratio (AAR) respectively. The estimated AAR was used to assess the glacial retreat. Thirteen glaciers were monitored for this study. The study reveals that during the monitoring periods of 2001-2007 and 2007-2009, the glaciers have experienced deglaciation of 7% and 2% respectively. These results were correlated with the mean accumulation area ratio which was derived using the data of 2001, 2005, 2006, 2007 and 2010. A good correlation was found between AAR and retreat of glaciers, indicating the significant effect of accumulation on deglaciation.

Key words: Retreat, Glaciers, Accumulation area ratio, Deglaciation

1. Introduction

Himalayan glaciers are a focus of public and scientific debate because of its highest concentration of snow and glaciers outside polar region. Nearly, 800 million people live in the catchments of the Indus, Ganges, and Brahmaputra rivers and rely to varying extents (in particular during dry seasons and in mountain valleys) on the water released from glaciers (Immerzeel et al., 2010; Kaser et al., 2010). Moreover, they are sensitive indicators of climatic variations too. Thus, large amount of studies has been carried out for monitoring the change in glaciers. Though, glaciers are on retreating phase, but in case of Karakoram region few glaciers are observed in advancing phase (Copland et al., 2009; Belo et al., 2008; Mayer et al., 2011). However, many glaciers are also observed in stable state in mountain ranges for few decades (Ajai et al., 2011). This retreat or advance of glaciers has been estimated based on either comparison of glacier extents extracted from satellite images, Survey of India topographical maps or the field investigations (Schmidt and Nusser, 2012; Kulkarni and Bahuguna, 2002; Bahuguna et al., 2004; Kulkarni et al., 2007; Bhambri et al., 2012; Yamada et al., 1992, Naithani et al., 2001; Dobhal et al., 2008). One of the earliest references of using images for glacier changes was carried out in Basapa basin using satellite images which has revealed the information about changes in snout position (Kulkarni and Bahuguna, 2002; Kulkarni and Alex, 2003). In addition, satellite data was used to study the glaciers of Parbati basin (Kulkarni et al., 2004). Overall, large amount of glacier retreat in Himalaya has been observed and monitored from 1962 using topographic maps and satellite images (Kulkarni et al., 2007). Moreover, great variations have been observed in glaciers of various parts of Himalaya. The glaciers located within a basin (i.e. Chandra) have also experienced the differences in deglaciation. These differences are due to the local climates and glacio-geomorphology of individual glaciers (Deota et al., 2011). Local climate includes the valley wind, slope wind, glacier wind whereas glacio-geomorphic parameters include slope, aspect, altitude, debris cover, areal extent, depth of ice, size of the valley, etc (Oerlemans, 2010). These parameters influence the accumulation and ablation of glacial ice which will result in loss or gain in glaciers. The large amount of supra glacier moraine over glaciers is one of the major reason for the variation in amount of retreat. Recently a study carried out by Venkatesh et al. (2012) has selected few glaciers of retreated glaciers of Chenab basin of Western Himalaya and found that slope is one of the key factors in variation of glacial retreat or advance.

Basically, retreat or advance of glaciers is the result of long term changes in mass balance of glaciers. There is a parameter known as AAR (Accumulation Area Ratio) which is used for determining mass balance of the glaciers at reconnaissance level. In this study, we have taken the few glaciers from Chenab basin of Western Himalaya, which are smaller in size and also debris free (Figure 1). One of the advantages of taking up small sized and debris free glaciers is that signatures of these glaciers on the image are so distinct that no ambiguity can be produced while interpreting the glacier extents. Another advantage is about the influence of climate on change in glaciers can be identified. For this study, IRS LISS III and IRS P6 AWiFS satellite data of different dates have been used in the investigation. The results mention that the smaller glaciers show a faster change in area than the large glaciers. The similar results have been reported in other parts of world such as Alpine glaciers (Grannshaw and Fountain, 2006), Wide Range River, USA (Cheesbrough et al., 2009), Andes (Masioka et al., 2009), etc.

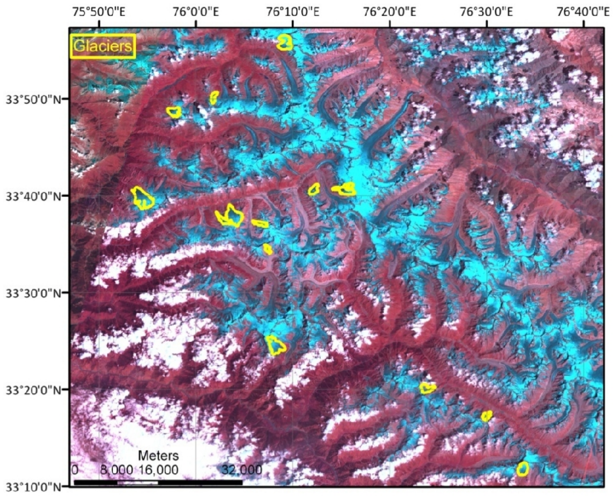

Figure 1: Location of glaciers in Chenab basin of Western Himalaya

2. Data and Methodology

The IRS LISS III and AWiFs data (FCC of band 1, 2, 3 and 4) were georeferenced with Landsat images. The details of data used are given in Table 1. Glacier extents were mapped from satellite images of LISS III data of 2001. Mapping from images requires use of elements of visual interpretation such as unique reflectance of snow and ice, shape of the valley occupied by the glacier, the flow lines of ice movement, shadow of the steep mountain peaks and presence of vegetated parts of the mountains. The SWIR band is used to discriminate cloud and snow in case of the glacier being covered by clouds in ridges. The snout is identifiable in debris free glaciers, its movement helps in recognizing advance or retreat of glaciers. For detection of change in area of glaciers, only the changes around the ablation zones were considered, as the accumulation zone is very dynamic in terms of snow cover and net change in the glacier is reflected at the snout. Estimation of change in glacial area was done using glacier extent extracted from different sources of datasets. Increase or decrease in areal extent of glaciers was calculated.

The uncertainties in mapping and retreat from satellite images were estimated using following equations (Basnett et al., 2013).

$$\text{Mapping uncertainity} = \frac{N}{2} * \text{Area of Pixel}$$

Where, N = number of pixel along the glacier boundary.

The following equation was used to estimate the error in retreat

$$\text{Uncertainity in retreat} = \frac{N1 - N2}{2} * \text{Area of Pixel}$$

Where,

N1 = number of pixel along the glacier boundary of data 1.

N2 = number of pixel along the glacier boundary of data 2.

Table 1: Details of data used in study

Satellite	**Date**	**Spatial Resolution (m)**
IRS 1C/1D LISS III	09 September 2001	23.5 (Band 1 to 3) 70.5 (Band 4)
IRS P6 LISS III	30 September 2006 08 August 2007 26 August 2008 03 October 2009	23.5
IRS P6 AWiFS	16 September 2005 18 August 2007 30 August 2010	56
Landsat TM	09 October 1989 04 July 1992	30

AWiFS images from July to September season were selected, because during this period snow cover is at its minimum and during this period maximum glaciers are snow free (Kulkarni et al., 1999). The snow line at the end of ablation, which roughly corresponds to the equilibrium line on glaciers in mountainous region, can be identified on satellite images (Ostrem 1973, 1975). This is the key parameter for estimating accumulation area ratio. Glacier boundaries were overlaid on all AWiFS scenes sequentially. Snow line was delineated for each glacier from each scene. Accumulation area ratio (AAR) was derived for each glacier based on location of snow line at the end of ablation season.

3. Results and Discussion:

Glacier cover change

In this investigation 13 debris free glaciers whose areal extent is less than 10 sq km were used in the analysis. Initially, the retreat was estimated from 2001 to 2007. All the glaciers showed loss in area during the monitoring period. Total area of these glaciers mapped using LISS III data was 38.3$\pm$2.41 sq km in 2001 which became 35.82$\pm$2.32 sq km. One of the examples of loss in glaciated area is shown in Figure 2. The loss of 2.5$\pm$0.04 sq km has been estimated. The annual loss in area is 0.42 sq km (1.08%) between 2001 and 2007. However, the annual loss in areal extent is substantially higher than general trend in the Western Himalaya (Bolch et. al., 2012). This is possibly due to the glaciers being small in size and also not covered by debris. In addition, the different rate of retreat was observed within these thirteen glaciers which vary from 2% to 16 %. This variation might be because of area altitude distribution and orientation of the glaciers. These factors influence equilibrium line and AAR (accumulation area ratio) of the glaciers. Therefore further investigation was carried out to understand the influence of AAR on surface area retreat. During 2007-2010, eight glaciers were monitored out of 13 glaciers. Other glaciers were snow or cloud covered. The total area of these 8 glaciers in 2007 was 26.06 sq km which had become 25.54±1.64 sq km in 2009. This gives a loss of 0.53±0.01 sq km (2%). Among 8 glaciers, 4 were found in stable condition.

AAR of glaciers

From the data of retreat it cannot be directly concluded that glacial retreat has taken place due to change in accumulation or ablation. However, accumulation can be directly observed on the satellite images unlike ablation. It is this basis which led to development of AAR based mass balance estimation. AAR for each of the 13 glaciers was extracted based on the snow line at the end of ablation season. The snow line is very crucial in glacier health studies for many reasons. Firstly it indicates the accumulation area of the glaciers and secondly it is treated as equivalent to equilibrium line for estimating mass balance. The upward or downward movement of this line indicates positive or negative mass balance. Thus, accumulation area ratio was estimated using various images of ablation season for the 2001, 2005, 2007 and 2010. As it is well known that long term variation in mass balance results in the changes in glacial extents, the data of glacial retreat and mean AAR of the glaciers has been correlated (Figure 3). The accumulation area ratio has significant effect on the retreat or advance of glacier. A good correlation has been observed between mean AAR (accumulation area ratio) and deglaciation ($R^2 = 0.76$).

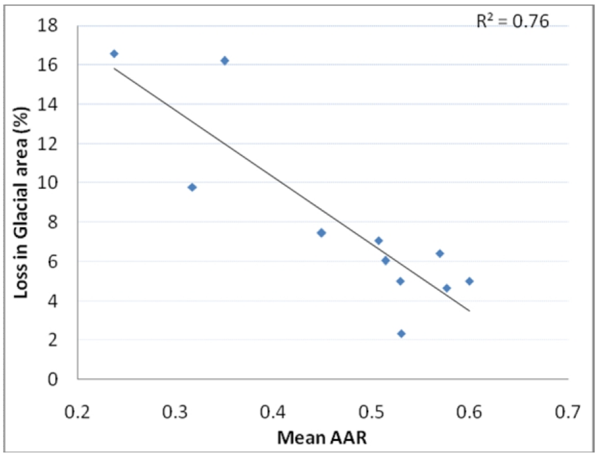

Figure 3: Influence of AAR (accumulation area ratio) on deglaciation (2001-2007)

Conclusion

The glaciers have experienced the retreat during both the monitoring periods. However, individual glaciers retreat at different rates depending on various glacio-geomorphic parameters (areal extent, ELA, slope, aspect, etc). In this investigation retreat for small and debris free glaciers was carried out which suggest that deglaciation in these glaciers is high. The inverse relation of accumulation area ratio and deglaciation suggest that solid precipitation on glaciers is necessary for better health of glaciers.

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References

Ajai and 53 others (2011). Snow and glaciers of the Himalayas. Space Applications Centre, ISRO, Ahmedabad. ISBN: 13 978-81-909978-7-4.

Bahuguna, I.M., A.V. Kulkarni and S.D. Nayak (2004). DEM from IRS 1C PAN stereo coverage over Himalayan glaciated region–accuracy and its utility. International Journal of Remote Sensing 25(19), 4029-4041

Basnett, S., A.V. Kulkarni and T. Bolch (2013). The influence of debris cover and glacial lakes on the recession of glaciers in Sikkim Himalaya, India. Journal of Glaciology 59(218), 1035-1046.

Belo, M., C. Mayer, C. Smiraglia and A. Tamburini (2008). The recent evolution of Liligo glacier, Karakoram, Pakistan, and its present quiescent phase. Annals of glaciology 48(1), pp. 171-176.

Bhambri, R., T. Bolch and R. Chaujar (2012). Frontal recession of Gangotri glacier Garhwal Himalayas, from 1965 to 2006, measured through high resolution remote sensing data. Current Science 102(3), pp. 489-494.

Bolch, T., A.V. Kulkarni, A. Kääb, C. Huggel, F. Paul, J.G. Cogley, H. Frey, J.S. Kargel, K. Fujita, M. Scheel, S. Bajracharya and M. Stoffel (2012). The state and fate of Himalayan glaciers. Science 336, pp 310-314.

Cheesbrough, K., J. Edmunds, G. Tootle, G. Kerr and L. Pochop (2009). Estimated wind river range (Wyoming, USA) glacier melt water contributions to agriculture. Remote Sensing 1, pp. 818-828; doi:10.3390/rs1040818.

Copland, L., S. Pope, M.P. Bishop, J.F. Shroder, P. Clendon, A. Bush U. Kamp, Y. Seong and A. Owen (2009). Glacier velocities across the central Karakoram. Annals of Glaciology 50 (52), pp. 1-9.

Deota, B. S., Y.N. Trivedi, A.V. Kulkarni, I.M. Bahuguna and B.P. Rathore (2011). RS and GIS in mapping of geomorphic records and understanding the local controls of glacial retreat from the Baspa valley, Himachal Pradesh, India. Current Science 100 (10), pp. 1555-1563.

Dobhal, D. P., J. T. Gergan and R. J. Thayyen, (2008). Mass balance studies of the Dokriani glacier from 1992 to 2000, Garhwal Himalaya. India. Bulletin of Glaciological Research 25, pp. 9–17.

Granshaw, F. D. and A. G. Fountain (2006). Glacier change (1958–1998) in the North Cascades national park complex, Washington, USA. Journal of Glaciology 52 (177), 251-255.

Immerzeel, W. W., L. P. van Beek and M. F., Bierkens (2010). Climate change will affect the Asian water towers. Science 328(1382) doi:10.1126/science.1183188 Medline

Kaser, G., M. Grosshauser and B. Marzeion (2010). Contribution potential of glaciers to water availability in different climate regimes. Proc. Natl. Acad. Sci. U.S.A. 107(20223) doi:10.1073/pnas.1008162107 Medline

Kulkarni, A. V and I. M. Bahuguna (2002). Glacial retreat in the Baspa basin, Himalaya, monitored with satellite stereo data. Journal of Glaciology 48(160), 171-172.

Kulkarni, A. V., G. Philip, V. C. Thakur, R. K. Sood, S. S. Randhawa and R. Chandra (1999). Glacial inventory of the Satluj basin using remote sensing technique. Himalayan Geology 20(2), pp. 45-52.

Kulkarni, A. V., B. P. Rathore and S. Alex (2004). Monitoring of glacial mass balance in the Baspa basin using accumulation area ratio method. Current Science 86 (1), pp. 185-190.

Kulkarni, A. V., I. M. Bahuguna, B.P. Rathore, S.K. Singh, S.S. Randhawa, R.K. Sood and Sunil Dhar (2007). Glacial retreat in Himalaya using remote sensing satellite data. Current Science 92, pp. 69-74.

Masiokas, M.H., B.H. Luckman, R. Villalba, S. Delgado, P. Skvarca and A. Ripalta (2009). Little ice age fluctuations of small glaciers in the Monte Fitz Roy and Lago del Desierto areas, south Patagonian Andes, Argentina**.** Palaeogeography, Palaeoclimatology, Palaeoecology 281, pp. 351–362.

Mayer, C., A. C. Fowler, A. Lambrecht and K. Scharrer (2011). A surge of North Gasherbrum glacier, Karakoram, China. Journal of Glaciology 57(204), 904-916.

Naithani, A. K., H. C. Nainwal, K. K. Sati and C. Prasad (2001). Geomorphological evidences of retreat of the Gangotri glacier and its characteristics. Current Science 80, pp. 87–94.

Oerlemans, J. (2010). The microclimates of valley glaciers. ISBN 987-90-393-5305-5.

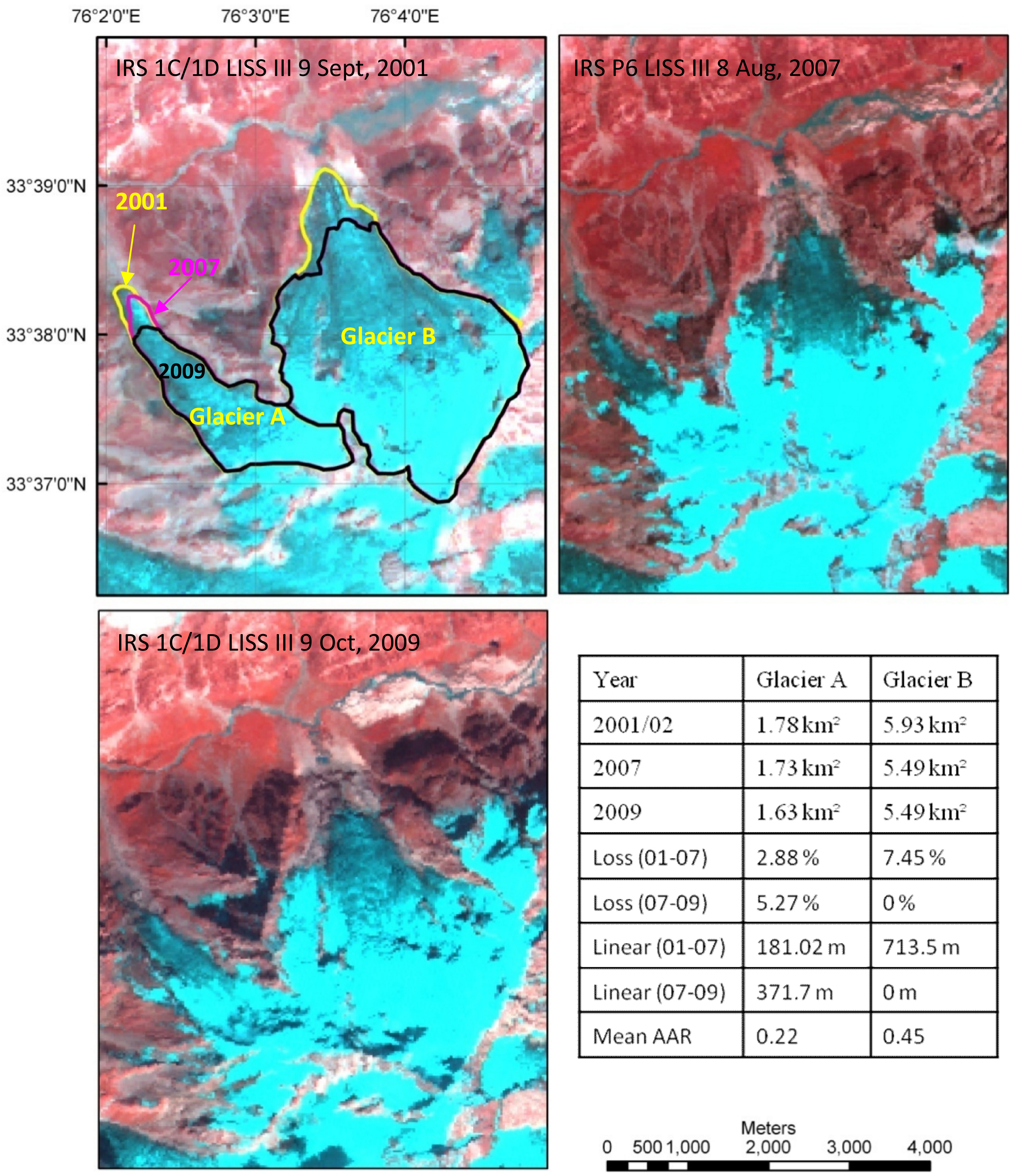
Ostrem, G. (1973). The transient snowline and glacier mass balance in southern British Columbia and Alberta, Canada. Geografiska Annaler 55A, pp. 93–106.

Ostrem, G. (1975). ERTS data in glaciology - an effort to monitor glacier mass balance from satellite imagery. Journal of Glaciology, 15(73), 403–415.

Schmidt, S. and M. Nusser (2012). Changes of high altitude glaciers from 1969 to 2010 in the Trans-Himalayan Kang Yatze Massif, Ladakh, Northwest Indian Arctic, Antarctic and Alpine Research 44(107), pp. 107-121.

Venkatesh, T. N., A. V. Kulkarni and J. Srinivasan (2012). Relative effect of slope and equilibrium line altitude on the retreat of Himalyan glaciers. The Cryosphere 6, pp. 301-311

Yamada, T., T. Shiraiwa, H. Lida, T. Kadota, T. Watanabe, B. Rana, Y. Ageta and H. Fushimi (1992). Fluctuations of the glaciers from the 1970s to 1989 in the Khumbhu, Shorong and Langtang regions, Nepal Himalayas. Bulletin of glacier research 10(11), pp. 11-19.



Year	Glacier A	Glacier B
2001/02	1.78 km²	5.93 km²
2007	1.73 km²	5.49 km²
2009	1.63 km²	5.49 km²
Loss (01-07)	2.88 %	7.45 %
Loss (07-09)	5.27 %	0 %
Linear (01-07)	181.02 m	713.5 m
Linear (07-09)	371.7 m	0 m
Mean AAR	0.22	0.45

Figure 2: Examples of deglaciation in glaciers since 2001