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Dynamics of Hamtah Glacier, Lahaul & Spiti district, Himachal Pradesh

S.P. Shukla*[1], Rakesh Mishra[1] and Alok Chitranshi[2]

[1]Glaciology Division, Geological Survey of India, Sector, 'E', Aliganj, Lucknow 220024, India
[2]Regional Training Institute, Geological Survey of India, Sector, 'E', Aliganj, Lucknow 220024, India
*Corresponding Author: satyashukla63@gmail.com

ABSTRACT

Understanding the glacier dynamics is significant for understanding the response of the glacier to the changing climate, i.e., determining how the glaciers change over time in response to a changing climate. It is well known that velocity of the glacier is a function of thickness and gradient of the glacier bed. In addition, the glacier velocity also depends on the availability of the water at the bottom as the basal sliding is considered as the most important factor affecting the dynamics of Himalayan glaciers. In order to understand the impact of changing glacier mass balance and the availability of melt water at the glacier bed, the glacier dynamics of Hamtah glacier, a small valley glacier in Chenab basin, Lahaul & Spiti district, Himachal Pradesh, has been studied. For this purpose the horizontal component of flow movement has been measured, during 2000-01 to 2005-06, using the stake network fixed for the assessment of annual mass balance.

The highest glacier flow velocities were recorded in the highest elevation zones whereas the least flow velocities were observed near the glacier snout. The annual horizontal component of flow velocities recorded successive decline from 2000-01 to 2003-04 with marginal upward trend in 2004-05, followed by decline in 2005-06. This variation in horizontal component of flow velocity was correlated with the mass balance recorded during the observation period. In addition, the annual and summer horizontal component of flow velocity was also compared to comprehend the effect of the increase in water availability at the glacier bed. It has been observed that the annualized summer flow velocities (Um*12) and the annual flow velocities (Ua) deduced from field measured summer flow and annual flow respectively show considerable variations, including during different observational years.

INTRODUCTION

Mass balance is intimately linked with glacier dynamics as well as with climate, and mass balance offers a convenient conceptual link between the broad environmental context of glaciation and the details of glacier behavior (Knight, 1999). Moreover, the retreat or advance of the glacier is delayed signal, depending on the geometry of the glacier, of the variation in the mass balance of the glacier. Understanding the glacier dynamics is, therefore, of fundamental importance as it gives an idea about the response of the glacier to the changing climate. Glaciers move, or flow, downhill due to gravity and the associated internal deformation of ice. The glacier flow velocity is a function of ice thickness and slope as glaciers flow under the influence of gravity. Also, ice can move as plastic material due to high pressure of thick accumulated ice/snow or due to basal sliding. Measurement of ice flow velocity can help in modelling the glacier dynamics. In order to understand the effect of changing mass balance on the glacier dynamics, glacier flow movement and mass balance data measured on Hamtah glacier was analysed and discussed. These studies have been conducted on a small valley glacier – Hamtah, located in Himachal Himalaya, India.

STUDY AREA

Hamtah (5Q212 <u>12</u> 180), is a northwesterly flowing small valley glacier which lies in Chandra fifth order basin (5Q212 <u>12</u>), of fourth order Chenab basin (Fig. 1), covering part of the Lahaul & Spiti district of Himachal Pradesh. Originating at an elevation of 5000 m asl, 6.0 km long glacier having an average width of 0.50 km and covering an area of about 3.3 sq km., descends with a gentle gradient with its terminus at about 4000 m asl. The glacier has a large ablation zone covered with thick blanket of supra-glacial moraines. A small ice stream located in the left part of the glacier originates close to the equilibrium line and flows downstream in the middle reaches and finally merges with the left bank of the glacier. It's very small accumulation zone is characterized by avalanche cones originating from the two small hanging glaciers and surrounding snow capped peaks and a narrow feeder in the left portion of the glacier (Fig. 2).

METHODOLOGY

Glacier flow movement studies on Hamtah glacier, were initiated during the year 2000. A network of stakes, having

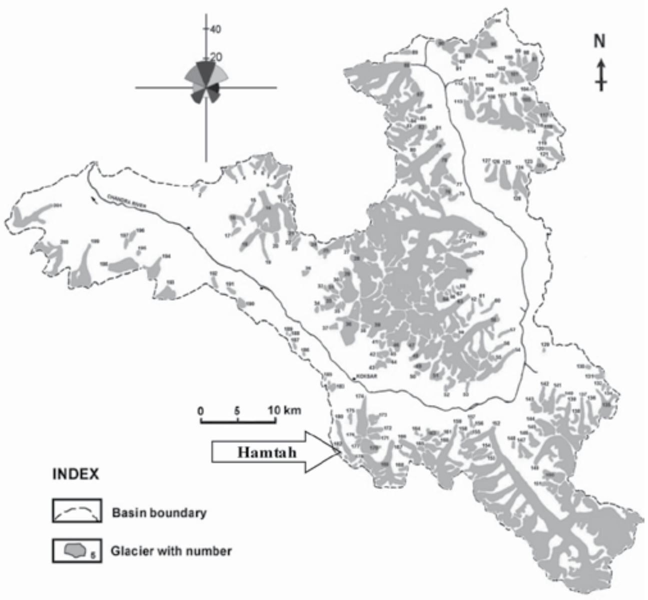

Figure 1. Location of Hamtah glacier

Figure 2. Higher reaches and accumulation zone of Hamtah glacier

two rows, *i.e.*, left and right with eight stakes each, were fixed on the glacier surface from the snout to the higher reaches of the glacier, close to the accumulation zone. Considering the width of the glacier two rows of stakes with alternating sequence and at regular intervals, excepting near serrac faces and crevasses, was fixed. The numbering was done with prefixes L and R depending on their fixation along left or right margins. This network was also utilised for the assessment of mass balance of the glacier (Fig. 3). From the figure it is clear that L1, L2, R1 and R2 were fixed in 4000-4200 m asl zone; L3, L4, L5, R3 and R4 were fixed in 4200-4400 m asl zone and L6, L7, L8, R5, R6, R7 and R8 were fixed in 4400-4600 m asl zone. The stakes were regularly re-fixed in subsequent years to obtain continuous data and given numbers as R1A, R1B etc. The glacier mass balance was computed by glaciological method wherein 30th September was taken as end of the ablation season. Here the ablation was measured by monitoring of the stakes, whereas accumulation was derived from the pitting and probing in the accumulation zone.

During 2001 – 2006 period, the stake network was coordinated (mapped) from the permanent survey stations fixed on the valley wall/ stabilized lateral moraines twice during the summer ablation season (during July –September period) using Electronic Distance Measuring (EDM) survey unit, to obtain both annual and summer horizontal component of flow velocities. The fixation of stations on the valley wall/ stabilised lateral moraines ensured precise measurement of the stakes at regular intervals.

The stake coordinates were generated in the form of eastings, northings and elevation. These coordinates were utilized for computation of horizontal component of annual (Ua) and monthly summer (Um) flow respectively. The difference in easting and northing of the stake coordinates

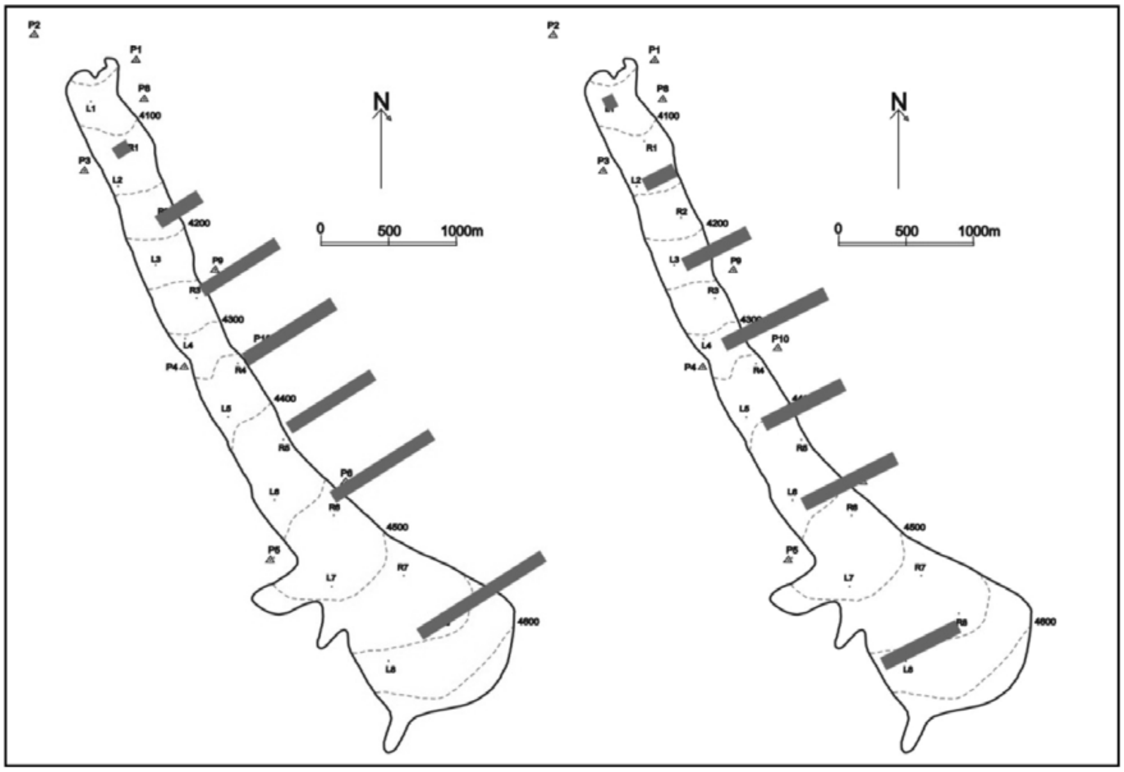

Figure 3. Stake network on Hamtah glaciers; bars showing the quantum of average horizontal component of flow velocity (m/y)

of two successive observations yielded the horizontal component of velocity using the empirical relation,

$U = (Ux^2 + Uy^2)^{1/2}$ Where Ux = Difference in easting and Uy = Difference in northing

In order to compute annual horizontal component of velocity (Ua), the stake displacement from one year to the next year was considered while for monthly summer horizontal component of velocity (Um), the coordinates of two successive observations were considered. Since the two observations in one ablation period could not be spaced exactly one month due to obvious reasons, the summer flow velocity (Um) data was re-calculated for 30 days. Hence this recalculated Um is taken as representative for that year and has been utilised for data analysis and drawing up further conclusions.

RESULTS AND DISCUSSION

Annual horizontal component of velocity (Ua) was computed for the period from 2000-01 to 2005-06. It has been observed that the highest velocities were recorded in 4400-4600 m asl zone whereas minimum velocities were observed in 4000-4200 m asl zone, *i.e.* close to the snout of the glacier (Table-1). Higher ice mass transfer from the upper reaches as evidenced by the faster movement of the glacier is well compensated in the lower altitudes, with reduced flow velocities that are attributed to ice ablation.

The two rows of stakes, *i.e.*, right and left have shown different velocities. Higher velocities were recorded along the right row of stakes *vis-à-vis* left row of stakes. This variation could be attributed to the drainage network and higher accumulation from the hanging glaciers located in the right part of the accumulation zone (Fig. 2). The alternate pattern of stakes network with right row of stakes fixed at relatively higher elevations, might have also resulted in higher velocities along the right row of stakes (Fig. 3). The average horizontal component of velocity, as shown in table-2, along the left row of stakes was found to be highest in the middle reaches (L4) while along the right row of stakes higher velocities were recorded in the higher reaches (R6 and R8), which could be attributed to the gradient of the glacier valley profile.

A reduction in speed in areas with negative mass balance has been observed for individual glaciers using ground observations (Haefeli, 1970, Span, N. and Kuhn, M., 2003, Vincent, et al., 2009). Quincey (2009a) measured glacier speed and noticed an increase at Baltoro glacier. Quincey, et al., (2009a) assumed that higher velocities may be associated with the mass surplus. This happens immediately as the mass balance changes are taking place. Based on their studies in Eastern Karakoram Himalaya, they attributed the moderate increase in glacier speeds in Eastern Karakoram as a response to the positive mass balance in this area (Heid, T. and K¨a¨ab, A., 2012).

Table 1. Variation in average annual horizontal component of velocities (m)

Altitudinal Range (m asl)	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
4400-4600	20.40	16.34	14.19	15.32	17.70	17.61
4200-4400	17.53	15.87	14.23	13.75	14.54	13.32
snout-4200	6.13	4.51	4.02	4.42	4.28	5.81

Table 2. Variation in average annual horizontal component of velocities (m) along two row of stakes

Stake no.	Average velocity (m/y)	No. of observations	Stake no.	Average velocity (m/y)	No. of observations
L1	1.808	4	R1	2.592	5
L2	5.385	3	R2	7.776	6
L3	11.510	6	R3	14.283	6
L4	18.229	6	R4	16.699	5
L5	14.209	6	R5	15.806	6
L6	16.498	6	R6	18.662	5
L7					
L8	13.468	5	R8	23.366	2

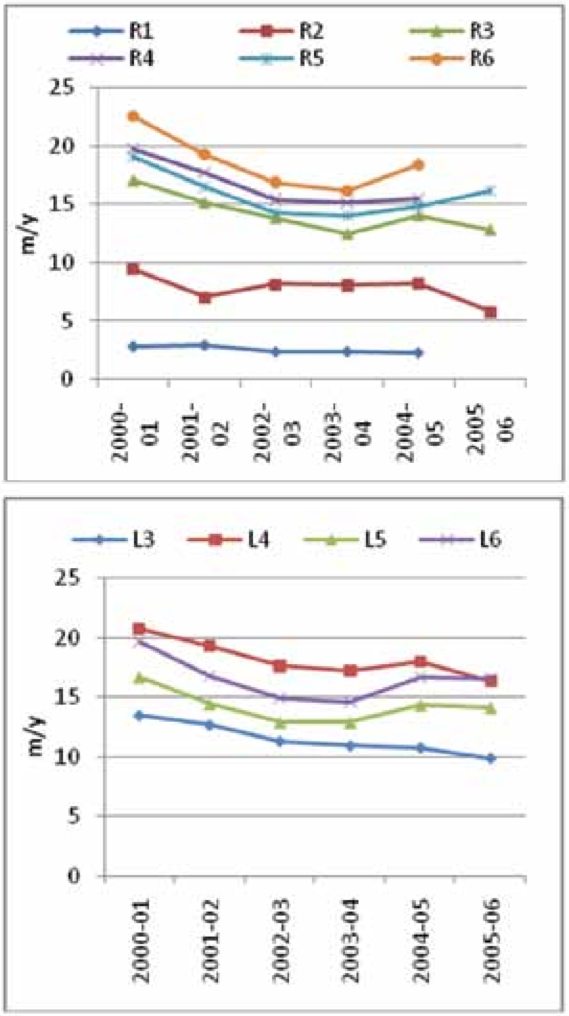

Figure 4. Successive decline in Ua from 2000-01 to 2004-05/ 2005-06 along right (top) and left (bottom) row of stakes on Hamtah glacier

Table 3. Variation in annual horizontal component of velocities (m/y) during different years along two row of stakes

Period/ St. no.	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	Period/ St. no.	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
L1	-	2.303	1.553	2.058	1.317	-	R1	2.85	2.951	2.401	2.429	2.328	-
L2	-	5.745	-	5.141	5.27	-	R2	9.41	7.027	8.119	8.066	8.219	5.815
L3	13.47	12.67	11.307	10.936	10.776	9.902	R3	17.1	15.196	13.901	12.509	14.11	12.885
L4	20.75	19.338	17.644	17.243	18.017	16.382	R4	19.71	17.729	15.433	15.156	15.465	-
L5	16.62	14.407	12.888	12.902	14.33	14.105	R5	19.06	16.457	14.265	14.035	14.867	16.152
L6	19.62	16.762	14.892	14.56	16.626	16.527	R6	22.51	19.308	16.888	16.186	18.42	-
L8	-	12.815	10.718	10.544	13.119	20.143	R8	-	-	-	21.272	25.46	-

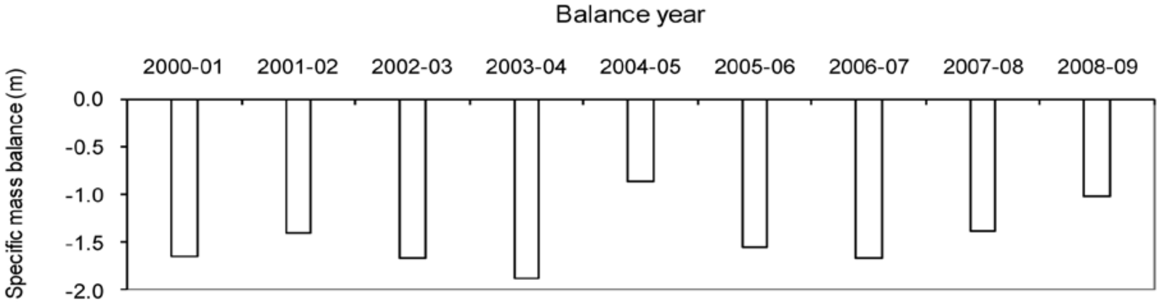

Figure 5. Specific mass balance (2000-01 to 2008-09) of Hamtah glacier

Quincey, et al., (2009a) also proposed that Baltoro accelerated due to positive mass balance. Quincey also derived speeds for six glaciers in the Himalaya region between 1992 and 2002. But these data show no clear sign of a reduction in speed with time (Quincey, et al., 2009b). Dunagiri glacier, Uttarakhand, which recorded a continuous negative mass balance during 1984-1990, has also shown continuous decline in the minimum velocity, from 1.85 m/y to 0.76m/y in 1985-86 and 1989-90 (Srivastava et al, 1992). With a view to understand the dynamics vis-à-vis its mass balance of Hamtah glacier recorded through field based studies undertaken during 2000-01 to 2005-06 assessment years, the flow parameters for different years were compared. Majority of stakes fixed on Hamtah glacier show successive decline in Ua from 2000-01 to 2005-06, which could be attributed to the thinning of the glacier due to continuous negative mass balance and recession of the glacier during the period of observation (Fig. 4). Even the variation in the negativity of the glacier mass balance was also found to be reflected in the annual flow velocities. During 2004-05 when glacier mass balance was least negative, the flow velocities have shown marginal upward trend. This again fell during 2005-06 (Fig. 5 and Table – 3). Thus, it can be suggested that the mass balance has instantaneous effect on the glacier dynamics.

Glacier mass balance changes can affect the glacier speeds in two ways. The local mass balance can change the local glacier thickness and thereby change the velocity both due to sliding as well as local deformation.

Himalayan glaciers are considered as warm based glacier, wherein the glacier dynamics is considerably influenced by the availability of the water at the glacier bed. Many studies have documented a relationship between water input, from surface melting and rainfall, and increased ice-flow speed on temperate and polythermal glaciers and ice caps (Anderson, et al., 2004). Purdie et al (2008) in their studies on seasonal variation in ablation and surface velocity on a temperate maritime glacier, Fox Glacier, New Zealand found that the surface velocity had shown seasonality, averaging 0.87 m/day during summer and 0.64m/day in winter, a reduction of -26%. They thought that the general reduction in velocity during winter could be attributed to a decrease in the supply of surface meltwater to the subglacial zone. Several studies on alpine glaciers have shown that glacier flow velocities can vary significantly over daily to annual time scales (Anderson, et al., 2004, Bartholomaus, et al., 2008). Such variations have commonly been attributed to melt water induced changes in sub-glacial hydrology that lead to variations in the speed of basal sliding. Intra-annual variations in motion reflect seasonally evolving sub-glacial conditions (Knight, 1999). However, it may be noted that many mountain glaciers show the highest flow velocities during spring to early summer, and before maximum ablation and pro-glacial stream discharge occurs (Scherler, Dirk, 2010).In order to understand the dynamics of the glacier during the summer ablation season, the annualized monthly horizontal component of velocity (=12*Um), wherein the Um has been computed on the basis of the two stake coordination

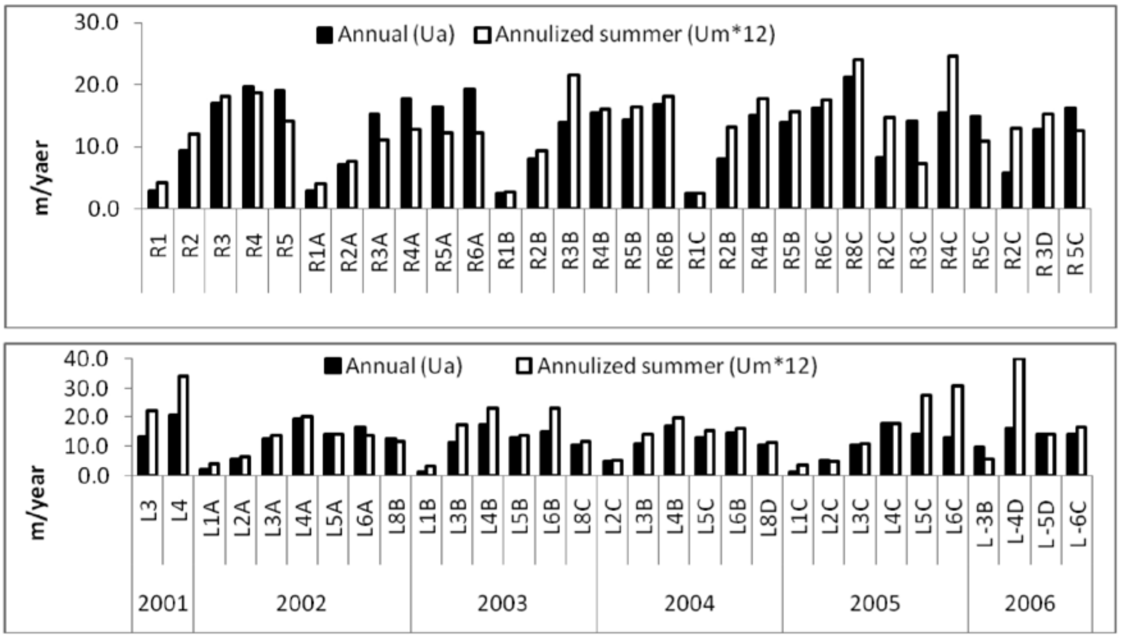

Figure 6. Variation in annualized summer horizontal component of flow velocity (Annual) and annual horizontal component of velocity (Yearly) on Hamtah glacier

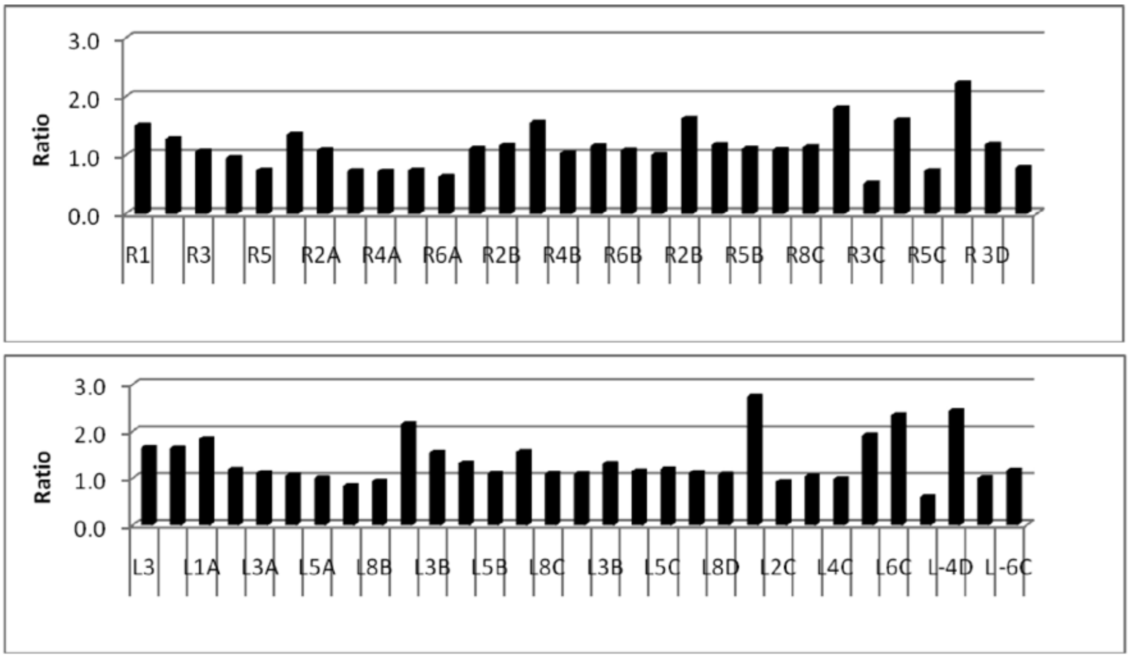

Figure 7. Ratio between summer horizontal component of flow velocity (Um) and annual horizontal component of velocity (Ua) on Hamtah glacier

data recorded during the summer ablation season and the annual horizontal component of flow (Ua) was compared. During the different years the flow velocity pattern shows considerable variation (Fig. 6), which could be attributed to the intra annual variability in the evolution of sub-glacial drainage network. The ratio between annualized summer monthly horizontal component of velocity (Um*12) and annual horizontal component of velocity (Ua) also shows large variation along the left and right row of stakes (Fig. 7 and Table-4). This could be ascribed to the effect of basal sliding on account of availability of more water in the basal layer during the summer ablation season due to the presence of moulins and supra-glacial melt stream along the left row of stakes.

Table 4. Variation in annual horizontal component of velocities (m) during different years along two row of stakes

Year	St. No.	Um*12/Ua	Year	St. No.	Um*12/Ua
2001	L3	1.65	2001	R1	1.51
	L4	1.64		R2	1.27
2002	L1A	1.83		R3	1.06
	L2A	1.18		R4	0.95
	L3A	1.11		R5	0.74
	L4A	1.05	2002	R1A	1.35
	L5A	1.00		R2A	1.09
	L6A	0.84		R3A	0.73
	L8B	0.93		R4A	0.72
2003	L1B	2.15		R5A	0.74
	L3B	1.55		R6A	0.63
	L4B	1.32	2003	R1B	1.11
	L5B	1.09		R2B	1.16
	L6B	1.56		R3B	1.55
	L8C	1.09		R4B	1.03
2004	L2C	1.09		R5B	1.15
	L3B	1.31		R6B	1.08
	L4B	1.15	2004	R1C	1.00
	L5C	1.19		R2B	1.62
	L6B	1.11		R4B	1.18
	L8D	1.07		R5B	1.11
2005	L1C	2.73		R6C	1.09
	L2C	0.92		R8C	1.13
	L3C	1.04	2005	R2C	1.80
	L4C	0.98		R3C	0.52
	L5C	1.91		R4C	1.59
	L6C	2.34		R5C	0.73
2006	L -3B	0.60	2006	R2C	2.23
	L-4D	2.43		R 3D	1.18
	L -5D	1.01		R 5C	0.78
	L -6C	1.16			
Average velocity		**1.36**	**Average velocity**		**1.13**

CONCLUSION

Understanding the glacier dynamics is significant for understanding the response of the glacier to the changing climate. Studies on Hamtah glacier have shown de-acceleration in horizontal component of velocity under continuous negative mass balance regime. The annual variation in the glacier velocity has also shown that mass balance has immediate effect on the glacier dynamics. However, making predictions of the impacts of future climate change on the mountain cryosphere is challenging, particularly for large debris-covered glaciers, as supraglacial debris affects the glacier surface energy balance and ice dynamics Hambrey et al., 2008).

The higher summer velocity as compared to annual velocity can be attributed to the availability of the water in the basal layer, besides residual snow thickness variation in the higher reaches of the glacier, at the start of the ablation season. Intra-annual variation in the flow velocity could also be linked with evolution of the sub-glacial drainage network.

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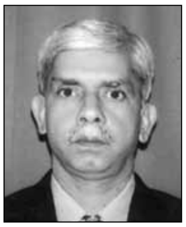
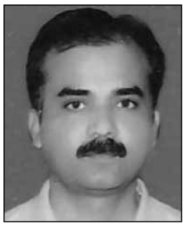


Dr. Satya Prakash Shukla, Director, Glaciology Division, joined Geological Survey of India in 1987. During initial years was associated with planning and monitoring of the scientific activities of the department. He has over two decades of experience in Himalayan glaciology and has carried out extensive work on the glaciers of Himachal Pradesh, Uttarakhand and Sikkim. In addition, he has also worked on glaciers of Arctic region. The experience gained in the field has been utilised in organizing, nationally acclaimed DST sponsored Field Training Courses in Glaciology initially as Core Faculty and later as Technical/Field Course Coordinator conducted by GSI Training Institute.

Shri Alok Chitranshi, Director joined Geological Survey of India in 1987. During the initial years of his career in GSI carried out Geological mapping, Mineral investigation and Palaeontological studies besides associated with planning and monitoring of the scientific activities of the department. He successfully led three glaciological expeditions on glaciers of Uttarakhand and H.P for generating base line data for the glaciers of this part of the Himalaya. He has been associated as a core faculty for the prestigious, DST sponsored Field Training Course in Glaciology conducted by GSI Training Institute.



Shri Rakesh Mishra, Senior Geologist in Geological Survey of India, Lucknow having more than fifteen years of experience in the field of Coastal Geomorphology, Environmental Geology, Quaternary Geology and Glaciology. Mainly engaged in glaciological studies in Himalayan and Arctic Region. Associated with various aspects of glaciological studies including mass balance, secular movement studies and associated specialized and societal issues related studies. He was also associated as a core faculty for the DST sponsored Field Training Course in Glaciology conducted by GSI Training Institute.