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First Global Positioning System (GPS) Derived Recession Rate in Milam Glacier, Higher Central Himalaya, India

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Abstract: *Present day climatic circumstances seem to be accountable for accelerating the recession of most of the Himalayan glaciers. In the present study, the rate of retreat in the Milam glacier (Higher Central Himalaya, India) is calculated for the first time by using Global Positioning System (GPS) in kinematic mode survey. The GPS measurements during 2004-2005 reveal a maximum retreat of 28 m/yr in the central part of the snout. The western side of the snout recedes at a rate of about 1.7 m/yr, whereas, the northeastern side is retreating at a rate of 6.7-13.2 m/yr. Based on mean values of all points, average recession rate is calculated as 9.54±1.3 m/yr for this glacier.*

Keywords: *Global Positioning System (GPS); Milam glacier; Recession rate; Central Himalaya.*

I. INTRODUCTION

For the Indian subcontinent, the regional hydrology and climatic variations are directly influenced by the Himalayan glaciers, which are second after the polar caps and cover about 33,000 sq km area [1]. In the Himalaya, about 1400 km^3 of snow/ice is locked, and it spreads over an area of nearly 33,200 km^2 in the higher altitudes [2]. A number of diverse studies on the mass balance, snout monitoring, geomorphological evidence, palaeoclimate, remote sensing and glacial hydrometeorology [3-15] have shown that the faster retreating rate in the Himalayan glaciers is mainly due to continuing climatic variability, behavior of summer and winter monsoons and morphogeometrical changes. Therefore, this aspect has initiated extensive discussions, especially in the context of global warming. The climatic variations are obviously among some of the controlling factors as far as the rate of retreat of glaciers is concerned. However, because such variations are coupled with the topography, landscape and slope configuration etc., the rate of recession and amount of snow/ice volume change are irregular for the Himalayan glaciers. The ongoing retreat of Himalayan glaciers seems also largely due to increase in the global average surface temperature which is projected to enhance between 1.4 to 5.8^{o}C by 2100 [16]. This may be analogous to the global retreat of glaciers due to an increase in heat and decrease in snowfall [17]. The recession of glaciers is also controlled by accumulation and ablation that occur during the winter and summer periods respectively within the glacial environment.

II. Study Area And Geological Background

The Milam glacier (30^{0} 27' 53" N: 80^{0} 06' 39" E) in the Pithoragarh district of Uttarakhand state is situated in the Higher Central Himalaya (Figures 1A-B) and has a total length of 19.32 km (Figure 1C). Two cirques on Trishuli Peak (6,400 m) and seven tributary glaciers (Sakaram, Pachhimi, Bamchhu, Magraon, Surajkund, Billanlari and one unnamed glacier) are main feeders of the main Milam glacier (Figures 1C-D). The River Goriganga, a melt-water stream, emerges through the snout (3,520m) of the glacier (Figures 1B-C). In the downstream, several sub-perennial as well as fluvial channels form one of the largest tributaries of the river Kali. Geologically, the Milam glacier lies in north of the Trans Himadri Fault (THF) in the Tethys Himalayan segment, which is mainly dominated by the rocks of the Tethyan succession (Figures 1A-B). The Tethys Himalaya constitutes Rilkot, Burfu, Belju, Milam and Ralam Formations. The calc phyllites and green siltstone of the Milam Formation are mainly exposed near the glacier and nearby Milam village [18]. In the glaciated area, this formation shows graded and cross bedding structures with medium to unsorted fine grained arenaceous component [19].

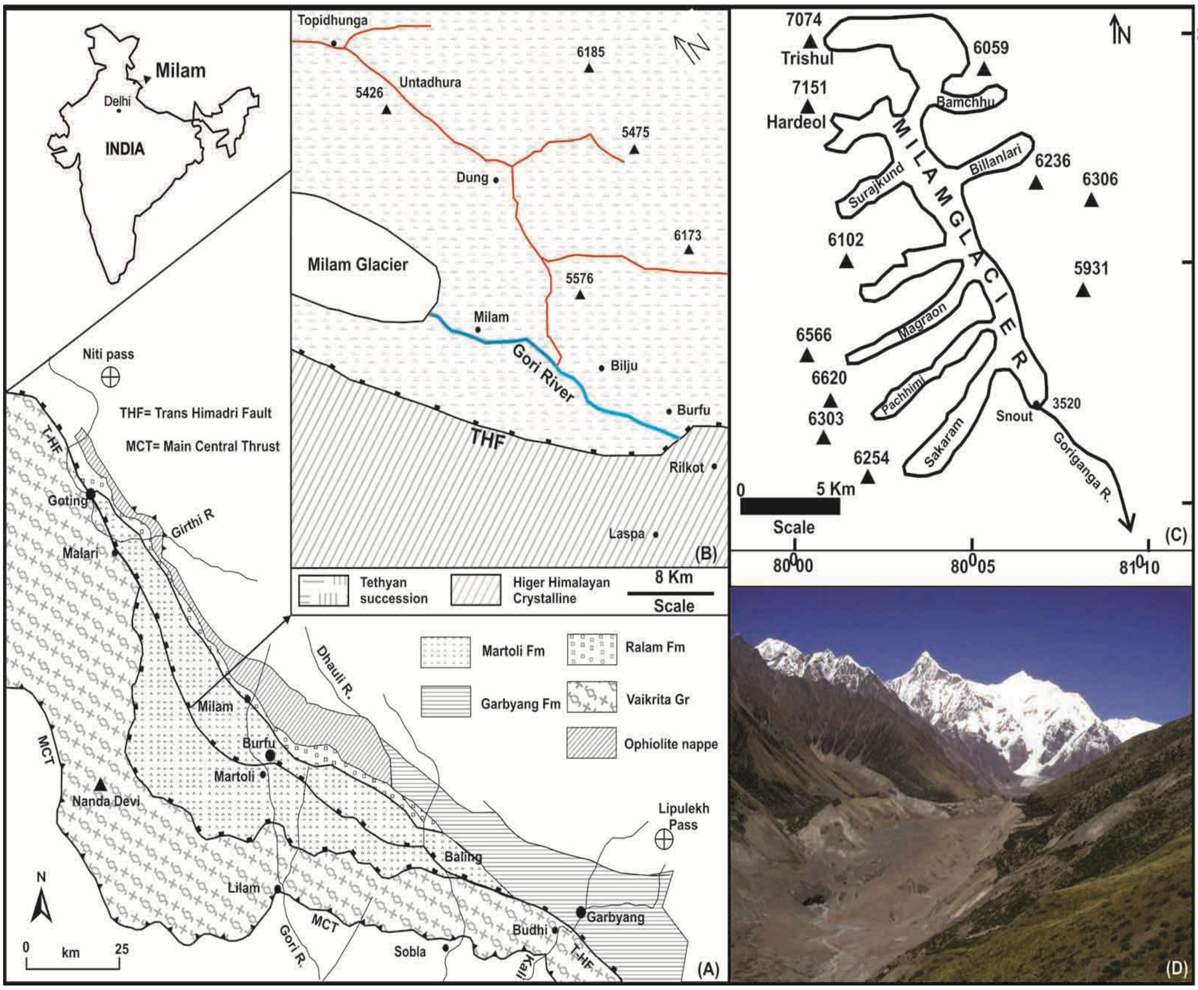

Figure 1. (A) Geological map around THF; (B) Detailed geology around Milam glacier. River Goriganga [20] is shown in blue colour while the drainage in the upper reaches is indicated by red colour; (C) Main trunk of Milam glacier along with its tributary glaciers; (D) A glimpse of the Milam glacier.

III. Methodology

Our study was focused on the assessment of recession rate of Milam glacier using Global Positioning System (GPS), a well known method for its ability to determine the highly precise coordinates of a point on the earth's surface. The most useful modes are static, fast static and kinematic. We used the Kinematic mode which is a relative positioning method in which one antenna with a receiver are stationary and other antenna with a receiver moving and provides accuracy of cm level. This method is especially significant for the glacier studies. In Kinematic mode, we used a pair of Leica SR 520 GPS receivers and AT502 antenna for two consecutive years (September 2004 and September 2005). The snout location of the glacier in both the years is shown in Figure 2. During the survey, one local base station ($30^0 27'51''$ N: $80^0 07'02''$ E) was installed on the bedrock towards the east of the snout (Figure 3A). The baseline between the base station and the snout is about 2 km. The active (frontal) part of the glacier including the snout was mapped through the rover station. The data in both the receivers were collected with observation rate of 5 seconds. The base station contained one each antenna and receiver, whereas, the rover contained an antenna fixed at the top of an iron rod and connected to the receiver through antenna cable and this was moved along the snout (closest possible track varying from 1 to 5 m from the glacier snout) in the frontal part of the glacier. This survey track was maintained at the same distance from the glacier boundary in both the years (2004 and 2005). The survey track was set in a way that at least four satellites were visible at both the receivers, recording the carrier phase observations continuously. The relative position was achieved from one phase observation from four satellites [21]. To achieve the accuracy, horizontal < 1 cm and vertical < 10 cm [22], at least ten observation epochs were recorded. The generated data were processed using Leica SKI-PRO 3.0 software with parameters as cut-off angle as 15°, broadcast ephemeris with automatic selection of solution type and frequency. For the analysis, tropospheric model of Hopfield[23] was used and position coordinates were obtained in WGS 84 coordinate system. The position quality defined as

RMS of standard deviations of *X* and *Y* coordinates was also calculated [13]. The recession rate was estimated by differentiating the point coordinates of the observed surveys in 2004 and 2005. During the survey, the antenna was moved along a prefixed survey line at about 1–5 m (measured using a steel tape with mm-level accuracy) from the snout surface in both the years to avoid accidents due to continuous ice and debris fall. The Geometric Dilution of Precision (GDOP) and position quality were found linearly correlated (R^2 = 0.78). To reduce this error, all GPS observations with GDOP > 8 were discarded in the final analysis, which maintained the position quality of centimeter level.

Figure 2. Photographs showing snout positions of Milam glacier in (A) 2004 and (B) 2005.

IV. Results And Discussion

Presence of geomorphological features associated with glacier recession indicates extension of glacier up to Bugdiyar village (34 km downstream of the snout) perhaps in the Pleistocene. Based on shape of the valleys and other evidences, Ahmed[24] suggested that even during the peak advancement, this glacier did not extend beyond Bugdiyar village. At present, the glacial activity is mostly limited to near the snout of glacier, but a part of recession can also be observed through the palaeo glacier marks on the valley walls. Due to vertical recession or excess melting of glaciers, huge load of sediment can be noticed on the surface of glacier (Figures 3 B-C). In addition, the crevasse are found throughout the snout (Figure 3D).The reccession rate of the Milam glacier in the frontal part is measured by GPS in the Kinematic mode. The recession is maximum towards the northwest of the main trunk (Figure 4). This is most likely influenced by the melt-water and dissolution of the ice caves. The minimum recession in the frontal part is observed towards the southern side, whereas, north or northeast parts (active part) register moderate retreat (Figure 4; Table 1).

The maximum reccession of approximately 28 m is observed near the central segment of the snout. However, a minimum recession of 1.7 m is observed towards western side which may be due to the closeness of valley wall. However, the northeastern side of the frontal part shows a recession range of 6.7-13.2 m/yr. Based on the mean values of all the points, the average recession rate is calculated as 9.54±1.3 m/yr. The recession observations by earlier simple and traditional methods are presented in Table 2, indicating a mix up of the recession rate during last several decades. Based on the conventional geomorphological evidences, the higher recession rate is observed as about 30.3 m/yr only during 1966–1997 (see Table 2). By combining all the earlier results, it can be suggested that the Milam glacier was receded with an average rate of 16.1 m/yr between 1849–1997 (Table 2). Comparatively lower recession rate in our study may be a result of a narrow groove in the main trunk. Nevertheless, our study with comparatively more accurate measurments by the GPS technique is the first in the Milam glacier. On the other hand, the measurments are based on only one year interval and long time monitoring of snout will open more realistic picture about the recesion of the glacier.

Figure 3. (A) Base station ($30^0 27'51''$ N: $80^0 07'02''$ E), installed on the bedrock towards east of the snout; (B) and (C) Palaeo glacier level and huge sediment load on the glacier surface, formed due to the shrinking of glacier; (D) Crevasse, a characteristic feature associated with glaciers.

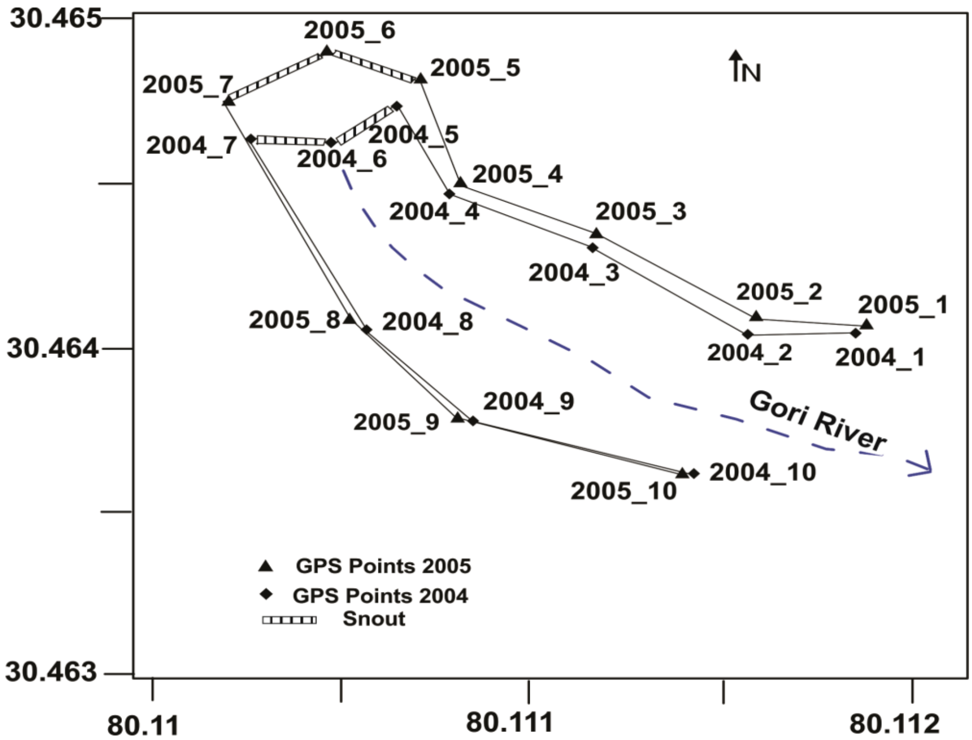

Figure 4. Survey lines Indicating recession in the Milam Glacier during 2004 and 2005.

Table 1. GPS derived recession rates at various points in the frontal part of the Milam glacier.

Point_code (Year_point)	Point coordinates		Position quality	Deviation in X (d X)	Deviation in Y (d Y)	Recession rate year^{-} (m) ± error
	Northing (X)	Easting (Y)				
2004_1	945393.468	5423583.445	0.4435	3.859	5.4793	6.702 ± 0.91
2005_1	945397.327	5423588.924	0.7949			
2004_2	945434.551	5423567.72	0.3058	4.5352	7.6284	8.875 ± 1.16
2005_2	945439.0862	5423575.348	1.1241			
2004_3	945499.5518	5423555.674	0.2687	7.1972	7.2539	10.219 ± 0.78
2005_3	945506.749	5423562.928	0.7352			
2004_4	945531.9031	5423536.79	0.4534	9.9081	8.6409	13.147 ± 0.96
2005_4	945541.8112	5423545.431	0.8515			
2004_5	945545.5405	5423521.218	0.3599	13.0144	12.8287	18.274 ± 2.18
2005_5	945558.5549	5423534.047	2.153			
2004_6	945560.0611	5423503.13	5.0553	21.7418	17.5604	27.948 ± 5.50
2005_6	945581.8029	5423520.69	2.1722			
2004_7	945550.5521	5423519.701	0.856	13.6807	11.7222	18.016 ± 1.22
2005_7	945564.2328	5423531.424	0.864			
2004_8	945584.2081	5423515.942	2.0577	1.158	1.2545	1.707 ± 2.23
2005_8	945585.3661	5423517.196	0.8682			
2004_9	945558.1027	5423552.029	1.178	0.2598	2.0445	2.061 ± 1.40
2005_9	945558.3625	5423554.074	0.761			
2004_10	945532.4637	5423570.523	1.7222	-0.2309	1.9612	1.975 ±1.88
2005_10	945532.2328	5423572.484	0.7639			
Mean				**5.8662**	**7.44115**	**9.546 ± 1.31**

Table 2. Recession rate in the Milam glacier as estimated in the previous studies.

Duration	**Years**	**Total recession (in meters)**	**Recession rate (m/yr)**	**Reference**
1849-1906	57	732	12.84	[25]
1906-1938	32	512	16	[26]
1938-1957	19	182	9.57	[27]
1957-1966	9	106	11.77	[28]
1966-1997	31	940	30. 32	[29]
2004 -2005	1	9.54	9.54	Present study

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