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MASS BALANCE OF LIDDAR GLACIERS

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ABSTRACT : The paper is mainly based on field observations carried out to study the mass balance of Liddar glaciers, particularly of Kolahoi and Shishram glaciers. The data on the mass balance were obtained by direct measurements of accumulation and ablation on the glaciers over a period of one year between April 1983 to April 1984. This paper deals with the procedure adopted and the results obtained for mass assessment of glaciers. The study reveals that Kolahoi and Shishram glaciers have net negative balance of 3.15 x 10^6 m^3 and 2.85 x 10^6 m^3 in terms of water equivalent respectively. Due to the negative balance the snout of two glaciers are retreating.

INTRODUCTION

There are nearly 15000 glaciers in the Himalayas, extending from Kashmir in the west to Sikkim in the east. The Western Himalayan glaciers contribute nearly 70 per cent of the annual flow of the major rivers of northern India in the form of meltwater and the Eastern Himalayan glaciers contribute relatively less due to high snowline and intense monsoons (Bhandari and [Nijampurkar (1981)]. On an average a Himalayan glacier produces 0.1 cubic kilometre of water during the summer season. This is of great economic value, as the melting reaches its maximum in the season when the non-perennial (seasonal) rivers dry up. There has been a general retreat of glaciers in the Himalayas since the middle of last century (Mayeswski and Jeschke, 1979; Tewari, 1971 and Raina, 1971). This is analogous to the global retreat of glaciers due to an increase in warmth and decrease in snowfall in the catchment areas. Due to these changes there has been a net reduction in the thickness and length of glaciers which have ultimately affected the rate of meltwater production and geometry of the channels. Liddar valley glaciers are also experiencing perceptible and measurable fluctuations. The largest of the Liddar glaciers (Kolahoi) has retreated nearly 2 kilometres from its snout position of 1857 A. D. (Neve, 1910 and Odell, 1963). The fluctuations have been documented on the basis of historical records, notes and photographs. Mayewski et. al. (1980) have attributed the fluctuation in the glaciers to monsoonal winds and variations in temperature and precipitation regime.

The purpose of this paper is to evaluate the overall condition of Liddar glaciers from its mass balance measurements and also assess its ablation potentialities from the discharge and climatic parameters.

The Liddar valley occupies the south-eastern part of the giant Kashmir Himalayan synclinorium and forms part of the middle Himalayas. The Liddar valley lies between the Pir Panjal range in the south, the North

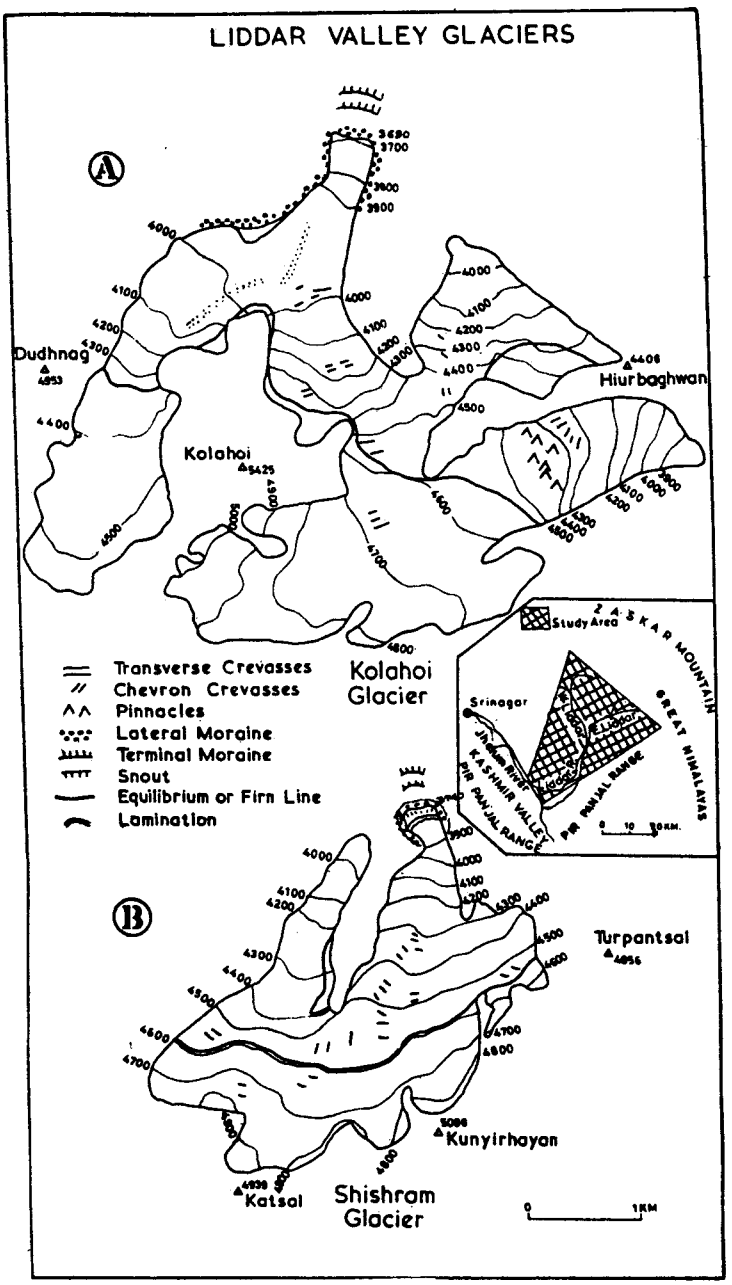


Fig. 1

Kashmir range in the main Himalayan range in the northeast and Zaskar range in the northwest (Fig. 1). The area gradually rises in elevation from south (1600 metres) to north (5500 metres). The Liddar valley is girdled on three sides by lofty ridges; the Sari bal – Katsal ridge (4800 metres) on the east, the Wokh bal (4200 metres) on the west and Basmai-Kazimpathlin bal (4800 metres) in the north. The interior of the northern part of the Liddary valley has a concentration of high mountain ridges like Dadwar (3560 metres), Kolahoi (5425 metres) and Kunyirhayan (5000 metres) which run parallel to the course of the river. There are nearly 17 glaciers in the Liddar valley ranging in length from 0.1 to 6 kilometres and are located near the ice-fences of the north and the east. In order to understand the general characteristics of all the 17 glaciers, the two glaciers : Kolahoi and Shishram have been selected for sample survey.

KOLAHOI GLACIER (WEST LIDDAR GLACIER)

The Kolahoi glacier is the largest in the study region. It is 6.5 kilometres long and 300 metres wide at the snout located at an altitude of 3690 metres above sea level. The glacier headwall is at an altitude of 5425 metres above sea level in Kolahoi mountain, located between the two peaks Dudnag (4925 metres above sea level) in the west and Hiurbagwan (4889 metres above sea level) in the east (Fig. 1A and 2). The glacier proper begins at an altitude of 5000 metres above sea level from the Kolahoi mountain and descends in deep trough through two branches, the right branch is irregular and shrinking and left massive and sub-divided into two lobes by pronounced central depression. Both these lobes merged together near an ice fall at an altitude of 4000 metres above sea level. The glacier has northwest trend line and its surface is slashed by crevasses along eastern margines (Fig. 2). There are small caves along the eastern margin of the snout which testify large scale meltwater production. Along the western margin there is extensive debris with ogives and crevasses (Fig. 2). There are two meltwater outlets, the most easterly having recently been developed by the glacier (Fig. 1A and 2). These meltwater channels have their origin in central depression at an altitude of 4100 metres above sea level. The snout is flanked by a series of fresh moraines

Fig. 2

Kolahoi glacier snout (a) slashed by Crevasses along the eastern margin (b) extensive mass of ogives (basalt dust) on the western margin (c) and easterly meltwater outlet.

which marks its northern extension in early times. The southern limit is marked by glacial horn at Kolahoi peak. The firm limit to which the winter snow recedes during the ablation season has been observed at an altitude of 4500 metres above sea level in the east and at 4400 metres in the west. It is somewhat irregular. During the accumulation season the glacier advanced to an altitude of 3400 metres above sea level. This line coincides with deposition of annual deteriatal material in nearby filled up lake. By 1984 the glacier had retreated to an altitude of 3690 metres above sea level, a distance of 210 metres. The snout has narrowed and moved away from lateral low moraines by a similar distance.

SHISHRAM GLACIER (EAST LIDDAR GLACIER)

The glacier originates in Kunyirhayan Cirque at an altitude of 4900 metres above sea level. The main ice field is on the eastern side of the peak and glacier descends from it by ice fall to a large basin where it meets the tongues of two glaciers from smaller ice fields. From this basin the glacier descends towards northwest and joins the Harnag glacier near Zamtirnag (Fig. 3). The Shishram glacier is 5 kilometres long and 230 metres wide near Zamtirnag, terminus. The terminus is located at altitude of 3740 metres above sea level. Shishram glacier is characterised by presence of sharply serated ridge along its southern and eastern side and prominent glacial horn at Kunyirhayan peak (Fig. 1E). The glacier has lobate form and protrudes from northwestern side of Zamtirnag Cirque at an angle of 45^{o}. The glacier is slashed by transverse and chevron crevasses between altitude of 3900 metres above sea level and 4600 metres above sea level. Near the snout ice reveals characteristic laminated structure from which individual laminae move out differentially (Fig. 3). The snout is flanked by lateral moraines on either side, but one to the west is more

Fig. 3

Shishram glacier snout and its icefield near the confluence of (a) Harnag glacier and (b) Shishram glacier (c) the snout is marked by laminated ice and (d) ice-caves.

massive and better preserved. The tip of the snout on the western side is covered by recent terminal of 8 metres height. The other two end moraines are observed near Zamtirnag mouthing (Fig. 1B).

The loose consolidate ice has been observed just near central notch at an average height of 4400 metres above sea level where ice has an average density of 0.51 gm./cm^3 and both accumulation and ablation measurements were somewhat uniform. During the winter season the snow line of the Shishram glacier advanced to 3400 metres towards the Shishramnag lake, where in early summer icebergs float. By 1984 the glacier has retreated to an altitude of 3740 metres, a distance of 505 metres from an altitude of 3580 metres above sea level in 1923.

MASS BALANCE

Mass balance is the most meaningful description of hydrological cycle of glacier and is best means of estimating the glacier movement and in understanding the glacial process. It has been most extensively investigated problem in the study of glacial geomorphology of Alps in Europe and of Rockies in north America (Hoinkes and Rudoloph, 1962; Grosval'd and Kotlyako, 1969; Mokievs, 1972 and Schytt, 1962). In contrast only a few studies on the mass balance of Himalayan glaciers have been conducted (Raina et. al., 1977; Mayewski and Ahmad, 1981 and Bhandari and Nijampurkar, 1981). Whereas in the study region no mass balance measurements have been made, the present investigation is preliminary contribution to the theme.

CONCEPT OF MASS BALANCE

Mass balance is theoretical state of glacier in which accumulation of snow and loss of ice mass through ablation tends to be equal. This state is rarely if ever attained. Mass balance in the life history of glacier at any particular time stage is either negative or positive, displaying a deficit or surplus of ice. These two conditions are the principal determinants of glacier movement while deficit result in retreat, the surplus result in advance. Advance and retreat of glacier in their own turn generate glacial process which create the erosional and depositional features in glacial geomorphological landscape (Fig. 4). The process are related to the movement and ultimately the mass balance are generated by specific climatic condition. (Nye, 1965).

ELEMENTS OF MASS BALANCE

Mass balance of glacier is mainly related to temperature and precipitation, but other micro metrological elements like radiation, humidity, evaporation and wind direction play their secondary role.

TEMPERATURE CORRELATE

The temperature is the important element of mass balance. Its variations effects the surface and basal melting of glacier and it reasonably correlates with ablation. The average summer temperature gives rough estimate about net annual ablation. Schytt (1967) evaluated that $1^{o}C$ temperature corresponds to 41 cms. of ablation. This relationship correlates closely with the field measurements in the study region. The Liddar glacier areas have an average summer temperature of $18.8^{o}C$, which corresponds

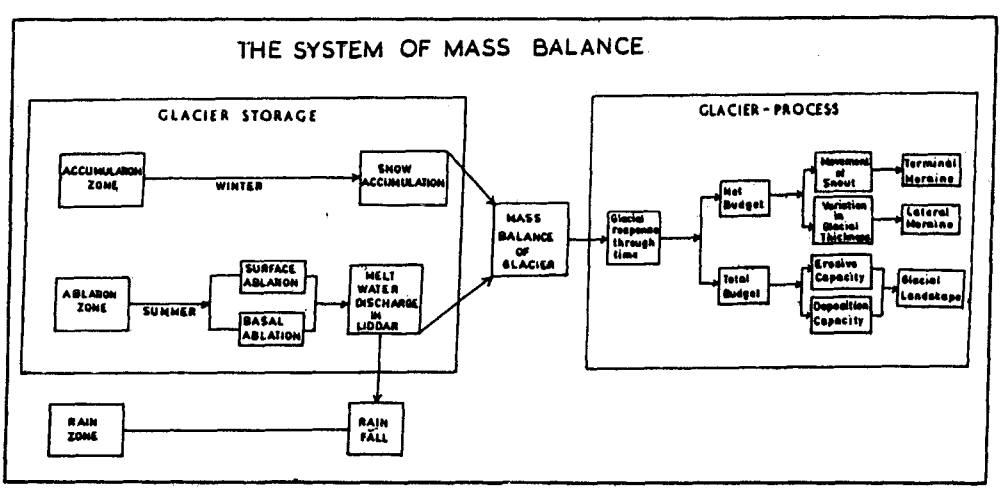


Fig. 4

to 770.8 centimetres of ablation. It is closely related to the ablation measurements recorded in the field.

PRECIPITATION CORRELATE

The precipitation has potent control over mass balance, as it brings positive change in net balance of glacier due to snow accumulation in catchment areas during winter season. The annual change in accumulation is mainly responsible for change in snout position, thickness of glacier, and length of rate of flow. The positive budget helps the glacier to advance the steep front, whereas negative budget effect a retreat of glacier and development of gentle slope. The glaciers receive very high winter precipitation with seasonal snow accumulation of 4 metres and above. It receives very little precipitation during the monsoon period. In the summer season the precipitation in the form of rainfall near the snout of glaciers of study region does not play any part in accumulation as it helps in surface melting of glacier near snout due to liberation of heat by latent heat of condensation. The snow and ice melt contribute nearly 92 per cent of the total discharge of the Liddar river. The high percentage of melt water is due to high radiation melt, accounting to 80–90 per cent of the total local balance. The maximum radiation balance recorded in the Himalayas has been 28 m.w.m.$^{-2}$ per day in August 1974.

METHOD AND RESULTS

The mass and total balance of the Liddar glaciers was measured by following methods: (1) the mass balance of glacier was measured by input-output relation of snow and ice with respect of net accumulation and net ablation. The net accumulation or winter balance was measured in terms of water equivalent volume in April 1984. Whereas net ablation or summer balance was measured in terms of water equivalent volume during summer 1983 and 1984. This value was subtracted from the net accumulation of 1984 to compute the mass balance; (2) by applying suitable climate–glacier model. The input parameters of such model were precipitation, discharge rate and temperature, whose data were created through field observation and climatic records and (3) the total balance of the present and past glaciers and their fluctuations were evaluated from historical records, moraine morphology and vegetation succession.

ACCUMULATION OR WINTER BALANCE

The field measurements of total winter accumulation were carried out at the end of accumulation season during the month of April 1984 along Kolahoi and Shishram glacier in the eastern and western parts of the Liddary valley. The most common technique adopted was by digging pits at different elevations both in glacier as well as in the adjoining areas, combined with network of snow depth sounding to assess the accumulation, density and water equivalent of snow (Ahlman, 1948 and Ostream and Stanley, 1966). The snow depth was measured by taking sounding with 4 metres long metalic rod with pointed edge through new snow to the rock of ice surface.

The sounding measurement of snow were taken for Pahalgam, Laripora, Chandanwari, Aru, Liddarwat etc. because no snowfall data was available either from meteorology department or from any other state government department. The snow pits were excavated with shovel at some of the sounding heights of glaciers to confirm their total accumulation, density and water equivalent. Few of the snow pits were dug other than glacier areas like Chandanwari, Shishnag in the East Liddar and Aru and Liddarwat in the West Liddar, to assess the density variation of snow at different

Fig. 5

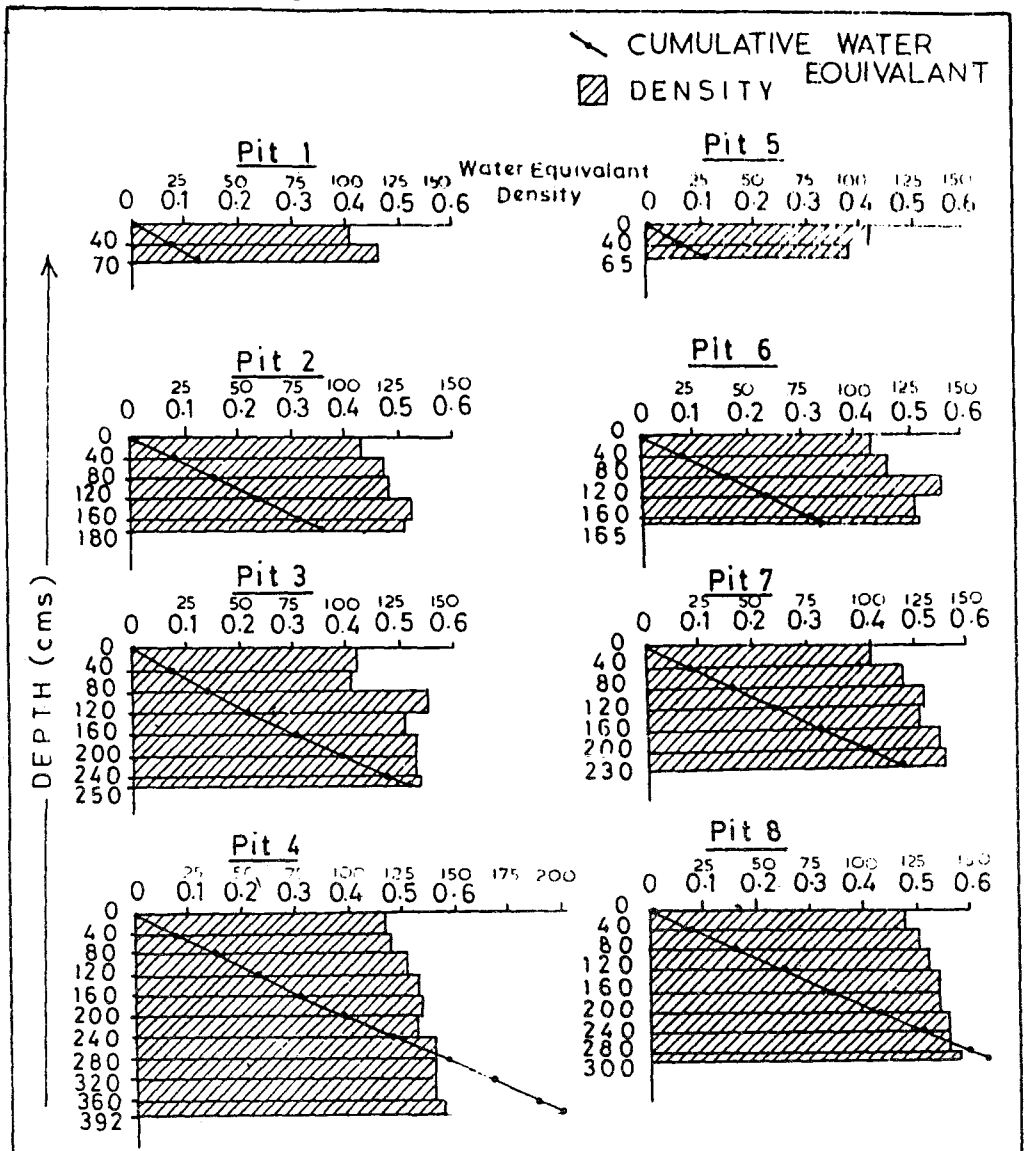
To find out the density and water equivalent of snowpeck of the Shishram glacier the known volume of snow is weighed in the field.

altitudes. The density measurements of pits were carried out by snow sampler of 40 centimetres length, by pressing it gently into the snow (Fig. 5). The sample so collected were weighed on spring balance (Fig. 5). The densities were calculated by dividing the weight by known volume of the sampler, and their water equivalent was computed by multiplying it with length of sampler. The densities and water equivalent of sample were determined both in accumulation as well as ablation areas.

The sounding and pit measurements records indicate that snow accumulation increases from 50 centimetres near Pahalgam to 3 metres near Kolahoi Ganj and Shishnag area during 1983-84 field season. The accumulation of snow in Kolahoi and Shishram glacier was very uneven and does not increase continuously with altitude. It is due to unevenness of bedrock surface and glacier surface (present of trenches and cliffs). The accumulation of winter snow in Kolahoi and Shishram glaciers ranged between 1 metre and 3.2 metres and 1 metre and 4 metres respectively (Fig. 6). The densities and water equivalent of snow also varied with accumulation. The density increased sharply from 0.41 to 0.60 gms. cubic centimetre upto the depth of 220 centimetres. Below that it remained constant. This variation was noticed in higher altitude of two glaciers around 4600 metres. It may be due to fresh snow cover. In higher altitude above 4600 metres the avalanches disturbed the stratification and made the travarse very difficult. The water equivalent of snow varied with snow accumulation. The cumulative water equivalent were computed at different depths of the pits dug in accumulation and ablation areas of Kolahoi and Shishram glaciers.

The volume of ice and its water equivalent were computed for accumulation and ablation zone of glaciers after every 100 metres contour interval. The value ranged between 50 centimetres to 2.0 metres of water equivalent. The total winter accumulation volume in Kolahoi and Shishram glacier amounted to 17.39 x 10^6 m^3 and 14.2 x 10^6 m^3 (Fig. 7). Their accumulation rate in water equivalent amounted to 1.464 x 10^6 m^3 / km^2 or 146.4 gm/cm^2 and 1.430 x 10^6 m^3 / km^2

or 143 gm/cm^2 respectively. The difference in the rate of accumulation in the two glaciers seems to be variation in accumulation areas over the whole length of glacier. The upper transverse profile above the quilibyium line at 4500 metres in two glaciers suggests that the Kolahoi glacier has lesser area in accumulation zone than the Shishram glacier, which reflects large accumulation in the latter.



Depth – Density Relationships in Snow Pits

Fig. 6

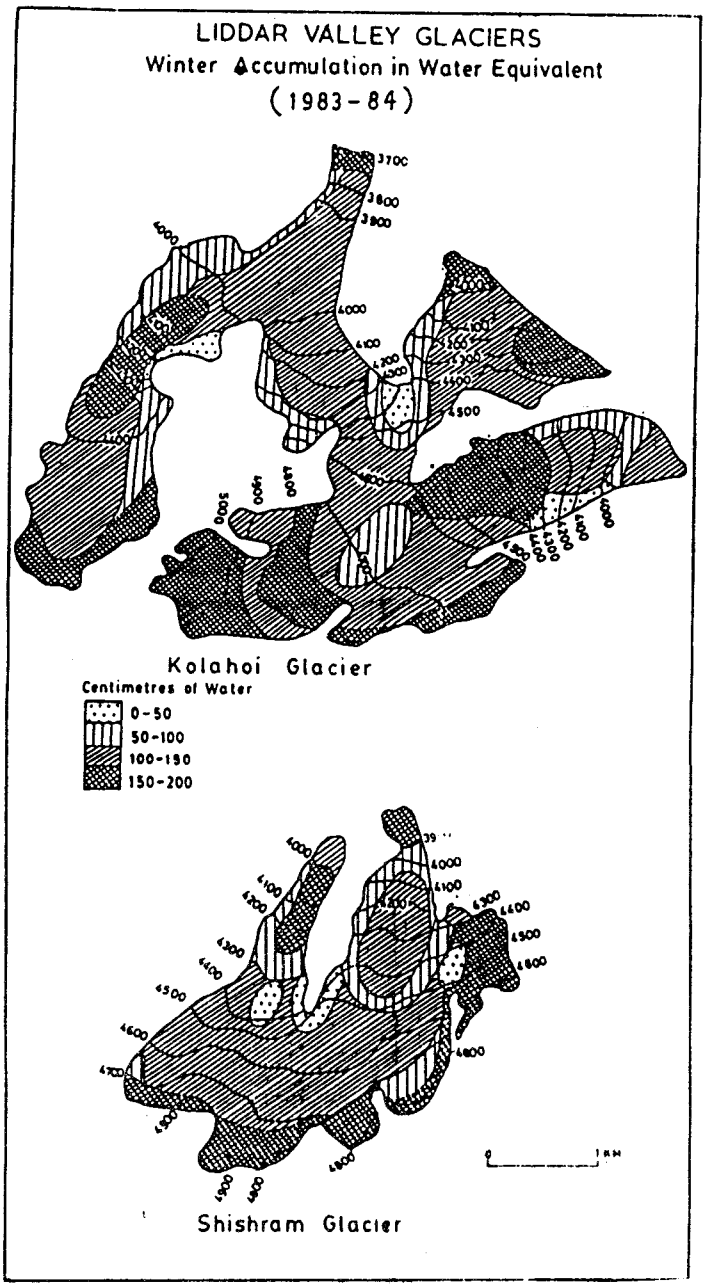


Fig. 7

ABLATION

The loss of ice and snow from the glaciers resulting from their melting during the summer season is termed ablation. Ablation is a function of air temperature, hence, it varies with altitude. It is large in the lower and smaller in the higher altitudes and lowest near the highest altitude of glacier. It is of two types : surface and basal.

SURFACE ABLATION

High air temperature prevalent in summer is the season of surface melting of glacier. Meltwater plays important part in lubricating the bed of glacier. The surface ablation values of Kolahoi and Shishram glaciers were measured during Aug.-Sept. 1983 field season by the following method. Ten stakes each 3 metres long with metallic ends were vertically driven through the surface. Hot water was poured around the stakes and snow and ice were packed around them so that they would freeze in place. These ten stakes were distributed in 'S' form so that most of them were planted in ablation zone and few in accumulation zone of the glacier. The stakes were kept under constant observation. The initial height of the stake above the ice surface was measured on 10th August in Shishram glacier and on 4th September in Kolahoi glacier. After three days the second measurements were taken. It was found that many stakes were leaning forward on the ice surface due to constant wind coming down from the ice field. Those which were leaning forward were adjusted to their original position. The height of the adjusted stake above the surface was measured and, later, the stakes were hammered down to a depth which they cannot be driven. After a gap of

TABLE 1 : SURFACE ABLATIONESTIMATES OF KOLAHOI GLACIER (WEST LIDDAR), 1984

Stakes	Ablation Stake Measurements				
	4th Sept. Initial Length	7th September		10th Sept. Adjusted Length	Ablation
		Adjusted Length	Initial Length		
2	143.7	156.7	–	–	13 cm. (4– 7 Sept.)
9	132.8	142.8	140.5	170.0	39.5 cm. (4–10 Sept.)
8	125.4	133.7	131.8	156.3	32.8 cm. (4–10 Sept.)
6	153	170.4	–	–	16.7 cm. (4– 7 Sept.)
4	Metal Stake Lost				
3	140.6	151.2	148.6	179.2	41.2 cm. (4–10 Sept.)
7	137.2	–	140.2	148.3	8.1 cm. (7–10 Sept.)
1	119.7	134.1	–	–	14.4 cm. (4– 7 Sept.)
5	122.9	135.6	145.1	169.6	37.2 cm. (4–10 Sept.)
10	96.65	106.55	–	–	9.9 cm. (4– 7 Sept.)

Average ablation rate during:

i) 4th Sept. to 7th Sept. = 3.1 cms.
ii) 4th Sept. to 10th Sept. = 6.4 cms.

three days (on 16 August and 10 September) the height of the adjusted stakes were again measured for the third time in Shishram and Kolahoi glaciers respectively. The difference between the adjusted and the initial length gives the measurement of the extent of ablation. The data is presented in Table 1.

The ablation data shows that as the mean daily temperature increased by $3^{o}C$ from the first period of four days to the second period of three days the rate of ablation also increased from 3.0 cms. to 6.4 cms. respectively (Table 1). This relationship approximates that of Schytt determined on Stos glacier in Sweedish Lapland. Schytt (1962) found that $2^{o}C$ rise in temperature doubled the ablation rate.

SUMMER BALANCE

The movement of glaciers is related to the basal movement of ice. The ice tends to flow faster in summer than in winter because of increased lubrication of the bed of the glacier by surface melting which percolates down the side of glacier in summer due to high radiation melt. The summer ablation of Shishram and Kolahoi glaciers were measured by network of stakes fixed over the two glaciers as explained in the discussion of surface ablation measurements and also by observing the pits already dug during the April field season. Some of the new pits were dug into accumulation zone during August/September 1984 season as well as in ablation zone. In ablation zone the blocks of ice were excavated by ice axe, at different sites to measure their density by weighing the known volume of ice with the spring balance. From these pits the ablation was measured in water equivalent from densities and also it was computed from the values of net reduction in the surface level of ice recorded by stakes in the surface and the basal ablation (Table 1). The ablation measurements were taken after every 100 metres in height. The gross ablation in Kolahoi and Shishram glaciers varied between 20.54 x 166 m^3 equivalent of water respectively. Their ablation rate also varied between 1.73 x 10^6 m^3/km^2 or 173 gms./cm^2 and 1.715 x 10^6 m^3/km^2 or 171.5 gms./cms.^{2} respectively (Table 2).

BALANCE

The Kolahoi and Shishram glaciers reveal greater ablation rate than that of accumulation rate. The net balance values were obtained by substracting the ablation from gross accumulation. Both Kolahoi and Shishram glaciers reveal a negative balance of 3.15 x 10^6 m^3 and 2.85 x 10^6 m^3 respectively. It shows that during 1983-84 budget season the Kolahoi and Shishram glaciers had a negative balance rate of 0.265 x 10^6 m^3/km^2 or 26.5 gms./cm^2 and 0.287 x 10^6 x m^3/km^2 or 28.7 gms/cm^2 respectively (Table 2). The negative mass balance of the glaciers have resulted in retreat of glacier snouts. The Kolahoi and the Shishram glacial snouts have retreated 3.5 and 3.0 metres respectively from the reference points marked in the field during 1983. The retreat suggest that Kolahoi has greater ablation rate than the Shishram. This is due to black basalt dust covering the Kolahoi glacier and promoting larger volume of melting.

HYDROLOGICAL MODEL

The changes in the mass balance of Liddar glaciers in general and the East and West Liddar glaciers in particular were evaluated by hydrological model (Paterson, 1969 and Mayewski, 1978). The input parameters of this model were precipitation and average discharge rate of meltwater channel. The model was applied to Aru (West Liddar), and Shishnag (East Liddar) because their meltwater directly enters through braided streams into each of their drainage basin. The annual discharge at the each station reflects the amount of glaciers melting in West and East Liddar respectively.

TABLE 2 : KOLAHOI-SHISHRAM GLACIER MASS BALANCE ESTIMATES (IN WATER EQUIVALENT), 1983-84

Elevation (Metres)	Kolahoi Glacier				Shishram Glacier			
	Area (Km^2)	Accumulation (10^6 m^3)	Ablation (10^6 m^3)	Net Balance (10^6 m^3)	Area (Km^2)	Accumulation (10^6 m^3)	Ablation (10^6 m^3)	Net Balance (10^6 m^3)
Ablation Zone								
3600 - 3700	0.107	0.194	0.228	- 0.034	–	–	–	–
3700 - 3800	0.243	0.284	0.518	- 0.234	0.248	0.446	0.616	- 0.170
3800 - 3900	0.650	0.826	1.643	- 0.817	0.467	0.520	1.102	- 0.582
3900 - 4000	0.625	1.216	3.458	- 2.242	0.465	0.365	0.969	- 0.604
4000 - 4100	1.248	1.248	2.563	- 1.315	0.625	0.888	1.487	- 0.599
4100 - 4200	1.750	2.065	3.428	- 1.363	0.630	0.883	1.496	- 0.613
4200 - 4300	1.150	1.356	2.425	- 1.069	0.816	1.192	1.950	- 0.758
4300 - 4400	1.300	1.776	2.445	- 0.669	0.925	1.554	3.192	- 1.638
4400 - 4500	1.515	2.128	2.335	- 0.207	1.755	2.204	4.282	- 2.058
Total	8.588	11.093	19.043	- 7.950	5.931	8.052	15.094	- 7.022
Accumulation Zone								
4500 - 4600	1.875	3.146	1.036	+ 2.110	1.375	1.717	0.884	+ 0.833
4600 - 4700	1.020	2.180	0.265	+ 1.915	0.925	1.650	0.698	+ 0.952
4700 - 4800	0.312	0.682	0.168	+ 0.514	1.155	1.752	0.301	+ 1.451
4800 - 4900	0.095	0.190	0.016	+ 0.174	0.525	1.036	0.072	+ 0.964
4900 - 5000	0.028	0.095	0.012	+ 0.083	–	–	–	–
Total	3.330	6.293	1.497	+ 4.796	3.980	6.155	1.955	+ 4.200
Total Mass Balance for whole glacier	11.918	17.386	20.540	- 3.154	9.911	14.207	17.049	- 2.842

The model was applied to Shishram glacier to corroborate the result obtained, as discussed earlier. Its melt water directly enters Shishnag lake through Zamtirnag stream which emerges at the terminus of the glacier. The gauging station is located at the mouth of East Liddar where Shishnag drains into the East Liddar.

The discharge at each of the gauging station reflect the amount of glacier melting and precipitation run-off. The amount of discharge reflects the result of temperature condition prevailing in glacier. Since there is no rain-gauge station near the Shishnag and Aru, the rainfall and temperature data of Chandanwari (2700 metres above sea level) has been taken as representative of two basins. The data reveals that discharge and temperature decreases with increasing rainfall because of overcast sky and low

radiation melt. In contrast the discharge peaked in hot summer, particularly in June-July when it reached 25.8 centimetres at Aru. It is due to high radiation melt and low run off rate.

The daily ablation rate has been calculated through the following steps:

1. The drainage basins of Aru and Shishnag have been divided into three physiographic zones to calculate net daily ablation (a) Ablation zone where most of melt water is produced. This zone ranges between 3400 and 4500 metres altitude. The upper limit of the zone is near the equilibrium line or summer snowline where as lower limit is near the winter snowline; (b) The rain zone of the basin lies below the altitude of 3400 metres, where summer precipitation is in the form of rain; (c) The entire basin includes the area above 4500 metres where precipitation is in the form of snow. The three physiographic zones were demarcated on the map and their areas were measured by planimeter. The areas of ablation zone in Aru and Shishnag, basins were 20.4, and 13.7, the rain zone 185.6 and 25 square kilometres and entire basin 260.5 and 55.5 square kilometres respectively.

2. The annual rainfall of Chandanwari was divided into different time periods of 365, 182, 91 and 30 days on the basis of season and temperature effectiveness. The rainfall in each period was calculated in millimeter.

3. The rainfall in each period was multiplied by the area of three physiographic zones to find out the volume of rainfall in cubic metres.

4. The average daily discharge rate in cubic metre per second was computed for different periods for Shishnag (East Liddar) and Aru (West Liddar) from gauge data (Table 3 and Table 4).

5. The total discharge in each time period was converted from cubic metre per second to cubic metre per day by multiplying the average daily discharge by 3600 x 24 and then by number of days in each period.

6. The average discharge volume in each period was calculated by substracting the rainfall volume from total discharge rate.

7. The meltwater in each physiographic zone was computed by dividing the total discharge volume found in step 6 by the area of the ablation zone.

8. Each estimate of meltwater in three zones was divided by number of days to calculate ablation rate per day.

The estimates for net balance apparently reflects the trend in fluctuation in surface melting of snow/ice in water equivalent in three physiographic zones of the basins (Table 4, Step 7). The highest estimates are found in ablation zone of glacier and the lowest in entire zone of the basin, because the former being the source zone of meltwater production and the latter the transfer zone. The total annual ablation in the East and West Liddar glacier ranged between 14.84 and 19.23 metres and 9.5 and 22.6 metres respectively. Nearly 80 per cent of this occurred during the summer season and rest in the winter season. The average daily ablation in East and the West Liddar glaciers decreased from 9 centimetres/day and 9.6 centimetres/day between the 15 May and 14 July to 2.6 cm./day between October 1983 to March 1984. This shows that more than two-thirds of the total ablation in Liddar glaciers occurred between May and July.

The above studies reveal that the glaciers in the West Liddar are ablating comparatively at faster rate than their counterpart in the East Liddar and the glaciers have overall negative mass budget. The ablation results of Shishram glacier

TABLE 3 : STEPS INVOLVED IN CALCULATING NET ABLATION RATE

– Sheshnag (East Liddar)

		Winter Period					Summer Period					
		365 days 1st Jan. to 31st Dec.	182 days 1st Oct. to 31st March	92 days 1st Oct. to 31st Dec.	90 days 1st Jan. to 31st March	30 days 15th Dec. to 14th Jan.	183 days 1st April to 30th Sept.	91 days 1st April to 30th June	92 days 1st July to 30th Sept.	30 days 15th May to 14th June	30 days 15th June to 14th July	30 days 15th July to 14th Aug.
1.	RT	1330 mm	662 mm	199 mm	463	204.5	708	478	230	164.8	162.3	98.5
2.	R	3.7 mm	3.6 mm	2.16	5.15	6.8	3.86	5.25	2.5	5.5	5.4	3.3
3.	R1 = RTx13	$0.176x10^8$	$0.085x10^8$	$0.025x10^8$	$0.06x10^8$	$0.02x10^8$	$0.09x10^8$	$0.06x10^8$	$0.03x10^8$	$0.02x10^8$	$0.02x10^8$	$0.012x10^8$
	R2 = RTx25	$0.34x10^8$	$0.15x10^8$	$0.047x10^8$	$0.12x10^8$	$0.05x10^8$	$0.17x10^8$	$0.12z10^8$	$0.057x10^8$	$0.04x10^8$	$0.04x10^8$	$0.025x10^8$
	R3 = RTx55.5	$0.75x10^8$	$0.36x10^8$	$0.1x10^8$	$0.25x10^8$	$0.097x10^8$	$0.38x10^8$	$0.27x10^8$	$0.13x10^8$	$0.88x10^8$	$0.09x10^8$	$0.054x10^8$
4.	Q (m^3/sec.)	8.5	4.56	4.0	5.1	3.8	12.5	12.8	12.3	15.4	15.8	14.2
5.	QT (m^3)	$2.68x10^8$	$0.72x10^8$	$0.32x10^8$	$0.097x10^8$	$0.098x10^8$	$1.98x10^8$	$1.0x10^8$	$0.98x10^8$	$0.4x10^8$	$0.41x10^8$	$0.37x10^8$
	Q1 = QT-R1	$2.504x10^8$	$0.635x10^8$	$0.295x10^8$	$0.337x10^8$	$0.078x10^8$	$1.89x10^8$	$0.94x10^8$	$0.95x10^8$	$0.38x10^8$	$0.39x10^8$	$0.36x10^8$
6.	Q2 = QT-R2	$2.34x10^8$	$0.57x10^8$	$0.273x10^8$	$0.277x10^8$	$0.048x10^8$	$1.81x10^8$	$0.88x10^8$	$0.92x10^8$	$0.36x10^8$	$0.37x10^8$	$0.34x10^8$
	Q3 = QT-R3	$1.93x10^8$	$0.36x10^8$	$0.22x10^8$	$0.147x10^8$	–	$1.60x10^8$	$0.73x10^8$	$0.85x10^8$	$0.31x10^8$	$0.32x10^8$	$0.32x10^8$
7.	A1 = Q1/13	19.23	4.85	2.23	2.6		14.5	7.23	7.3	2.92	3.0	2.77
	A2 = Q2/13	18.0	4.4	2.1	2.1	0.6	13.9	6.76	7.08	2.77	2.84	2.6
	A3 = Q3/13	14.84	2.8	1.7	1.15	0.38	12.3	5.6	6.5	2.38	2.46	2.46
8.	A1/days cms.	5.2	2.6	2.4	2.9	2.0	7.9	7.9	7.9	9.7	10.0	9.2
	A2/days cms.	4.9	2.4	2.2	2.3	1.2	7.5	7.4	7.6	9.2	9.4	8.6
	A3/days cms.	4.0	1.5	1.8	1.3	–	6.7	6.2	7.1	7.9	8.2	8.2
		4.7	3.2	2.1	2.2	1.6	7.4	7.2	7.5	8.9	9.2	8.9

ARU (West Liddar)

		Winter Period					Summer Period					
		365 days 1st Jan. to 31st Dec.	182 days 1st Oct. to 31st March	92 days 1st Oct. to 31st Dec.	90 days 1st Jan. to 31st March	30 days 15th Dec. to 14th Jan.	183 days 1st April to 30th Sept.	91 days 1st April to 30th June	92 days 1st July to 30th Sept.	30 days 15th May to 14th June	30 days 15th June to 14th July	30 days 15th July to 14th Aug.
1.	RT mm	1370	662	199	463	204.5	708	478	230	164.8	162.3	98.5
2.	R	3.7	3.6	2.16	5.15	6.18	3.86	5.25	2.5	5.5	5.4	3.3
3.	R1 = RTx22.4	0.31×10^8	0.14×10^8	0.045×10^8	0.1×10^8	0.045×10^8	0.16×10^8	0.1×10^8	0.05×10^8	0.37×10^8	0.036×10^8	0.02×10^8
	R2 = RTx185.6	2.54×10^8	1.21×10^8	0.37×10^8	0.85×10^8	0.37×10^8	1.31×10^8	0.88×10^8	0.42×10^8	0.3×10^8	0.3×10^8	0.18×10^8
	R3 = RTx260.5	3.56×10^8	1.72×10^8	0.51×10^8	1.2×10^8	0.53×10^8	1.84×10^8	1.24×10^8	0.6×10^8	0.43×10^8	0.42×10^8	0.25×10^8
4.	Q (m^3/sec.)	16.6	7.76	9.2	6.3	7.4	25.43	30	20.86	34.8	28.74	23.65
5.	QT (m^3)	5.23×10^8	1.22×10^8	0.73×10^8	0.49×10^8	0.19×10^8	4.0×10^8	2.35×10^8	1.65×10^8	0.3×10^8	0.74×10^8	0.61×10^8
6.	Q1 = QT-R1	4.92×10^8	1.06×10^8	0.685×10^8	0.49×10^8	0.145×10^8	3.84×10^8	2.25×10^8	1.60×10^8	0.863×10^8	0.704×10^8	0.59×10^8
	Q2 = QT-R2	2.69×10^8	0.01×10^8	0.40×10^8	–	–	2.69×10^8	1.47×10^8	1.23×10^8	0.6×10^8	0.44×10^8	0.43×10^8
	Q3 = QT-R3	1.67×10^8	–	0.22×10^8	–	–	2.16×10^8	1.15×10^8	1.05×10^8	0.47×10^8	0.32×10^8	0.36×10^8
7.	A1 = Q1/22.4	21.96	4.73	3.0	1.74	0.64	17.24	10.10	7.14	3.85	3.14	2.63
	A2 = Q2/22.4	12.0	0.04	1.8	–	–	12.0	6.56	5.5	2.68	1.96	1.96
	A3 = Q3/22.4	9.5		Nearly 1.0	–	–	9.6	5.14	4.69	2.1	1.43	1.60
8.	A1/days cms.	6.0	2.5	3.2	2.0	2.1	9.4	11.0	7.8	12.8	10.5	8.8
	A2/days cms.	3.3	–	2.0	–		6.5	7.2	6.0	9.0	6.5	6.4
	A3/days cms.	3.0	–	1.1	–		5.2	5.6	5.0	7.0	4.8	5.3
		3.8	2.5	2.1	2.0	2.1	7.0	7.9	6.3	9.6	8.3	6.8

TABLE 4 : AVERAGE MONTHLY DISCHARGE AT SELECTED STATIONS OF LIDDAR RIVER (m^3/Second), 1983

Month	Gauge Station	Gauge Station	Gauge Station
	Shishnag (3500 Metres)	Chandanwari (2700 Metres)	Aru (2400 Metres)
January	5.2	5.7	6.2
February	4.4	5.2	5.9
March	5.8	7.3	7.9
April	7.0	14.3	20.3
May	14.2	20.6	35.7
June	16.8	25.2	34.2
July	14.3	21.6	26.4
August	14.4	19.2	21.4
September	8.2	9.6	14.8
October	4.5	5.5	9.9
November	3.8	5.3	9.2
December	3.7	4.4	8.5
Mean	8.5	12.0	16.6

Source : Power Development Department, Anantnag Division, Srinagar, 1983.

computed for summer months by hydrological method closely correlate with mass balance measurement and surface ablation measurement recorded in the field.

CONCLUSION

The negative mass budget of Liddar glaciers clearly indicates that its glaciers are shrinking and retreating. Two of its largest glaciers Kolahoi and Shishram have net average retreat respectively of 3.5 and 3.0 metres annually. The different amounts of average retreat suggest that Kolahoi has greater ablation rate than Shishram. This is due to the black basalt dust covering the Kolahoi glacier and promoting a larger volume of melting. Ultimately the basalt dust reduces the albedo and increases the absorption of heat. Further Kolahoi experienced larger ablation due to small accumulation area than the Shishram.

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