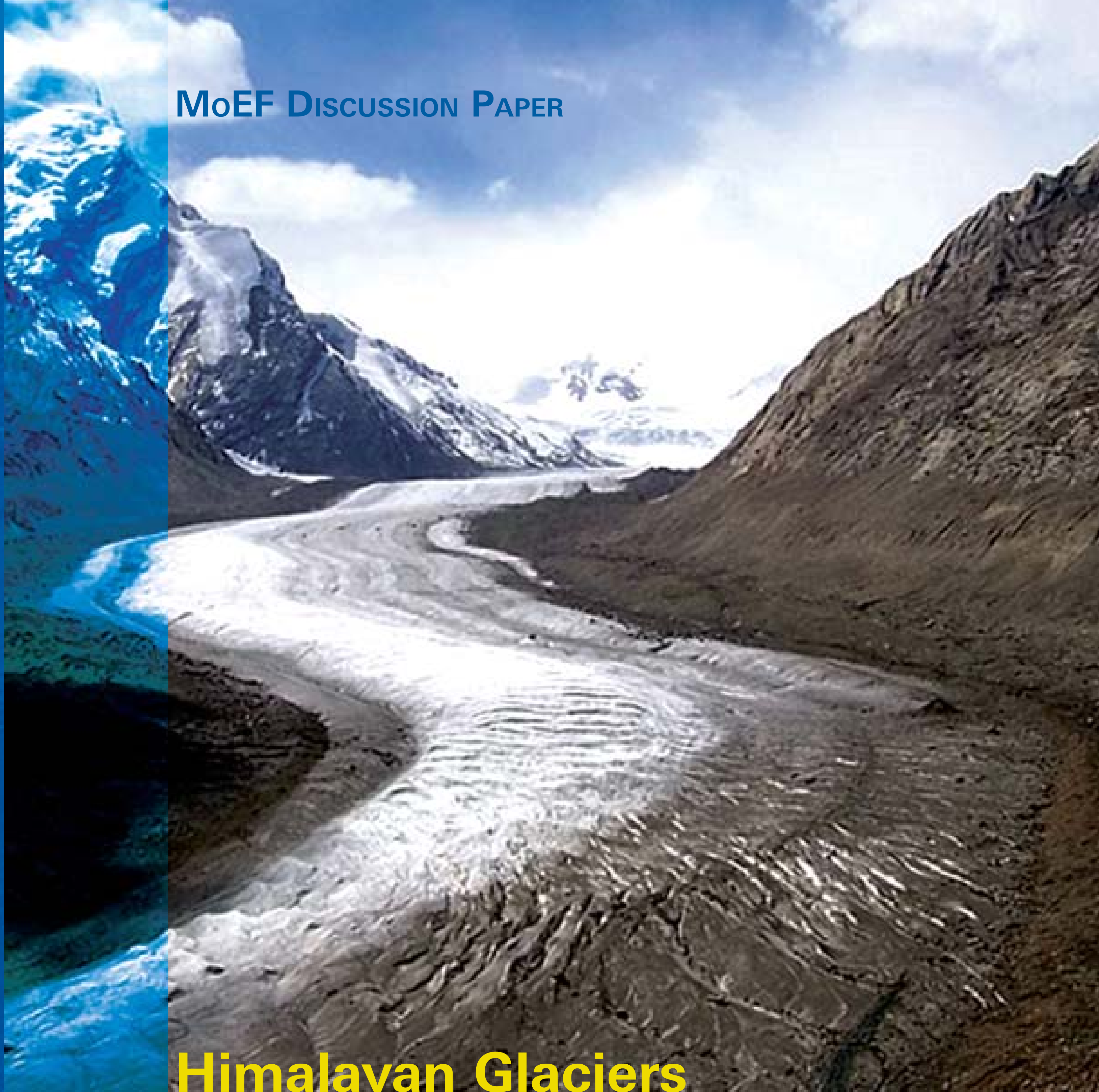
MoEF Discussion Paper



Himalayan Glaciers

A State-of-Art Review of Glacial Studies, Glacial Retreat and Climate Change

- V.K.Raina, Ex. Deputy Director General, Geological Survey of India

Ministry of Environment & Forests
Government of India

G.B. Pant Institute of Himalayan Environment & Development
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The views expressed in this Discussion Paper are not necessarily endorsed by the Ministry of Environment and Forests, Government of India.

This series is meant to serve as a basis for informed debate and discussion on critical issues related to the environment.

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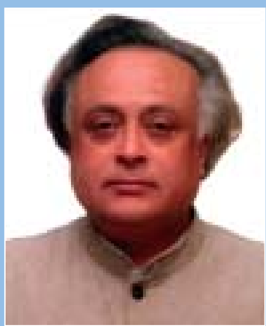
From the Minister's Desk



I am delighted to introduce the Discussion Paper: *"Himalayan Glaciers: A State-of-Art Review of Glacial Studies, Glacial Retreat and Climate Change"*. This is the first of what promises to be a stimulating working paper series that we aim to put in the public domain. The aim of this series is to encourage informed science-based discussion and debate on critical environmental issues. Each of these papers will provide an expert perspective, backed by rigorous evidence, on important issues related to the environment. The views expressed in these papers are not meant to represent the views of the Ministry of Environment & Forests, or the Government of India; instead we hope to gain useful lessons for public policy from the discussions contained in these papers and feedback received on them.

In some ways, a paper on the Himalayan Glaciers is a befitting way to launch this working paper series, as it is an issue on which there is considerable academic and popular limelight, with a number of varying points of view. Study of the phenomenon of glaciation and glacier dynamics in the Himalayas has, in recent years, attained significant attention, on account of the general belief that global warming and climate change is leading to fast degeneration of glaciers in the Himalayas. It is argued that this would, in the long run, not only have an adverse effect on the environment, climate and the water resources but also on other concerned and connected activities. This paper provides a summary of the literature, as well as some fresh analysis of the issue. An interesting point made in this paper is that while glaciers are the best barometers known to assess past climate, the same may not be true for glacier fluctuations being an accurate guide of future climatic changes.

This Paper draws upon Mr. V.K. Raina's original research conducted in the Geological Survey of India (GSI) over several decades, starting in 1956, backed by painstaking on-the-ground observations. In this age of readily available satellite imagery, Mr. Raina's epic efforts, which involved several long expeditions to remote glaciers, in trying circumstances and with limited resources, are particularly commendable. I want to sincerely thank Mr. Raina for putting this Paper together on my personal request.

It is my sincere hope that this paper, and subsequent papers in this series, will inspire critical debate. I invite you to read and challenge the ideas presented in these papers. I look forward to your feedback.

Jairam Ramesh
Minister of State for Environment & Forests
(Independent Charge), Government of India
& President, G.B. Pant Society of
Himalayan Environment & Development

Executive Summary

Background to Glacier Monitoring

Almost a century ago, fears began to be expressed about the possible impact of the rise in atmospheric temperature on mountain glaciers. The fears led to the initiation of concerted scientific efforts to identify and examine the fluctuations along the front-snout of glaciers. It was believed that such studies, over the next century or so, would enable scientists to establish the relationship between the climate change and the glacier fluctuations.

Monitoring of a glacier, in specific terminology, means the study of glacier growth or degeneration over a specific period of time, laterally, vertically and in its longitudinal profile. Monitoring of glaciers, sensu stricto, is restricted to the study of the glacier snout, i.e., the front end of the glacier. The general belief is that the snout or the lowest extremity of a glacier reflects its health. A glacier in the Himalayas, on average, moves downward at a daily rate of one to three cm along the lower limits. It was the general belief of early glaciologists that the snout, in certain respects, denoted the altitudinal level where the melting of the glacier ice caused by the increased temperature of lower altitudes balanced the glacier's downward movement. It was believed that the position of a glacier snout would undergo change - both in altitude and appearance - with changes in temperature and snow precipitation. Later studies have revealed that in reality things don't pan out that way. The regional and the local geomorphic features have been observed to have as much influence in the glacier snout fluctuations as the climatic parameters.

Glacier Monitoring in the Indian Himalayas: A Brief History

Glacier Monitoring in the Indian Himalayas started in the early 20th century, when 20 odd glaciers in the Himalayas, located across the Indian Himalayas, from Jammu and Kashmir in north-west to Sikkim in north-east, began to be monitored by the Geological Survey of India (GSI), the organisation that was entrusted with the task. The GSI began making a repository of all the data generated. The analysis showed that most glaciers were retreating or showing degenerated conditions along the glacier front. The average annual retreat was around 5m, although a few glaciers were observed to have higher retreat, such as the Pindari glacier in the Central Himalayas which was observed to have an annual retreat of 8-10m[1]. Studies also revealed that fluctuation of the glacier snout is not a simple phenomenon that can be attributed to climate change, but in fact is the result of complex regional and local phenomenon.

There was an enhanced focus on glacier snout monitoring in the Himalayas beginning the mid 1950s, which led to an improvement in the knowledge base of Himalayan ice cover and better documentation of the perennial ice masses of the Himalayas. This activity was extended - rather intermittently - till the 1970s. The glaciers covered during this period were: Siachen, Mamostang, Kumdan, Machoi in J&K, Barashigri, Sonapanii, Guglu in Himachal Pradesh, Gangotri, Arwa, Poting, Milam, Pindari, Shankalpa, Kalganga, Bamlas, Safed, Bhilmagwar, Pachu, Burphu in Uttarakhand and Zemu in Sikkim. All these glaciers exhibited continuous retreat as compared to their earlier positions, as well as considerable vertical shrinkage.

Glaciological studies received a considerable impetus and a new direction with the advent of the International Hydrological Decade (IHD) Programme in India. A systematic work plan that laid emphasis on all aspects of the glacier study was evolved under the aegis of UNESCO and International Commission on Snow and Ice (ICSI). Initially for a period of two decades (mid 1970s to mid 1990s), most of the work plan was executed by the GSI. From the mid 1980s, on the initiation and funding support of the Department of Science & Technology, Government of India, other scientific institutes and universities joined in.

Key Findings of Recent Glacial Studies in the Indian Himalayas

The studies undertaken from mid 1970s till date have revealed the following interesting findings related to the glaciers in the Indian Himalayas:

- All the glaciers under observation, during the last three decades of 20th century have shown cumulative negative mass balance[2]. Degeneration of the glacier mass has been the highest in Jammu & Kashmir (single glacier, 10 years record), relatively lower in Himachal Pradesh (3 glaciers, 10 years record), even lower in Uttarakhand (one glacier, 10 years record) and the lowest in Sikkim (one glacier,10 years record), thus clearly showing a declining trend from north-west to north-east[3].

- Irrespective of latitudinal differences, glacier melt contributes to about 25% to 30% of the total discharge of glacier ice. Maximum discharge takes place from mid-July to mid-August.
- On an average, the sediment load producing capacity of glacier ice in the Himalayas has been found to be to the order of 30 tonnes of ice per day per square km^2 during the melt season in a granite / gneissic terrain.
- Ice, forming a glacier in the Himalayas, in its vertical profile, can exhibit the characteristics of a cold glacier at certain levels and that of a temperate glacier at other levels.
- Smaller glaciers in the Himalayas - less than 5km long - exhibit an ice thickness of the order of 250m in the cirque region, and an ice thickness of the order of 40-60m along the middle regions, though some larger glaciers like Zemu exhibit an ice thickness of over 200m in the middle regions.
- An aerosol/ dust cover of $400gm/m^2$ – a thickness of about 2mm - has the maximum effect as far as melting of glaciers is concerned. This impact is maximum on north facing glaciers in the month of September. Additional thickness of dust up to 4mm does not make any appreciable change in melting. In fact thickness of dust beyond 6mm serves more as an insulator rather than a conductor of solar heat.
- Himalayan glaciers, although shrinking in volume and constantly showing a retreating front, have not in any way exhibited, especially in recent years, an abnormal annual retreat, of the order that some glaciers in Alaska and Greenland are reported[4].
- Glaciers in the Himalayas, over a period of the last 100 years, behave in contrasting ways. As an example, Sonapani glacier has retreated by about 500m during the last one hundred years. On the other hand, Kangriz glacier has practically not retreated even an inch in the same period. Siachen glacier is believed to have shown an advance of about 700m between 1862 and 1909, followed by an equally rapid retreat of around 400m between 1929 and 1958, and hardly any retreat during the last 50 years. Gangotri glacier, which had hitherto been showing a rather rapid retreat, along its glacier front, at an average of around 20m per year till up to 2000 AD, has since slowed down considerably, and between September 2007 and June 2009 is practically at a standstill[5]. The same is true of the Bhagirathkharak and Zemu glaciers.
- It is premature to make a statement that glaciers in the Himalayas are retreating abnormally because of the global warming. A glacier is affected by a range of physical features and a complex interplay of climatic factors. It is therefore unlikely that the snout movement of any glacier can be claimed to be a result of periodic climate variation until many centuries of observations become available. While glacier movements are primarily due to climate and snowfall, snout movements appear to be peculiar to each particular glacier[6].

[1] *Some of these glaciers have record of observations for over 100 years but this has not been continuous. Pindari glacier, for example, was examined 1884, 1894, 1906, 1958, 1966, 1976, 1999 and 2003.*

[2] *Mass balance is primarily determined by annual snow precipitation.*

[3] *A glacier, so far as the snout is concerned, does not respond to immediate changes in the glacier regimen. [o]A positive mass balance does not neces sarily lead to glacier advance and the negative balance to glacier retreat*

[4] *One has to realise that the snouts of the glaciers in Alaska and Greenland are close to the sea level where as that of the glaciers in the Himalayas, on an average, are around 4,000m.a.s.l[o]*

[5] *An interesting observation about the Gangotri glacier: As had been first postulated by Auden, the Gangotri glacier was believed to have once ex tended down to Jhala - about 47km down stream of its present position. It has now been confirmed, by dating (CNR dates) of the glacier landforms, that the glacier had indeed extended up to Jhala around 58ky BP.*

[6] *There may be little resemblance between the periodic movements in neighbouring glaciers of a range, even if they have the same exposure. Some times two branches of the same compound glacier; and, occasionally, one side of a glacier tongue may be advancing while the other is stagnant or even retreating.*

Chapter 1

Introduction

Global glacier cover, at present, is reported to be about 15,000,000 km² of which slightly more than 14,000,000 km² is restricted to the two icy continents of Antarctica and Greenland. Rest of the ice cover is distributed within the mountain ranges of the northern hemisphere: Alps, Rockies, the Himalayas that include the Karakoram; and also the New Zealand Alps. Distribution of the glaciers within these mountain ranges is so vast and wide that no specific latitudinal or morpho-climatic zones can be defined. Nature and number of the glacier bearing basins in these ranges has fluctuated from a much larger expanse during the Pleistocene to comparatively limited expanse at present.

Glaciation in the Himalayan mountain chain is a consequence of the last ice age-Pleistocene, two million years to date. What led to this ice age is still a matter of discussion. Many a theories have been put forward to explain the advent of glaciation and the origin of glaciers. What ever the explanation, the fact is that we did have an Ice Age. It was not a continuous phase; there were periods of cold climate with accumulation and advance of ice cover with periods of warm climate and ice degeneration. The northern hemisphere ice cover and its periodic fluctuations are now, generally, believed to be the direct consequence of the periodic instability and surging of the Antarctic ice sheet.

Glaciologists believe that there may have been as many as 21 glacial cycles during the last ice age, alternating with number of interglacial warm periods. Each successive glacial cycle, obviously, being less than the previous ones. Present era, which is attributed to the interglacial warm period, has, by and large, been the period of glacier retreat. Within the Himalayan Mountain chain, the territorial limits of India have the largest ice cover in terms of number of glaciers. These comprise glaciers varying in size from a small niche glacier to as large as 74 km long-Siachen glacier, the second largest glacier outside the Polar Regions. These glaciers are distributed within the latitudes 27°N to 36°N and longitude 72°E to 96°E. in the states of Jammu &Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. According to the compiled data, out of a total number of 10,000 or so, maximum number of glaciers- 2,053- exists within J&K state. And more than 90% (1,899) of these exist within the Karakoram ranges. Mean level of glaciation varies from 6,000m above sea level in the Karakoram to 4,600masl in Arunachal Pradesh.

Prior to going in the detail study of the glaciers in India, it would, perhaps, be proper to give a brief explanation as to what is a glacier and its characteristics?

What is a glacier?

A glacier is a large mass of ice formed by compaction and re-crystallisation of snow, moving slowly by creep down slope, due to the stress of its own weight, and surviving from year to year. The flow movement, irrespective of whether it is a few centimetres a day or, as in the case of surging glaciers, tens of metres a day, differentiates a glacier from a dead ice body.

Ice forming a glacier can derive either directly from liquid transformed to ice at the glacier surface or, as is generally the case, from the precipitation of snow and ice crystals from the atmosphere. Water vapour, which freezes on contact with the glacier surface, forms several types of ice, the most important of which is rime. It is formed when super-cooled water droplets strike a cold solid object and freeze on impact. Major contributor to the ice formation is, however, the annual snow fall-direct precipitation, which may continue, at a stretch, for months, during the winter season.

Snow that accumulates, over the glacier surface, during the previous winter, if it is not removed in the following summer, will gradually undergo a change to glacier ice. The term firn is generally applied to the snow that has survived a summer melt season and has begun its transformation to ice. Transformation of firn to ice takes place through a variety of processes, whose, over all, effect is to increase the crystal size, eliminate the air passages and thus increase the over all density of ice to any where around 0.85gcm³ to 0.90gcm³.

A normal valley glacier, in its longitudinal profile, from the head to the terminus exhibits two characteristic zones: 1. Accumulation zone; 2. Ablation zone.

Accumulation Zone

Accumulation is the addition of ice or snow to the glacier surface by snowfall, hail, drift snow, avalanche snow and the rain that freezes. The zone, over the glacier surface, where the accumulation takes place relative to the previous year's surface, is termed as the accumulation Zone. It is easily identifiable in a glacier as a clear white snow/ice surface devoid of any surface moraines.

Ablation Zone

Ablation is the loss of ice from the glacier by melting, evaporation, calving and deflation etc. The zone, over the glacier surface, within which the loss of ice takes place, as compared to the previous year's surface, is called the Ablation Zone. It is highly dirty and rubble covered and often the glacier surface is marked by melt water ponds, or even occasionally with the presence of supra-glacial lake.

Equilibrium Line

Line that theoretically separates the accumulation zone from the ablation zone over the glacier surface is called the Equilibrium Line. This line, presumably, marks the surface of the glacier where the accumulation and ablation are at par. Basically the position of the line is governed by the mass balance of the glacier. Positive balance brings down the position of this line on the glacier surface and the negative balance leads to the recession of this line on the glacier surface. Equilibrium line, in a broad way, corresponds to the permanent snow line and is used; now days, by glaciologists to identify the two zones of a glacier on satellite imageries/vertical air photographs.

The Snout-lowest extremity of a glacier

The snout-the lowest extremity of a glacier, basically, a part of the ablation zone reflects the personality and the health of a glacier. Snout of an advancing glacier is relatively clean and shows a bulging nature while that of a retreating glacier is highly degenerated. It is this characteristic feature of the

Fig. 1:
A glacier in the Himalayas with well developed accumulation and ablation zone.

Gara Glacier

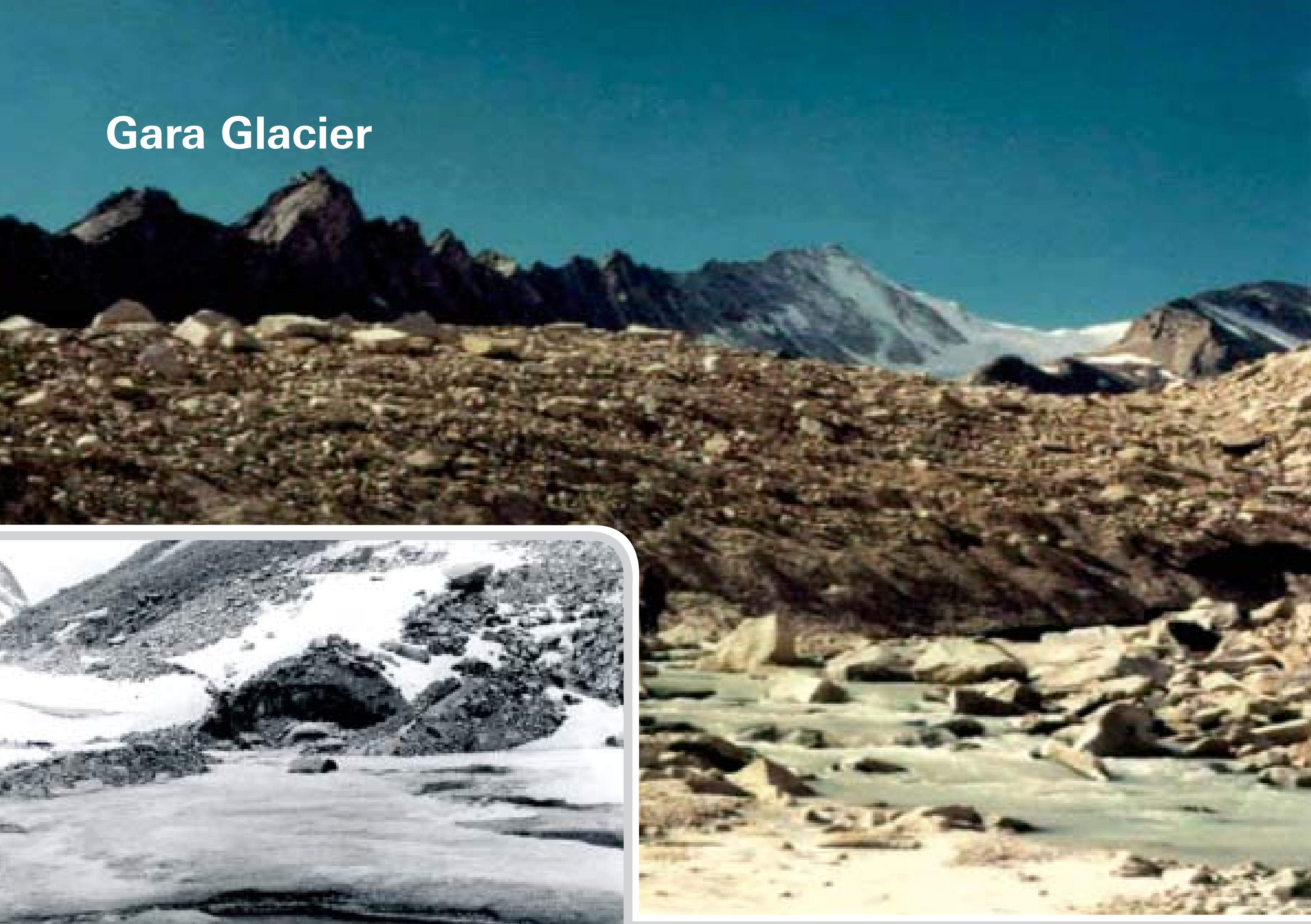


Fig. 2: Advancing and retreating snout of a small glacier, in the Himalayas (in different years)

snout that had led the glaciologists to believe that, "the snout marks the point where the melting caused by the increased temperatures of the lower altitudes balances the supply of ice from above".

The region above the snow-line on any glacier is its region of supply; below the snow-line is the region of waste. Yet during the colder months of the year on most glaciers there is constant supply and little waste taking place right down to the snout. In the depths of winter all precipitation feeds the glacier as snow, the sun has little power, radiation and conduction are consequently negligible, rain and running water non-existent. Some times, though very rarely, it may lead to a seasonal advance in winter, a seasonal retreat in summer. The summer retreat is usually accompanied by a flattening and temporary degeneration of the snout.

In the winter and spring a glacier, more than often, exhibits the nature of a steep-fronted clean glacier with the winter snow/ice covering the supra-glacial moraine; in summer and autumn the sun and rain flattens the snout by melting, and en-glacial moraine comes to the surface. These are normal seasonal signs and should not be wrongly adduced as evidence of secular or periodic movement, as they often are. Reversal of the above, i.e., when a glacier in summer shows a steep-fronted end, or in winter a flattened can be considered as evidence for periodic or secular advance or retreat.

Chapter 2

Glaciological Studies in the Indian Himalayas

The earliest record -1780 AD - of the glacier observation, in the Himalayas, is the mention of the floods caused by the Kumdan glaciers in the upper Shyok valley, Ladakh, J&K. These were followed by the sketches of the glacier fronts of Rimo glacier, Kumdan glaciers and Sonamarg glacier of J&K, and a photograph of 'Cow's mouth' (Gaumukh), snout of the Gangotri glacier, Uttarakhand, published in mid nineteenth century. A detailed report on Machoi glacier, J&K, was published in the records of the Geological Survey of India way back in 1895, probably the first publication on any Indian glaciers per se.

Glacier studies in the Himalayas, over the last 150 odd years, has evolved from simple glacier front monitoring to the more comprehensive advance studies encompassing a holistic approach, in a three phase manner:

1st phase- Early 20th century up to 1950 AD
(Based on published data)

With the formation of the International Glacier Commission at the 6th International Geological Congress in Zurich, Switzerland in 1894, the data collection on glaciers was channelled along a specific format to provide answer to two fundamental questions:

- Understanding of the complexity in the behavioural aspect of the glaciers, regional ice-cover extension and basin glacial geomorphology etc., and
- The mechanism of their secular and temporal variation in response to climate and, the process of the geologically most recent Ice Age.

Observation, identification and co-ordinating the location of the glacier, in the Himalayas, specifically the position of the glacier snouts, began in the mid 19th century. To begin with, these were initiated by explorers and free lance adventurers who were more interested in geography and accessible routes to Central Asia and Tibet than glaciology per se.

With a vast area like Himalayas to be covered, it was felt by the interested researchers of that era, that, "the work required co-operation of every one likely to visit the glacier regions of the Himalayas." In 1905 Mr. D. W. Freshfield, on behalf of the Commission International des Glaciers, brought the matter to the notice of Sir S. G. Burrard, who, in turn, referred the question of glacier study to the Board of Scientific Advice to the then Government of India. And, on the recommendation of a sub-committee comprising Col. F.B. Lange, RE, Surveyor General, Survey of India, Dr. G.T. Walker, FRS and Dr. T.H. Holland, Director, Geological Survey of India, the Scientific Board agreed on a system of observations and recommended that the Geological Survey of India should be the repository of all the data generated on the glaciers in the Himalayas. Required approval of the Government of India was accordingly issued. It will not be far from truth to state that the Geological Survey of India has been and continues to be the main architect of glacier research in India and remains to be the sole agency for maintaining the archival records of the glacier studies under taken in the Himalayas.

Systematic monitoring of the snouts of glaciers in the Himalayas–secular and annual fluctuations - was first carried out by the members of the Geological Survey of India in the year 1906.

In earlier stages, geologists of the Geological Survey of India visited a number of isolated Himalayan glaciers, from Jammu and Kashmir in the North West to Sikkim in the east, and modestly documented the parameters, which were conventional during that time. Marks were cut deeply into the rocks adjacent to the snouts of the glaciers, and cairns erected over the same for use by the future workers. Large scale maps of the snout and the adjacent area were made with the help of plane table and telescopic alidade. Photographs of the snouts were taken from various angles from different places and the position, for the purpose of future correlation, fixed vis-à-vis mountain peaks of the area.

The reports prepared contained a brief general description of each glacier, evidence of recent fluctuation, and an account of its demarcation illustrated with plates and sketch-maps. Altogether 19 glaciers were examined.

Summarised Results

In the Kashmir region, most of the glaciers were found to be showing recent retreat with some, where the previous data was available, having retreated about 100 yards (30metres) in the previous ten years. Some of the glaciers like Minapain and Hassanabad were, however, found to have advanced very rapidly

In Lahul, Himachal Pradesh two glaciers, Bara Shigri and Sonapani, which were examined in detail showed signs of retreat.

Four glaciers, in Kumaon, namely the Pindari, Milam, Shankalpa, and Poting, were examined. In all cases, except perhaps the last, when compared with the local information available, were found to be retreating. Pindari glacier appeared to have retreated by about 1400 yards (425m) in fifty seven years. The Poting glacier was found to be stationery.

In 1909 two glaciers in Sikkim, the Alukthang and Zemu, were examined. Neither of the glaciers appeared to have retreated since I899; though from the available evidence, Alukthang was thought may have retreated half a mile since 1861.

In 1912, six more glaciers in Kumaon-the Sona, Baling, Naulphu, Nipchungkang, Kharsa, and Chingchingmauri were examined and practically all appeared to be or were retreating.

The snout of the Gangotri glacier, Uttarakhand, was first time mapped in detail in 1935 and it was postulated from various geo-morphological features that this glacier had been constantly retreating.

In addition to the glaciers studied by the teams from the Geological Survey, a few more glaciers namely: Siachen, Kumdan, Mamostang, Kangriz (Gannri), Shafat, Thajwas and Kolhai in J&K; Barashigri in Himachal Pradesh; Arwa, Satopanth, Bhagirathkharak, Poting, Milan and Pindari in Uttarakhand and Zemu in Sikkim were examined by free lancers/travellers. Glaciers, in general were found to be retreating, though some were reported to have advanced during the decade of ‘30s.

The studies, during this early phase, were, by and large, restricted to the snout monitoring and glacier shrinkage observations. General belief being that the condition and the position of the snout or the lowest extremity of a glacier reflects the health of a glacier, and the position of the glacier snout was delicately poised between two main parameters: temperature and snow precipitation, and would under go change in its position-both altitude wise and in its appearance- with change in either of the two parameters. However, data generation led to some rethinking and most of the workers realised that the problem was not that simple.

The data, on glacier studies, generated during this phase, either by Geological Survey of India or by the outsiders, was, by and large, published in the Records of the Geological Survey of India, The Geographical Journal of the Royal Geographical Society, The Himalayan Journal of the Himalayan Club and also in the Journals of the Asiatic Society of Bengal.

2nd phase - From the International Geophysical Year in 1957 up to 1970 AD

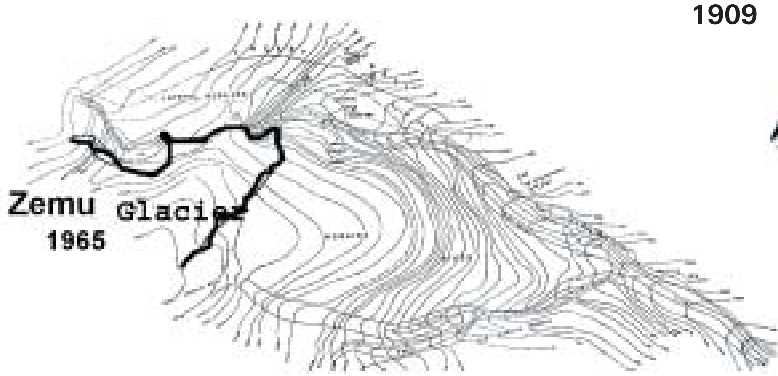
(Based on published data)

Advent of International Geophysical year, led to increase, many folds, in the activity of glacier studies all over the world, and like wise in India also. A greater thrust on a complementary and parallel observation programme of widely apart glaciers in the Himalayas during the International Geophysical year (IGY) (1957) by the officers of the Geological Survey of India (GSI) led to a better contribution and up-gradation of the knowledge of the Himalayan ice cover, and thus to an increasing awareness towards documenting the perennial ice masses of the Himalayas. This activity was extended - rather intermittently - almost till seventies. While in other parts of the world, these studies now started to cover-glacier regimen and hydrometry, in India the studies still, by and large, continued to restrict to monitoring of glacier snouts and glacier shrinkage. The glaciers covered during this period were: Siachen, Mamostong, Kumdan, Machoi in J&K, Barashigri, Sonapanii, Guglu in H.P., Gangotri, Arwa, Poting, Milam, Pindari, Shankalpa, Kalganga, Bamlas, Safed, Bhilmagwar, Pachu, Burphu in Uttarakhand and Zemu in Sikkim.

The studies, like that of the earlier phase, were restricted to plane table mapping, on large scale, of the snout position of the individual glacier, for comparison with its earlier mapped position. Conception, even though facts to the contrary had started to evolve, that the condition and the position of the snout or the lowest extremity of a glacier reflects the health of a glacier, continued to influence the work ethos.

It was in 1965 that a slight deviation - very little - but significant, in the form of assessment of glacier ice thickness by geophysical methods- Seismic and Resistivity was initiated at the Zemu glacier (Sikkim). For the first time it was scientifically established that a glacier of the size of Zemu had ice thickness of above 200m, about a kilometre up stream of the snout.

Large scale map showing the position of the snout of the Zemu glacier (1909 La Touche; 1965 Raina et al)



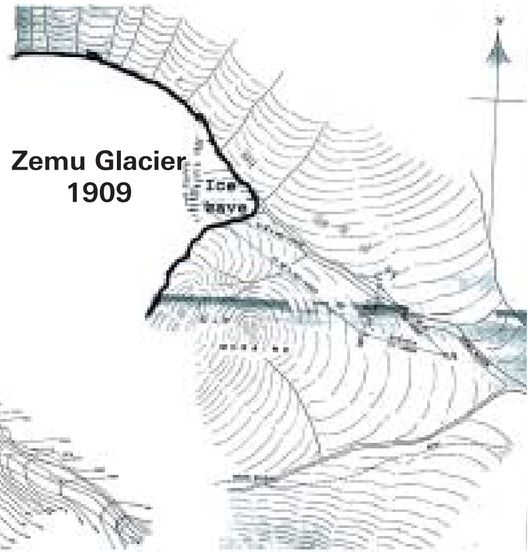


Fig. 3: Relative positions of the snout of the Zemu glacier in 1909 and in 1965

Summarised Results

All the glaciers surveyed, during this period, showed a continuous retreat as compared to their earlier positions and also a considerable vertical shrinkage. The retreat, however, varied from around average of about 5m to a very high rate for some of the glaciers in the Kumaon Himalayas (Uttarakhand).

Fig. 4: Seismic survey at Zemu glacier

Siachen glacier, as a lone case, retreated by about 400 m. between the years1929 AD and1958 AD. Rapid retreat was attributed to the degeneration of dead ice front that had developed as a result of accidental rapid advance of the snout front at the beginning of the century.

Gangotri glacier exhibited an annual retreat of around 18m during this period. It is interesting to note that some of the glaciers that had shown slight advance during the thirties were observed to have now started retreating.

Kumdan glaciers (Surging glaciers) of the Upper Shyok valley were found to be undergoing different phases of surging activity during the period of study in the year1958:

- **Aktash glacier** was advancing rapidly and was expected to cross the Shyok river as usual, but with no chance of blocking the course of the river.
- **Kichik Kumdan** glacier was found to have degenerated considerably and was in retreating phase and was already back on the west bank of the river after the earlier surge.
- **Chong Kumdan** glacier was, however, still advancing and was likely to block the river.

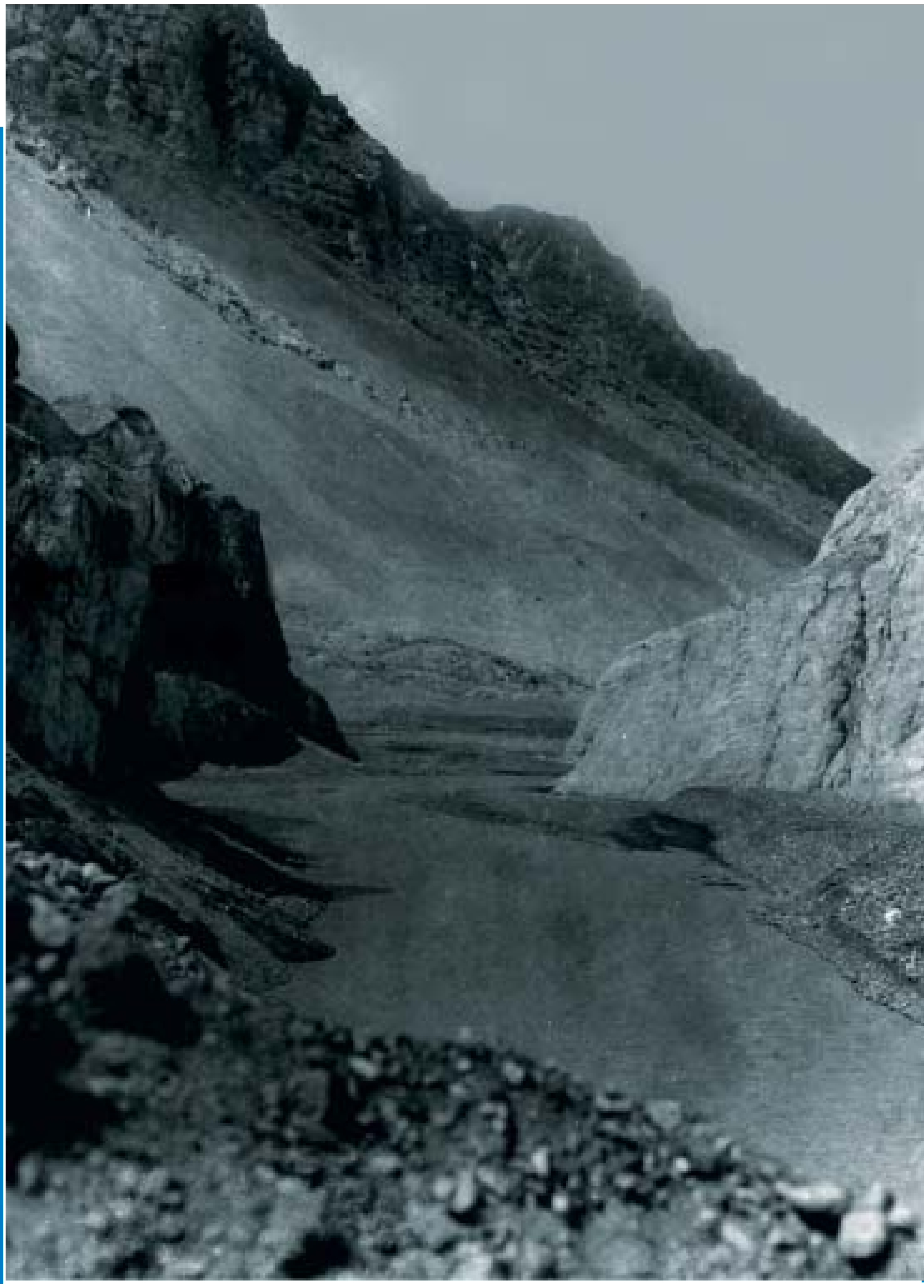
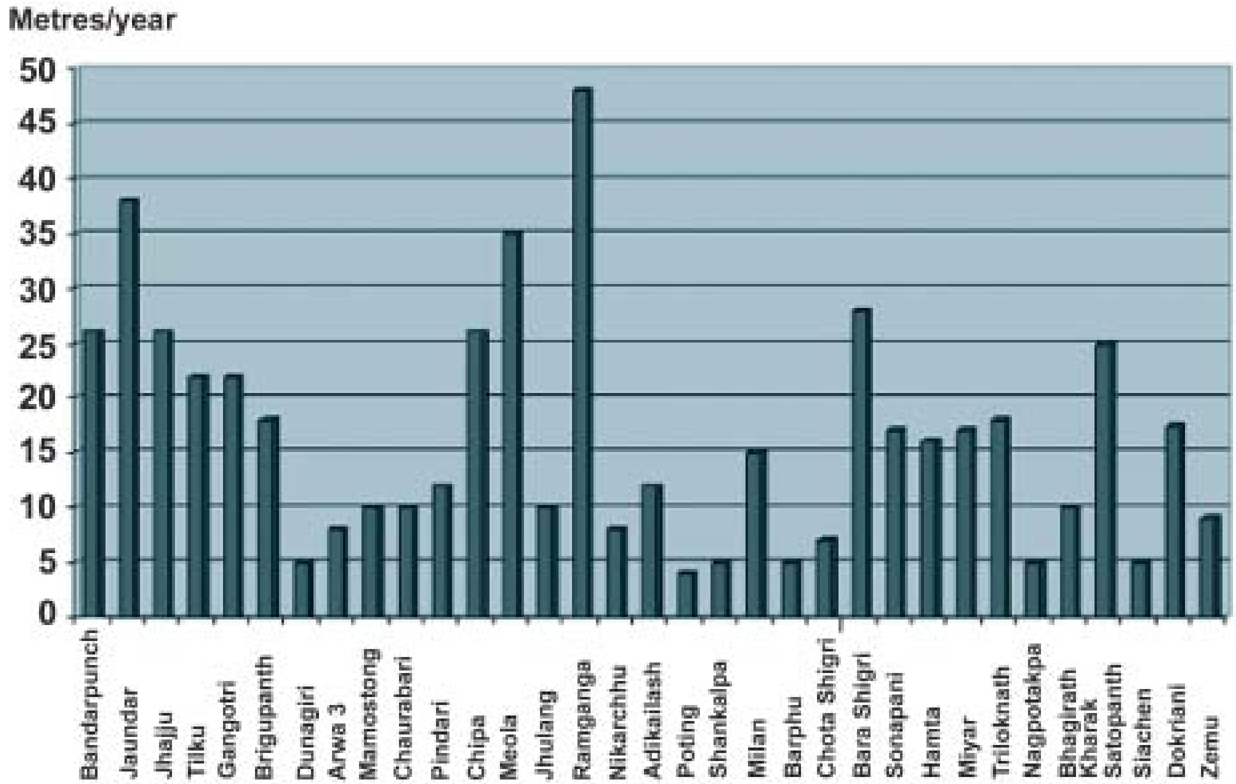


Fig.5:

Surging Chong Kumdan glacier (1958) on the verge of blocking the course of Shyok river, Ladakh, India.

Data generated in course of these studies was considerable, but, by and large, has remained confined to the archives of the Geological Survey of India as Office file report (Un-published Reports), as the work on the glaciers, for what ever the reason, was declared as classified. Brief data, if any, dealing with the work done, have, however, been published, time to time, as short papers/notes within the country and without.

Fig.6: Annual (average) retreat of some of the glaciers, in the Indian Himalayas, for which more than 20 years data is available, assessed till the end of 20th century.



3rd phase - Induction of the International Hydrological Programme - post1970

(Based on published data)

It was during the International Hydrological Decade (IHD), and later as the International Hydrological Programme (IHP), that a concerted effort was made to systematise glaciological studies in the Himalayas and, to execute the same, separate Glaciological Division, first within the Northern Region of the Geological Survey of India at Lucknow and later within the Eastern Region, at Kolkata were set up. Glaciological studies received a considerable impetus and a new direction with the advent of the International Hydrological Decade (IHD) Programme in India. One could say the glaciological studies in India came of age. It was realised that these perennial ice masses mean a huge reserve of fresh water with a tremendous potential for power production and irrigation, and consequently a systematic monitoring was essential for the proper management of these water resources.

A systematic work plan was evolved and adopted by the Geological Survey under the aegis of UNESCO and ICSI to cater to the above needs. This work plan laid major emphasis on the following aspects of the glacier study:

1. Glacier Inventory.
2. Glacier Regimen or Mass Balance.
3. Glacier Hydrometry.
4. Suspended Sediment Transport.
5. Glacier Flow Movement.
6. Monitoring of the glacier snout.
7. Geo-morphological studies of the peri-glacial zone, including the identification and mapping of the glacier landforms, to establish the extent of ice cover during the various phases of the last Ice Age.
8. Special studies like Thermal profiling of the glacier ice and artificial augmentation of glacier ice melting.

Geological Survey of India earmarked and carried out studies, as per the programme above, on as many as ten glaciers namely: Nehnar (J&K), Gara, Gorgarang, Shanegarang, Baspa (H.P.), Gangotri, Dunagri, Tipra Bamak, Chorabari (Uttarakhand) and Zemu and Changme Khangpu (Sikkim)

Summarised Results

Glacier Inventory

Inventory of the glaciers in the continuous stretch of the Himalayan Range set the ball rolling for a systematic study of the glaciers in India. Temporary Technical Secretariat (TTS} for the World Glacier Inventory (WGI) stationed in Zurich, had been entrusted the job of co-ordination of Glacier Inventory and the compilation of the World Glacier Atlas. To achieve more or less, a singular system of inventory world over, TTS devised Master Card for the recording of information for each individual glacier and also an illustrated guideline for the field workers. The first Master card of Glacier Inventory in India, produced by the Glaciology Division of the Northern Region of GSI, was that of the Baspa basin, Himachal Pradesh. A major handicap faced by the concerned scientists was the non availability of proper aerial photograph- satellite imagery was still to come in vogue- this consequently created difficulty in the proper demarcation of the accumulation and the ablation zones, the snout front and assessment of the glacier volume. TTS in their guide lines, based upon their work in Alps, had suggested various approaches to overcome these constraints, which, when applied were found to give erroneous results and hence had to be discarded.

The code for the identification of the individual glacier basin, initially, supplied by TTS had included the entire glacier bearing areas of India with in the first order basin viz: **5-Q-INDUS BASIN** and **5-O-GANGA BASIN**. Each first order basin identification procedure had been serialised up to a 4th order sub-basin. In the course of inventory it was observed that for a high rate of accuracy, even basins up to 5th order would have to be dealt with separately and in some cases, where even a 2nd order basin had only one or two glaciers, the same may have to be incorporated with the adjacent larger basin. TTS agreed to these suggestions.

Glacier Regimen / Mass Balance Study

An important aspect of the glacier study is to assess the regimen/health of the ice body, i.e. to evaluate as to whether an ice body has increased or decreased in its volume during the period of study. Assessment of the Regimen or Mass Balance, as it is generally referred to, is done by evaluating each succeeding year's glacier surface vis-à-vis its position in the previous year and or, evaluating the respective glacier surface at the end of accumulation and ablation season. Such a study helps not only in evolving the impact of climatic changes on a glacier but also the likely impact on the glacier melt water released.

Table 1: Distribution of glaciers in Indus and Ganga Basin

5-Q-Indus Basin				5-O-Ganga Basin			
Basin	No.of glacier	Glacier covered Area (km^2)	Ice volume (km^3)	Basin	No. of glaciers	Glacier covered Area (km^2)	Ice volume (km^3)
Ravi	172	193	8.04	Yamuna	52	144	12.20
Chenab	1,278	3,059		Bhagirathi	238	755	67.02
Jhelum	133	94	206.30	Alaknanda	407	1,229	86.38
Beas	277	579		Ghagra	271	729	43.77
Satluj	926	635	3.30	Tista	449	706	39.61
				Brahmaputra	161	223	10.00
Upper Indus	1,796	8,370	36.93				
Shyok	2,454	10,810					
Nubra	204	4,288	34.95				
Giligit	535	8,240					
Kishenganga	222	163					
			73.58				
	7,997	36,431			1,578	3,787,00	259
Total number of glaciers: 9,575 (Nine Thousand Five Hundred and Seventy Five)							

The first ever glacier of which Mass Balance studies were carried out in India was the Gara glacier in Himachal Pradesh. Studies were carried over a decade from 1974 onwards. Subsequently, nine more glaciers were under taken by GSI for such studies. Glaciers selected were of different orientation and from different latitudes within the states of J&K, H.P., Uttarakhand and Sikkim.

Table 2: Net Mass Balance, in millions of cubic metres of water equivalent recorded for some of the glaciers in the Himalayas.

Name	74-'75	75-'76	76-'77	77-'78	78-'79	79-'80	80-'81	81-'82	82-'83	83-'84	84-'85	85-'86	86-'87	87-'88	88-'89	89-'90	90-'91
Nehnar	...	0.41	0.78	1.47	0.91	0.56	0.81	0.30	0.02	0.79							
Gara	(+)2.50	(+)1.30	4.33	4.63	3.45	3.57	1.03	(+)0.33		...							
Gorgarang	...	...	1.36	1.22	0.50	0.99	1.97	(+)0.53	(+)0.10	1.53	0.85						
Shaune Garang								1.19	(+)0.11	3.94	3.15	1.05	3.93	3.10	(+)1.68	1.35	4.10
Dunagiri								...	...	...	1.98	2.41	2.65	3.30	2.50	3.10	
Tipra Bank								2.39	1.06	1.63	1.90	4.24	...	...	0.98		
Changme Khangpu						1.70	1.77	1.33	1.31								

(Values given in red indicate a positive balance, and the values in black are negative balance).

These studies revealed:

- An Inverse relation between the positive glacier regimen and monsoon precipitation.
- Accumulation area ratio to the ablation area is slightly more than 2:1 duringthe positive balance year.

Identification/observation of the factors that are responsible for the glacier having either a positive balance or a negative balance is difficult in the Himalayas. Hardly any information is available regarding winter precipitation / accumulation. Even during summer months, though meteorological stations had been established at each and every glacier under observation, no data about snow precipitation was available.

Lack of this data has been a major constraint in evaluating a specific factor that leads to fluctuation in glacier regimen. To assess the winter accumulation, Geological Survey of India, had to launch expeditions in late February and early March, not an easy prospect in the Himalayas. With the advent of satellite imagery, it has now been possible to demarcate and assess the snow precipitation cover during the winter season-October to March- and its depletion during the summer months-April to September.

Studies have revealed that the major factor for the negative regimen of the glaciers in the Himalayas is the relatively less snow precipitation during the winter than enhanced glacier melting in summer.

Glacier Hydrometry

Rivers originating in the Himalayas receive a substantial contribution from the glacier melt that goes up, considerably, during the melt season. Any fluctuation in this contribution is bound to have impact on the hydroelectric power potential and the irrigations potential of these rivers. Positive mass balance of a glacier means less melt water, as less surface of the glacier is subjected to annual melting and the negative balance vice-versa. This coupled with the fact, that glacier mass balance has been found to show an inverse-relation with the monsoon precipitation, further complicates the problem in the Himalayas. Glacier Hydrometry and the prediction technique of forecasting the expected runoff of the glacier melt has, in recent years, attained a very high importance and become an inevitable and essential aspect of glacier studies. It also has a very important role for the proper management of these water resources in designing the projects.

It is essential to know the exact fluctuation of the glacier melt contribution vis-à-vis the mass balance of a glacier. To do so, it becomes imperative that round the clock monitoring of water discharge, during the entire melt season- June to September- be carried out at as many glaciers as is possible. Various teams, which are carrying out glaciological studies in the Himalayas, have carried out the monitoring of the glacier melt streams either by erecting a weir, across the melt stream, downstream of the snout; or installing an Auto stage recorder. These are generally established where the stream course is braded or spread out so that data recording is manageable even at the height of the melt season, when the discharge rate goes up many folds In some cases usage of current meter has also been undertaken. Considerable data has so far been generated and various prediction models devised, yet due to rather poor response from the user agencies this data has remained, by and large, un-tested.

Interesting facts that came to light as a result of these studies were:

- On an average, irrespective of the latitudinal variation, contribution from the glacier melt, during the melt season, has been of the same order- about 25% to 30% of the total discharge, per day, per km^2 of glacier ice. During the positive balance years contribution from the glacier melt gets slightly reduced due to reduction in the ablation area, but is more then compensated by the melting of the enlarged snow cover.·
- Maximum discharge takes place from middle of July to middle of August. Glacier melt is directly related to surface ablation during the early part of the day but, by afternoon, with the thermal gradient going up considerably, contribution from the ice cored moraines becomes substantial leading to maximum discharge by evening.

Table 3: Average melt water discharge, in million cubic metres, per day, recorded at some of the glaciers during the melt season

Name	'74	'75	'76	'77	'78	'79	'80	'82	'83	'84	'85	'86	'87	'88	'89	'90	'92
Nehnar, J&K 5Q21407 022					0.08	0.07	0.06	0.09	0.13	0.15							
Gara, H.P. 5Q22204 050	0.09	0.16	0.08	0.04	0.11	0.04	0.09	0.10									
Shaunegarang H.P. 5Q22213 084									0.51	0.27	0.33	0.39	0.45	0.46	0.43		
Dunagri Uttarakhand 5O13209 044											0.15	0.22	0.22		0.16	0.20	0.22
Tiprabank Uttarakhand 5O132 06 092								0.50	0.71	0.60	0.59				0.98		
Zemu, Sikkim 5O201 05 032			24	24													
Changme Khangpu, Sikkim 5O20104 022							0.40										

Suspended Sediment Transport

Melt water streams, originating from a glacier, carry sediment load partly in suspension and partly as bed load. Suspended material transported by a glacier melt stream is considerable enough to impart a milky white colour to such streams.

Regular monitoring, on 24 hour basis, to assess the quantity of the suspended sediments carried by glacier melt streams was part of the study programme.

Table 4: Suspended sediment load, in metric tonnes, (daily average) carried in the melt water streams of small glaciers in the Himalayas, during the melt season.

Glacier with code number	Orientation	Area (km^2)	Cumulative specific bal.(m)	Summer mean daily discharge (10^6 m^3)	Av. Daily suspended sediment (Tonnes)	Year of observation
Neh Nar, 5Q21407 022 J&K	N	1.69	(-)2.37	0.10	06	1975-1984
Triloknath, 5Q21209 019 H.P.	NE	7.00	-	0.33	63	1995-1996
Gara, 5Q22204 050 H.P.	NE	5.19	(-)2.87	0.12	22	1974-1983
ShauneGarang 5Q22213 084 H.P.	W-N	4.94	(-)2.87	0.41	30	1981-1991
Hamtah, 5Q21212 180 H.P.	NW-N	3.24	(-)8.40	0.38	127	2000-2006
Tipra Bank, 5O13206 092 Uttarakhand	NW	7.00	(-)1.34	0.67	40	1981-1988
Dunagiri, 5O13209 044 Uttarakhand	N-NW	2.56	(-)6.26	0.20	47	1984-1992

- No linear relation exists between the melt water discharge and the suspended sediment transport except that with the increase in discharge, the transported sediment load increases many fold.
- melt stream may carry up to 30% of the total suspended sediment load, derived during the melt season, within just few weeks time even within one week of heavy discharge. Consequently no average values can be used.
- In fact, the only point of observation that has been found to be almost universal, so far as the suspended sediment load, in a melt water stream, is concerned, is that the peak in the sediment transport precedes that of the discharge, if the observation is made just down stream of the snout.
- Lithology of the country rock has a direct bearing on the quantum of suspended sediments produced. A granite or gneissic terrain has been observed to produce a larger quantity of the suspended sediments in a glacier stream as compared to a limestone country.

Assessment of the Thickness / Volume of the Glacier Ice

For the assessment of the glacier ice thickness and the volume there of, TTS, in their guide lines, had suggested the usage of a rating curve based upon their work in Alps. This rating curve was, however, found to give erroneous results. A rating curve that was suitable for the conditions in the Himalayas was evolved by assessing the thickness of the glacier ice in some selected glaciers by geophysical methods: electric resistivity, magnetic and seismic (refraction) techniques followed by thermal/rotary drilling for confirmation of the same.

Glacier ice was found to be around 250m thick in the cirque region of small glaciers of 5km length or less. Thickness of the glacier ice comes down to around 60m in the middle. On the other hand, a large glacier like Zemu was found to be having an ice thickness of over 200m midway from the snout.

Total ice volume, in each individual basin, in the Himalayas, was calculated on the basis of these findings. Jhelum basin in NW was found to have over all ice volume of $94km^3$; while Bhagirathi basin had $67km^3$ and Tista basin as low as $40km^3$

Glacier Flow Movement & Mass Transfer

Glacier movement can be envisaged as a dynamic link between the accumulation and the ablation systems which are normally spatially distinct. Some of the movements are more or less continuous while others, such as surges, are periodic with brief periods of intense activity and intervening periods of quiescence. Generally the discharge of ice, in the longitudinal profile of a glacier, is at the maximum at the equilibrium line and decreases downwards.

The cumulative volume of ice in a glacier increases only up to its equilibrium line, beyond which there is net loss of ice and hence the volume decreases.

Besides, the two horizontal components of the glacier ice movement, there is a significant component of vertical velocity which varies in relation to the accumulation and the ablation zones in a glacier. Above the equilibrium line, there is a downward component as fresh accumulation builds up. Below the equilibrium line, ablation removes the surface layers and as a result there is an upward component of movement.

The glacier flow movements-all the three velocity components- was measured in all the glaciers which had been under observation in the Himalayas during this period. Mass transfer studies were, however, carried out only at the Gara glacier as all the parameters needed were available. In the case of other glaciers, for want of data about the thickness of the glacier ice, along specific cross sections, mass transfer studies could not be carried out.

Table 5a: Relation of mass transfer of the glacier ice to mass balance,1974-75 positive balance year, Gara glacier, H.P.

Mean level of the equilibrium line	5,050 m.a.s.l.
Mass balance	(+) 2.50x10^6m^3 (w.e.)
Total accumulation	4.38x 10^6m^3 (w.e.)
Highest value of accumulation	2.00 m/m^2. (w.e.)
Total ablation	1.88 x 10^6m^3 (w.e.)
Highest value of ablation	1.67 m/m^2.(w.e.)
Total length of the glacier	5,818 m.
Distance of equilibrium line from the head of the glacier	3,130m.

Cross Section No	Distance from head of the glacier (m)	Average bulk velocity (v)	Steady State discharge Qo	Actual discharge eQ	Discharge per unit width Qw	Ratio Qo/Q
A	2,400	13.5	1.22	1.34	5.33	1.17
B	2,560	10	1.08	0.92	4.90	1.17
C	3,100	15	0.07	1.29	12.28	0.05
EQUILIBRIUM LINE						
D	3,370	10	0.]7	i.12	12.44	0.15
E	3,520	20	0.28	1.87	21.87	0.]4
F	3,745	12	0.40	0.41	6.07	0.97
G	4,210	15	0.50	0.63	9.33	0.79
H	4,425	5	0.49	0.13	2.16	3.76

Table 5b: Relation of mass transfer of the glacier ice to glacier mass balance, 1976-77, in negative balance year, Gara glacier, H.P.

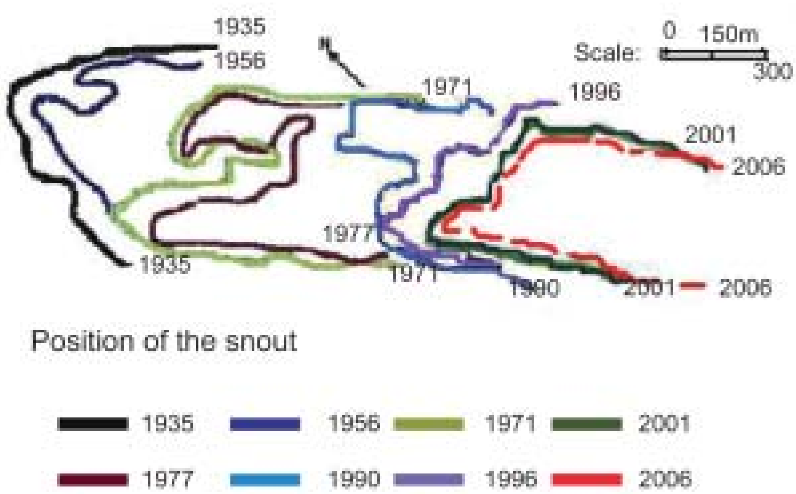
Mean level of the equilibrium line	5,250 m.a.s.l.
Mass balance	(-) 4.33x 10^6 m^3 (w.e.)
Total accumulation	0.83x $10^6 m^3$ (w.e.)
Highest value of accumulation	0.62m/ m^2 (w.e.)
Total ablation	5.16x $10^6 m^3$ (w.e.)
Highest value of ablation	2.75m/ m^2 (w.e.).
Total length of the glacier	5,815m
Distance of equilibrium line from the head of the glacier	1,500m

Cross Section No	Distance from head of the glacier (m)	Average bulk velocity (v/m/year)	Steady State discharge Qox$10^6 m^3$	Actual discharge QoX$10^6 m^3$	Discharge per unit width Q/ wxX$10^6 m^3$	Ratio Qo/Q
A	2,400	11.35	1.49	1.13	5.79	1.30
B	2,560	13	1.58	1.47	7.34	1.07
C	3,100	13.5	1.64	1.45	14.80	1.13
D	3,370	15	1.69	1.66	18.44	1.01
E	3,520	15.5	1.60	1.50	11.54	1.06
F	3,745	10.40	1.52	0.34	5.03	3.88
G	4,210	9.00	1.30	0.32	4.74	4.00
H	4,425	4.5	1.16	0.10	1.66	11.60

Monitoring of the glacier snout

Monitoring of the glacier snout by preparing large scale contour maps of the glacier front, using the survey stations fixed by earlier workers, where ever preserved, was carried out annually of every glacier, under study, during the two decades. Comparison of each year's map, with the one's made earlier, helped in assessing the fluctuation- retreat/advance of the glacier front, area vacated and changes in the vertical thickness of the glacier ice, along the snout front.

Fig 7: Retreat of the Gangotri glacier snout. (1935 to 1996 based on maps made by the Geological Survey of India; 2001AD interpreted from the satellite imagery, and 2006AD by GPS positioning)



Geomorphological Studies of Periglacial Zone

Identification and the mapping of the glacier landforms is an important aspect of the glacier studies. Tracing the continuity of the features, like lateral moraines etc. which are associated with glacier activity, beyond and far away from the current glacier bearing physiographic limits, helps in tracing the extension of the glacier cover in past times. Large scale maps of the peri-glacial zones of all the glaciers, under observation, were made for the said purpose. In India (Himalayas) mapping of the similar features have not been extended beyond a certain limit from the glacier front. Further with non availability of the dating facilities, position of each glacier landform has been fixed on a comparative relative age of antiquity.

Fig. 8: Large scale map showing sequence of terminal moraine ridges, documenting the retreat of the main glacier and its tributary.

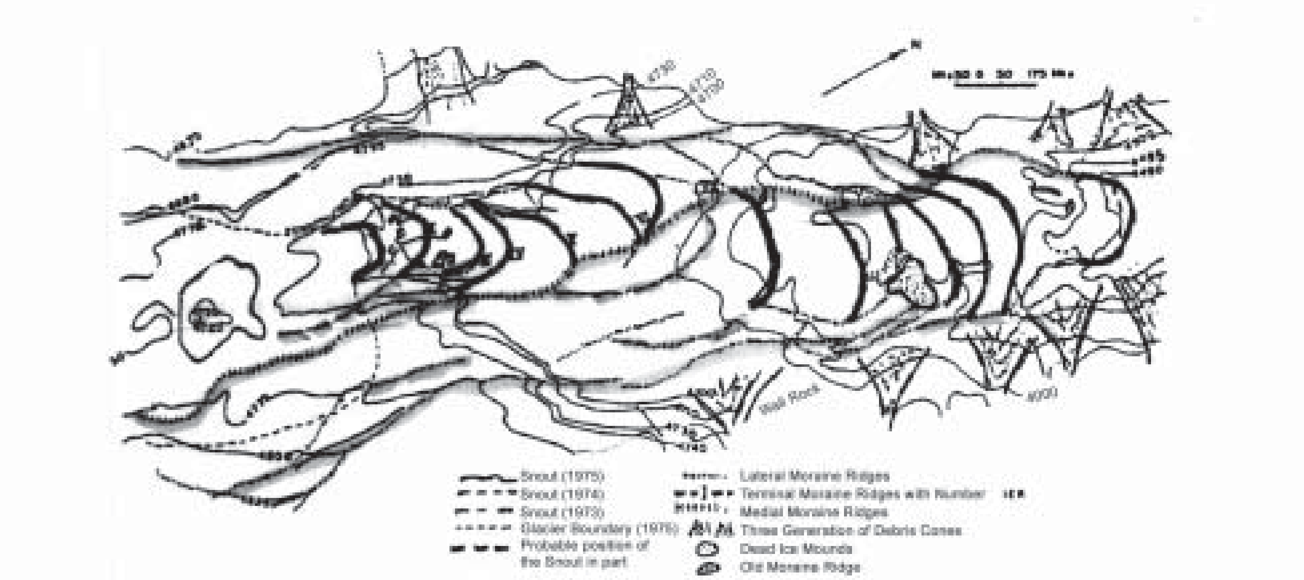


Fig.9: Deep drilling for ice core recovery in progress on a glacier in the Himalayas.

Dating of the Glacier Ice

Glacier ice is often referred as the barometer for the past climates. Attempts were made by the Geological Survey teams, in collaboration with Physical Research Laboratory, Ahmedabad, for the dating of the glacier ice using $_{31}$Si: $_{32}$Si method. For the purpose of this study, recovering un-contaminated ice cores, from three glaciers: Nehnar (J&K); Gara (H.P.) and Changme Khangpu (Sikkim), deep drilling had to be carried out with the help of heavy duty rotary drills. Transporting heavy drills to the glacier sites, four days climb from the road head, involved breath taking enterprise on the part of the scientists and the porters. Dating results revealed the ice of these smaller glaciers, close to the snout, to be around 250-300 y, BP.

Artificial Augumentation of the Gglacier Melt

An experiment to increase the glacier melt contribution during the lean period was carried out at the Gara glacier (H.P.) and the Changme Khangpu glacier (Sikkim). In the case of former, glacier ablation was increased by covering the glacier surface with fine coal dust, while at the latter, chemical sprays were used. These experiments have revealed that a coal dust of 30 mesh size spread at the rate of 400g/m^2 produces the maximum effect on a north facing glacier in the month of September. Increase in aerosol/dust cover from 2mm to 4mm thickness is not likely to increase the glacier ice melting.

Table 6a: Excess melt water yield as a result of increased glacier melting induced by a coal dust spread of 2mm thickness

Date	Daily yield of melt water from		Excess yield from TP	Average of column 4	Average excess discharge calculated km^2 of treated plot
	Treated plot	Untreated plot			
5.9.75	6.28m^3	4.08m^3	2.20m^3	1.35m^3	0.16m^3/sec
6.9.75	2.12m^3	1.53m^3	0.59m^3		
7.9.75	3.58m^3	2.35m^3	1.23m^3		

Table 6b: Excess melt water yield as a result of increased glacier melting induced by a coal dust spread of 4mm to 6mm thickness

Date	Daily yield of melt water from		Excess yield from TP	Average of column 4	Average excess discharge cal-culated km^2 of treated plot
	Treated plot	Untreated plot			
13.9.75	1.30m^3	0.73m^3	0.57m^3	0.29m^3	0.03m^3/sec
14.9.75	0.59m^3	0.35m^3	0.24m^3		
15.9.75	0.79m^3	0.68m^3	0.11m^3		
16.9.75	0.77m^3	0.53m^3	0.24m^3		

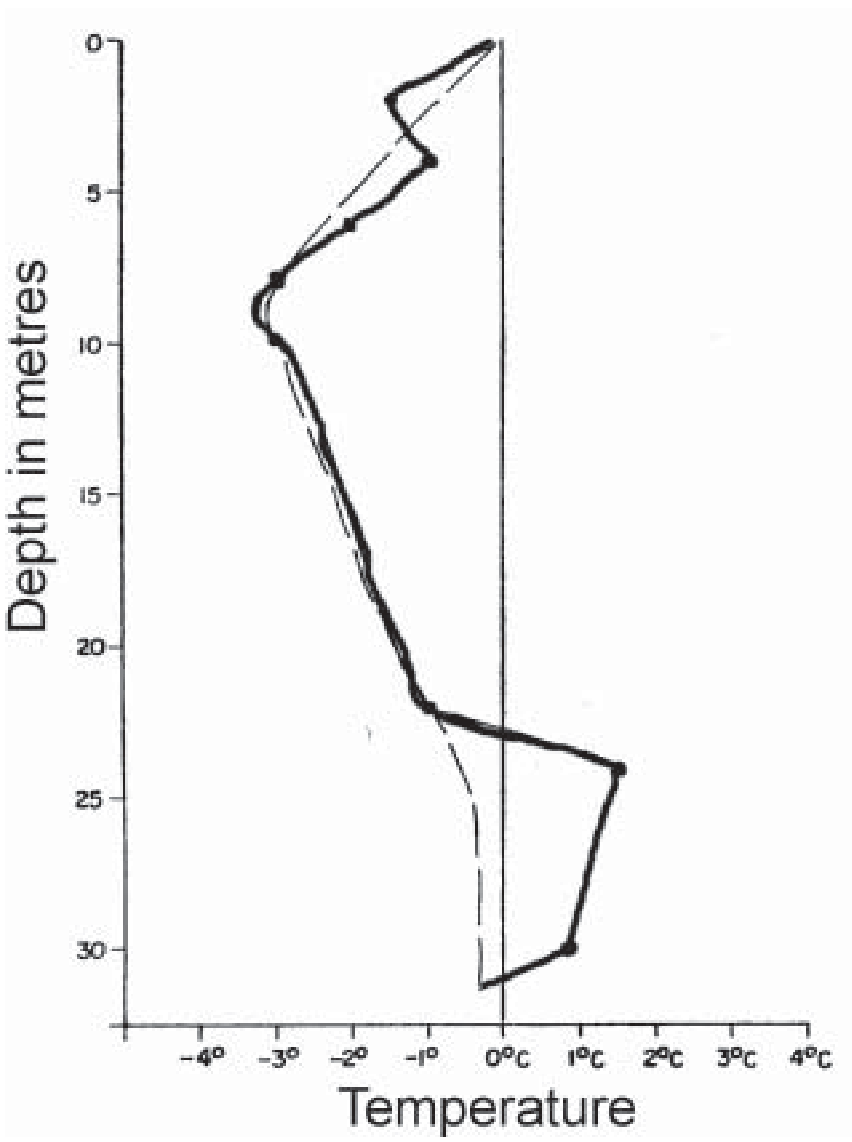
Thermal Profiling of the Glacier Ice

Thermal profiling of some of the glaciers, in the Himalayas, was carried out, from the surface downwards, by drilling holes either by rotary drills or thermal drills. Thermisters were lowered, in to these holes, to record temperature by remote sensing. It had been generally believed that the glaciers in the Himalayas belong to the "warm" glacier type category meaning there by that the temperature of the glacier ice would be at and around the pressure temperature range. The studies carried out by GSI at Gara and other glaciers revealed the rather intriguing nature of the glacier ice in the Himalayas. While the temperature of the glacier ice at and close to the base is, what can be termed as at pressure melting point, in the middle ranges of the vertical column the ice temperatures recorded were very low, indicative of cold glacier category. In other words a glacier may show "cold" glacier ice nature at one place and "warm" glacier ice nature at other, a feature that is now being recognised in glaciers in other parts of the world also

Lichenometry

Measurement of the gradual growth-diameter- of a lichen Thali, especially that of Rhizocarpen and Xenotheria species- on the boulders, in a glaciated valley down stream of the snout was carried out in Bhagirathi, Uttarakhand and Panjtarni, J&K, to establish, indirectly, the possible position of the glacier front and its retreat there after during the last 200 years or so.

Fig.10: Temperature profile of a small glacier in the Himalayas, India.



Chapter 3

Glaciological Studies by various agencies under the PAMC/DST funding programme

Glacier studies in the Himalayas, had, exclusively, been a prerogative of the Geological Survey of India till up to mid eighties. Department of Science and Technology (DST), Ministry of Science and Technology, Government of India, under the Programme Advisory and the Monitoring Committee for the Himalayan glaciers (PAMC) of the Earth Sciences Division, initiated and funded, in early eighties, a multidisciplinary programme for glacier studies at Chhota Shigri glacier in Himachal Pradesh. Activity under the PAMC has since increased many folds. The number of glaciers, under study, under this funding programme of DST has gone up, and so has the number of the institutes that have taken up such studies.

Glacier studies undertaken by the Wadia Institute of Himalayan Geology, Dehradun

(Data made available by Dr. D.P.Dobhal)

WIHG has since 1986, under the PAMC programme, been carrying out glaciological studies that involves monitoring of mass balance, snout recession, glacial hydrology, meteorology and morpho-geometry of the following glaciers:

Chhota Shigri glacier, Himachal Pradesh-1986 to 1989

Dokriani glacier, Uttarakhand-1992- Till date

Chorabari glacier, Uttarakhand-2003-Till date

Summarised Results

Table 7a: General features of Chhota Shigri, Dokriani and Chorabari glaciers

Parameters	Chhota Shigri Glacier	Dokriani Glacier	Chorabari Glacier
Co-ordinates a) Latitude b) Longitude	 32°12' to 32°17'N 77°30' to 77° 32'E	 30°49' to 30°52'N 78°47' to 78°51'E	 30° 42' to 30° 47'N 79° 01' -79° 12'E
Length	9 km	5 km.	6.5km
Catchment area	45.0 km^2	15.1 km^2	27.8 km^2
Glacier ice cover	8.75 km^2	5.76 km^2	5.90 km^2
Accumulation area	5.43 km^2	3.85 km^2	2.19 km^2
Ablation area	3.32 sq km	1.19 sq km	3.71km^2
Snout altitude	4055 m (in 1989)	3910 m (in 2007)	3860m (in 2008)
Orientation	North facing	NW facing	South facing
Surface Slope	12.5°	12°	11°
Debris cover	15.-20%	30.-40%	60-65%
Mass balance w.e.	$-1.35x10^6m^3$ (1987-89)	$-2.55x10^6m^3$ (1992-2000)	$-4.4x10^6m^3$ (2003-07)
Glacier ice thickness	15 m to 130 m	15 m to 120 m	-
Equilibrium line altitude (ELA)	4840--4845m (1987-1989)	5030--5100m (1992-2000)	4960-5000 (2003-2008)

Table 7b: Annual retreat/advance, in metres, recorded at the snouts of the Chhota Shigri, Dokriani and Chorabari glaciers.

Name	62-84	85-86	88-87	88-89	92-93	93-94	94-95	95-97	97-98	98-99	99-20			Area km²
Chhota Shigri	7.6	2.58	17.5 (Adv)	19.1										8.75
	62-91	91-92	92-93	93-94	94-95	95-97	97-98	99-92	20-01	01-02	02-03	02-03	03-04	
Dokriani	16.5	16.5	16.5	18.5	18.7	17.8	18.5	18.5	18.75	17.0	18.0	07.0	22.0	5.76
	Averaged retreat 1962-2003							Averaged retreat 2003-2008						
Chorabari	6.5							9.7						

Table 7c: Mass balance and melt water discharge data of Chhota Shigri and Dokriani glaciers.

Mass Balance in millions of cubic metres ($x10^6m^3$) of water equivalent								
Name/Period	87-88	88-89	92-93	93-94	94-95	97-98	98-99	99-2000	Area km²
Chhota Shigri	(-)1.01	(-)1.70							8.75
Dokriani			(-)1.54	(-)1.58	(-)2.17	(-)2.41	(-)3.19	(-)2.65	5.76

Average daily melt water discharge in millions of cubic metres ($x10^6m^3$) during ablation season											
Name/Period	'88	'89	'94	'98	'99'	'2000	'01	'02	'03	'04	Catchments area km²	Glacier area
Chhota Shigri	0.88	0.87									45.0	8.75
Dokriani			0.34	0.30	0.24	0.29	0.31	0.40	0.32	0.36	15.1	5.76

- Thickness of ice of Dokriani glacier as measured by Ground Penetrating Radar varied between 25-120 m.
- Maximum suspended sediment load of 1,740 tonnes was recorded on 30th June 1994 and minimum of 1.8 tonnes on 11th Oct. 1994.

Glacier studies undertaken by the Regional Centre for Field Operations and Research on Himalayan Glaciology, University of Jammu, Jammu

(Data made available by Dr. R. K. Ganjoo)

RCFOR has carried out extensive glaciological studies in Zaskar and Leh, Jammu & Kashmir State and Baspa valley, Himachal Pradesh

Summarised Results

a) Naradu Glacier, Baspa valley, Himachal Pradesh - 2001-2003

- The snout of Naradu Glacier has retreated from 4,450m amsl in 1995 to 4,465m amsl in 2001 to 4,470m amsl in 2003, i.e. a distance of around 12m.
- There has been a fluctuation of snout both on left and right margins of the ice body. During 2001-2002 the left lobe advanced slightly where as right lobe retreated slightly.
- The slow rate of retreat of glacier and the oscillations in east and west lobes of the ice body is due to thick debris cover on ice body which extends to nearly 1km that retards the ablation rate by nearly 50% to 55% in comparison to snout and the upper reaches of ablation zone.
- Retreat of Naradu Glacier in Himachal Himalaya (south slope) has been both in the vertical lowering and horizontal shortening.

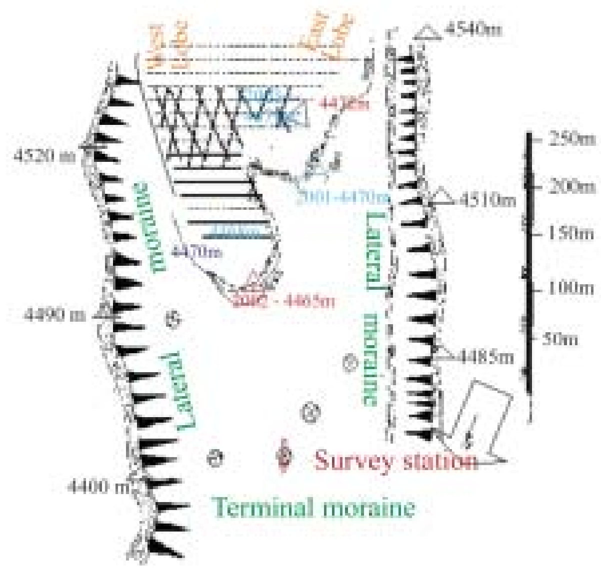


Fig 11: Map showing retreat of the Naradu glacier 2001-2003

b) Durung Drung glacier: Zaskar –Suru Valley - 2006-2008

- The glacier exhibits a very high and rapid ablation during the month of July- a maximum of 3.2cm/day; being maximum along the east flank of the glacier.
- During this period, snout of this glacier caved in by 2.85m, along the central part, whereas along the east side the glacier did not show any retreat. Along the west side a retreat of 3 m was noted.
- Western disturbances in the later part of August-early part of September 2006 resulted in the snowfall to the tune of 20cm in the glacier valley. Soon after the western disturbances, there was an excessive ablation (3.0 cm/day) in the month of September 2006 in comparison to the months of July (2.67 cm/day) and August (0.75 cm/day). This resulted in excess discharge near the snout of Durung Drung glacier that lead to the melting of dead ice in front of the snout and forming of a melt water lake.
- Over all the terminus of Durung Drung glacier, for the past three years, has not revealed any significant retreat
- **The western disturbance air mass was also responsible in bringing in locust larve** *(Schistocerca gregaria)* that invaded the glacier valley up to an altitude of 4300 masl.

Geo-morphological studies and dating of these deposits have revealed that the Durung Drung glacier once covered the area up to Pensi La an altitude of 4,400m, and also extended further down to 4,000 masl covering a total distance of 15 km around 21,000 cal yrs BP. The glacier, though reduced in size, continued to occupy the Pensi La almost till 15,000 cal yrs BP. The glacier had a gradual shift from due west to north- northeast and in the process it moved over the ridge leaving the polished erratic and striations on the top. The shift of the glacier from Pensi La pass to its present position has taken place in last about 7,000 cal yrs BP.

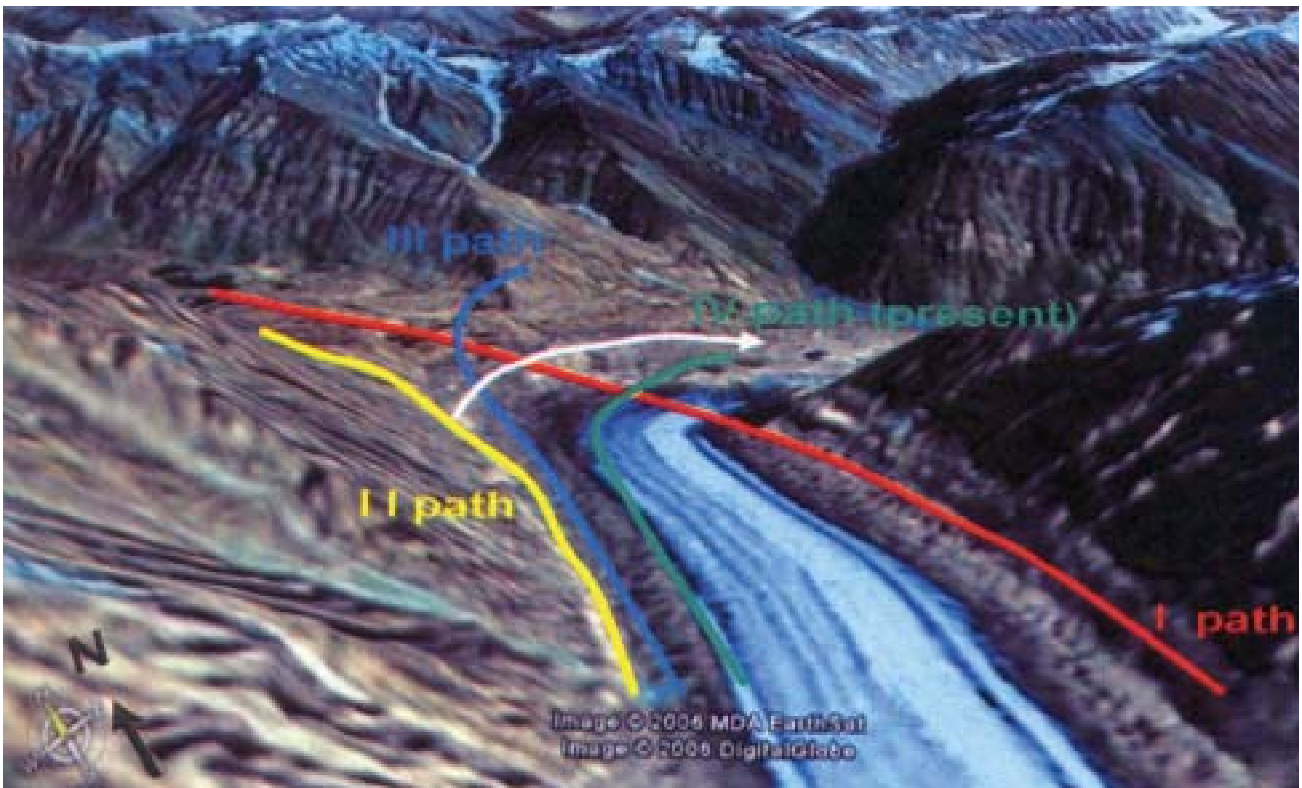


Fig 12: Shift in the path of Durung Drung glacier – response to tectonics

Institute has recently taken up the monitoring of the snout of the Siachen glacier. Studies carried out during the summer of 2008, have revealed that the, over whelming, evidences- geo-morphological evidences, are indicative of poor response of the Siachen glacier to global warming. The snout of the Siachen glacier of 2008 has retreated by about 8–10m since 1995.

Fig 13: The OP Baba shrine constructed in AD 1995 (according to the record on the foundation stone of the shrine) could only have been possible when the area was vacated by glacier.

Glacier studies undertaken by the Glacier Study Centre of G.B.Pant Institute of Himalayan Environment and Development, Almora

(Data made available by Er. Kireet Kumar)

Summarised Results

1. **Glacier retreat studies:**

Gangotri glacier and Milam glaciers, Uttarakhand

- Differential GPS derived retreat rates of Gangotri and Milam glaciers have shown lower rate of retreat (11.95 ± 0.04 ma^{-1}) in 2004-07 than the past of approx 17.15 ma^{-1}(1971-2004) without any significant influence on melt water discharge.
- Between the years 2005- 07, the Gangotri glacier has retreated at much lower rates (11.80 ± 0.035 ma^{-1})

2. **Hydrometry and sediment load studies**

- Continuous monitoring of discharge and sediment load of Gangotri glacier system has been made to correlate it with retreat pattern and climatic parameters. Marginal shift in discharge peak towards late summer months has been noticed with several sporadic sediment flushing events. In year 2007 season, the lower flow has been recorded in all glaciers of the system.
- Mean monthly melt water discharge in last 9 years has varied from as high as 114.55 m^3/s in July 2004 to as low as13.56 m^3/s in Sept. 2007, with no specific trend of these variations. Lower discharge is observed after 2004, when retreat has also been lower.

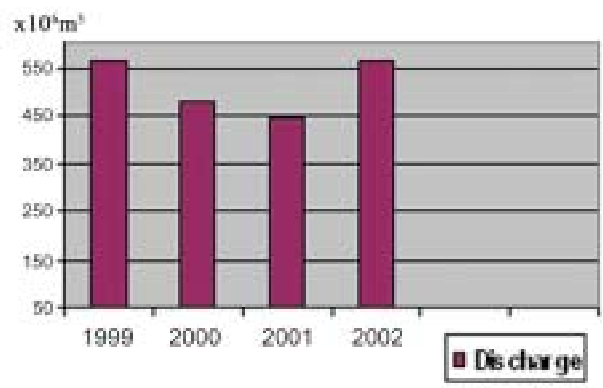


Fig 14: Melt water discharge recorded earlier near the snout of the Gangotri glacier.

3. **Chemistry of the Melt water:**

- The study was undertaken to investigate solute dynamics in melt water of Gangotri glacier system in terms of association of different chemical compounds with geology of the area. In the melt water, the presence of cations is c(Mg^{++}) > *c*(Ca^{++}) > *c*(Na^{+}) > *c*(K^{+}), while order of anions is *c*(HCO_3) > *c*(SO_4^{--}) > *c*(Cl^{-}) > *c*(NO_3^{-}) in year 2003 and 2004.
- The magnesium and calcium are the dominant cations while bicarbonate and sulphate are dominant anions. The high *c*(Ca^{++} + Mg^{++})/ total cations and high *c*(Ca^{++}+Mg^{++})/*c*(Na^{+}+K^{+}) indicates that the melt water chemistry of the Gangotri glacier system catchment is controlled mostly by carbonate weathering and only partly by silicate weathering.

4. **Environmental Studies of Dokriani Glacier, Uttarakhand**

- The atmospheric CO_2 levels in Dokriani area varied from 369 μmol mol^{-1} to a maximum of 390 μmol mol^{-1}, while near Gaumukh (Gangotri glaciers it ranges from 353 μmol mol^{-1} to a maximum of 367 μmol mol^{-1}. Higher values at Dokriani could be due to fossil fuel burning in nearby villages.
- The trend of vegetation and species found in the study area indicate that the tree line in this area is moving towards the glacier.

Glaciological Studies carried out by National Institute of Hydrology, Roorkee

(Data based on published material)

- National Institute of Hydrology (NIH) carried out hydrometric studies of the Bhagirathi river, originating as a melt water stream from the Gangotri glacier, by establishing a gauging site at Bhojbasa, just downstream of the glacier snout.

Summarised Results

Fig. 15: Daily mean discharge, observed for the various months of the year, of the Bhagirathi stream- 1999 to 2003.

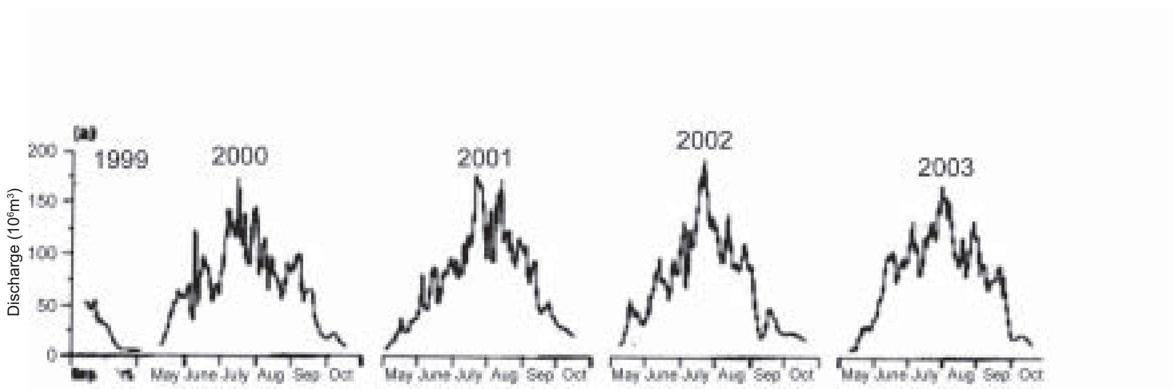
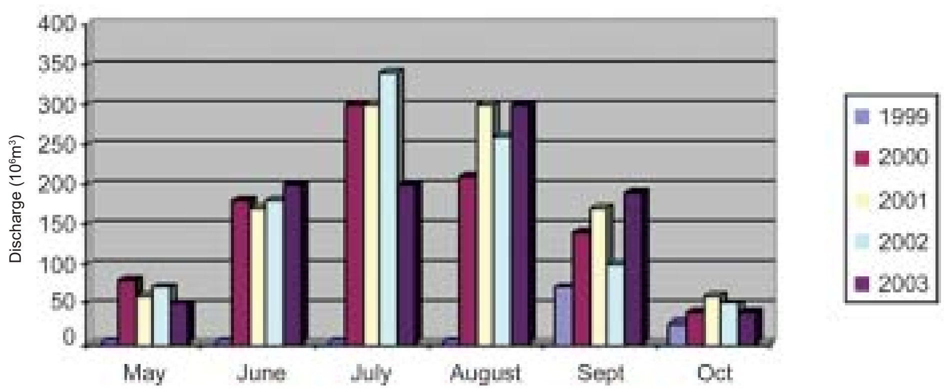


Fig. 16: Monthly discharge of the Bhagirathi stream observed from 1999 to 2003.



Glacier studies undertaken by the Geology department of the H. N. Bahaguna Garhwal University, Uttarakhand.

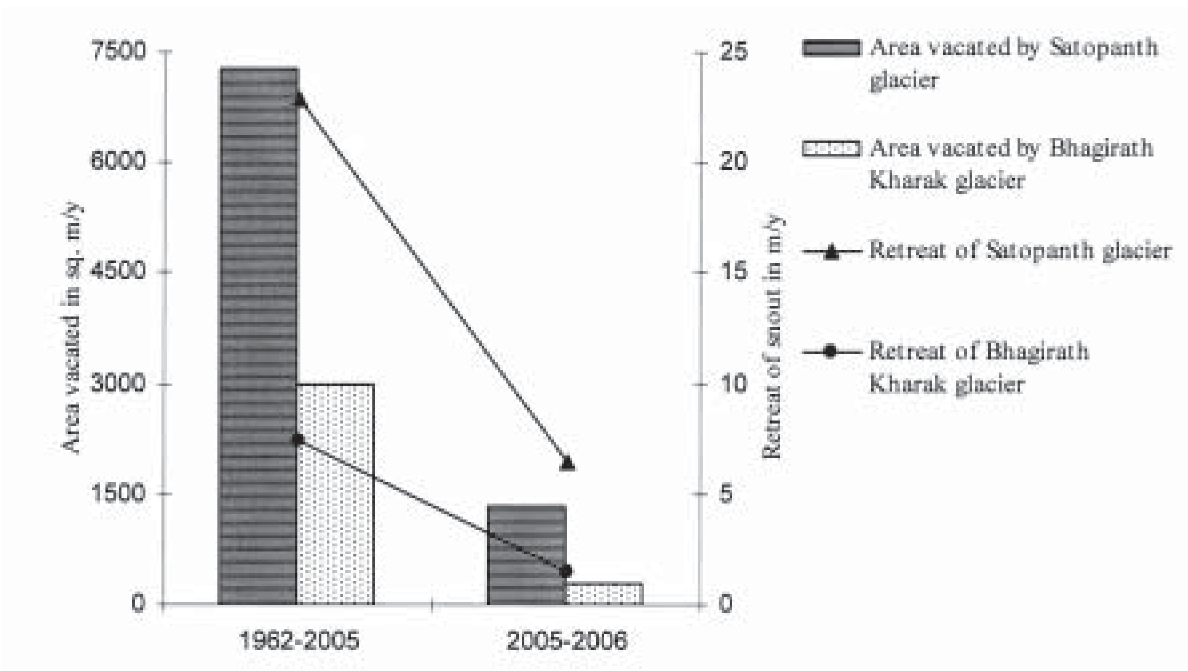
(Data made available by Dr. Nainwal)

HNB Garhwal University has carried out Glaciological Studies in the Alaknanda valley, Uttarakhand, on two glaciers: **Bhagirath Kharak** and **Satopanth glacier** - 2005 to 2008

Summarised Results

- Snout of Satopanth glacier was observed to be at an altitude of 3,866.342 m in 2005 and at 3,868.234 m in 2006. The snout had retreated by 6.5 m. No major change in the shape and size of the snout front of the glacier was observed. Mean annual retreat of Satopanth glacier from its position shown in SOI map of 1962 to 2005 AD has been calculated to be around 22.88 m/year, which is considerably higher than the current rate of retreat.
- The snout of Bhagirath Kharak glacier, in September 2005, was observed at the altitude of 3,785 m. By September 2006, the snout had retreated to an altitude of 3,768 m altitude, recording a retreat of only 1.5m during this period. The glacier had retreated 319.34 with an average rate of 7.42 m/year from 1962 to 2005

Fig. 17: Columnar chart showing the comparative retreat of Satopanth and Bhagirathi Kharak glaciers



- The average annual recessions of snout front of Satopanth and Bhagirath Kharak glaciers during 2005-2008 declined by about 82% & 90% of the corresponding value for the year 1962-2005 respectively.

Table 8a: Retreat of the snout of Bhagirath Kharak and Satopanth glacier.

	Bhagirathi Kharak	Satopanth
Period	Retreat in m/year	Retreat in m/year
2005-2006	1.5	6.5
2006-2007	1.0	5.0
2007-2008	1.0	4.5

Area Vacated by the Glaciers

The survey of the snout and adjoining areas was carried out during the field season of 2005 and 2006 and the total station survey map prepared was superimposed on the Survey of India topographic map of 1962 to measure the area vacated. During the period of 1962 to 2008, Satopanth glacier vacated an area of about 6.9×10^{-3} km^2 /year and Bhagirath Kharak glaciers vacated 2.8×10^{-3} km^2 /year.

- Reconstruction based on the presence of lateral moraine and other relict peri-glacial features in Upper Alaknanda basin indicate three phases of glaciation during the Late Quaternary. The oldest Stage-I was the most extensive glaciation in the basin that reached south of Badrinath (2,604 m). Compare to this, the other two glaciations: Stage II and Stage-III were terminated around 3,550 m and 3,700 m respectively in the N-S trending Upper Alaknanda basin.
- Chronology of glacial stages using optical dating technique has revealed that the Stage-III was around 4.5±0.5 ka, where as Stage-II around 12.4±1.4 ka. Total Station survey has indicated that the Satopanth glacier extended in past (Stage-I) about 17 km downstream in Alaknanda valley from the present position of snout, whereas Stage-II and Stage-III extended 6.05 km and 2.10 km downstream, respectively.

Glacier studies undertaken by the Centre for the Study of Regional Development, School of Social Sciences, Jawaharlal Nehru University.

(Data made available by Dr. Milap Sharma)

JNU teams worked at Chhota Shigri glacier and Dokriani glacier for the assessment of suspended stream sediment evaluation during the eighties. In last one decade JNU teams have carried out extensive Geo-morphological studies in the Bhagirathi basin, down stream of the Gangotri glacier. Glacier inventory and glacier snout fluctuation studies of the Tista basin, Sikkim, have now been taken with help of satellite imagery and selected field trips.

Summarised Results:

Gangotri glacier, Uttarakhand

- Dating of the glacier landforms sediments have established that Gangotri glacier had once extended up to Jangla around 58ky BP. The retreat from Gangotri is well represented by both OSL and CRN dates to have taken place around 3.5-5.5ka OSL & 3.5-3.9ka CRN. Tapoban moraines have shown an exposure age of 1.6-1.9 ka. Bhojbasa definitely had ice cover some 400 years ago (CRN of 440 years).

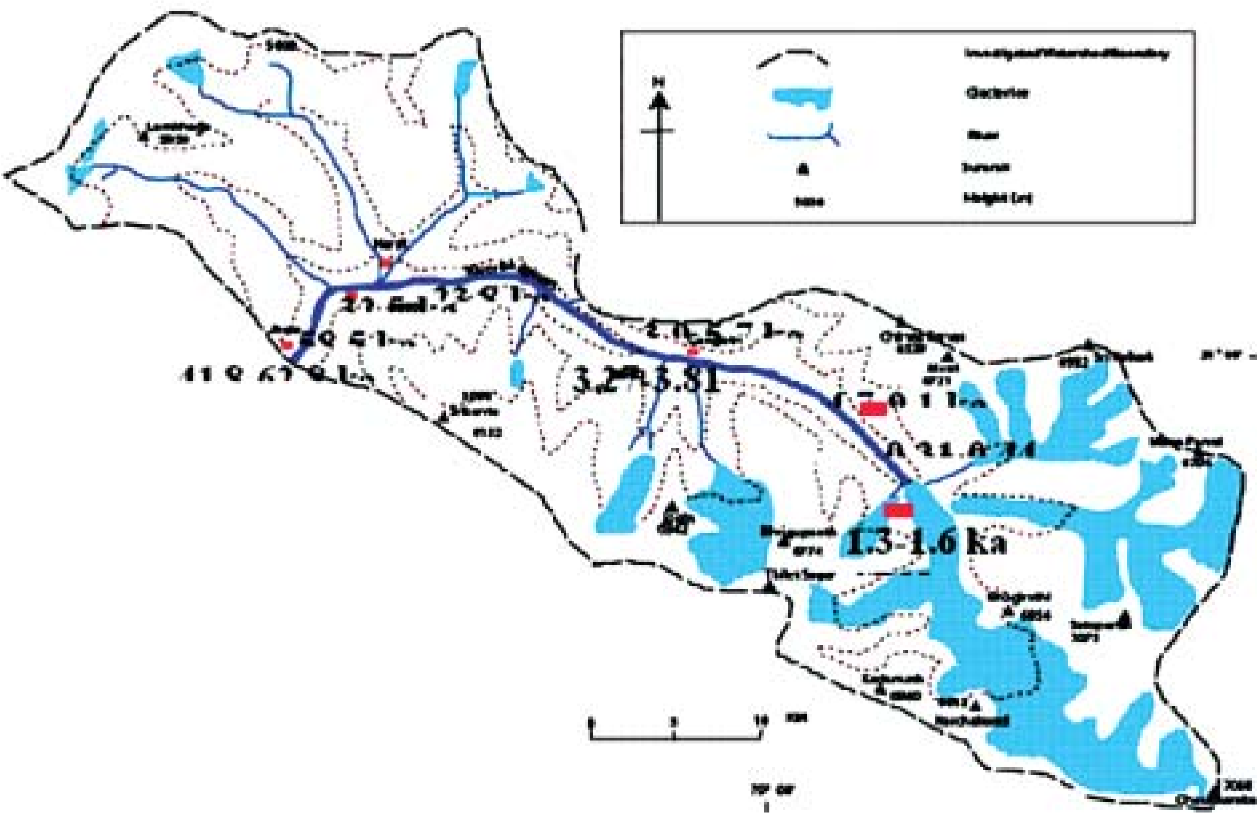


Fig 18: OSL and CRN ages in the upper Bhagirathi Basin, Uttarakhand

Sikkim

- Studies carried out in North eastern state of Sikkim have revealed: Individually, glaciers behave in a different manner to factors beyond the climate such as morphology of valley, shape and size, aspect and slope and etc. However, there is large number of glaciers with retreated fast, yet there are other glaciers which advanced during the same period of analysis. The average rise of the ELA in Sikkim stands at 47m. There are 10 glaciers which show large rise in ELAs. There are 8 glaciers which had little rise in the ELA. There are other glaciers which show depression in ELAs during these 30 years. The total ice reserve in Sikkim has reduced to 25.7029m^3 in 2005 from 26.2986m^3 in 1976.

- The average rate of retreat of glaciers in Sikkim has been calculated to be about 13.02 m per year from1976 to 2005. Out of a total 26 glaciers that were analyzed, 12 glaciers had retreated at a faster rate than the average (13.02m per year): Zemu (14.10 m per year), Tista (14.83m per year)), Jongsang (38.20 m per year), S. Lhonak (33.10 m per year), Changsang (22.37 m per year), Lhonak (27.10 m per year), E. Langpo (23.97 m per year), Rathong (18.20 m per year), S. Simpu (17.27 m per year), Umaram (14.03 m per year), N. Lhonak (13.27 m per year) and Tonsang (14.00 m per year). Rest of the glaciers, have shown a below average retreat rate.

- From 1909 to 2005, Zemu glacier has retreated approximately ~863 m. However, the retreat was punctuate between 1988 and 2000 with an advanced of ~92 m. (7.67 m. per year). The areal coverage of glacier increased during this period. In a nutshell, Zemu retreated between 1976, advanced for 12 years and again retreated thereafter. One can not correlate the impact of global warming on the glaciers on the basis of these small term variations in Sikkim. These variations at short time scale may be helpful to see the 'weather change' but not the 'climate change'.

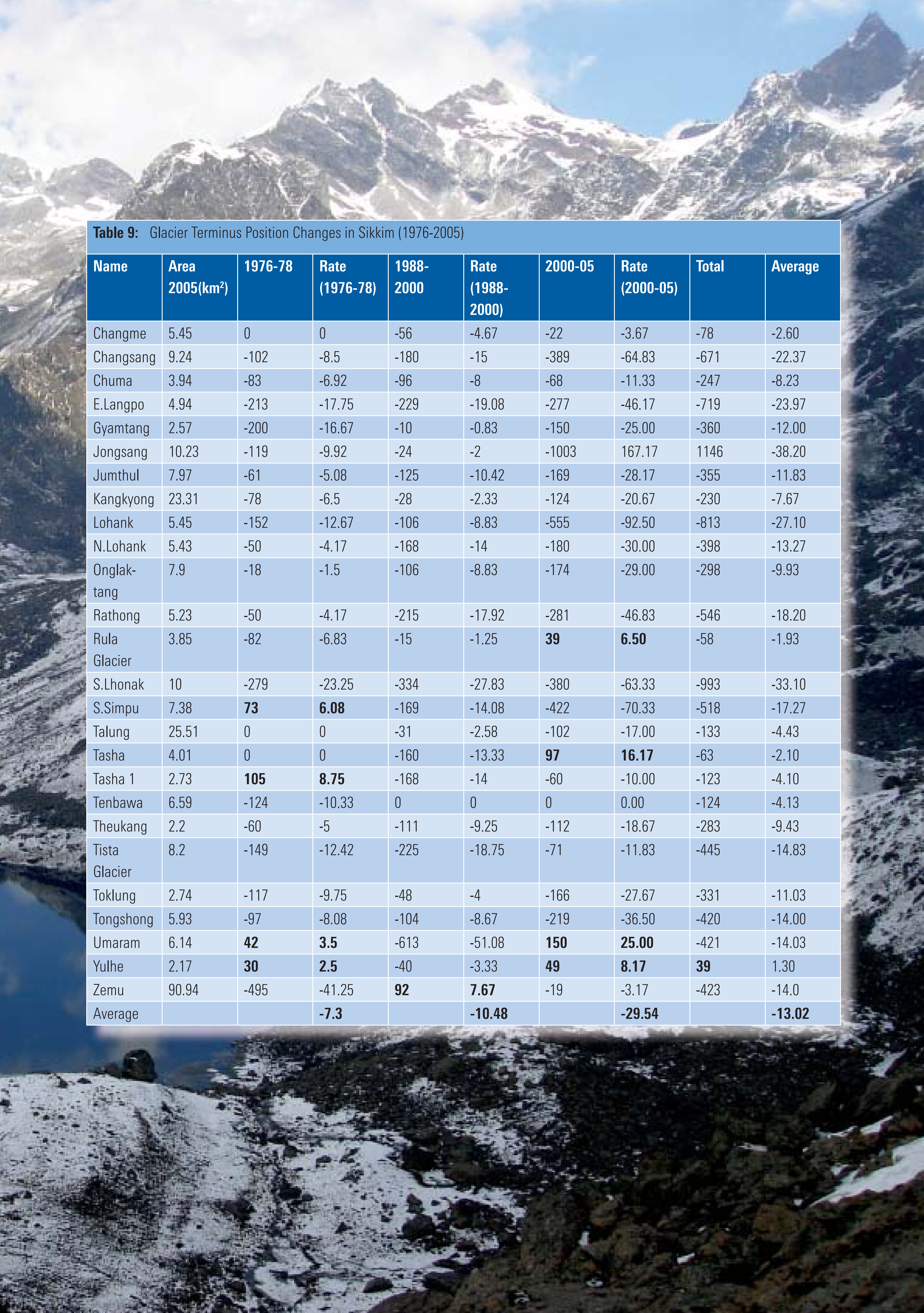


Table 9: Glacier Terminus Position Changes in Sikkim (1976-2005)

Name	Area 2005(km^2)	1976-78	Rate (1976-78)	1988-2000	Rate (1988-2000)	2000-05	Rate (2000-05)	Total	Average
Changme	5.45	0	0	-56	-4.67	-22	-3.67	-78	-2.60
Changsang	9.24	-102	-8.5	-180	-15	-389	-64.83	-671	-22.37
Chuma	3.94	-83	-6.92	-96	-8	-68	-11.33	-247	-8.23
E.Langpo	4.94	-213	-17.75	-229	-19.08	-277	-46.17	-719	-23.97
Gyamtang	2.57	-200	-16.67	-10	-0.83	-150	-25.00	-360	-12.00
Jongsang	10.23	-119	-9.92	-24	-2	-1003	167.17	1146	-38.20
Jumthul	7.97	-61	-5.08	-125	-10.42	-169	-28.17	-355	-11.83
Kangkyong	23.31	-78	-6.5	-28	-2.33	-124	-20.67	-230	-7.67
Lohank	5.45	-152	-12.67	-106	-8.83	-555	-92.50	-813	-27.10
N.Lohank	5.43	-50	-4.17	-168	-14	-180	-30.00	-398	-13.27
Onglak-tang	7.9	-18	-1.5	-106	-8.83	-174	-29.00	-298	-9.93
Rathong	5.23	-50	-4.17	-215	-17.92	-281	-46.83	-546	-18.20
Rula Glacier	3.85	-82	-6.83	-15	-1.25	**39**	**6.50**	-58	-1.93
S.Lhonak	10	-279	-23.25	-334	-27.83	-380	-63.33	-993	-33.10
S.Simpu	7.38	**73**	**6.08**	-169	-14.08	-422	-70.33	-518	-17.27
Talung	25.51	0	0	-31	-2.58	-102	-17.00	-133	-4.43
Tasha	4.01	0	0	-160	-13.33	**97**	**16.17**	-63	-2.10
Tasha 1	2.73	**105**	**8.75**	-168	-14	-60	-10.00	-123	-4.10
Tenbawa	6.59	-124	-10.33	0	0	0	0.00	-124	-4.13
Theukang	2.2	-60	-5	-111	-9.25	-112	-18.67	-283	-9.43
Tista Glacier	8.2	-149	-12.42	-225	-18.75	-71	-11.83	-445	-14.83
Toklung	2.74	-117	-9.75	-48	-4	-166	-27.67	-331	-11.03
Tongshong	5.93	-97	-8.08	-104	-8.67	-219	-36.50	-420	-14.00
Umaram	6.14	**42**	**3.5**	-613	-51.08	**150**	**25.00**	-421	-14.03
Yulhe	2.17	**30**	**2.5**	-40	-3.33	**49**	**8.17**	**39**	1.30
Zemu	90.94	-495	-41.25	**92**	**7.67**	-19	-3.17	-423	-14.0
Average			**-7.3**		**-10.48**		**-29.54**		**-13.02**

Glacier studies by the Remote Sensing Application Centre, Uttar Pradesh, Lucknow.
(Data made available by Dr. Tangri)

Summarised Results

Deciphering the new tectonic activity in Gangotri glacier area

Regular monitoring of Gangotri glacier area through large scale satellite data and field expeditions has enabled establishing the presence of neo-tectonic activity in the area. This has affected not only the Gangotri glacier body but has also affected the Raktvaran Bamak glacier and the Meru Bamak glacier.

Preparation of Geomorphic map of Gangotri glacier area

A detailed geo-morphological map of Gangotri glacier area on 1:50,000 scale using precision geocoded satellite data and extensive field surveys has been prepared.

Temporal Monitoring of Surging Glaciers of Kumdan Group and Rimo Group Glaciers

Rimo Group of Glaciers: This is a complex basin glacier having two distinct limbs – the northern limb & southern limb. Each of these limbs behaves in a different manner. Survey of India topographical sheets of 1962 have been taken as the base data for reference and successive variations have accordingly been monitored. With respect to 1962, the 1990 satellite data demonstrate that during this period there has been a retreat of 1.5 Kms. This retreat continued up to 1996 where after the glacier began to advance from 1997 to 1999. The glacier remained in quiescent stage during 2000 to 2003 where after from 2004 onwards, the northern limb again started retreating.

The southern limb of Rimo glacier experienced a retreat of approx. 1 km. between 1962 and 1990, where after the glacier again advanced ahead up to 1996. Subsequently, the southern limb experienced a quiescent stage up to present with minor retreats during 2005 and 2007.

Chong Kumdan Glacier: This glacier has three prominent limbs, the northern, central and southern. The 1975 topographical sheets demonstrate that all three limbs are merging together to form a single snout. The 1990 satellite data shows that the northern and the central limbs still remain merged together while the southern limb shows a slight retreat. From 1993 to present (i.e. 2007) the northern limb is continuously surging ahead and during this period it has advanced by approx. 2.5 Kms. The central limb retreated between 1997 & 2001 then after, it surged ahead up to the present i.e. 2007. With respect to 1990 the central limb shows an advance of approx. 1.75 Kms. in the year 2007. The southern limb of the Chong Kumdan glacier advanced, by approximately 1.25 Kms, between 1997 & 1990. It then started retreating up to the year 2006 with a total magnitude of 0.75 km.

Kichik Kumdan glacier: This glacier has a northern limb and southern limb. The 1975 topographical map has shown both limbs merging together to form a single snout. The northern limb exhibited a marked retreat of 0.53 km during 1990 to 1997. Subsequently, the glacier started advancing up to 2004, where after between 2005 & 2007, the northern limb has retreated back by 0.6 km. The southern limb showed an initial retreat up to 1992, where after it advanced up to 2005. The frontal part of glacier experienced a retreat during 2006 & 2007.

Aktash Glacier: This is a single limb glacier and the multi-date satellite data indicates an advance of 0.4 km. during 1975 & 1990. Subsequently the glacier has been fluctuating with an overall retreat of 0.25 km. during 1990 & 2007.

Results & Discussions

The temporal monitoring of different glaciers using multi-date satellite data have been attempted and the preliminary results demonstrate that all the four glaciers i.e. The Chong, Kichik, Aktash and Rimo group of glaciers are showing positive evidences of different stages of Surging phenomenon

Glacier studies undertaken by the teams from Birbal Sahini Institute, Lucknow
(Based on Published data)

Scientists from this institute have used the Dendrochronology and Radio Carbon dating technology to assess the age of trees growing, down stream of the Gangotri glacier, Uttarakhand and Zemu glacier, Sikkim. Their studies have revealed that the trees growing on the moraines at Chirbasa and like wise in Zemu valley are around 400 (+) years old, indicating that the glacier in either case had vacated the area more than 400 years back.

Glacier studies undertaken by the teams from the University of Lucknow, U.P.
(Based on Published data)

Geo-morphological studies of glacier landforms and also Lichenometry studies were carried out in the upper reaches of the Bhagirathi basin by the teams from the university. Studies on neotectonic activity and its impact on the Gangotri glacier have also been carried out by the research scholars from the university.

Glacier studies undertaken by the teams from the Physical Research Laboratory, Ahmedabad

Dating of glacier ice by $_{31}Si$:$_{32}Si$ technology was carried out on the ice cores collected from Gara, Nehnar and Changme Khangpu glaciers. Ice close to the snouts of these glaciers was found to be as old as 250 to 400 years . The team also reported the presence of Nuclear debris in the Changme Khangpu glacier of Sikkim.

Glacier studies undertaken by the teams from IIT, Bombay, Mumbai

(Data made available by Dr. Venkataraman)

Scientists from IIT Bombay have been involved in mapping glacier facies using Radar Backscattering Properties and Glacier Dynamics using InSAR on Siachen glacier, J&K, Gangotri glacier, Uttarakhand, and Beas glacier in H.P.

Summarised Results

- With the help of multi-temporal synthetic aperture RADAR image (winter, early summer and late summer) attempt has been made to delineate different facies (Zones) of Beaskund and Gangotri glaciers. Dry snow facies was absent in both these glaciers. Percolation facies and wet snow facies together made the accumulation zone and ice facies the ablation zone. It was possible to demarcate the equilibrium line which is very useful in mass balance calculations. or the progress of any glacier.
- On the basis of SAR inter-ferometry technique, using ERS-1/2 tandem data, it was observed that Gangotri glacier had moved by 8.4cmd-1 during March25-26, 1996 while Siachen glacier showed movement about 22.4cmd-1 during April 1-2, 1996, along the line of sight of RADAR. A velocity profile drawn along the central line of the glacier showed decreasing trend of movement from accumulation zone to terminus zone of both these glaciers.
- Attempt was made to assess the retreat and advance of glaciers in Himalayas by using multi-temporal synthetic aperture radar (SAR) data as well as optical data.
- Gangotri glacier was monitored, along its central line using, Terra SAR-X (TS-X) data of 28th August, 2008 and 30th September, 2008. Magnitude of displacement was calculated to be around 9.37cm per day, and the glacier calculated to be retreating at the rate of 4 cm per day or 14.6m per year.

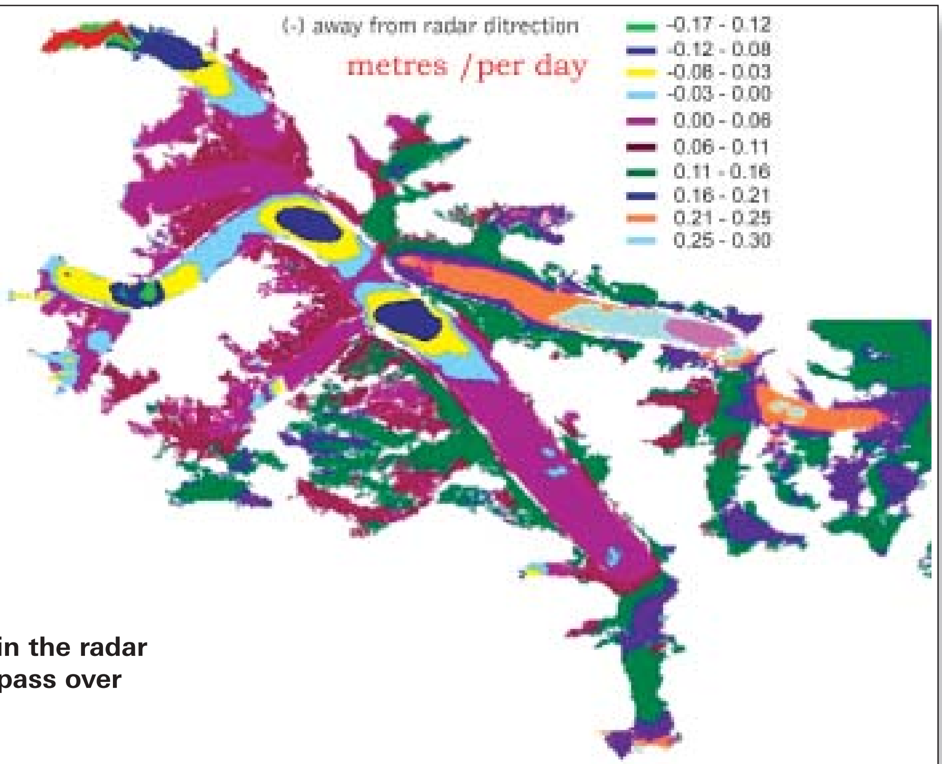


Fig. 19: Plot of velocity in the radar direction for ascending pass over Siachen glacier.

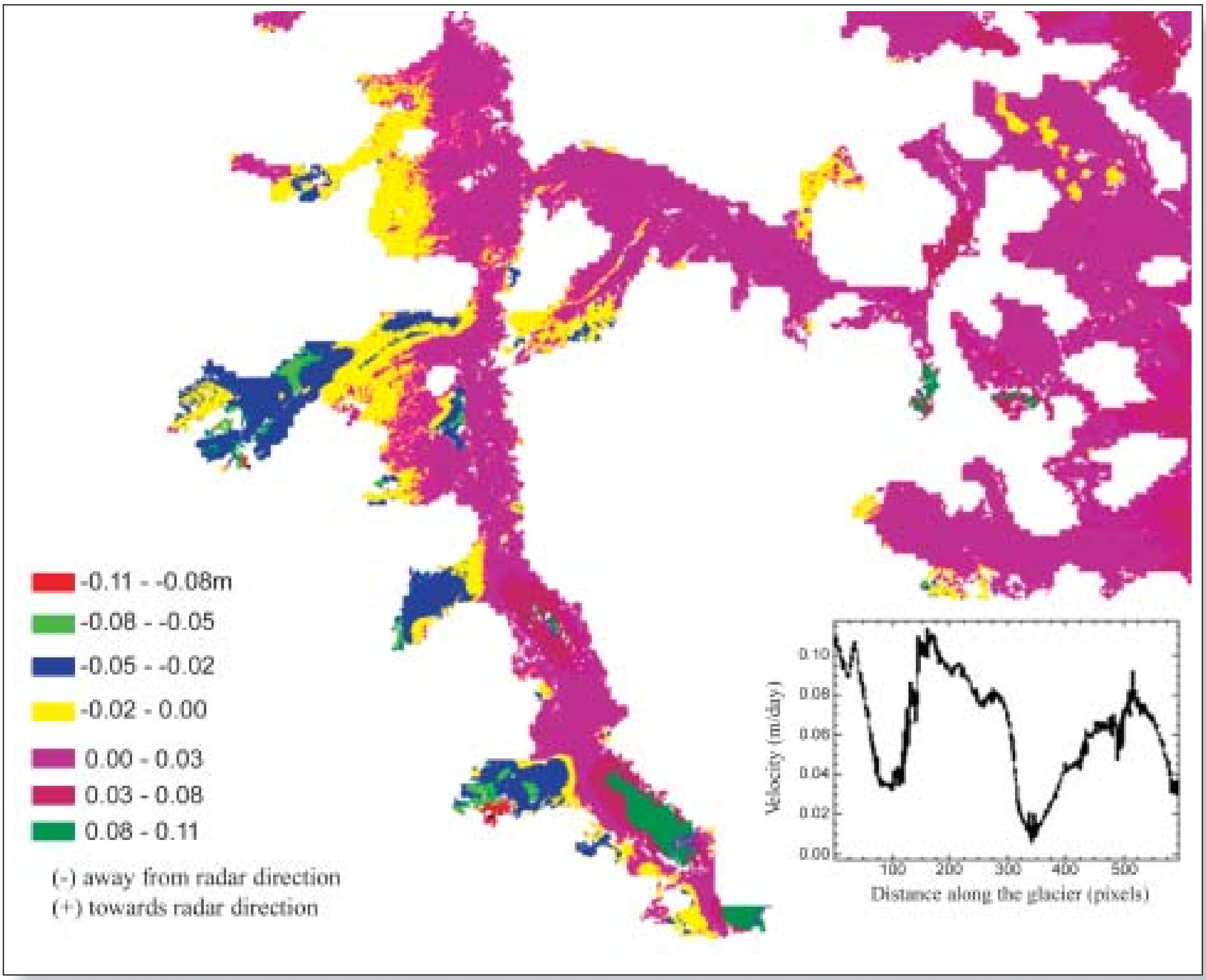


Fig. 20: Plot of velocity in the radar direction for ascending pass over Gangotri glacier.

Chapter 4

Glacier Studies undertaken by Snow & Avalanche Study Establishment, Chandigarh

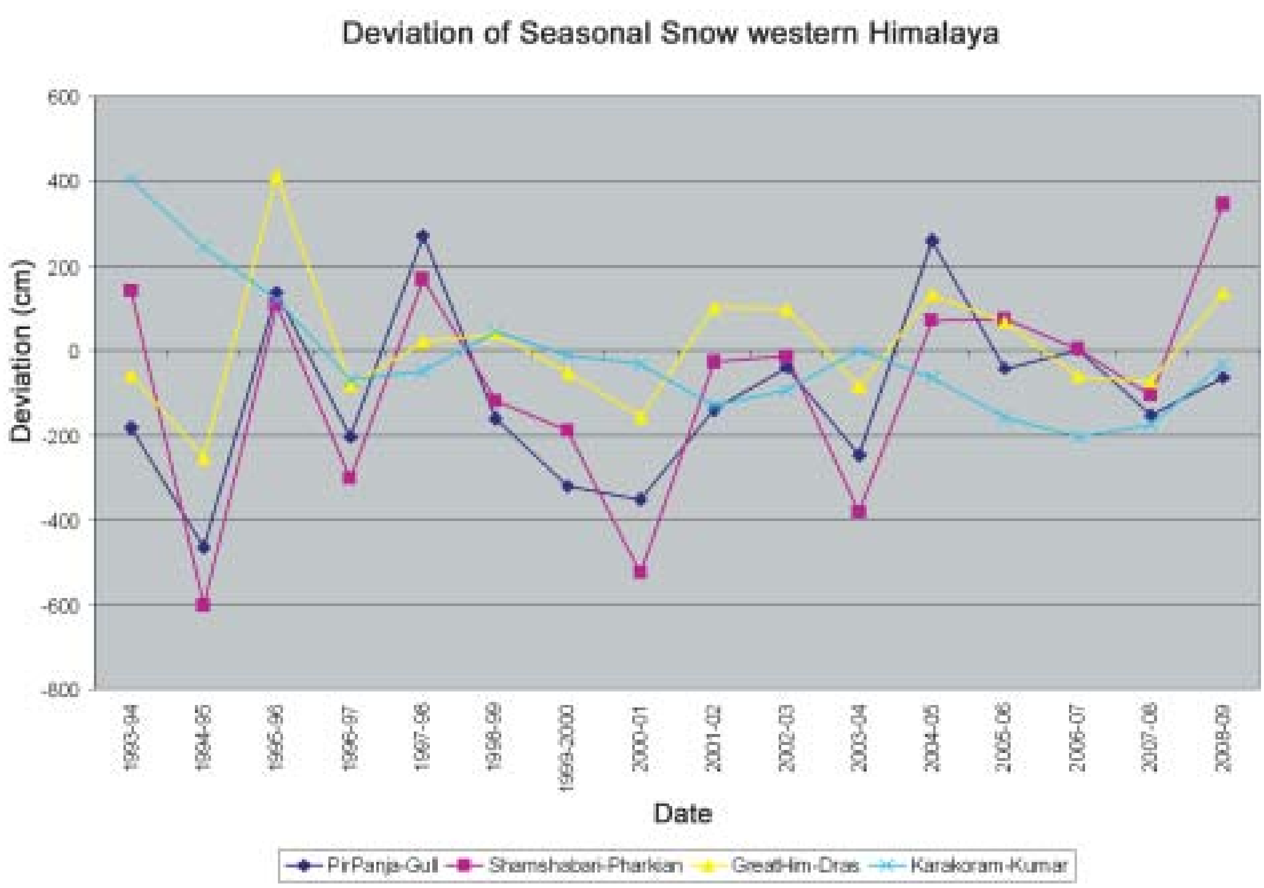
(Data made available by SASE, Chandigarh)

Snow Avalanche Study Establishment (SASE) maintains a number of meteorological stations- both automatic and manual in J&K. and makes the meteorological data available to the scientists working on glaciers. On the request of PAMC, SASE agreed to maintain Automatic Weather Stations (AWS) close to the glacier snouts that were under study and funded by DST, one of which is at Bhojbasa, down stream of the Gangotri glacier, in Bhagirathi valley, Uttarakhand.

SASE teams also carried out Identification of crevasse zones, hidden under winter snow, on a glacier using remote sensing and GIS techniques.

Summarise Results

Fig. 21: Deviation of the seasonal snow cover, western Himalayas.



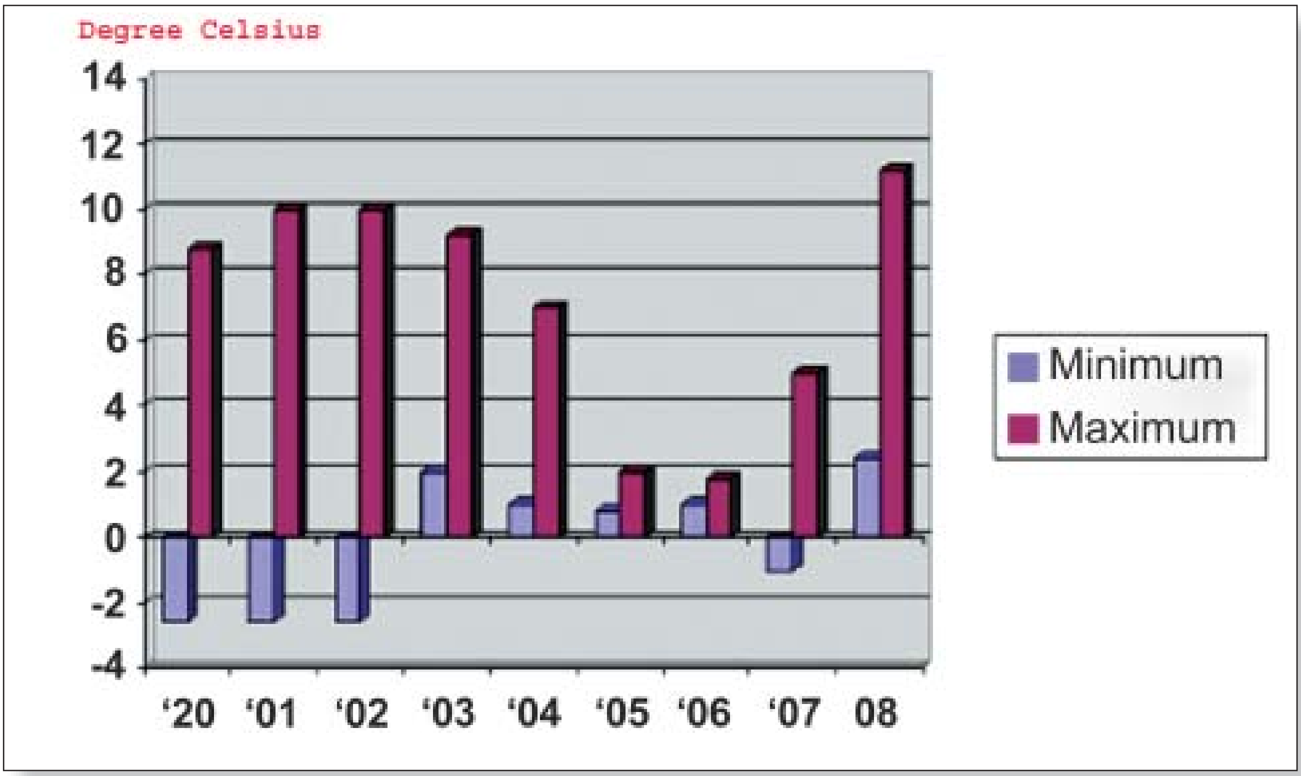


Fig. 22: Total winter Snow precipitation (October month of the previous year to April month of succeeding year) as recorded at Bhojbasa, Uttarakhand. Horizontal line marks the average of the last eight years.

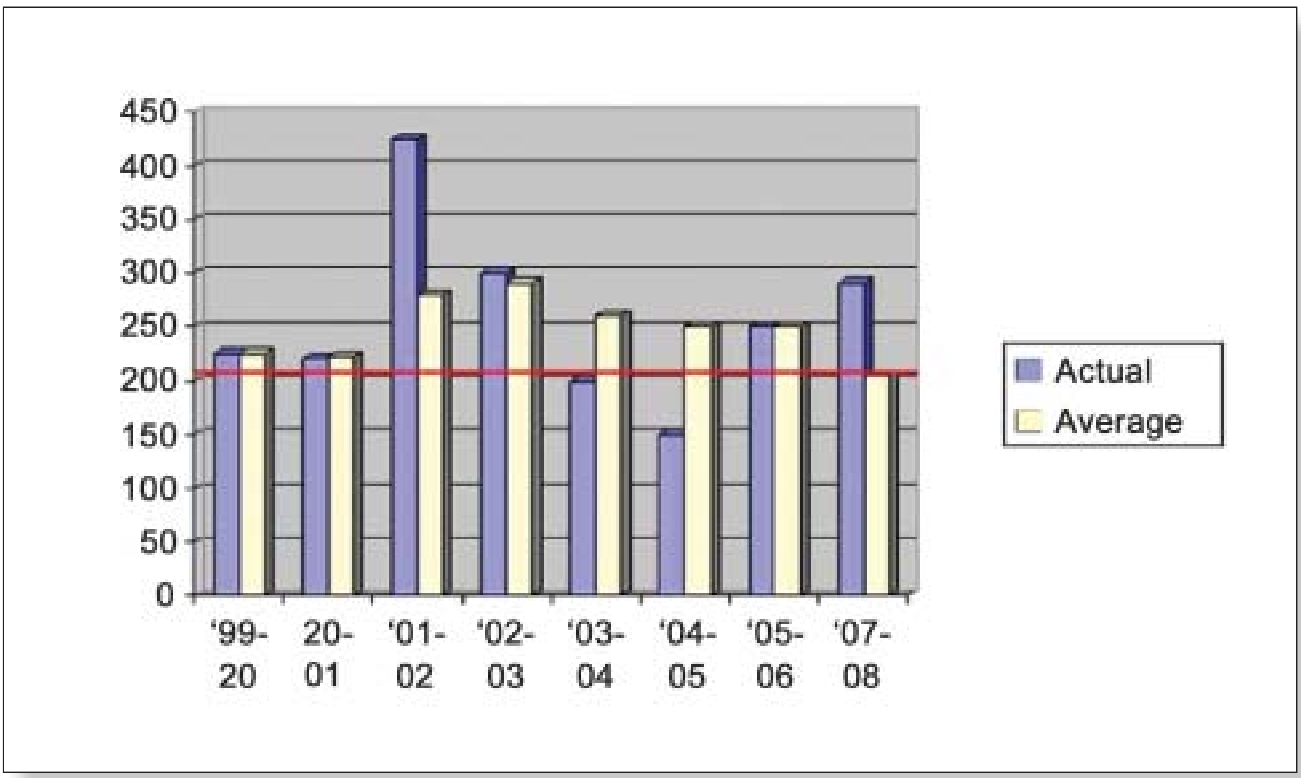


Fig.23: Annual (average) temperatures as recorded at Bhojbasa

Chapter 5

Glaciological Studies carried out by Space Application Centre, Ahmedabad

(Data made available by SASE, Chandigarh)

Monitoring of Himalayan glaciers, using conventional methods, is normally a difficult exercise due to the rugged and inaccessible nature of the terrain.

Scientists from SAC initiated the snow and ice monitoring, in the Himalayas, with the application of remote sensing techniques in mid-seventies. Extensive work, based on spectral reflectance characteristic of snow and glacier, was done, in the early stages on the Chhota Shigri glacier, H.P.

Teams from SAC have since increased this type of the studies many folds and a number of glacier bearing basins Chenab, Parbati and Baspa have been covered. These are important river basins for Indian economy, as numerous power projects are under operation and construction here. Therefore, changes in glacial extent and their influence on river run-off are important to plan future strategies of power generation.

Methodology

This investigation has been carried out using data from a number of Indian Remote Sensing satellites. In Parbati basin LISS-IV data of IRS-P6 and in Baspa and Chenab basins LISS-III data of IRS-1D were used. IRS-P6 satellite was launched on 17 October 2003 and satellite images of Parbati basin were collected in the summer of 2004. Spatial resolution of this sensor is 5.8 m and data are available in three bands. Therefore, this sensor can be used to monitor small glaciers and ice fields. The oldest information about glacial extent is available on Survey of India topographic maps, surveyed in 1962, using vertical air photographs and limited field investigations. Mapping of glacial extent in 2004 was carried out using LISS-IV images and in 2001 using LISS-III images. Images covering July–September period were selected, because during this period snow cover is at its minimum and glaciers are fully exposed. Glacier boundary was delineated using topographic maps and digitized using Geographic Information System. On satellite images glacial boundary was mapped using standard combinations of bands. Image enhancement technique was used to enhance the difference between glacial and non-glacial areas. Field investigations were carried out at five glaciers to assess position of the snouts. These include Shane Garang glacier in Baspa basin, Parbati glacier in Parbati basin and Chhota Shigri, Samudra Tapu and Patsio glaciers in Chenab basin. Snout positions of selected glaciers were marked using Global Positioning System (GPS) and by comparing the relative position of snouts with geomorphologic features such as moraines, origin of streams from snouts and moraine-dammed lakes. Glacier retreat was measured along the centreline and the relative position of the terminus estimated using geo-morphological features.

This means glacial retreat can be estimated by combining field and satellite observations. This procedure is now being improved using a combination of laser range finder and GPS.

Summarised Results

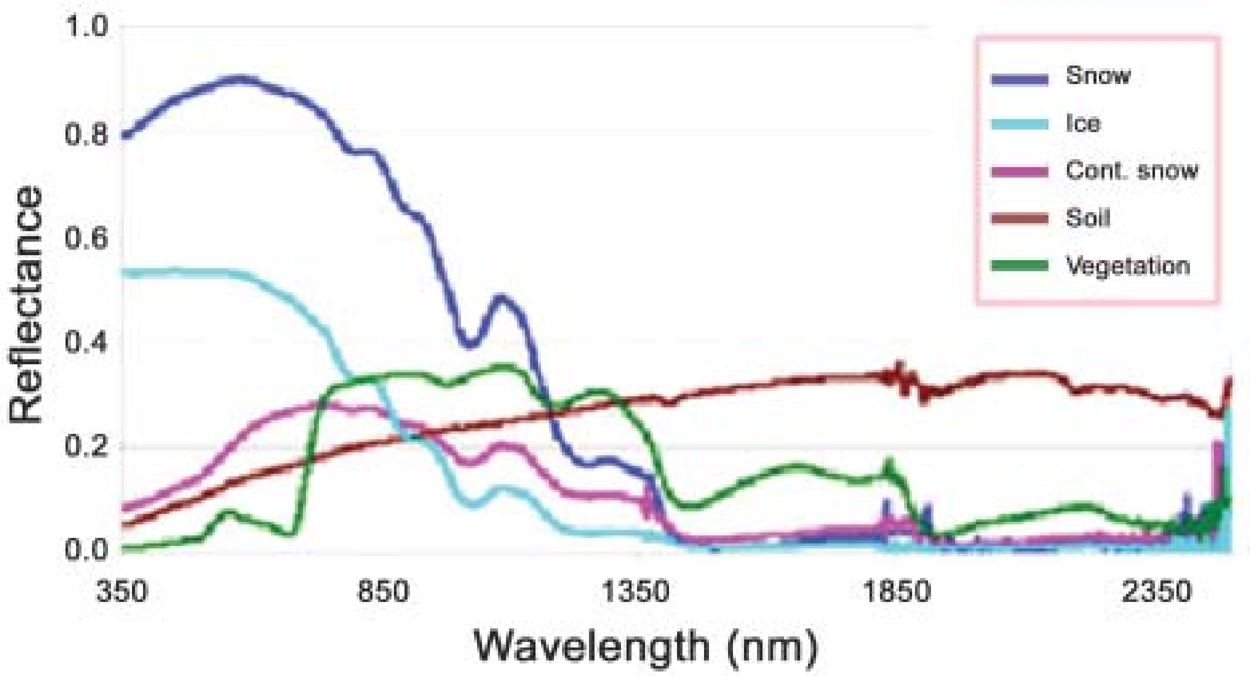


Fig. 24: Spectral reflectance of snow, ice, contaminated snow, vegetation, and soil. observations taken using spectral radiometer near Manali, H.P.

Basin	Glacier Number	Glacier area (sq.km) 1962 2001-04 Loss (%)			Volume (cubic km) 1962 2001-04 Loss (%)		
Chenab	359	1414	1110	21	157.6	105.03	33.3
Parbati	88	488	379	22	58.5	43.0	26.5
Baspa	19	173	140	19	19.1	14.7	23.0
Total	466	2077	1628	21	235.2	162.73	30.8

Glacier area km^2	No. of Glacier in 1962	Glacier area in km^2 1962	2004	Change (%)
<1	127	68	42	38
1-5	159	382	269	29
5-10	48	329	240	27
>10	25	635	559	12
Total	359	1414	1110	21

Chapter 6

Conclusions drawn on the basis of the work done till date

1. Glaciers in the Himalayas (India) have been exhibiting a continuous secular retreat since the earliest recording began around the middle of the nineteenth century. Kumdan glaciers, of the Upper Shyok valley, have been the only exception for their periodic fluctuations.

Average annual retreat of the glaciers, under observation, which generally was around 5m till up to late 50s of the 20th century, increased many folds in some glaciers in the Central and the Eastern Himalayas during the decade of mid seventies to late eighties, touching a value of as high 25m-30m as in the case of the Gangotri glacier. The retreat, with the advent of the decade of the nineties, began to slow down and in some cases like the Siachen glacier, Machoi glacier, Darung Drung glacier, Gangotri glacier, Satopanth-Bhagirath Kharak glaciers and the Zemu glacier, it has practically come down to stand still during the period 2007-09. It may be noted here that some of the glaciers in the Kumaon Himalayas like the Pindari glacier have been exhibiting a high annual retreat of the order of 8m-10m since the first recording was made in 1906.

2. Kumdan glaciers of the Upper Shyok valley have been recognised as surging glaciers with a periodic cycle of around 40 to 50 years for the three phase activity of surging:

- **Advance phase** covers about 15-17 years during which the glaciers advance rapidly;
- **Quiescent phase**-breaking and reforming in one position covers almost a period of 20 odd years- and finally the
- **Retreat phase** of 13 odd years when the glaciers retreat to their original position away from the river.

3. All the glaciers under observation, during the decade of 70-90, showed a cumulative negative mass balance. There were a few years, when one or two glaciers showed a positive balance or very low negative value, but the over all cumulative balance, over an observation period of ten years, for each glacier, continued to be negative. Two glaciers that are under observation, at present, in the states of Himachal Pradesh (Hamta glacier) and Uttarakhand (Chorabari glacier) have also been showing negative mass balance.

4. Annual snow precipitation, during the accumulation season, is the parameter primarily responsible for the glacier having either a positive or a negative balance. Cumulative negative mass balance values showed a gradual decrease from the glaciers in the north- west to the glaciers in the north- east. Space Application Centre scientists, tracking the fluctuation of the Equilibrium Line altitude on the glaciers in the Himalayas, with the help of satellite imagery, have opined that the glaciers are exhibiting a negative annual mass balance. Substantiating the fact, that the annual snow precipitation has a direct bearing on the mass balance, for SASE has indicated a gradual decrease in precipitation during the last decade.

Table 11: Decrease in cumulative mass balance from North West to East

Name	76-'77	77-'78	78-'79	79-'80	80-'81	81-'82	Cum/m²	Area km²
Nehnar (J&K) 34⁰08'50":75⁰ 1'30"	0.78	1.47	0.91	0.56	0.81	0.30	64cm	1.25
Gara (H.P) 31⁰28'30":78⁰25'00"	4.33	4.63	3.45	3.57	1.03	0.33	53cm	5.19
Gorgarang (H.P.) 31⁰25'54":78⁰23'00"	1.36	1.22	0.50	0.99	1.97	0.53	45cm	2.02
Changme Khangpu (Sikkim) 27⁰57'43":88⁰41'17"				1.70	1.77	1.33	28cm	5.60

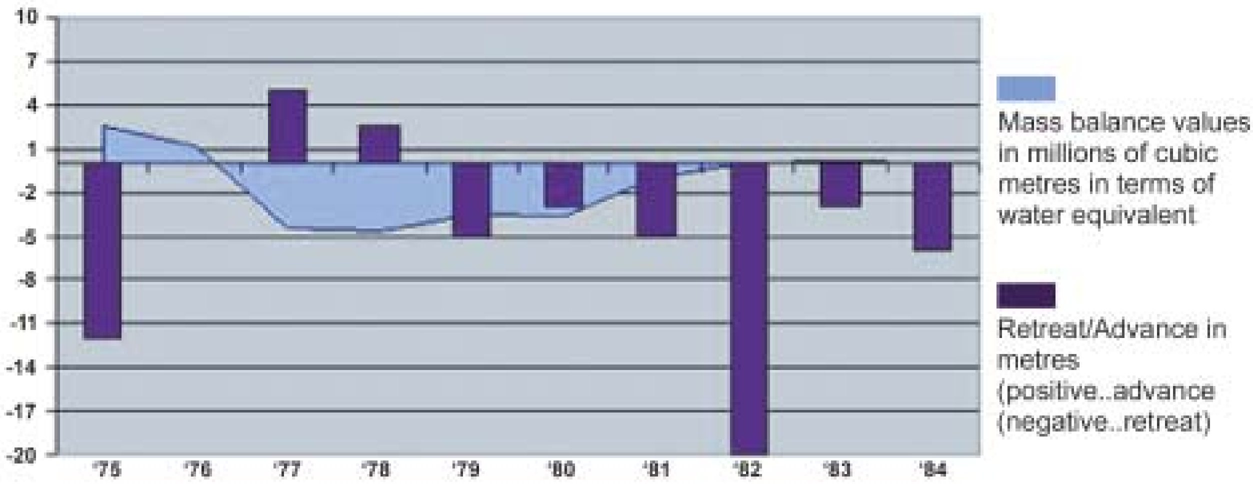


Fig.25: Cartoon showing mass balance values, in 106 m3 of water equivalent, and advance/retreat of the snout in metres of Gara glacier, Himachal Pradesh

5. A glacier, so far as the snout is concerned, does not respond to immediate changes in the glacier regimen. A positive mass balance does not necessarily lead to glacier advance and the negative balance to glacier retreat.

Table 12: Correlation between Mass balance, glacier snout fluctuation and melt water discharge of a small glacier (Gara glacier) in Himachal Pradesh
(+)Values show positive balance/advance along the front)

Period	75	76	77	78	79	80	81	82	83	Area
Mass Balance $10^6 x m^3$ (we)	(+)2.50	(+)1.30	4.33	4.63	3.45	3.57	1.03	(+)0.33		5.19 km²
Secula movement (metres)	12	nil	(+)5.0	(+)2.5	5.0	3.0	5.0	20.0	3.0	
Discharge $10^6 m^3$/day	0.16	0.08	0.14	0.11	0.04	0.09		0.10		

Table 13: Correlation between Mass balance, glacier snout fluctuation and melt water discharge of a small glacier (Dokriani glacier), in Uttarakhand

Period	'93	'94	'95	'98	'99	'20	'01	'02	'03	'04	Glacier area km^2
Mass balance $x10^6 m^3$ (we)	-1.54	-1.58	-2.17	-2.41	-3.19	-2.65					
Discharge $x10^6 m^3$		0.34		0.30	0.24	0.29	0.31	0.40	0.32	0.36	5.76
Retreat in metres	16.5	18.5	17.8	18.5	18.5	18.7	17	18	7	22	

6. On an average, irrespective of the latitudinal variation, contribution from the glacier melt, during the melt season, has been of the same order- about 25% to 30% of the total discharge, per day, per km^2 of glacier ice. During the positive balance years contribution from the glacier melt gets slightly reduced due to reduction in the ablation area, but is more then compensated by the melt waters released from excessive winter snow accumulation that is responsible for the positive balance.

7. Maximum discharge takes place from middle of July to middle of August. Glacier melt is directly related to surface ablation during the early part of the day but, by afternoon, with the thermal gradient going up considerably, contribution from the ice cored moraines becomes substantial leading to maximum discharge by evening. Melt water discharge, in the Himalayas, as recorded at some small glaciers, was found to be independent of mass balance and or glacier retreat.

8. A glacier melt stream, from even small glaciers with an area of $5km^2$, can transport as much as 4,000-5,000 tonnes of suspended sediment during the high discharge period of the melt season. On an average, sediment load producing capacity of the glacier ice in the Himalayas has been found to be of the order of 30 tonnes per day per square km^2 of ice during the melt season in a granite / gneissic terrain, which is rather very low when one compared with those of the glaciers in Alps.

9. Smaller glaciers in the Himalayas -less than 5km long - exhibit an ice thickness of the order of 250m in the cirque region, and an ice thickness of the order of 40m to 60m along the middle reaches while larger glaciers like Zemu exhibit an ice thickness of over 200m in the middle zone.

10. An aerosol/ dust cover of $400gm/m^2$ -thickness of about 2mm- has the maximum effect on a north facing glacier in the month of September so far as the excess melting is concerned. An additional thickness of dust up to 4mm does not make any appreciable change in melting. In fact, thickness of the dust beyond 6mm serves more as an insulator than a conductor of solar heat.

11. Glaciers in the Himalayas are broadly classified as belonging to the temperate category. Studies, however, have revealed that the ice, forming a glacier in the Himalayas, in its vertical profile, can exhibit the characteristics of a cold glacier at certain levels and that of a temperate glacier at other levels.

12. Gangotri glacier, as was first postulated by Auden, had once extended down to Jhala-about 47km down stream of the present position. CNR dates of some of the glacier landforms have now confirmed that the glacier had indeed extended up to Jhala around 58ky BP.

Importance of glacier studies in recent years has become the need of the hour, the fact remains that due to lack of interests on the part of the various institutes and equally poor response by the user agencies, this work has considerably slowed down. It may not be far from truth to state that for the proper management of the Himalayan river system, which has a direct bearing on the National growth, the study of the fluctuation of glaciers, their annual balance, their hydrological behaviours and the assessment of the winter snow pack is of great significance. The study attains further importance when it is faced with the ground reality of less annual snow precipitation over the last decade and the continuous normal process of the degeneration of the glacier cover.

Chapter 7

Suggested Guidelines for Future Work

Future plan of action

Glaciers are grouped under different categories based primarily on: location; size; nature of the feeders; nature of precipitation and flow direction etc. To obtain a broad spectrum of knowledge of various aspects that control the growth/ degeneration of these ice masses, it is essential to expand the study areas to get more variant data and parameters.

Experience gained, as a result of the glaciological studies carried out in the Himalayas, till date, has revealed that, to be in a position for the accurate prediction of impact of the meteorological parameters on any glacier bearing basin - prime object of the glacier study- will require a consolidated effort both in the field and labs.

By and large the proposals for such studies, in future, could be grouped under two heads:

1. **Research and documentation**
2. **Applied aspects**

Department of Science and Technology, Government of India, has now initiated action to create an Institute exclusively for research on glaciers in the Himalayas. The kind of research required, in the inaccessible and relatively hazardous high altitude terrain of the Himalayas, can not be under taken by any single agency. It requires a large number of suitable personnel to execute the job and equally large financial support. It is paradoxical that an organisation like Geological Survey of India, which had, at one time, as many 10 glaciers under the observation during the two decades of 70-90, has now reduced its work load to just one glacier. Glaciology Division at Kolkata, catering to the studies in the Eastern Region has been closed down. Government of India will have to lay stress on these agencies to re-activate their work programme, and train new personal before the old experienced hands retire. Similarly universities/institutes that are, at present, carrying out such studies under the funding support from DST, should be encouraged to expand their area of work/number of glaciers and adequate funds and facilities be made available to them.

Reported abnormal retreat of the glaciers in the Himalayas, more so since 1962, is often the result of the position of the glacier front-snout- in Survey of India maps, published post 1962 not having been correctly recorded. Accuracy rate of the topographic maps of Survey of India, so far as the other physical features are concerned is exceptionally high. The same, however, can not be said about the position of the individual glacier snout. Obvious reason for this being that the maps are based on the aerial photography done during the 1961-62 (November-January) when, even in field, it becomes difficult to differentiate between the actual glacier front and the snow covered terminal moraines.

Survey of India may have to be requested to recheck the position of the glacier snouts using the latest remote sensing technology to facilitate the glacier snout monitoring accurately in future.

Research activity will have to be broad based with specific programmes under:

- **Long term projects**
- **Short term projects**

Former will cover projects that has to have a continuity like glacier snout monitoring, while the latter may cover experiments like fore cast of run off models.

The programme activities may even have to be commercialised to the extant that the user agency/ agencies who, in the long run, would be benefited by the data generated should be asked to pay for the Research activities. This way, their interests in the research would be more than superficial and also the research scholars, or the institutes involved will have to face the accountability, which appears to be lacking at present.

Training Programme

Glaciological studies covering various aspect of glacier dynamics and hydrology does not form the syllabus / curriculum in any of the Universities or-Training Institutes in this country. Research Scientists who take up such studies are thus faced with the handicap of having very little or rather limited knowledge of this subject. Scientists who are already well versed with this specialised subject, and institutes like Geological Survey of India who are at present running such training course on the initiative of DST, could be requested to run such courses annually till a substantive team of experts is generated to cover much larger areas of the Himalayas.

Seminars and workshops

To evolve better understanding of the subject matter and spread the knowledge to wider audience regular workshops and seminars could be held and funds made available for the same.

Chapter 8

Global Warming and the Glacier Retreat - A Review

It has been rightly said, "Glaciers do odd things sometimes. You could anthropomorphize them [apply human characteristics to] and say they have a mind of their own". What else can one say, when glaciers behave in such a contrasting manner: Sonapani glacier has retreated by about 500m during the last one hundred years; on the other hand Kangriz glacier has not retreated, as one would say, even an inch in the same period.

Fig.26: Relative positions-1906 (Walker) and 2008 (Milap) of the snout of the Sonapani glacier

Fig.27: Relative positions-1910 (Neve) and 2007 (Ganjoo) of the snout of the Kangriz glacier

Impact of global warming on the glacier/ice cover in the Himalayas is an agenda for discussion. Perception, among the general public is that the global warming is likely to lead to rapid melting of the ice cover in the Himalayas, which could have devastating effects. While one may not doubt the fact that the climate, by and large, does appear to be getting warmer; what, however, does tax the mind is the attempted linkage of the glacier retreat in the Himalayas to the global warming.

Glaciers in the Himalayas, barring a few exceptions, here and there, have been reported to be in constant retreat, since when the observations started in mid-nineteenth century. There are no two views about it. It is an established fact- a nature's act that has to be accepted and can be reversed only by nature. Questions that remain to be answered are:

- **Glacier retreat:** Are the glaciers in the Himalayas retreating at an abnormal rate?
- **Global warming:** Do the glaciers respond to immediate climatic change?

Glacier Retreat in the Himalayas

The glacier ice cover, in the Himalayas, during the last Ice Age, is believed to have been at least three times than what it is today. It started dwindling, with more and more area getting exposed from under the ice cover, with each successive Interglacial warm period. Evidences have come forth, which would postulate that, at the end of the last glacial cycle of the Quaternary Ice Age-15ky-17ky BP, glaciers in general, in the Himalayas, may not have extended beyond the limit of 20-30 odd kilometres from the present snout position. And the current retreat of the glaciers, in the Himalayas, barring the advance during the Younger Dryas Period (9ky-10ky) and the Little Ice Age (around 200-300 years, BP), is, more or less, in consistent with and continuance of the retreat that began at the end of the last glacial cycle.

Data that has been generated from the glacier studies, in the Himalayas, over the last 100 years or so, indicates that the glaciers, in the Himalayas, have been, by and large, shrinking and retreating continuously, barring a flip here and there, but the rate of retreat can not be considered as alarming/ abnormal, especially in the last decade or so.

To illustrate the point, example of a few glaciers, from the various physiographic zones of the Himalayas, those having an observation record of more than 100 years, is sited below. True! A few glaciers can not be taken as the representative of around 10,000 glaciers of various sizes that exist in the Indian part of the Himalayas. All the same, these have been selected specifically, as there had been reports, floating around, that these glaciers were under going an abnormal retreat, due to global warming, and were likely to vanish in next 50 odd years or so.

Siachen glacier: (IN 5Q 131084)

Siachen glacier, the second largest glacier known outside the polar and sub- Polar Regions, is a valley glacier, about 74km long, situated within the coordinate 35^0 12′ & 35^0 41′ N: 77^0 11′ & 76^0 47′ E, Survey of India, Sheet No. 52E. Snout of this glacier has been under observation, off and on, since 1848 and has not shown any abnormal retreat in the last fifty years that would justify the sensational forecast made that this glacier is going to finish in next 50 years.

Fig.28: Siachen glacier: Comparative position of the glacier front-eastern side-shows very little retreat-1958 (Raina) and 2008 (Ganjoo)

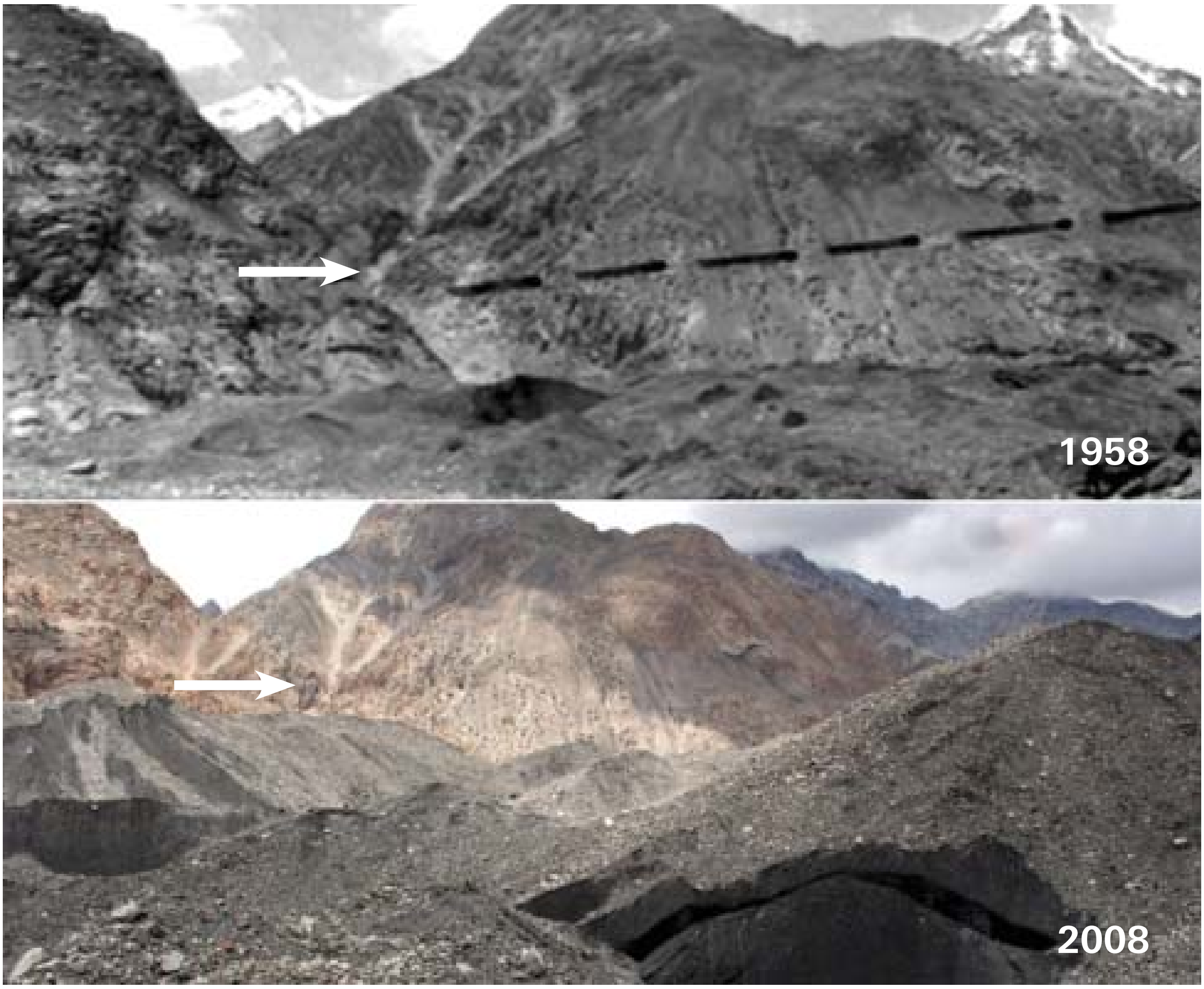


Fig.29: Siachen glacier: Glacier front-western side - viewed with respect to the avalanche chutes (arrow marks), does not show any retreat between 1958 (Raina) and 2008 (Ganjoo). The glacier front in 2008 AD appears to have thickened as compared to 1958 AD.

Machoi glacier: (IN5Q 13202237)

Machoi glacier is a small transverse glacier, less than two kilometres long, situated east of Zoji La, within the co-ordinates: 34° 16´N: 75° 32´E, very close to the National Highway that connects Srinagar to Leh in Ladakh. This glacier is probably the only glacier in the Himalayas, which has, practically, a continuous photographic record of the snout (glacier front) since 1875 AD. The glacier does not appear to have undergone any major retreat in the last 50 years.

Fig. 30: Machoi glacier: Comparative position of the glacier front – 1957 (Raina) and 2007(Raina).

Gangotri glacier: (IN 5O 131 06 029)

Gangotri glacier 30° 56' N: 79° 04' E is about 30Km long with a glacier covered area of about 110km². It is situated in the Bhagirathi valley of the Uttarakhand, India, and is the largest glacier in the Central Himalayas. Snout of the Gangotri glacier, as is typical of glaciers in the Himalayas, is marked by a prominent ice cave that is renowned under the name of Gaumukh-mouth of the cow- from where the Bhagirathi river, one of the main tributaries of the river Ganges, originates. It has been the connoisseur of the explorers and the religious pilgrims over the centuries and has been photographed at regular intervals from 1860 onwards.

Gangotri glacier, it may be noted, had been showing a rather rapid retreat at an average of around 20m per year till up to 2000 AD, which had led to the imaginative prediction of the end of this glacier in next 35 years or so. In actual fact, since 2001AD, rate of the retreat has come down considerably and between September 2007 and June 2009 this glacier is practically at stand still.

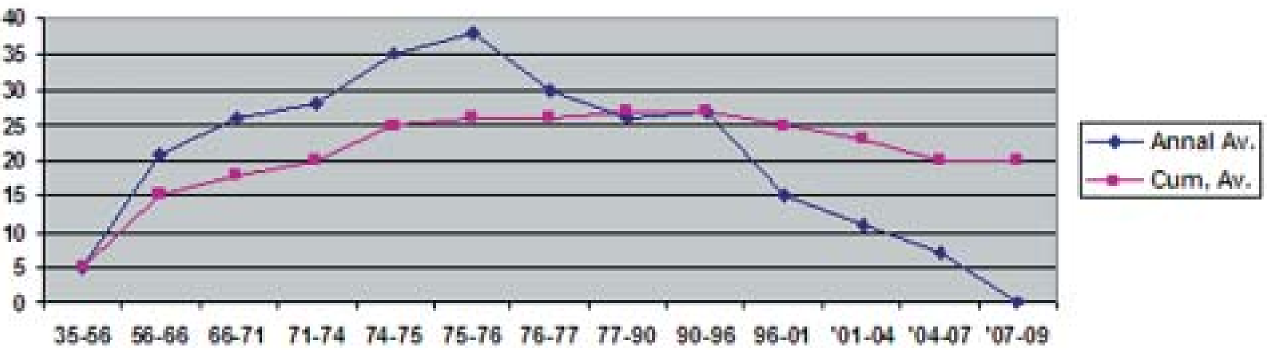


Fig. 31: Graph showing average annual retreat and the cumulative average retreat (in metres) of the Gangotri glacier over last 75 years

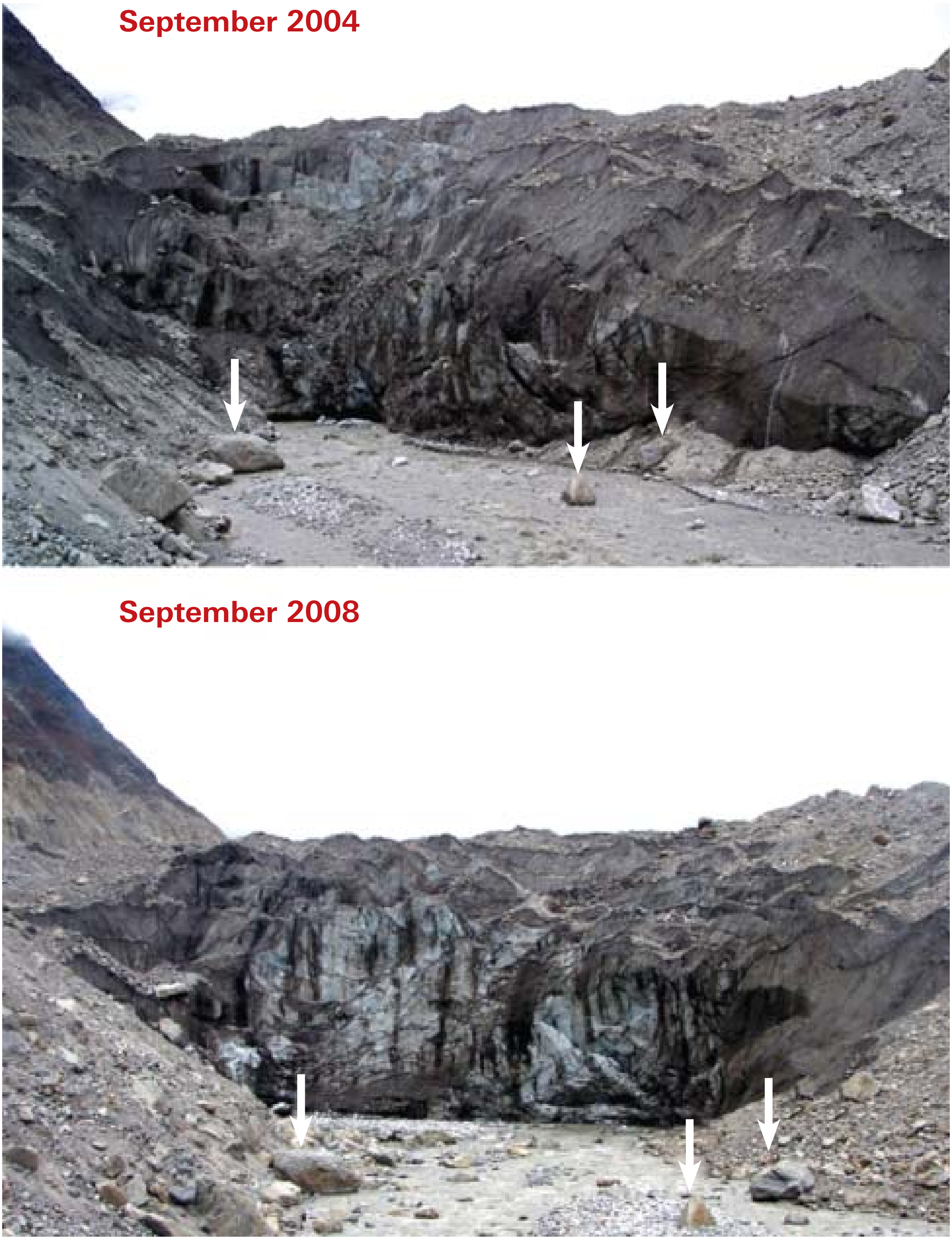


Fig.32: Gangotri glacier: Relative changes in the position of the glacier front between 2004AD (IIT Mumbai) and 2008AD (Ishwar) viewed viz the micro glacier landforms (marked by arrows) can hardly be considered as abnormal retreat.

Fig. 33: Gangotri glacier: Position of the glacier front has hardly changed-except the shift in melt water source- between September 2007 AD (Ishwar) and June 2009 AD (Kireet Kumar)

Glaciers, in the Himalayas, although shrinking in volume and constantly showing a retreating front, have not in any way exhibited, especially in recent years, an abnormal annual retreat, of the order that some glaciers in Alaska and Greenland are reported to be showing. One has to realise that the snouts of the glaciers in Alaska and Greenland are close to the sea level where as that of the glaciers in the Himalayas, on an average, are around 4,000m.a.s.l. In fact, if we go by 'the topographic theory' that maintains that because the temperature decreases with the altitude, mountain uplift causes glaciation, Himalayas should always retain glaciers in one form or the other.

Global warming: Do the glaciers, in the Himalayas, respond to immediate climatic changes?

It was around the beginning of the 20th century that the international community first time realised the possible impact, the rise in atmospheric temperature, was likely to have on mountain glaciers. A concerted effort, world over including the Himalayas, was initiated to identify and examine the fluctuations that glaciers showed along the front-snout, which has continued since. It was believed that such a study over next 100 odd years or so would enable the scientists to establish the relationship between the climate change and the glacier fluctuations.

Glaciologists of the early 20th century were handicapped by the fact that very little information was at hand about the accumulation zone of a glacier, as compared to the present time, when the satellite imagery reveals all. Not only that, in some cases, rather in most of the cases, unless surveyed fully, one did not even have the knowledge as to how many tributaries were feeding the glacier. Despite this, a general conception, in those days, had been arrived at, that by recording the secular movements of glacier snouts, a measure of secular climatic change, either of snowfall, or of temperature, or of both could be derived at. Changes in the glacier snout positions would help in deciding, whether there is a definite recession of the snow-line; whether the climate is getting warmer or colder; a perception that, in one way or the other, has been persisting since.

The problem, however, is not as simple. A glacier is not only effected by complicity of the physical features that affect the glacier itself, but there are so many complications of climate that it is surprising that the snout movement of any glacier should reveal the periodic climate variation or the phases of the climatic variations till many centuries of observations become available. These complicated factors affect the periodic movements of the snouts of glaciers in a very marked manner. Ultimately the movements are due to climate and snowfall in particular, but the factors are so varied that the snout movements appear to be peculiar to each particular glacier. There may be little resemblance between the periodic movements in neighbouring glaciers of a range, even if they have the same exposure. Sometimes there is no similarity between the periodic movements in two branches of the same compound glacier; and, occasionally, one side of a glacier tongue may be advancing while the other is stagnant or even retreating.

Fig.34: Un-named glacier in Suru valley. Two tributaries show different character: Branch (A) has advanced while branch (B) continues to be stagnant.

Glacier snout fluctuation can be in response to: Secular movement; Periodic movement, Seasonal movement or even Accidental. The problem of resolving glacier movement into its various components, secular, periodic, seasonal is extremely complicated. Unless and until the basic difference between the types of the glacier snout movement is understood, it may be erroneous to co-relate glacier snout fluctuation with one atmospheric parameter or the other. The more glaciers we can examine in a given area, the better are the chances of coming to a correct conclusion. Every glacier in a region should be studied, for there are few that will not teach us something.

Their peculiarities should be studied before we can even say which are likely to give us the most information, and all observations should be made with such care that no doubt exists concerning their accuracy.

We know today, with a great degree of certainty that glaciers can be considered as nature's secular barometers, which can help in deciphering the climatic changes that the earth has undergone since a particular glacier has come into existence. But to postulate that a glacier can warn of the climate changes likely to take place in future is a big question mark. A glacier as, already, stated does not necessarily respond to the immediate climatic changes, for if it be so then all glaciers within the same climatic zone should have been advancing or retreating at the same time.

Local changes in the glacier front may some times show close relation with the climatic parameters but these could be mere coincidence and, it would not be proper to come to any conclusion with the limited data available. One has to remember that what ever studies we make on the glaciers are mainly supra-glacial and we have very little knowledge of what is happening en-glacial or sub-glacial.

In deriving a definite conclusion for the response of the glaciers, in the Himalayas, to the climatic changes, a major handicap faced is the fact that no data, what so ever, about the annual snow precipitation and the atmospheric temperature, in the Himalayas, in general, and in the 4th order basins that are glacier bearing, in particular, is available.

An AWS was established at Bhojbasa, about 3km downstream of the Gangotri glacier snout, in the year 1999, that records and relays hourly fluctuations in atmospheric temperature, daily snow/rain precipitation, wind velocity and humidity. Correlation of the meteorological parameters: the atmospheric temperature and annual snow precipitation recorded at Bhojbasa, with the glacier retreat as depicted by the snout of the Gangotri glacier, has not shown any specific relation that could be indicator of the Impact of the global warming

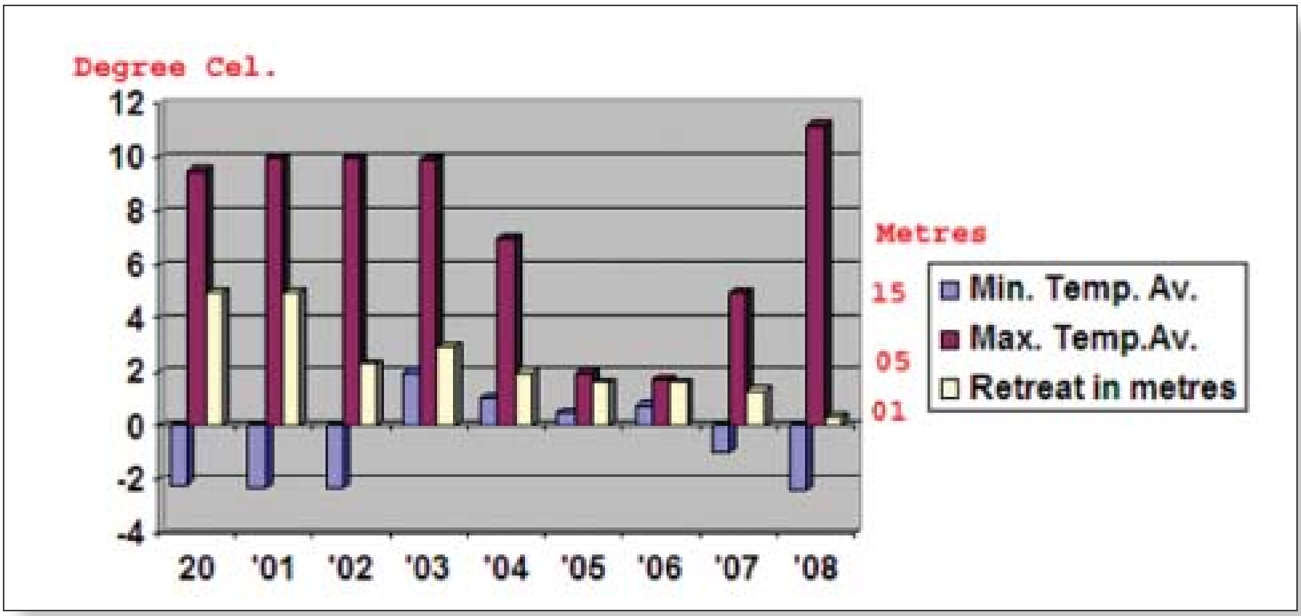


Fig.35: Columnar chart showing relation between maximum/minimum temperature (average), recorded at Bhojbasa, with the retreat of the snout of the Gangotri glacier

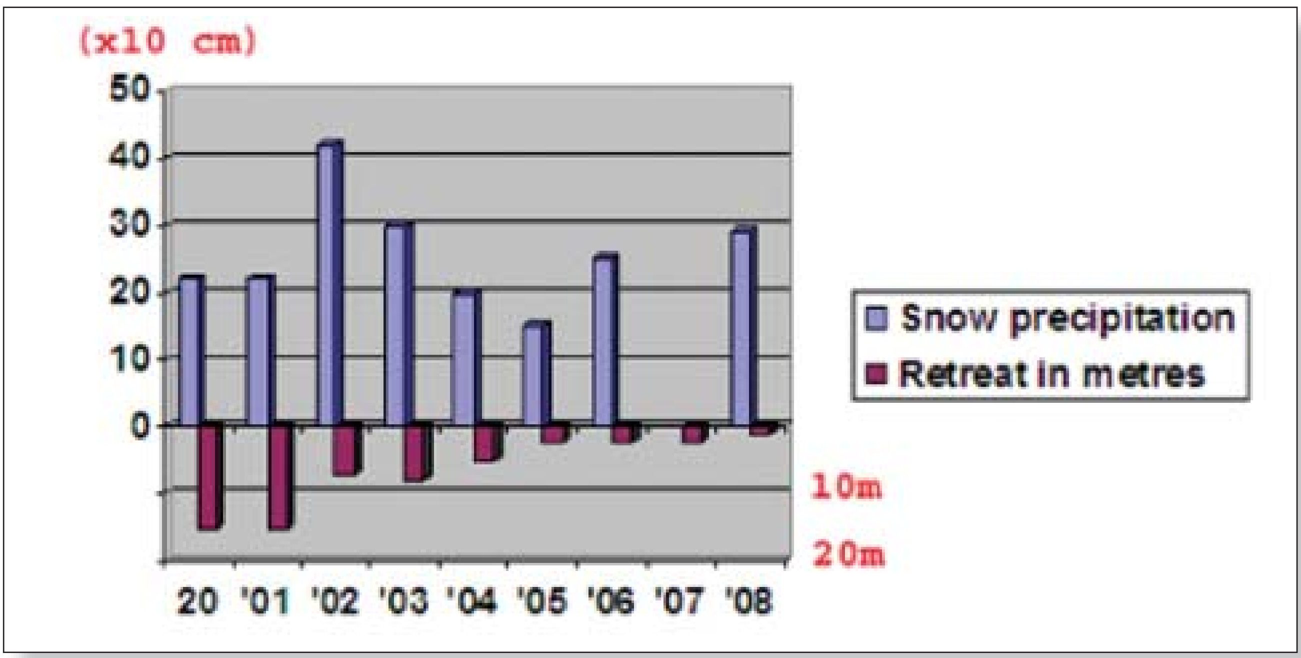


Fig.36: Columnar chart showing relation between annual snow precipitation, recorded at Bhojbasa, with the retreat of the snout of the Gangotri glacier

There is a school of thought that postulates that the current fluctuations, in the form of glacier advance or retreat, is likely to be more in response to the past climate than the immediate one. Scientists working on similar problems in Rockies and Alps, are of the opinion that, "A large mountain glacier would take 1,000 to 10,000 years to respond to warming today, while a small mountain glacier would take 100 to 1,000 years to respond. Thus, one explanation for the glacier retreat could be: they are responding to natural warming that occurred either during the Medieval Warm Period in the 11th century or to an even warmer period that occurred 6,000 years ago"

Mass (glacier ice) transfer studies that were carried out at Gara glacier revealed that it would have taken slightly more than 300 years for the mass accumulated in the accumulation zone of this glacier (2.5km long) to reach the snout position. Dating of the glacier ice, from the core samples collected from near the snout, substantiated this by revealing the ice to around 250y BP to 300y BP. Using the corollary that the glacier snout fluctuation is in response to past climate would mean that the fluctuations exhibited by the snout of the Gara glacier may have been depicting weather/climatic conditions of 300 years back and not that of mid-seventies of the 20th century?.

If that be so, fluctuations exhibited by the glacier of the size of Gangotri or Siachen, along the snout today, based on glacier ice flow movement, may, in fact, be in response to the climate of 6,000y BP in the case of former and around 15,000y BP in the case of latter. Fact remains that the glaciers, so far as the snout fluctuation is concerned, do not show any immediate response to meteorological parameters.

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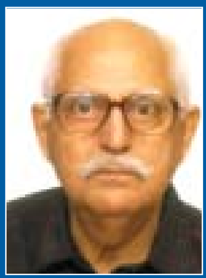
Annexure

List of Government Agencies, Institutes and Universities involved in Glaciological Studies in the Himalayas in India

- Geological Survey of India, Northern Region, Lucknow, UP
- Wadia Institute of Himalayan Geology, Dehradun, Uttarakhand
- Space Application Centre, Ahmedabad,
- Regional Centre for Field Operations and Research on Himalayan Glaciology, University of Jammu, Jammu
- Geology department of the of the H. N. Bahaguna, Garhwal University, Uttarakhand
- Centre for the Study of Regional Development, School of Social Sciences Jawaharlal Nehru University, New Delhi
- Remote Sensing Applications Centre, Uttar Pradesh, Lucknow
- Glacier Study Centre of G.B.Pant Institute of Himalayan Environment and Development, Almora
- Snow Avalanche Study Establishment, Chandigarh
- Indian Institute of Technology, Bombay, Mumbai
- Birla Institute of Technology, Jaipur
- Geology Department, University of Lucknow, Uttar Pradesh
- Birbal Sahini Institute of Palaeobotony, Lucknow, Uttar Pradesh
- National Institute of Hydrology, Roorkee, Uttarakhand
- Physical Research Laboratories, Ahmedabad, Gujarat
- The Energy Research Institute (TERI)



About the Author

V.K.Raina, superannuated as Deputy Director General, Geological Survey of India, after an active field oriented service of over 36 years. An ardent mountaineer, his field activities covered extensive research on the geology and the glaciers of the Himalayas, Andaman Islands that included research on the volcanoes in the Bay of Bengal. He led two Indian Scientific Expeditions to Antarctica when the Indian activities in Antarctica were in formative stage that earned him the National Mineral Award and the Antarctica Award. He has authored over 100 scientific papers and three books: 'Glacier Atlas of India' dealing with various aspects of glacier studies under taken in the Himalayas; 'Glaciers, the rivers of ice' and 'Images Antarctica, Reminiscences', last one dealing with his experiences in the icy continent of Antarctica. He is currently busy in bringing out yet another book on glaciers of the Himalayas entitled, 'Glacier monitoring in the Himalayas- an Atlas'.

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