*Proceedings WARMICE-2012*
*Sudhir Kumar, et al. (eds)*
*I.A.H., 2012*

**III-1**

# Gangotri Glacier Study using Remote Sensing, GIS and Long Term Temperature Data

**Praveen K. Thakur[1], Vaibhav Garg[1], Purevdagva Khalzan[2] and S.P. Aggarwal[1]**
[1]Indian Institute of Remote Sensing, Dehradun, India
[2]Institute of Meteorology and Hydrology, Mongolia

**Abstract** : In this study Gangotri glacier movement with respect to time as well as changes in the air temperature has been studied using remote sensing and climatic data. The multi-temporal mapping of the snout position using Landsat and Liss-III data and height with SRTM and ASTER GDEM is used to calculate retreating velocity of glacier. Monthly mean air temperature at 2 m above ground level has been used for climatic study. This data has been taken form NCEP/NCAR web site. The ortho-rectified images of Landsat MSS (1974, 1976, 1979, 1980), TM (1990, 1998), ETM+ (2002, 2003) and IRS-P6 Liss3 (2009) were used for snout position identification and supervised land use land cover classification. Thermal channel (band 6: 12.4-12.5 ìm) has been used in TM and ETM+ data for classification and snout position identification.

Gangotri glacier is retreating by 16.56 m every year in horizontal (moving direction) axis, 0.82 m retreating by vertical axis (elevation) due to changes in air temperature, which is increasing *0.03°C* every year. Also retreating velocity is increasing 1 m/year. Maximum speed observed from 1983 to 2003, in these 5 years speed was 23 m/year and temperature also observed maximum (4°C in 1999). The glacier movement has also been studied using ERS1/2 tandem SAR data using interferometric techniques. Based on fringe analysis of main Gangotri glacier, the glacier movement has been found to of the order of 4-6cm per day or 16-21m per year.

## INTRODUCTION

Glaciers are ancient rivers of compressed snow that creep through the landscape, shaping the planet's surface. They are the Earth's largest freshwater reservoir, collectively covering an area the size of South America. Glaciers have been retreating worldwide since the end of the Little Ice Age (around 1850), but in recent decades glaciers have begun melting at rates that cannot be explained by historical trends. Global Warming is melting glaciers in every region of the world, putting millions of people at risk from floods, droughts and lack of drinking water. Projected climate change over the next century will further affect the rate at which glaciers melt.

The majority of the Himalayas Rivers have their origin in the snow and ice covered glaciers. These rivers provide water for drinking, food production, energy production, industrial development of this region. About 10% of total area of the Himalaya is covered with glaciers and additional area, nearly 30% support the snow cover (Singh and Singh 2001, Singh *et al.* 2011). According to estimation, there are about 9575 glaciers, covering an area of about 38000 km$^2$ in the Indian part of the Himalaya (Raina 2009). It has been noticed that Himalayan glaciers have melted more than normal over the past century. It was argued in the past that this was a normal process that takes place over time, but this is now proving wrong. Shukla and Siddiqui (1999) monitored the Milam Glacier in the Kumaon Himalaya and estimated that the ice retreated at an average rate of 9.1m per year between 1901 and 1997. Dobhal *et al.* (2008) monitored the shifting of snout of Dokriani Bamak Glacier in the Garhwal Himalaya and found 586m retreat during the period 1962 to 1997. The average retreat was 16.5m per year. Matny found Dokriani Bamak Glacier retreated by 20m in 1998, compared to an average retreat of 16.5m over the previous thirty five years.

(Matny, L., 2000). Oerlemans (1994) quantified the global warming from the retreat of glaciers. Average global temperatures are expected to rise 1.4-5.8°C by the end of the 21st century (IPCC). Simulations project that a 4°C rise in temperature would eliminate nearly all of the world's glaciers (the melt-down of the Greenland ice sheets could be triggered at a temperature increase of 2 to 3°C). Even in the least damaging scenario – a 1°C rise along with an increase in rain and snow – glaciers will continue to lose. With these scenarios and background, the present study has been taken up to study the Gangotri glacier using multi-temporal remote sensing data and long term air temperature data.

## OBJECTIVES AND STUDY AREA

The main objectives of this study are

- To detect changes in the snout position of Gangotri Glacier with RS and GIS using multi spectral and ERS1/2 tandem SAR data.
- Hydro-meteorological variations and analysis in and around Gangotri Glacier using long term temperature data.

## STUDYAREA

The study area for this work is Gangotri glacier. The Gangotri glacier is one of the largest Himalayan glaciers, which is about 30.20 km long[1] with its width varying from 0.5 to 2.5 km (figure 1).

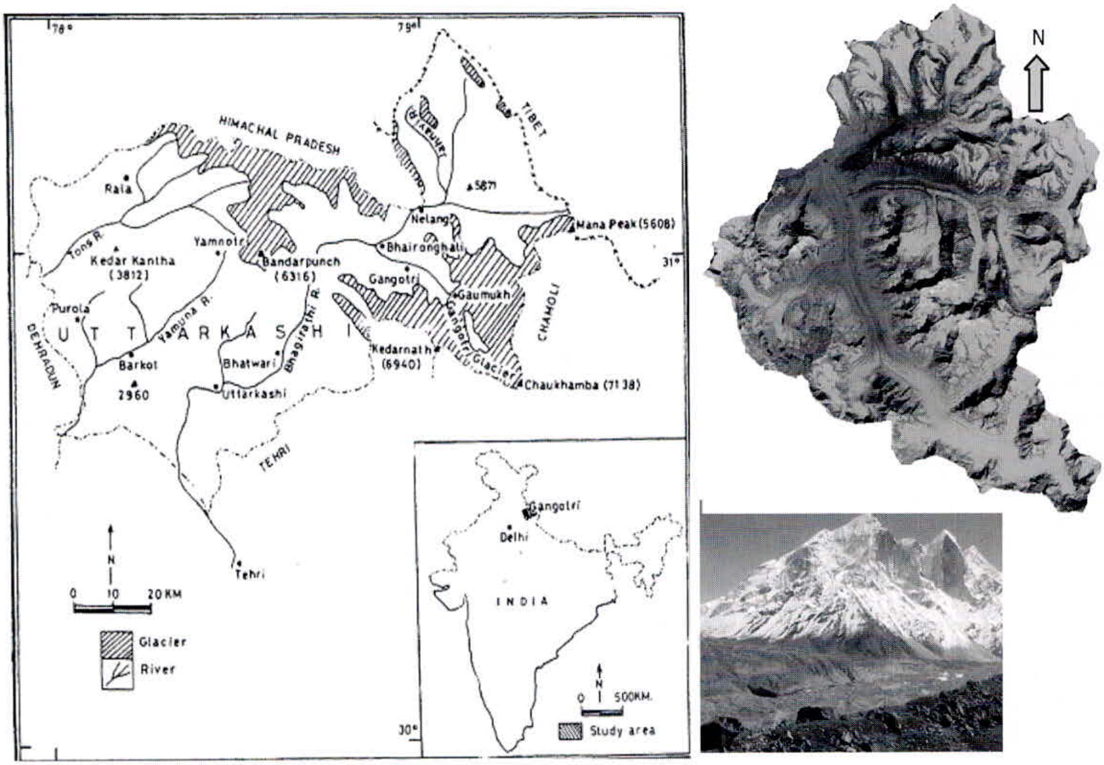


**Fig.1a).** Location map of Gangotri glacier ((Naithani *et al.* 2001); b): 29 Sep, 09 LISS-III, FCC of Gangotri group of glaciers and; c): Field photograph of Gangotri glacier.

It is a valley-type glacier, situated in the Uttarkashi district of Garhwal Himalaya, Uttarakhand (figure 1) and it flows to NW direction. This glacier is bound between 30°43'22"–30°55'49" (latitude) and 79°04'41"–79°16'34" (longitude), extending in height from 4120 to 7000 m. above mean sea level (a.m.s.l.). This area is situated north of the Main Central Thrust (MCT) and comprises bed rocks of granites, garnet mica schist, quartz biotite schist, kyanite schist, augen gneiss and banded augen gneiss. The southwest Indian monsoon with an average annual precipitation of 1550 mm influences the climate of the area. The microclimate of this region may be affected by both the valley aspect and altitude. The broadleaf thick forests are rare in this valley, upstream to Harsil (2400 a.m.s.l.), may be due to the sharp turn of the valley lying at right angles to the advancing monsoon front direction and consequently a ecrease in rainfall. Here the arid element Himalayan cedar (Cedrus deodara) dominates the vegetated slopes up to timberline. The tree which reaches to the highest elevation of about 4100 m.a.s.l. near Bhojbasa is Indian birch, bhojpatra (Betula utilis). This glacier comprises three main tributaries, namely Raktvarn (15.90 km), Chaturangi (including Kalandini bamak) (22.45 km) and Kirti (11.05 km) and more than 18 other tributary glaciers are almost transverse to subtransverse (Naithani *et al.* 2001). The Raktvarn system contains 7 tributary glaciers; among them Thelu, Swetvarn, Nilambar and Pilapani are important. Similarly the Seeta, Suralaya and Vasuki are the major tributaries which make up the Chaturangi system, while the Kirti system comprises only three tributary glaciers. Besides these three major tributary systems, some other tributary glaciers of this area are directly draining into Gangotri glacier; among them Swachand, Miandi, Sumeru and Ghanohim are important. Four other glaciers, which are directly draining into the river Bhagirathi, are Maitri, Meru, Bhrigupanth and Manda. The total glacierized area of the catchment is 258.56 $km^2$, out of which the Gangotri system comprises 109.03 sq km, followed by Chaturangi (72.91 $km^2$), Raktvarn (45.34 $km^2$) and Kirti (31.28 $km^2$). The remaining four glaciers contain 29.41 $km^2$ of glacierized area; among them maximum contribution is from Bhirgupanth glacier (14.95 $km^2$) (Naithani *et al.* 2001). The gradient of Gangotri glacier is lowest (0.045), followed by Chaturangi and Raktvarn (0.146 and 0.210 respectively), while Kirti glacier has the highest gradient.

**Glacier features of study area**

The various landforms and features of glaciated terrain such as accumulation zone, the ablation zone, equilibrium line, Snout and glacial moraines have been identified in this area. Of all these features, the *snout position* is one of most useful characteristic of glacier dynamics.

The snout-the lowest extremity of a glacier, is basically, a part of the ablation zone, which reflects the characteristics 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 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".

**DATA USED AND METHODOLOGY**

The present study has used 09 images of LANDSAT (MSS, TM and ETM+), one image of IRS-P6 LISS-III and two SAR images of ERS 1/2. The changes Gangotri glacier were calculated in steps of data preparation as given in methodology flowchart (figure 2). The Meteorological data was taken from the NCEP/NCAR website which is 2m from surface of monthly mean of air temperature data from 1979 to 2008. The Center for Ocean-Land Atmosphere Studies (COLA) near-surface data set for ISLSCP-II has been derived from the (National Centers for Environmental Prediction /Department of Energy) NCEP/DOE AMIP-II reanalysis covering the years from 1979-2008.

**Fig. 1d).** Field photograph of Snout of Gangotri glacier (Praveen Thakur, 30 Sep. 08)

**Table 1.** List of data used in the study

| Satellite | Sensor | Date | Spatial Resolution (m) | temporal resolution |
|---|---|---|---|---|
| Landsat | MSS | 12-Jun-74 | 83 | 2 week |
| Landsat | MSS | 19-Nov-76 | 83 | 2 week |
| Landsat | MSS | 8-May-79 | 83 | 2 week |
| Landsat | MSS | 4-Jul-80 | 83 | 2 week |
| Landsat | TM+ | 15-Nov-90 | 30 | 2 week |
| Landsat | TM+ | 5-Jun-98 | 30 | 2 week |
| Landsat | TM+ | 9-May-00 | 30 | 2 week |
| Landsat | ETM | 14-Oct-02 | 30 | 21 days |
| Landsat | ETM | 10-May-03 | 30 | 21 days |
| IRS-P6 | LISS3 | 14-Apr-09 | 23.5 | 5 days |
| ERS-1 | SAR | 16-May-96 | 25 | 1-day (tandem mission) |
| ERS-2 | SAR | 17-May-96 | 25 | |

As given in the figure 2, multi-date remote sensing and hydrometeorological data has been processed for finding the various land use land cover classes, along with snout position of Gangotri glacier. The relative position of snout has been used along with one benchmark position in all satellite images to estimate the retreat or advance of the glacier. Similarly interferometric techniques (Rosen *et al.* 2000) have used to estimate the glacier movement rate (Mattar *et al.1998*).

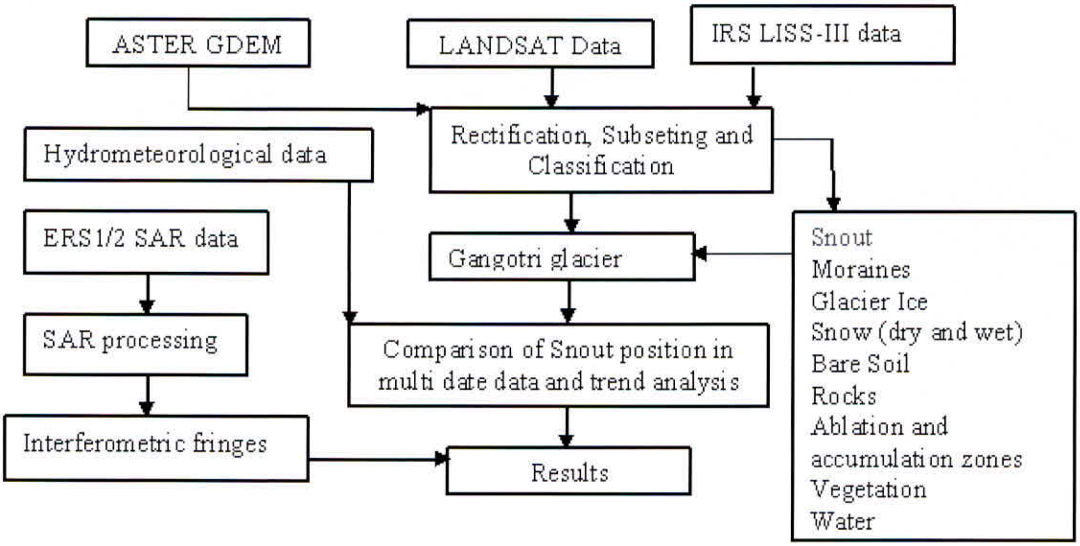


**Fig.2.** Methodology flow chart used in the study

## RESULTS AND DISCUSSIONS

A benchmark has been chosen in downstream of glacier. The distance between snout position and benchmark has been measured for every year under consideration (figure 3b) and it was found that the glacier has retreated about 515m since 1974 to 2003. Therefore, the velocity of retreat is about 15 meter per year (figure 3c). Calculated change in elevation of snout is 0.82m per year and last 30 years has been shifted up in elevation by 24m (figure 3d). This result given by slope of retreating snout which is calculated 0.092 %. Gangotri retreat rate of 6cm per day or 21m/year was found from ERS1/2 data of 16-17 may 1996. The estimated retreat rates are similar to those found using kinematic GPS survey results (Kumar *et al.* 2008).

According to the NCEP data, air temperature has increased about 1$^0$C in last 30 years. In last 30 years, there are 3 phases of temperature change (figure 5). In figure 5, green, blue and red areas represent the increasing and/or decreasing temperatures. Green area shows increasing period from 1983 to 1988, red area shows increasing temperature from 1998 to 2003, and blue area shows that air temperature has decreasing trend from 1990 to 1998 period (figure 5a).

## CONCLUSIONS

This study concludes that Gangotri glacier movement rate every year is 16.56m retreating in horizontal (moving direction) axis, 0.82 m retreat by vertical axis (elevation) with air temperature change of increasing 0.03 $^0$C every year. Also

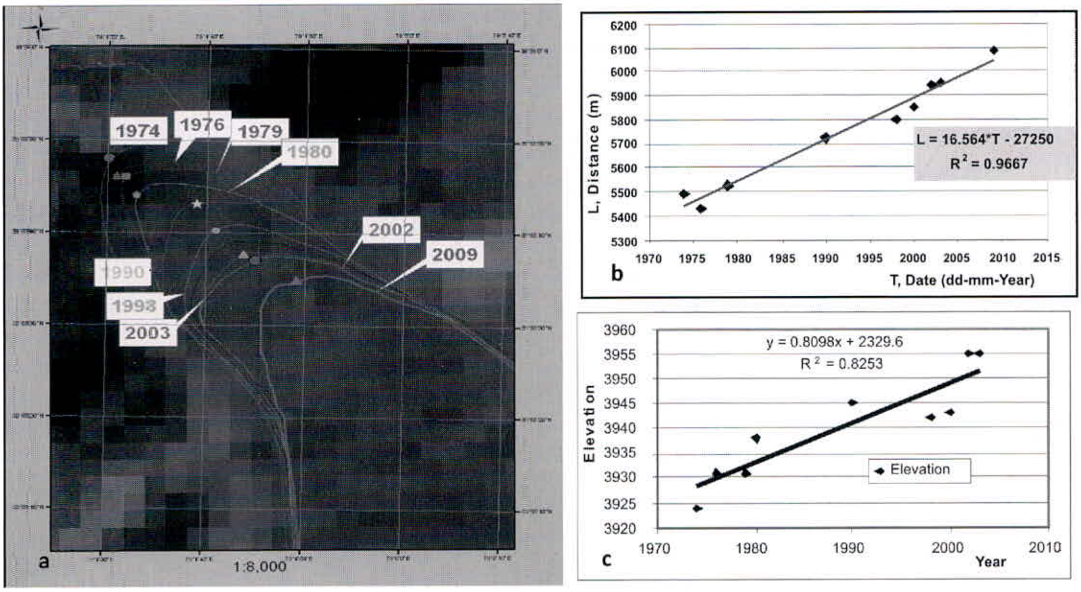


**Fig. 3a).** Movement of snout position of Gangotri glacier; b): Movement rate (benchmark to snout position) and; c): Snout position vs snout elevation relation

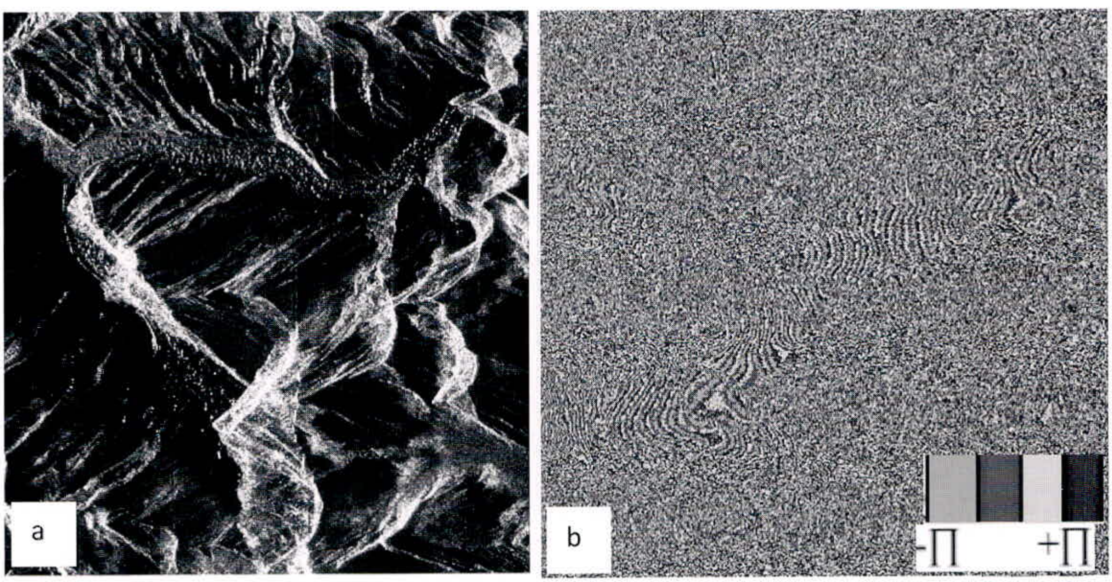


**Fig. 4a).** ERS 1 intensity image of Gangotri glacier; b): D-Int fringe of Gangotri area, ERS 1/2, 16-17 May 1996.

**Table 2.** Three phases of air temperature

| Value | Years | Period | Temperature |
|---|---|---|---|
| Temp. increase | 6 | 1998-2003 | 3.26 |
| Temp. decrease | 9 | 1990-1998 | 2.59 |
| Temp. increase | 6 | 1983-1988 | 2.93 |

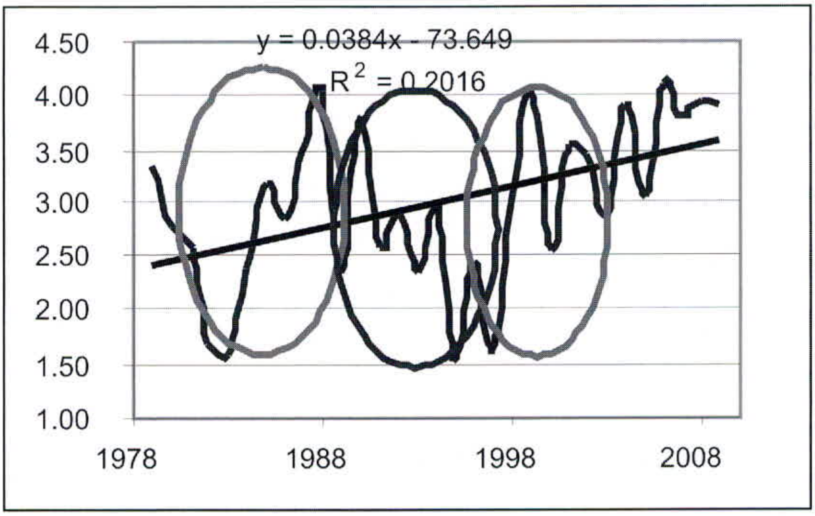


**Fig. 5.** Average air temperature for Gangotri area from year 1979-2008

glacier retreating velocity is increasing by 1 m/ year. Based on these results, a simple linear regression model (figure 3b) has been made to estimate future retreat of Gangotri glacier. For example, using this relation for year 2030, the Gangotri glacier would be retreated by ~927.6m with respect to its 1974 position.

## ACKNOWLEDGEMENTS

The authors acknowledge the support from Dr P.S Roy Director IIRS and Director CSSTEAP for their valuable suggestions on this paper. Authors are also thankful to all the field staff and scientists at SASE field stations at Bhojbasa, Gangotri for their support and help during field work. Funding for this project was provided by ISRO under TDP and RISAT-UP project on snow and glaciers studies with optical and microwave remote sensing.

## REFERENCES

**Climate of Uttar Pradesh,** Indian Meteorological Department, 1989, pp. 372–375.

**Dobhal D.P., Gerganj.T. and Thayyen R.J. (2008).** Mass balance studies of the Dokriani Glacier from to, Garhwal Himalaya, India. Bulletin of Glaciological Research, Japanese Society of Snow and Ice, 25: 9-17.

**Forster, R.R. Rignot., E. Isacks B.L. and Jezker, K.C., (1999).** Interferometric radar observations of Glaciares

Europa and Penguin, Hielo Patagonico Sur, Chile. *J. Glaciology,* Vol. 45, No. 150, pp325-337.

**Inventory of Himalayan Gaciers,** Geological Survey of India, 1999.

**IPCC 2001.** Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 881 pp.

**Kulkarni, A.V.; Rathore, B.P.; Mahajan, S.; Mathur, P. (2005).** Alarming retreat of Parbati glacier, Beas basin, Himachal Pradesh. Curr Sci, 88 (11), 1844-1850.

**Kumar, K., Dumka, R.K., Miral, M. S., Satyal, G.S. and Pant, M., (2008).** Estimation of retreat rate of Gangotri glacier using rapid static and kinematic GPS survey. *Current Science*, Vol. 94, No. 2, 25, 258-262.

**Law, B. C., (1968).** In Mountains and Rivers of India (ed. Law, B. C.), pp. 187–210.

**Mattar E.K., Vachon, P.W., Geudtner, D. and Gray, A.L., (1998).** Validation of Alpine glacier velocity measurements using ERS tandem-mission SAR data. *IEEE Trans. Geosci. and Remote Sens.,* vol. 36, pp.974-984.

**Matny, L. (2000)** Melting of Earth's Ice Cover Reaches New High. Worldwatch News Brief.

**Naithani, A. K., Nainwal, H. C., Sati K. K. and Prasad C., (2001).** Geomorphological evidences of retreat of the Gangotri glacier and its characteristics. *Current Science,* 80, 1, 87-94.

**Oerlemans, J., (1994)** Quantifying global warming from the retreat of glaciers. Science 264, pp 243 - 245.

**Owen, L. A., Sharma, M. C. and Bigwood, R., (1995).** *Geomorphology and Land Management in a Changing Environment* (eds McGregor, D. F. M. and Thompson, D. A.), John Wiley, , pp. 69–88.

**Raina, V.K. (2009).** Himalayan Glaciers - A State-of-Art Review of Glacial Studies, Glacial Retreat and Climate Change, *MOEF discussion paper*, by Ministry of Environment & Forests (MOEF), Government of India and G.B. Pant Institute of Himalayan Environment & Development Kosi-Katarmal, Almora, 1-60.

**Raina, V. K., (2004).** Is the Gangotri glacier receding at an alarming rate? *J. Geol. Soc.* India, 64, 819–821.

**Rosen, P.A., Hensley, S., Joughin, I.R., Li, F.K., Madsen, S.N., Rodriguez, E. and Goldstein, R.M., (2000).** Synthetic aperture radar interferometry. *IEEE Trans. Geosci. Remote Sens,* Vol. 88, pp.333-382.

**Singh, P. and Singh, V.P., (2001).** *Snow and glacier hydrology.* Kluwer Academic Publishers, Dordrecht.

**Singh, V.P., Singh, P. and Haritashya, U.K., eds. (2011).** *The Encyclopedia of Snow, Ice and Glaciers.* Berlin, Springer. pp 1254. ISBN-10:9-048126-41-X, ISBN-13:978-9-048-12641-5.

**Sharma, M. C. and Owen, L. A., (1996).** *J. Quat. Sci. Rev.,* 15, 335–365.

**Shukla, S. P. and Siddiqui, M. A., (1999).** Recession of the snout front of Milam glacier, Goriganga valley, Pithoragarh District, U.P., *Proceedings of the Symposium on Snow, Ice and Glacier, Geol. Surv. India Spl. Publ.*, 2001, 53, pp. 71–85.

**Surazakov, A.B.; Aizen, V.B.; Aizen, E.M.; Nikitin, S.A. (2007).** Glacier changes in the Siberian Altai mountains, Ob river basin (1952 - 2006) estimated with high resolution imagery. *Environ Res Lett*, 10.1088/1748-9326/2/4/045017.

**Thakur, V. C., Virdi, N. S., Gergan, J. T., Mazari, R. K., Chaujar, S. K. and Philip, G., (1991).** Scientific Report submitted to DST, New Delhi.

**Tewari, A. P., (1976).** Study of Gangotri glacier, Uttarkashi District (Central Himalaya), Uttar Pradesh. *Rec. Geol. Surv. India,* 106, 248–256.

**Vohra, C. P., (1981).** *The Himalayas: Aspects of Change* (eds Lall, J. S. and Moddie, A. D.), Oxford University Press, New Delhi, , pp. 138–151.

**Vohra, C. P., (1988).** Indian Mountaineer, Indian Mountaineering Foundation, 1–8.

**http://www.esrl.noaa.gov/psd/data/gridded/ data.**ncep.reanalysis2.gaussian.html