Mountains Witnesses of Global Changes
R. Baudo, G. Tartari, and E. Vuillermoz (Editors)

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Climate research in the Nepal Himalaya

Saraju K. Baidya

Abstract

Nepal is a mountainous country with extreme topographical variation. This paper discusses some climatic research works in Nepal, mainly focusing on climate change and its impact, as well as the monsoon in Nepal. Studies have indicated increasing trends of maximum temperature in most parts of the country, with high warming trends in the Himalayan and middle mountain regions compared to lower altitudes and plains. This result is also supported by the retreating glacier trend in the Nepal Himalaya. Studies show that these glaciers are retreating at an alarming rate, with a potential negative impact on water resource management and threat of glacier lake outburst floods. General circulation models were used in 1994 and climate change scenarios were developed to study the impact of climate change on water resources and agriculture. The Department of Hydrology and Meteorology in Nepal has now started experiments on a high-resolution regional climate model, the RegCM3 to study the impact of climate change and to assess vulnerability. The role of the Himalaya on the Asian Summer Monsoon (ASM) has been well recognized in many modeling studies. In 1999, the Monsoon Himalayan Precipitation Experiment was carried out to study the interaction of the Himalaya and the ASM.

1. Introduction

Nepal is a small mountainous country situated on the southern slope of the Himalaya. Although it lies near the northern limit of the tropics, the climate varies from tropical in the southern plain area to polar and arctic in the high Himalaya due to intense north/south topographical variations (60 m a.s.l. in the south to 8848 m a.s.l. in the north) within a short horizontal distance of about 200 km.

The main source of precipitation in Nepal is the summer monsoon (June to September), which results in response to the large thermal gradient between the warm Asian continent to the north and the cooler Indian Ocean to the south (Slingo et al., 2002), and due to seasonal shifting of thermally induced planetary belts of pressure and winds under continental influences (Pant and Kumar, 1997). About 80% of the annual rainfall occurs during this period (Nayava, 1974; Shrestha, 2000). This monsoon current enters Nepal from the southeast direction. Once it enters Nepal, topography

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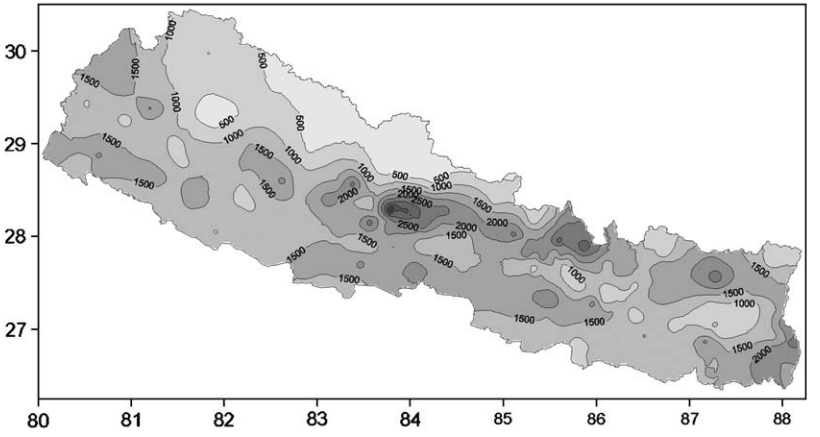

Figure 32.1. Spatial distribution of monsoon rainfall.

determines the spatial distribution of rainfall. The windward side of the mountain barrier receives a lot of rainfall while the leeward side receives comparatively less rainfall and is almost dry. But there are some high rainfall pockets, which are favored by the topography (windward side) and its orientation (Fig. 32.1).

The rugged mountain topography, the fragile geology of the young Himalayan Mountains, and high intensity of monsoon rainfall makes Nepal prone to natural disasters such as floods, landslides, droughts, and other problems. With global warming and climate change in the limelight for quite some time, Nepal is no exception. This paper discusses some climatic research work in Nepal, mainly focusing on climate change and its impact; as well as the monsoon in Nepal.

2. Climatic trends in Nepal

The subject of global warming and climate change has become an issue of great concern to the scientific as well as political communities. Studies of long-term global temperature change (Jones et al., 1986; Hansen and Lebedeff, 1987) show a meaningful warming trend in the past century. Similarly, Hingane et al. (1985) found a slight but definite warming trend in the mean annual Indian temperatures. The first study of such kind for Nepal was done by Shrestha et al. (1999) based on temperature data from a network of surface observations. Shrestha et al. (1999) found increasing trends of maximum temperature in most parts of the country after 1977 (Fig. 32.2), with high warming trends in the Himalayan and middle mountain regions (0.06°C to 0.12°C) and low warming (less than 0.03°C) over most of the Siwalik and Terai (southern plains) regions. The capital city, Kathmandu, shows the increase in mean annual temperature by 0.05°C/yr.

The monsoon rainfall of Nepal for the period 1971–2000 (Fig. 32.3) shows a large year-to-year variation. Although there is evidence of a slight increasing trend, the result is statistically insignificant. So, it can not be concluded with certainty that the rainfall over Nepal is increasing, and besides, a regional variation in rainfall

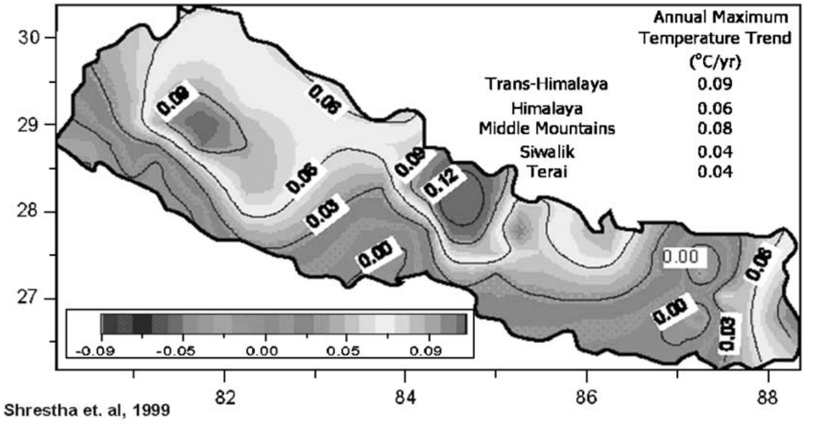

Figure 32.2. Spatial distribution of annual maximum temperature in Nepal.

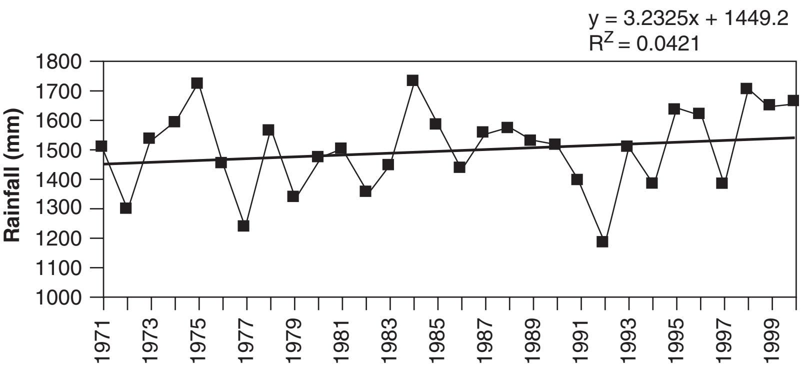

Figure 32.3. The monsoon rainfall trend in Nepal.

pattern exists. The rainfall usually decreases from south to north and east to west (Shrestha, 2000).

3. Climatic research

The glaciological and meteorological observations of the glaciers and climate in the Nepal Himalaya started in the early 1970s as the "Glaciological Expedition to Nepal (GEN)" Higuchi (1976) with the aim of obtaining data on the state of glaciers and their variations to understand the relation between glaciers, climate, and water resource development. Since then, a lot of other research has been carried out in the Nepal Himalaya. The country is rich in water resources, with over 6000 rivers, and major ones are fed by glaciers and glacial lakes located at the source of these rivers (Mool et al., 2001). The rivers finally drain into the Ganges. So any major changes in the Nepal glaciers will have regional scale impact on water resources (WWF, 2005). The Department of Hydrology and Meteorology of Nepal has installed six regular high altitude stations in the Nepal Himalaya for such study purpose. Glaciers are also important indicators of climate and climate change (Higuchi, 1976; Oerlemans, 1994). Though the Himalayan glaciers have been retreating for a long time, the studies show that there is compelling evidence of these glaciers retreating at an alarming rate and the rate of retreat is accelerating in conformity with the high rate of warming over the Himalaya. This leads to a heightened concern as to what effect such warming will have on the seasonal and long-term water resource management on glacier-fed rivers. Therefore, glaciological studies are important to study the impact of climate change and assess the water resources of this region.

The inventory compilation of glaciers in the Nepal Himalayas started in the early 1970s (Müller, 1970; Higuchi et al., 1976). The latest study on glaciers of the Nepal Himalayas revealed 3252 glaciers (Mool et al., 2001). Many of these glaciers are found to be in a general recession. Glacier AX010 is one of the most studied such glaciers in Nepal. Monitoring of the glacier terminus started from 1978. Photographs of the glacier terminus in different years (Fig. 32.4) clearly depict the retreat of the glacier. The glacier retreated by 30 m from 1978 to 1989, which is equivalent to a 12 m thinning of the glacier surface (WWF, 2005). The retreat of such glaciers results in the formation of the treacherous glacier lakes. Most of these lakes in the Nepal

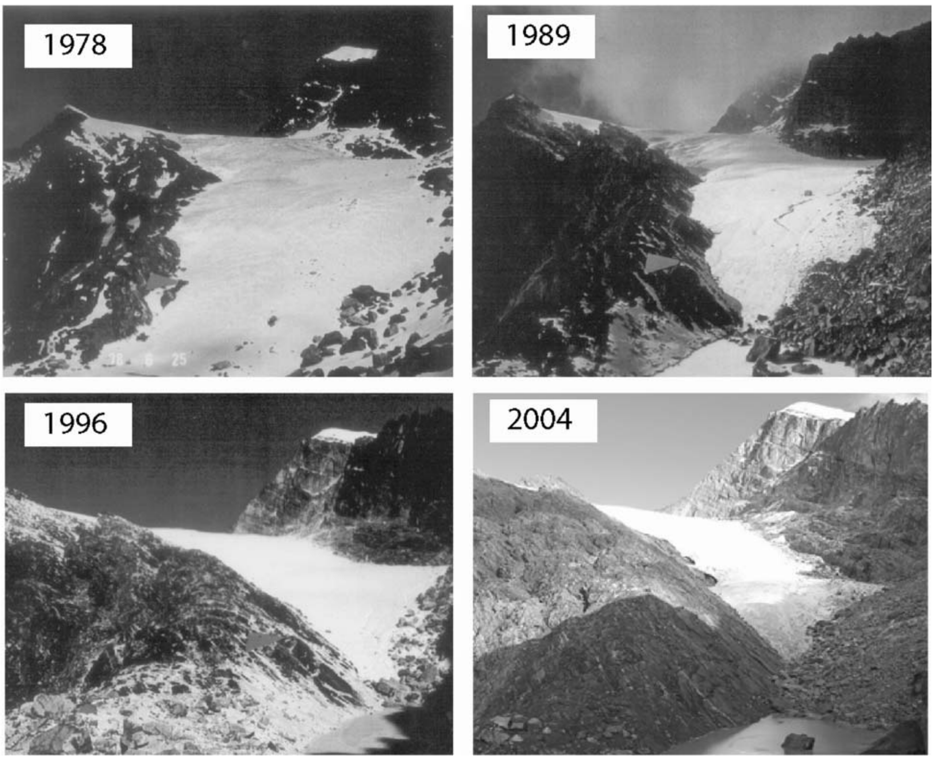

Figure 32.4. Retreat of the AX010 glacier in the Nepal Himalaya.

Himalayas are moraine dammed. The natural moraine dams are structurally weak and unstable, and are susceptible to breaching as their banks release the enormous amount of water causing the catastrophic glacier lake outburst floods (GLOF) downstream. Such GLOF events cause extensive damage to constructions, infrastructures, environment, and even claim human lives. There are records of several such disastrous events in Nepal, the latest being the Dig Tsho GLOF on August 4, 1985, in the Langmoche Valley, Khumbum (Ives, 1986; Yamada, 1998). A survey by ICIMOD in Nepal revealed 2323 glacier lakes and identified 20 of them as potentially dangerous lakes. Imja is one of such potentially dangerous lakes. The lake started to form as small ponds in the late 1950s (Fig. 32.5). The size of the lake has grown to 0.86 km^2 by 2002, which was 14.7% more than in 1999. Many researches in the Nepal Himalaya highlight the impacts on water resource management and GLOF.

Nepal ratified the June 1992 Rio Earth Summit, committing to the objective of United Nations Framework Convention for Climate Change to take necessary steps and measures to reduce greenhouse gas emission in the atmosphere for mitigating the climatic change process and adopt national policies. The Nepal Himalaya being most vulnerable to the climate change and its impact, His Majesty's Government of Nepal instituted a Country Study program on climate change in 1994. For the first time in Nepal, results of general circulation models (GCMs) were used and climate change scenarios were developed. Four models were used (Shrestha, 1997), the Canadian Climate Centre Model (CCCM), Geophysical Fluid Dynamics Laboratory R-30 Model (GFD3), United Kingdom Meteorological Office Model (UK89), and Goddard Institute for Space Sciences (GISS). According to this study, out of the four, only the CCCM and GFD3 were able to simulate the climatology of the region satisfactorily and were therefore used to develop the climate change scenario for Nepal with a doubling of the carbon dioxide. The climate change scenario developed for temperature was more realistic than for precipitation. CCCM and GFD3 estimated the temperature to increase on an average by 2.9°C and 3.1°C, respectively. Both models showed more increase in temperature at higher elevations than at lower elevations. Precipitation-wise the estimation was 36% and 67% increase from the

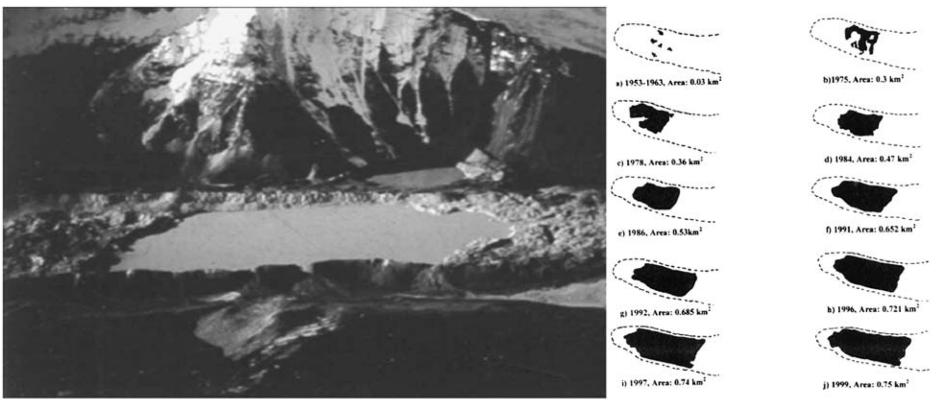

Figure 32.5. Growth of Imja glacier lake (Sources: WECS and DHM).

baseline (1971–1990) for CCCM and GFD3, respectively. The models results show a general tendency of more precipitation in summer months than in other months. This indicates that the wet seasons will be even wetter, i.e., extreme rainfall events will be more frequent in the future warm climate. This study provided the indication of the change in climate by doubling of carbon dioxide. But, because of the complex topography and low resolution of GCMs, the results of such models were not realistic for regional and local impact studies.

In order to study climate change on a regional scale, especially in a complex topographic region like Nepal, high-resolution models are required. Currently, Nepal is experimenting with a high-resolution Regional Climate Model (RCM), RegCM3 developed by NCAR. The main aim of this model is to study the climate change impact in the country. Preliminary results of RegCM3 show that the spatial precipitation pattern improved when the resolution of the model increased from 75 km to 30 km. But it is still not able to reproduce the observed pattern. Using 15 km nesting (Fig. 32.6), the model was able to simulate the observation precipitation amount and pattern fairly well. But the high rainfall pockets in the simulation are slightly shifted southward more than their actual observed location. This shows that the model still needs to be refined. The main problem in using the high-resolution model is the lack of high-speed computing facilities and computational time. Figure 32.7 shows the computational time required for different resolutions for a 1-month simulation with the current available facilities in the department.

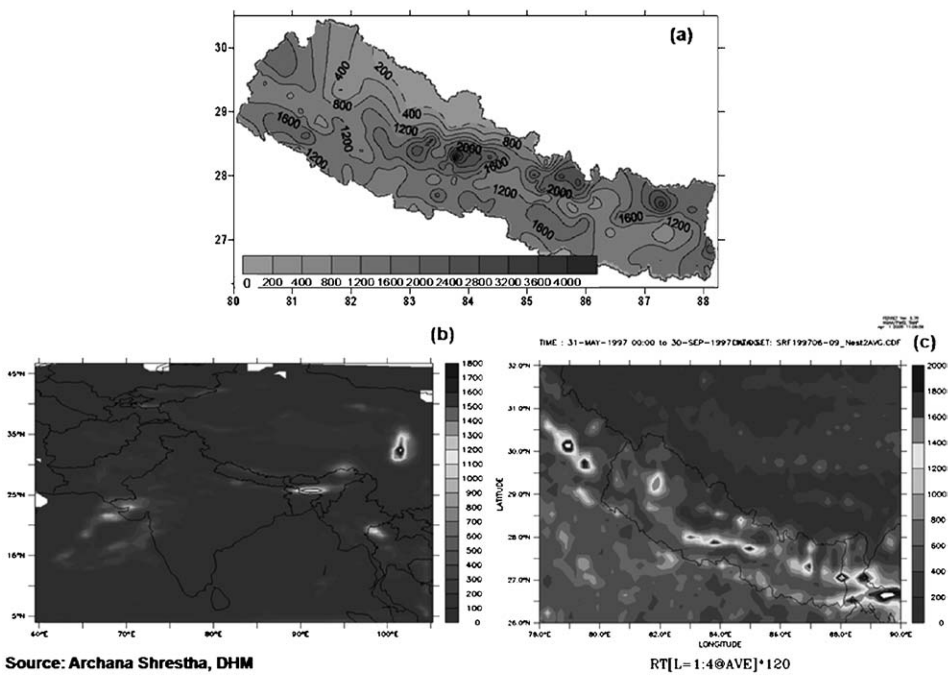

Figure 32.6. Comparison of 1977 monsoon precipitation with (a) observation and simulation at resolutions (b) 75 km and (c) nested 15 km.

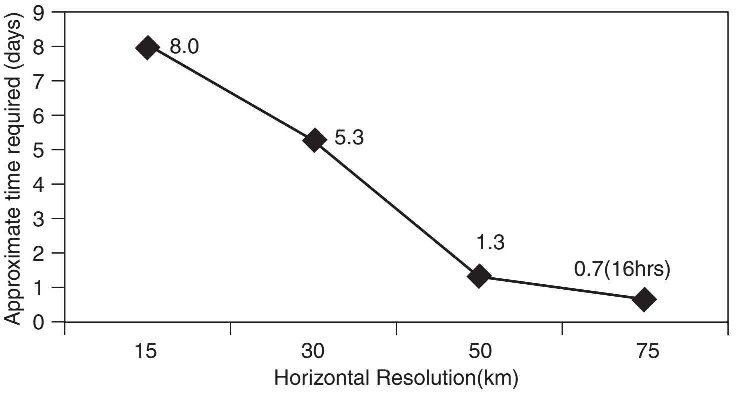

Figure 32.7. Consumption of computing time.

Hahn and Manabe (1975), using numerical simulation methods, demonstrated the role of the Himalaya and Tibetan plateaus in generating and maintaining the South Asian monsoon. In spite of the importance of the high mountains and the Himalaya in Asian summer monsoon, only a few studies have been done over these regions, especially in Nepal. In 1999, a network of rain-gauge stations at a variety of elevations from 528 to 4435 m a.s.l. was installed in the Marsyangdi river basin in central Nepal in order to study the orographic effects on precipitation over the south-facing slopes of the Himalaya. Using the first set of observation data from 1999 and the Tropical Rainfall Measuring Mission derived 3D precipitation radar (PR) rain rates, Barros et al. (2000) showed that there exists a strong interaction between mesoscale convective systems and steep terrain at elevations of 1 to 2 km, which agreed with the observational rainfall of more than 300 cm at these elevations ($\geq$2000 m). They also found a substantial variation in seasonal rainfall within less than a few km distance suggesting the importance of orographic effects on rainfall.

The most important study so far in this region probably is the monsoon Himalayan precipitation experiment (MOHPREX) that occurred during June 2001 along the southern slopes of the Himalaya in central Nepal. The main aim of the project was to better understand the spatial and temporal variation of precipitation along the south-facing slopes of the Himalaya (Barros and Lang, 2003). Analyzing the MOHPREX data, they showed that the total moisture column and convective instability gradually built up during the onset phase of monsoon. The middle (500 hPa) and upper (200 hPa) level westerly winds weakened considerably. They found that the 500 hPa westerly wind shifted to a more easterly track. A significant reduction in 200 hPa westerly wind from $>20\,\mathrm{ms}^{-1}$ to a light and variable westerly is quite remarkable. The lower level winds were, however, modulated by the diurnal cycle of upslope (during day) and downslope (during night). In harmony with the diurnal cycle of moisture and instability, they found the post-midnight maximum in rainfall and postulated a mechanism to explain this phenomenon (Fig. 32.8). The southeasterly monsoon flow from the Bay of Bengal encounters the mountains that act as barriers to the flows and consequently low-level convergence occurs. But during the day time, upslope and upvalley flows reduce this convergence. The upslope flow, however, leads to high-level convection and a secondary

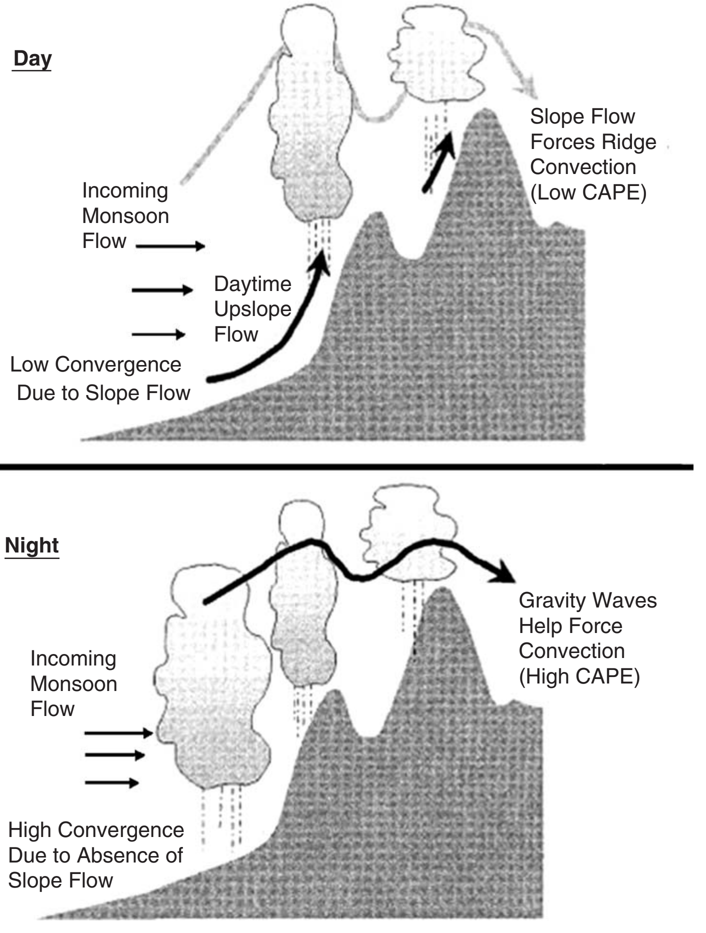

Figure 32.8. Schematic diagram of the proposed mechanism to explain nocturnal rainfall in the Himalaya (Barros and Lang, 2003).

peak in precipitation. In contrast, during the night, with the absence of upslope winds, and prevalent downslope winds, strong convergence of the moist advected monsoon flow occurs that acts to force convection. Atmospheric instability is also maximum during the night. All these factors lead to the nocturnal peak in rainfall in these areas. They also indicated that interaction between mountain-forced gravity waves and the thermodynamics of the Himalayan atmosphere could enhance nocturnal convergence, thus favoring nocturnal precipitation maxima.

4. Conclusion

The Himalaya of Nepal provide a unique opportunity for scientists and researchers to study climate change impacts and the effect and role they play in the regional monsoon circulation. Because of the complex topography of the region, climate change studies require the use of high-resolution models such as the RCM. While deglaciation is considered to be a worldwide problem, the retreat of Himalayan glaciers at an alarming rate and rapid growth of several Himalayan glacier lakes in the recent decades could create serious consequences for regional water-resource management and threat of catastrophic GLOF. Studies have shown that the local scale modification by the mountains and the Himalaya on the large-scale monsoon flow play an important role in spatial and temporal distribution of seasonal rainfall. Nepal therefore deserves special attention in climate-related research.

References

Barros, A.P., Joshi, M., Putkonen, J., and Burbank, D.W., 2000. A study of the 1999 monsoon rainfall in a mountainous region in central Nepal using TRMM products and raingauge observations. Geophysical Research Letter 27, 3683–3686.

Barros, A.P. and Lang, T.J., 2003. Monitoring the monsoon in the Himalayas: observations in Central Nepal, June 2001. Monthly Weather Review 131, 1408–1427.

Hahn, D.G. and Manabe, S., 1975. The role of mountain in the South Asian Monsoon Circulation. Journal of the Atmospheric Sciences 32, 1515–1541.

Hansen, J. and Lebedeff, S., 1987. Global trends of measured surface air temperature. Journal of Geophysical Research 92, 13345–13372.

Higuchi, K., 1976. Outline of the glaciological expedition to Nepal. Journal of the Japanese Society of Snow and Ice 38, 1–5.

Higuchi, K., Iozawa, T., and Higuchi, H., 1976. Flight observations for the inventory of glaciers in the Nepal Himalayas. Journal of the Japanese Society of Snow and Ice 38, 10–16.

Hingane, L.S., Kumar, K.R., and Murti, B.V.R., 1985. Long term trends of surface air temperature in India. Journal of Climatology 5, 521–528.

Ives, J.D., 1986. Glacial lake outburst floods and risk engineering in the Himalaya. Occasional Paper No. 5, ICIMOD.

Jones, P.D., Wigley, T.M.L., and Wright, P.B., 1986. Global temperature variations between 1861 and 1984. Nature 322, 4030–4434.

Mool, P.K., Bajracharya, S.R., and Joshi, S.P., 2001. Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods. ICIMOD.

Müller, F., 1970. Inventory of glaciers in the Mount Everest region. "Perennial ice and snow masses", Technical papers in Hydrology 1, UNESCO/IASH: 47–59.

Nayava, J.L., 1974. Heavy monsoon rainfall in Nepal. Weather 29, 443–450.

Oerlemans, J., 1994. Quantifying global warming from the retreat of glaciers. Science 264, 243–245.

Pant, G.B. and Kumar, R., 1997. Climates of South Asia. Wiley, New York.

Shrestha, M.L., 1997. Development of Climate Change Scenarios with Reference to Nepal. Proceedings of the Workshop on Climate Change in Nepal, pp 16–32.

Shrestha, M.L., 2000. Interannual variation of summer monsoon rainfall over Nepal and its relation to the Southern Oscillation. Meteorology and Atmospheric Physics 75, 21–28.

Shrestha, A.B., Wake, C.P., Mayewski, P.A., and Dibb, J.E., 1999. Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971–94. Journal of Climate 12, 2775–2787.

Slingo, J., Inness, M., and Sperber, K.R., 2002. Monsoon overview. Encyclopedia of Atmospheric Sciences, pp. 1365–1370.

WWF, 2005. An overview of glaciers, glacier retreat, and its subsequent impacts in the Nepal, India and China. WWF, pp. 68.

Yamada, T., 1998. Monitoring of glacier lake and its outburst floods in Nepal Himalaya. Journal of the Japanese Society of Snow and Ice. Monograph No. 1.