Recent Trends in Melting Glaciers, Tropospheric Temperatures over the Himalayas and Summer Monsoon Rainfall over India

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- United Nations Environment Programme (UNEP)
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Introduction

There are growing concerns about the impact melting glaciers in the Himalayas will have on about 1.5 billion people of vulnerable densely populated communities in downstream river basins. Yet there is huge uncertainty about how snow and glacial melting in the Himalayan region will continue to respond to climate change, and how such change will affect ecosystems and human well-being. There is a notable lack of available observations in order to make robust quantitative assessments about the significance and extent of the issue. The threat associated with the potential consequences is so great that the scant knowledge must not be an excuse for failing to act. Scientific research is critical to help reduce uncertainty and to underpin sustainable mitigation and adaptation strategies. In this context following are some of the scientific and institutional issues which need to be addressed:

Scientific inquiry

- How much do we know about the changing climate in the Himalayas? Is it changing? Have potential changes been detected in atmospheric/surface temperature trends based on observations from ground and satellite data as well as from model simulations?
- What are the different sources/causes of climate warming over the Himalayas (greenhouse gases, aerosols, black carbon)? Atmosphere-surface feedback is a very important component through which energy exchange takes place. How is the atmospheric forcing altering the important feedback processes in the Himalayas?
- What are the potential and observed impacts on water resources and the regional hydrological cycle, and what are the consequences for humans and ecosystems?
- The Himalayas glaciers and snow pack are known as the 'water tower of Asia'. How are they changing in today's climate in the Himalayas?
- The Monsoon is the region's lifeline and its strength is fundamentally influenced by spring-time warming in the Himalayas-Tibetan Plateau, which acts as an elevated heat source. What is the South Asian monsoon variability response to climate change in the Himalayas and how do they act together?
- How is vegetation in the high altitude responding to the changing climate and how it will impact biodiversity in the region?

Institutional inquiry

- What data and models are available for adaptation planning? How can data sharing within countries and among countries, which is a major issue, are improved?
- How can scientific research be strengthened to promote evidence-based policies?
- What is needed to enhance cooperation among countries in the region to provide early warning information by integrating physical and social sciences?
- What kind of a focused working group could foster important strengthened collaboration among international scientific communities to address various aspects of climate change research in the Himalayas and further guide concerned policymakers?

In order to focus on some of the above issues and assess the current state of the knowledge, an extensive literature search was conducted to develop background documents and an international workshop was organized on 28-29 December, 2010 in New Delhi, India which was attended by 75 experts and 28 technical papers were presented. This report includes the summary of the workshop and a state–of–the–art review of the scientific knowledge on the topics covered.

Due to time constraints it was not possible to go through a peer review process before finalizing the report. There seems to be different figures from different sources on a number of issues which were difficult to reconcile so it was decided to refer to published sources enabling readers to draw their own conclusions.

Dr. Ritesh Gautam of NASA- Goddard Space Flight Center, Maryland USA , Professor Ramesh P. Singh Chapman University, California , Mr. Gyde Lund , Ms. Jane Barr and Dr. Promode Kant generously contributed their time and expertise towards this report. Ms Arshia Chander and Ms Kim Giese helped with editing, lay-out and design of the report at a very short notice.

UNEP SPONSORED INTERNATIONAL EXPERT WORKSHOP ON EMERGING ISSUES IN CLIMATE CHANGE

State of Tropospheric Temperature, Pollution, Melting Glaciers and their Potential Impact on Monsoon and High Altitude Vegetation in the Himalayas-Tibetan Plateau

Dec 28-29, 2009, New Delhi. India

SUMMARY REPORT

Background:

Climate change is affecting the temperatures, amount of snow and ice in the Himalayan region as well as rainfall patterns in the densely populated downstream regions of Asia which would have enormous significance for livelihood and well being of the people of the region. There is a need to prepare the people, institutions and countries of the region to anticipate the consequences of climate change and evolve suitable and cost-effective adaptation responses. However, there is inadequate availability of information on these processes of change making it both difficult to plan appropriate responses and create public opinion in favour of drastic actions that are needed to address the issues.

An extensive literature review was undertaken and an international expert consultation workshop was organised to begin a multi-stakeholder consultation process and assess the current state of scientific knowledge on climate change over the Himalayas, atmospheric and surface temperature trends and the effect of warming on the glaciers and the monsoons, role of aerosols in both moderating and accentuating warming under differing circumstances and the response of high altitude vegetation to climate change. Additionally, the workshop was also expected to recommend steps to encourage more national and international research initiatives in this direction and broaden access to databases, strengthen national capacities in research, monitoring and data sharing for sustainable development in the region and also to create sufficient awareness among public for wider policy and financial support for necessary action.

The workshop was attended by a total of 75 scientists, subject matter experts, academics from universities and specialised institutions from a number of countries, senior government functionaries and representatives of international organizations. The workshop was inaugurated by Dr P J Dilip Kumar, Special Secretary in the Ministry of Environment and Forest, Government of India. A total of 28 presentations were made by the participants on the trends in changes in temperature and precipitation over the Himalayas, contribution of aerosols to these trends, glacier melt and observed and simulated changes in monsoonal patterns. Towards the end of the workshop group discussions were held on four central issues and this summary report is based on the consensus developed during the workshop as reflected in the outcome of the Group discussions as well as discussions during the technical sessions.

The state of melting glaciers

There was no consensus on the changes in nature of ice cover in the Himalayas (including the Tibetan plateau). The main glacial parameters are length, area, volume, mass and thickness and ***the glacier length alone can not be taken as the only parameter that signifies mass balance changes***. In general, the majority of Himalayan glaciers are shrinking in area and thickness and the extent and nature of shrinkage has not changed significantly over the last 100 years. The nature of changes in glaciers are varied and complex with some glaciers exhibiting changes in length in an observational relationship to area and mass while some have changed in length with little change in mass and yet others show changes in thickness but not length. Glacier behaviour varies across the region with higher retreat rates recorded in the east.

Prof. Murari Lal, one of the authors of the Intergovernmental Panel on Climate Change (IPCC) report, said that the IPCC statement that the Himalayan glaciers are likely to melt by 2035 had been made on the basis of a report of the World Wide Fund for the Nature (WWF) 2005 that had quoted Prof Syed Hasnain. He noted that it was wrong to assume, as has been done in sections of media that the year 2035 had crept in the report by mistake. But Prof. Syed Hasnain, who was also present on the occasion, stated that he had never mentioned any such date in his scientific papers purportedly quoted in the WWF report. The workshop participants are of the opinion that the IPCC conclusion that the Himalayan glaciers could melt by 2035 may have to be revised as our understanding of the phenomena has matured since the period of data collection and synthesis for the Fourth Assessment Report of IPCC. The participants, however, wanted to emphasize that this does not, in any way, reduce the need for mitigation of, and adaptation to, climate change that has been initiated by the international community.

Impact of Dust, Black Carbon and Chemical Pollution on Himalayan Glaciers

Causes for climate change over the Himalayas include aerosols with black carbon and dust, deforestation, forest fires, human-induced pollution and many other anthropogenic activities besides the emission of greenhouse gases. The black carbon deposition in Tibetan Himalayas is higher than other places in the northern hemisphere and has been a cause of significant albedo reduction in central Tibetan plateau. Studies in USA indicate that dust-induced albedo decrease could cause early snow melts by as much as 30 days and increased evapotranspiration due to early melt-out may decrease basin runoff by 5 per cent. Similar effects are possible in Himalayas too but there is severe lack of data that precludes drawing of any conclusions on dust and black carbon induced melting of snows. There is little scientific work done yet on the source identification of atmospheric chemical pollutants, their composition and deposition in the Himalayas-Tibetan Plateau. Also, the role of aerosol deposition was realized to be a complex one as its impact on the albedo varies greatly with the type of glaciers. In order to systematically prepare realistic models of all the above sources causing the environmental degradation, there is a need of equipping some of the observatories with devices for collecting related ground and atmospheric observations.

Temperature trends

Ground observations of air temperature measurements show strong spatial and seasonal gradients across the Himalayas-Tibetan Plateau. For example, the atmosphere over the western Himalayas, which contain major glaciers and make headwater to major rivers including the Indus and the Ganges, were found to be associated with enhanced warming trends in the past three decades from the longest record of microwave satellite observations. The two crucial seasons, i.e. the winter season (snow accumulation period) and pre-monsoon season (snow-melt period and important to the onset of the monsoon) are associated with increasing temperatures most discernible in the past 2-3 decade period. Among ground measurements, however, there is an urgent need to have adequate data quality control and dissemination of data in public domain in order to fill the gaps between various data sources and make consensus on the magnitude of temperature trends. Proxy data in the form of tree ring and ice core isotope analysis are also highly useful and have been used to infer the temperature trends in the long-term (a few hundred years) and characterize the seasonal trends.

Potential impact on Monsoon

One of the major issue for deliberation before the Workshop was the likely effect of the changing climate on the monsoons as it would have enormous socio-economic consequences for the Himalayan region and the downstream plains. Clearly more research on the monsoon variability in the changing climate over the South Asian region is needed both over the downstream Plains as well as over the slopes and valley regions of the Himalayas. The all India average monsoon rainfall in the past half century was associated with a neutral-weak negative trend while the early summer monsoon rainfall was showed to be on the rise in the recent past decades. One of the research areas discussed was the impact of aerosols and the phenomenon of the Elevated Heat Pump on monsoon as well.

Data Inadequacy and Access

Lack of sufficient meteorological data from Himalayas has been a major handicap in drawing conclusions on the impact of climate change on the glaciers and snow cover. Multi-sensor satellite coverage of entire Himalayas is essential for a detailed examination of the glacier dynamics and associated phenomena like Glacial Lake Outburst Floods (GLOFs) and this data has to be validated by means of statistically valid field measurements to ensure a complete understanding. Participants felt that it was necessary to have an adequate network of Automatic Weather Stations (AWS) for collecting meteorological data and stated that the costs of setting up and maintaining these AWSs would be manageable if the data generated are made accessible to its many users on a differentiated price basis. The workshop recommended detailed studies on a few representative benchmark glaciers in the four 'glacier zones' of the Himalaya: Afghanistan and Pakistan, NW Himalaya and Karakorum; Central Himalaya including SW Tibet; and Eastern Himalaya including SE Tibet, Nepal, Bhutan and NE India, over a longer period encompassing both field observations and remote sensing.

Since the Himalayas are spread over eight countries with different technological strengths, financial capabilities and socio-economic objectives a long term program of this nature would need to be coordinated by an international organisation with participation of the government organisations from the concerned countries. This will require a huge effort since the data will have to be collected from ground as well as remote sensing and proxy data may have to be used. This process would also need significant efforts towards developing guidelines and standardisation of measurements.

The Workshop Participants felt that there was an urgent need to have adequate data quality control and data dissemination in order to fill the gaps between various data sources and develop deeper understanding of the magnitude of the temperature and precipitation trends. Proxy data in the form of tree ring and ice core isotope analysis can also be used to characterize the seasonal trends.

The Workshop expressed its deep concern that there is very little data in the public domain on this most important of issues and recommended that this aspect of the Southwest and East Asian monsoon variability response to climate changes with likely differential responses in summer as well as winter precipitations should be studied in a holistic manner for the entire Himalayas.

Impact on River Discharge

On the question of changes in river discharges there is some evidence that the precipitation and river discharge over the north western Himalayas is decreasing while increasing over the central Himalayas but lack of adequate scientific data prevented the Workshop from arriving at a conclusion in this regard. The Workshop felt that this issue needs a detailed and systematic research.

Impact on High Altitude Vegetation

At present, the knowledge available on the impact of climate change on the high altitude vegetation is very limited. However, the likely changes on the basis of existing information are altitudinal and latitudinal shifting of the species due to change in the hydrology and temperature, changes in the floral and faunal species composition and forest types variations in phonological behaviour of species the extension or shortening of vegetation cycles and in biogeochemical cycles, structural and morphological changes affecting the biomass production, alteration in the processes of speciation and extinction and increased rates of biodiversity loss and shifts in genetic corridors. The degree of such changes may vary in an area due to topography, soil and geographic location and biotic factors may aggravate the process of change.

The main challenges are collection of statistically sound and reliable data on long term basis, capacity building and standardization of techniques and tools, lack of suitable techniques and protocols for detecting effects of climate change on vegetation such as bio-markers and molecular indicators and developing the requisite international cooperation among the Himalayan countries. The Workshop recommended well coordinated research in important aspects of the impact of climate change on vegetation.

Institutional Issues and Mechanism

Networking for enhancing capacities and utilizing resources

Recognizing the commonality of the issues but differential human and technological capacities of the relevant institutions across the eight countries of the Himalayan region the Workshop recommended creation of a network of existing institutions for enhancing their capacities and efficient utilization of available resources that are likely to flow to the countries of the region under the UNFCCC Adaptation Fund. Such a network could be called Himalayan Climate Adaptation and Research Network. This could be easily created with international support from adaptation funds and the task of coordinating its activities could be assigned to an existing international institution.

The Workshop felt that water is one of the most precious commodities for this heavily populated region and it could be under threat in the changing climate and yet there are constraints in sharing information on this across the region on account of considerations of national security. In addition there is a general lack of observation stations and of systematically collected and aggregated data. A regional network and a data sharing mechanism are of urgent need.

Some activities specifically recommended were

1. *Enhanced cooperation for early warning*

   Accurate mapping of glacial lakes for managing Glacial Lake Outburst Floods (GLOFs) through scientific study of the morain dams, regulated drainage of the water, and sharing of information for development of a suitable early warning system has been recommended by the Workshop.

2. *Institutional Strengthening*:

   The Workshop recommended that relevant national institutions may be assisted in the task of preparing adaptation plans and programmes for social and economically vulnerable groups or community in different countries.

   The Workshop recommended that the summary conclusions may be brought to the notice of

   - UN Commission for Sustainable Development – for policy recommendation
   - Governments in the regions
   - International and regional organizations
   - IPCC WG2
   - World Glacier Monitoring Centre/Global Land and Ice Monitoring System (GLIMS).

CHAPTER 1

The State of Melting Glaciers of Himalayas and Climate Change

The Himalayas, which some refer to as the 'Third Pole' or the 'Water Tower of Asia', store one of the world's greatest bodies of ice outside the polar region. Meltwaters feed some of the Earth's greatest rivers, which supply water to one of its most densely populated regions (see Table 1 for Principal glacier-fed river systems).

Table 1: Principal glacier-fed river systems of the Himalayas

River	Mountain area (km^2)	Glacier area (km^2)
Indus	268 842	7890
Jhelum	33 670	170
Chenab	27 195	2 944
Ravi	8 092	206
Sutlej	47 915	1 295
Beas	12 504	638
Jamuna	11 655	125
Ganga	23 051	2 312
Ramganga	6 734	3
Kali	16 317	997
Karnali	53 354	1 543
Gandak	37 814	1 845
Kosi	61 901	1 281
Tista	12 432	495
Raikad	26 418	195
Manas	31 080	528
Subansiri	81 130	725
Brahmaputra	256 928	108
Dibang	12 950	90
Lohit	20 720	425

Sources: Compiled from Hasnain 1999, Nandy et al. 2006

The Glaciers in Context

There are an estimated 160 000 glaciers on earth (Meier and Bahr, 1996), of which the Himalayan range encompasses about 15 000 glaciers (Wikipedia n.d.).

- Afghanistan has approximately 3 000 glaciers (USGS n.d.).
- India has 9 575 glaciers under the aegis of the Geological Society of India (Anand 2007).
- Pakistan's glaciated area is 15 040.70 km^2, including 5 218 glaciers with 2 738.51 km^3 of ice reserves. There are a total of 2 420 glacier lakes, of which 52 are dangerous (WRRI 2006).
- There are 3 252 glaciers in Nepal and 2 323 glacial lakes, of which 20 were considered potentially dangerous (Mool et al. 2001).
- Bhutan has 677 glaciers occupying an area of around 1 317 km^2, and an estimated ice reserve of 127 km^3. There are 2 674 glacial lakes, of which 24 were considered potentially dangerous (Mool et al. 2001, ICIMOD 2002).

Table 2: Glacier distribution in countries of the Tibetan Plateau (Shen 2004)

Country	Glacier area (km^2)	Sources
China	49 873	Liu et al. (2000)
India	23 000	Kulkarni and Buch (1991)
Pakistan	16 933	Shen (2004)
Nepal	5 322	Bajracharya. et al. (2002)
Bhutan	1 318	Bajracharya. et al. (2002)
Sikkim	912	Hasnain (2000)
Tajikistan	7 493	Liu et al. (2000)
Total	104 850	

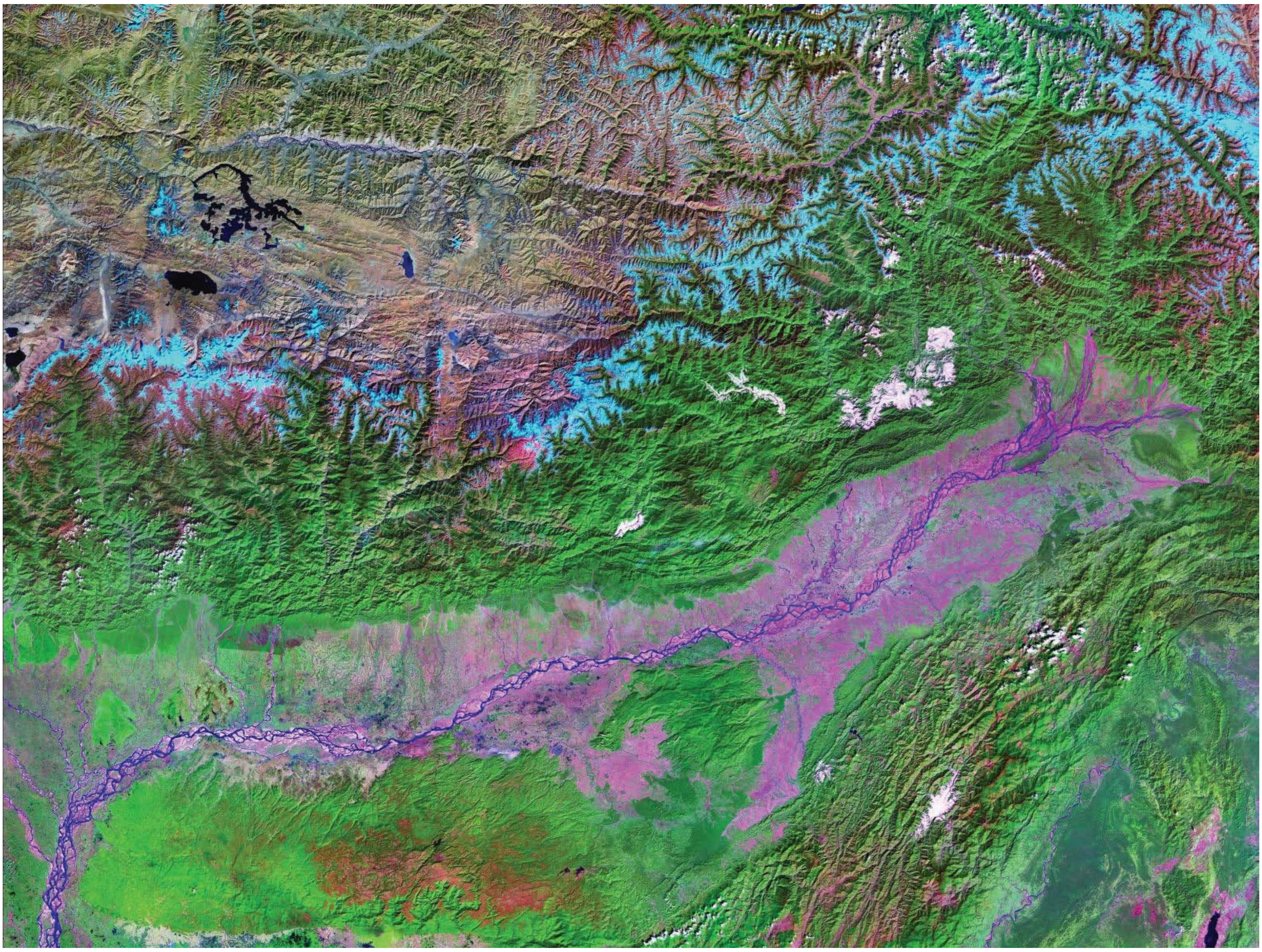


Figure 1: Landsat image showing glaciers of the Himalaya Mountain Range (light blue) and the sediment-choked and braided valley of the Brahmaputra River (purple) of Eastern India. High Resolution Image - 862KB (GN 2007).

According to Yao Tandong, China's Chief Glaciologist, the Qinghai-Tibet Region has 46 298 glaciers, covering a combined area of 59 406 km^2 that stores a total 5 590 km^3 of moisture (CTIC 2004).

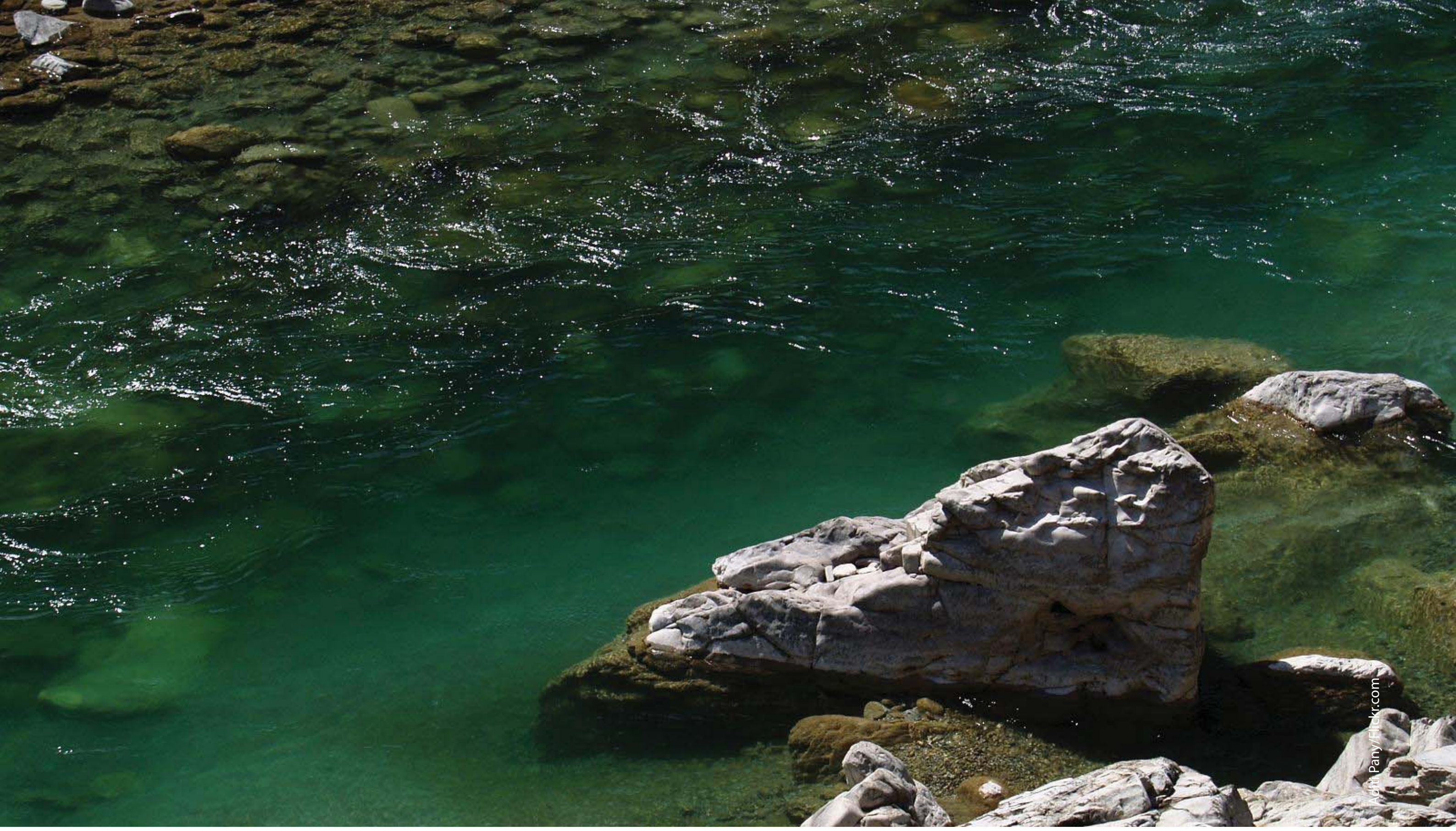
With glaciers covering an area of 104 850 km^2, the Himalayas-Tibetan Plateau (HTP) is the most concentrated glacier centre in the Earth's middle and low latitudes (see Table 2 for country distribution). The Himalayas, with a total 34 660 km^2 under glaciers, has the region's largest glacier cover (Shen 2004). China's inventory of glaciers has identified 36 793 glaciers in its Tibetan Plateau, with a total area of 49 873.44 km^2 and ice volume of 4 561.3857 km^3 (Liu et al. 2000, Shen 2004).

Impact of Climate Change

Climate change will have environmental and social impacts that will likely increase uncertainty in water supplies and agricultural production for people across Asia (Xu 2009). The cascading effects of rising temperatures and loss of ice and snow in the region are already affecting water availability (amounts, seasonality), biodiversity (endemic species, predator-prey relations), ecosystem boundaries (tree-line movements, high-elevation ecosystem changes), and global feedbacks (monsoonal shifts, loss of soil carbon) (Xu 2009).

A report on *Climate Change as a Security Risk* (Schubert et al. 2008) identifies a number of regions that are particularly vulnerable to the impacts of climate change due to their socio-economic and ecological conditions:

> *The South Asia region is one of the hotspots. The consequences of climate impact include a rise in sea level, threatening areas such as the densely populated Ganges delta, changes in the monsoon rains that are so important for agriculture, the melting of the glaciers in the Himalaya region and the foreseeable increase in heavy rain events and intensity of tropical cyclones. These consequences will affect a region that is already among the most crisis-ridden in the world and whose state*



institutions and intergovernmental capacities are weak to address the issue. Climate change will overwhelm political structures and will further exacerbate economic and social problems in South Asia (Roul 2009)

The impacts of climate change on the Himalayan glaciers could be catastrophic for an estimated 1.5 billion people living in affected river basins in much of inland China, Central and South Asia, as well as Southeast Asia.

Not only are the Himalayas a primary source of water for Asia, the region is also responsible for much of South Asia's climate (Singh 2008). Because of its important geographical position and immense height, Tibet has a considerable influence on global weather patterns. The Plateau's huge land surface acts like an enormous iceberg in the ocean affecting the jet streams and the stability of the monsoon (CTA n.d.) Changes in the jet stream may cause Pacific typhoons and the El Niño (warm ocean current) phenomenon, which stirs up ocean water and disrupts ecosystems in North and South America, Australia, and Africa (CTA n.d.). The El Niño effect may influence the weather patterns of Europe, the USA, Mexico, Peru, India, China and other adjoining areas, with resulting impacts on their economies (Dekhang 2005).

Some effects of climate change

Negative Side	***Positive Side***
• Sea levels rise will inundate some coastal areas • Oceans and seas become desalinated, which will disrupt marine ecosystems • Water from melting glaciers may form glacial lakes and cause glacial lake outbursts, which in turn cause floods and may be followed by drought • There is the potential for thawing permafrost, which creates unstable areas • Current biological diversity will likely be threatened • The warming may foster avalanches and landslides • It may bring about processes of desertification	• Tree lines may advance to higher elevations • More land may be exposed for agriculture or other uses • The warming may create new ecosystems that are beneficial to people

Box 1 - Quotes on the state of the Himalayan Glaciers

The Inter-Governmental Panel on Climate Change (IPCC) states that the Himalayan glaciers "*are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate*" (Cruz et al. 2007).

Dr. R.K. Pachouri, Chairman of the IPCC reports that "*The IPCC has recorded increased glacier retreat since the 1980s. This was due to the fact that the carbon dioxide radioactive forcing has increased by 20 per cent particularly after 1995. And also that 11 of the last 12 years were among the warmest 12 years recorded so far*" (Anand 2007).

Prime Minister Manmohan Singh observes that "*We have anecdotal evidence that glaciers may be receding, but we need precise and carefully vetted data, both through satellite imaging and ground surveys*" (2009).

A white paper by V.K. Raina, former Deputy Director General of the Geological Survey of India on the status of Himalayan glaciers and global warming "*suggests that in most cases glaciers have stopped retreating. While the Gangotri glacier stopped receding in the 2007-09 period, it says, glaciers like Pindari in Kumaon continue to record a high annual retreat of almost 10 metres annually*" (Padma 2007).

V.K. Raina also states that "*The glaciers are undergoing natural changes, witnessed periodically. Recent studies in the Gangotri and Zanskar areas (Drung- Drung, Kagriz glaciers) have not shown any evidence of major retreat*" (Anand 2007).

Indian MoEF Minister Jairam Ramesh notes that "*The Himalayan glaciers are in trouble. Some are retreating, but others seem to be advancing. However, there is no robust scientific evidence to suggest that climate change is causing the retreat*" (Sinha 2009).

Jeffrey S. Kargel, Glaciologist at the University of Arizona, Tucson, USA says that the IPCC's "*extremely provocative findings are consistent with what I have learned independently. Many glaciers in the Karakoram Mountains… have stabilized or undergone an aggressive advance*" (Bagla 2009).

Kenneth Hewitt, Glaciologist at Wilfrid Laurier University in Waterloo, Canada "*challenges the view that the upper Indus glaciers are 'disappearing' quickly and will be gone in 30 years. There is no evidence to support this view and, indeed, rates of retreat have been less in the past 30 years than the previous 60 years*" (Bagla 2009).

Syed Iqbal Hasnain, India's best-known Glaciologist, observes that "*The Ganga system is about 60 to 70 per cent snow and ice. There are more than 800 glaciers in the Ganga basin. The Gangotri is the big one. It used to cover more than 250 square kilometers, but now it's breaking up in many places. You will see blocks of dead ice that are no longer connected to the main ice body. I'm afraid that if the current trends continue, within 30 or 40 years most of the glaciers will melt out*" (Black 2009).

Energy CEO Don Blankenship records that "*The 9 575 glaciers in the Himalayas show no trend either way in 200 years. Many are advancing*" (Bosley 2009).

Geologist Vijay Kumar Raina is sure that "*Himalayan glaciers are retreating. But it is nothing out of the ordinary. Nothing to suggest as some have said that they will disappear*" (Ramesh 2009).

Dr R. R. Navalgund of ISRO says "*We have looked at snowy glaciers, some of them in the past 20 years, specially the ones at lower latitudes and altitudes, have retreated. It is difficult to say whether it is due to global climate change. It could be a part of the inter-glacial period and other related phenomena*" (Nandi 2009).

Other observers note the following:

"*Glaciers at the edge of the plateau tend to melt more than those in the middle; one study, for instance, showed that glaciers in the eastern part of the Kunlun Mountains retreated by 17 per cent over the past 30 years, which is ten times faster than those in the central plateau. If current trends hold, two-thirds of the plateau glaciers could be gone by 2050*" (Yao et al. 2006).

"*In Kashmir Valley of India, the surface area of the glaciers has been decreased by two thirds in many cases. In the Peerpanjal mountain range, some glaciers have been totally disappeared. You can't find glaciers beyond July-August in most of the Peerpanjal range. According to locals residing in Sonmarg, most of the glaciers, including Thajiwas and Kolahoi, have receded during the last 50 years*" (TNN 2007).

"*Himalayan glaciers have shrunk by 38 per cent in 40 years. The overall process of shrinking is leading glaciers to fragment and, therefore, paradoxically enough, the total number of glaciers in the Himalayas is increasing*" (Sethi 2009).

"*The 15 000 Himalayan glaciers that create the "Water Tower of Asia" —the largest block of fresh water outside the Polar Ice Caps—have been melting forever. But they are suddenly melting so fast that they are drying up. It will take decades, but at the rate the earth is warming, they may simply disappear*" (Schifrin 2008).

"*On most glaciers, a clear thinning is measured at low elevations, even on debris-covered tongues. Between 1999 and 2004, we obtain an overall specific mass balance of -0.7 to - 0.85 m/a (water equivalent) depending on the density we use for the lost (or gained) material in the accumulation zone. This rate of ice loss is twice higher than the long-term (1977 to 1999) mass balance record for Himalaya indicating an increase in the pace of glacier wastage*" (Berthier et al. 2007).

Box 1 lists some comments made by experts about what is happening in the Himalayan Region. There are a variety of opinions about whether the Himalayan glaciers are retreating or advancing.

At the 2007 Annual meeting of the Geological Society of America, Bishop et al. (2007) reported on the results of their remote-sensing studies of Himalayan glaciers:

> *Himalayan glaciers are thought to be sensitive to climate forcing due to the high altitude and significant debris-cover variation. Remote-sensing based studies in the eastern Himalaya reveal systematic retreat patterns for some glaciers. In the western Himalaya, glacier fluctuations are known for a limited number of glaciers, and retreat rates in Afghanistan have not been reported. Given that glacier sensitivities to climate forcing across the western Himalaya and Afghanistan Pamir are relatively unknown, our objectives were to estimate glacier retreat rates in the Nanga Parbat and Hunza Karakoram Himalaya, and Afghanistan Pamir regions. Specifically, we used satellite multi-temporal imagery and maps to compute retreat rates for different time periods ranging from 1934-2006. Results indicate significant variations in glacier fluctuations within and among the three regions. We found retreat rates ranging from 0-36 m/yr from 1976-2004 in the Pamir region. Many glaciers have significantly downwasted, and new high-altitude lakes and proglacial lakes now exist. Some of the glaciers in the Hunza Karakoram region have also retreated and downwasted, although retreat rates from 1992-2001 are relatively low. Furthermore, glacier advances, probably caused by surging have been documented. Further south, glaciers in the Nanga Parbat Himalaya were found to exhibit oscillating terminus positions, with several glaciers advancing over time, and others exhibiting relatively low retreat rates or recent acceleration of retreat. Collectively, our results indicate that glacier fluctuations in the western Himalaya are spatially and temporally complex, reflecting topography-climate multi-scale interactions. They also reveal that specific glacier ablation and mass-balance estimates/conditions should not be extrapolated to represent adjacent glacier conditions or to generate regional estimates. Our results suggest that the glaciers in the western Himalaya of Pakistan may be reacting differently to climate forcing compared to glaciers in the Wakhan Pamir region and eastern Himalaya.*

Thus, as the quotes in Box 1 and above reveal, there has been some disagreement about the melting of the Himalayan glaciers between and within the science community, government officials, and the public, such as those presented in Alford et al. (2009), Armstrong et al. (2009b), Bagla (2009), Ramesh (2009), Singh (2009), and Sinha (2009).

Most of the controversy centres around the Intergovernmental Panel on Climate Change's (IPCC's) statement "Glaciers in the Himalaya are receding faster than in any other part of the world … and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate. Its total area will likely shrink from the present 500 000 to 100 000 km^2 by the year 2035" (Cruz et al. 2007).

Critics of the IPCC statement generally question two points:

1. The sizes given for the areas of mountain glaciers in the Himalaya Region; and
2. The rate of retreat.

So what's the truth? Tracing the possible sources of the IPCC statement may shed some light on the conundrum (Box 2).

If one can assume the above sequence of events to be true, then the following may account for the IPPC's statement:

Box 2: Possible sources of the IPCC statement

The IPCC cites the World Wildlife Fund (WWF 2005) as its source. The WWF report states that "*glaciers in the Himalayas are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 is very high*". The report makes no mention of the 500 000 and 100 000 km^2 areas that appear in the IPPC statement. The WWF credits the 2035 prediction to a 1999 report by the Working Group on Himalayan Glaciology (WGHG) of the International Commission for Snow and Ice (ICSI).

The ICSI stated that "*Glaciers in the Himalaya are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 is very high*" (Down to Earth 1999). In the following paragraph, the same article went on to say "*The glacier will be decaying at rapid, catastrophic rates. Its total area will shrink from the present 500 000*[1] *to 100 000 km^2 by the year 2035.*" There was no reference to the Himalaya Mountains in this particular paragraph although, as shown above, they were mentioned in the previous one. The ICSI credits a United Nations Educational, Scientific and Cultural Organization (UNESCO) report edited by V.M. Kotlyakov (1996) as its source.

In that 1996 report, Kotlyakov wrote "*The degradation of the extrapolar glaciation of the Earth will be apparent in rising ocean levels already by the year 2050, and there will be a drastic rise of the ocean thereafter caused by the deglaciation-derived runoff. This period will last from 200 to 300 years. The extrapolar glaciation of the Earth will be decaying at rapid, catastrophic rates—its total area will shrink from 500,000 to 100,000 km^2 by the year 2350. Glaciers will survive only in the mountains of inner Alaska, on some Arctic archipelagos, within Patagonian ice sheets, in the Karakoram Mountains, in the Himalayas, in some regions of Tibet and on the highest mountain peaks in the temperature latitudes*". In his statement, both the 500 000 and 100 000 km^2 areas applied to mountain glaciers world-wide, not just the Himalayas, and the prediction was for the year 2350, not 2035.

1. Regarding the area the IPCC gives for mountain glaciers in the Himalaya Region: if the IPCC intended for the areas to apply to the Himalayas, then it is wrong. Berthier et al. (2007) reported that there were only 33 000 km^2 of mountain glaciers in the region. Since then, estimates of glacial coverage in the Himalayas have been refined. Independent geologists claim that there are 18 065 small and big glaciers with a total area of 34 659.62 km^2 and a total ice volume of 3 734.4796 km^3 in the whole of the Himalayan range (Tribune India 2008). In both cases, the estimated current area of Himalayan mountain glaciers is far below the 100 000 km^2 predicted to remain in 2035;
2. Regarding the rate of retreat: the rate stated by the IPCC does not appear to be based upon any scientific studies and therefore has no foundation.

The upshot is that the critics are correct. The 2007 IPCC statement of glacial area is erroneous if one interprets them to apply to the Himalayas, and there appears to be no scientific foundation for the IPCC's prediction for the year 2035.

Does that mean that one should not pay attention to the IPCC's statement? Indeed, no! There is ample evidence that glaciers are melting throughout the world and that global warming is the cause. The IPCC is correct in that regard. In addition, the IPCC is also correct in warning that we need to be concerned about climate change and take steps to mitigate the causes and support measures to adapt to its negative impacts.

Recent findings on current status of the Himalayan Glaciers

A glacier changes its size and shape due to the influence of climate. It advances when the climate changes to a cool summer and a heavy snowfall in winter and the monsoon season. As it advances, it expands and the terminus shifts down to a lower altitude. On the other hand, a glacier retreats when the climate changes to a warm summer and less snowfall. As the glacier retreats, it shrinks and the terminus climbs up to a higher altitude. Thus, climatic change results in a glacier shifting to another equilibrium size and shape (Lizong et al. 2004).

The temperature increase in the Himalayan region has been greater than the global average of 0.74 °C over the last 100 years (IPCC 2007, Du et al. 2004). The higher the altitude, the more rapid the warming, a fact that can also be noted in temperature records from Nepal (Shrestha et al. 1999) and China (Liu and Chen 2000). This ongoing rapid warming has a profound effect on the Himalayan environment and may be most visible in the rapid retreat of Himalayan glaciers and diminishing snow fields (Dyurgerov and Meier 2005).

The annual melting of glacial ice provides important water resources for downstream populations and ecosystems, particularly in arid areas of the Himalayas

[1] Berthier et al. (2007) *provide a more precise estimate of 546 000 km^2 for world-wide coverage by mountain glaciers.*

Figure 2: Evidence of glacier retreat. (Image from: NASA Earth Observatory, Jesse Allen)

and during the critical seasonal dry periods. The supply of water resources, or the snow-and-ice-melt water component, is projected to increase in the coming decades as the perennial covering of snow and ice decreases. On a longer-term scale, however, water scarcity, particularly during the dry season, is likely to be a future challenge (Eriksson et al. 2008)

Remote-sensing based regional studies provide an overview of recent changes in the Central Asian ice cover. Glacier retreat was dominant in the 20th century, except for a decade or two around 1970, when some glaciers gained mass and even reacted with re-advances of a few hundred metres. After 1980, ice loss and glacier retreat dominated again (Eriksson et al. 2009).

Observations of individual glaciers indicate annual retreat rates varying from basin to basin—in some instances showing a doubling in recent years compared to the early 1970s (Eriksson et al. 2009).

Karma et al. (2003) observed an eight per cent area loss for glaciers in Bhutan, Eastern Himalaya, between 1963 and 1993 (UNEP and WGMS 2008). The Imja Glacier in the Dudh-Koshi basin of the Everest region retreated almost 1 600 m between 1962 and 2001 and another 370 m by 2006. The Gangotri Glacier in Uttaranchal, India, retreated about two km between 1780 and 2001 (WWF 2005).

Glaciers in China have been retreating with an area loss of about 20 per cent since the Little Ice Age maximum extent in the 17th century (Shi and Liu 2000, Su and Shi 2002, UNEP and WGMS 2008). Retreat increased during the last century, especially during the past ten years (Yao et al. 2004, Liu et al. 2006, UNEP and WGMS 2008). About 90 per cent of glaciers are retreating, and glacier retreat increases from the continental interior to the coastal margins (Yao et al. 2004, Liu et al. 2006, UNEP and WGMS 2008).

Li et al. (in press) estimate the area loss since the 1960s to be about six per cent. It is more pronounced in the Chinese Himalayas, Qilian Mountains, and Tien Shan, but with rather small recessions in the hinterland of the Tibetan plateau (UNEP and WGMS 2008).

Using remote sensing data to investigate glacier thickness changes in the Himachal Pradesh, Western

Figure 3: A receding glacier.

Himalaya, Berthier et al. (2007) found an annual ice thickness loss of about 0.8 metres water equivalent (m w.e.) per year between 1999 and 2004 – about twice the long-term rate of the period 1977-1999 (UNEP and WGMS 2008).

Over the 20th century, glacier area is estimated to have decreased by 25-35 per cent in the Tien Shan (Podrezov et al. 2002, Kutuzov 2005, Narama et al. 2006, Bolch 2007, UNEP and WGMS 2008), by 30-35 per cent in the Pamirs (Yablokov 2006), and by more than 50 per cent in northern Afghanistan (Yablokov 2006, UNEP and WGMS 2008).

Kulkarni et al. (2007) investigated glacial retreat in 466 glaciers in the Chenab, Parbati, and Baspa basins beginning in 1962. The investigation has shown an overall reduction in glacier area from 2 077 km^2 in 1962 to 1 628 km^2 in 2007, an overall deglaciation of 21 per cent. Because of fragmentation, however, the number of glaciers has increased. Mean area of glacial extent declined from 1.4 to 0.32 km^2 between 1962 and 2001. In addition, the number of large glaciers (those with higher areal extent) declined and the number of small ones (with lower areal extent) increased during that period. Small glaciarates and ice fields have shown extensive deglaciation. For example, 127 glaciarates and ice fields less than 1 km^2 have retreated by 38 per cent since 1962, possibly due to a small response time. This indicates that a combination of glacial fragmentation, higher retreat of small glaciers, and climate change are influencing the sustainability of Himalayan glaciers (UNEP and WGMS 2008).

Unlike the rest of the Himalayas and most Inner Asian ranges, however, Hewitt (2009) found no net reduction in the ice cover in the last three decades in glaciers in the KaraKoram Himalayas. Many glaciers have retreated or thinned slowly, but since 1995, he found more than 35 glaciers advancing, mid-glacier thickening in a dozen others, and a sudden increase in glacier surges.

The Intergovernmental Panel on Climate Change's (IPCC) projections of glacier retreat scenarios in the region suggest that increases in the mean annual temperature for High Asia in the range of 1.0°C to 6.0°C (low to high estimate) by 2100 are likely to result in a decline in the current coverage of glaciers by 43-81 per cent (Böhner and Lehmkuhl 2005, UNEP 2007). The worldwide and rapid, if not accelerating, glacier shrinkage on the century time scale may lead to the deglaciation of large parts of many mountain ranges this century (UNEP and WGMS 2008).

With the impact of global warming on the region, (Yao et al. 1995, Yao et al. 2004, Yao et al. 2006) glacier shrinkage will be faster and pose a serious threat to water resources in this region (UNEP 2007). The IPCC predicted that Himalayan glaciers could vanish within three decades at the present rate of warming (Xiaojuan 2009).

Raina (2009) writes as follows:

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 500 m 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 700 m between 1862 and 1909, followed by an equally rapid retreat of around 400 m 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 20 m per year till up to 2000 AD, has since slowed down considerably, and between September 2007 and June 2009 is practically at a standstill. The same is true of the Bhagirathkharak and Zemu glaciers.

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.

Tables 3 and 4 summarize changes observed on some of the glaciers in the Himalayan region. Most studies report that glaciers are receding, while only some indicate that a few glaciers are advancing.

Table 3: Evidence of Himalaya glacial retreat and advance

Glacier or location	Period	Receding	Stable or Advancing	Source	Method of measurement
Ak-shirak Range, central Tien Shan plateau	1943-1977	The wasting of the Ak-shirak glacier system features a decrease in average glacier size and an increase in the area of outcrops. A small shrinkage during 1943-1977		Khromova et al. (2003)	Using air photo mapping surveys (1943 and 1977), an ASTER imagery (2001), and long term glaciological and meteorological observations
Ak-shirak Range, central Tien Shan plateau	1977-2001	Greater than 20 per cent reduction during 1977-2001 in response to increases in summer and annual air temperature and decreases in annual precipitation		Khromova et al. (2003)	Using air photo mapping surveys (1943 and 1977), an ASTER imagery (2001), and long term glaciological and meteorological observations.
Bara Shigri Glacier (Himachal Pradesh)	1977-1995	650 m retreat of Snout; 36.1 m/yr average retreat of glacier		Cruz et al. (2007)	Maps and Field Observation
Batal Glacier, Chenab Basin	1980 -2006	Receded by about 25.7 m each year		TNN (2007)	National Institute of Hydrology
Chhatru Glacier, Chenab Basin	1980-2006	Receded 1 400 m-54 m a year		TNN (2007)	National Institute of Hydrology
Baturat Glacier, Pakistan	1992-2000	A decrease of about 17 km^2		Munir (2008)	Comparison of Landsat images of Batura glacier for October 1992 and October 2000. Although accurate changes in glacier extent cannot be assessed without baseline information, these efforts have been made to analyze future changes in glaciated area.

Glacier or location	**Period**	**Receding**	**Stable or Advancing**	**Source**	**Method of measurement**
Beaskund Glaciers, Beas Basin	1980-2006	Shrunk to half		TNN (2007)	National Institute of Hydrology
Chenab, Parbati and Baspa basins (466 glaciers)	1962-2007	The investigation has shown an overall reduction in glacier area from 2 077 km^2 in 1962 to 1 628 km^2 in 2007, an overall deglaciation of 21 per cent. However, the number of glaciers has increased due to fragmentation. Mean area of glacial extent has reduced from 1.4 to 0.32 km^2 between the 1962 and 2001		Kulkarni et al. (2007), UNEP and WGMS (2008)	Remote Sensing
China	Not known	The overall glacier area loss is estimated at about 20 per cent since the maximum extent in the 17th century		Su and Shi (2002), UNEP and WGMS (2008)	Remote Sensing
China	1960-2008	The area loss since the 1960s is estimated to be about six per cent, and is more pronounced in the Chinese Himalaya, Qilian Mountains and Tien Shan, but with rather small recessions in the hinterland of the Tibetan plateau		Li et al. (in press), UNEP and WGMS (2008)	Remote Sensing
Chota Shigri Glacier (Himachal Pradesh)	1986-1995	60m retreat of Snout; 6.7 m/yr average retreat of glacier		Cruz et al. (2007)	Maps and Field Observation
Dokriani glacier, Gangotri Valley	1962-1995	Average annual rate of recession was 16.5 m		TNN (2007)	Studied by D, P, Dobhal of the Wadia Institute of Himalayan Geology and his colleagues
Dokriani glacier, Gangotri Valley	1991-1995	The rate of meltdown 17.4 m per year		TNN (2007)	Studied by D. P. Dobhal of the Wadia Institute of Himalayan Geology and his colleagues
Dokriani glacier, Gangotri Valley	1993-1998	Receded 20 m in 1998 compared with an annual average of 16.5 m from 1993 to 1998		Down to Earth (1999), Mirza (2007), ADB (2009)	
Gangotri glacier	1842-1935	Receded at an annual average of 7.3 m		Hasnain (2002), Mirza (2007), Cruz et al. (2007), ADB (2009)	
Gangotri glacier	1962-2001	Retreat – amount not specified in abstract		Bahuguna et al. (2007)	A merged image of nadir viewing PAN and LISS III data of 2000 and PAN stereo data of 2000-2001 from Indian Remote Sensing satellite (IRS)-1C covering Gangotri glacier was interpreted to identify its snout or terminus and to measure the

Glacier or location	Period	Receding	Stable or Advancing	Source	Method of measurement
					retreat of this glacier with respect to the position of snout in a topographical map of 1962. Elevations from the map and DEM generated from stereo data were compared to determine the thickness of the glacier ice across the section of retreat prior to year 1962. The annual retreat of the glacier at the end of the ablation season during the year 2000-2001 was measured using PAN orthoimages
Gangotri glacier (Uttaranchal)	1985-2001	368 m retreat of snout. Receded 23 m a year		Hasnain (2002), Mirza (2007), Cruz et al. (2007), ADB (2009)	
Gangotri Glacier (Uttar Pradesh)	1977-1990	364 m retreat of snout; 28.0 m a year, average retreat of glacier		Cruz et al. (2007)	Maps and Field Observation
Gangotri Glacier	1934-2003	Retreated an average of 22 m a year and shed a total of 5 per cent		Raina (2009) Bagla (2009)	
Gangotri Glacier	2004-2005	Retreat slowed to about 12 m a year		Raina (2009) Bagla (2009)	
Gangotri Glacier	2007-2009		Practically at a standstill	Raina (2009) Bagla (2009)	
Gangotri	Last 30 years	1.5 km retreat		Nandi (2009)	ISTO Satellite Imagery
Gangotri Glacier in Uttaranchal, India	1780-2001	2 km		WWF (2005)	The average rate of recession has been computed by comparing the snout position on a 1985 toposheet map and the 2001 panchromatic satellite imagery
Himachal Pradesh, Western Himalaya	1999-2004	Annual ice thickness loss of about 0.8 m water equivalent (m w.e.) per year		Berthier et al. (2007), UNEP and WGMS (2008)	Remote Sensing
Imja Glacier	1962- 2001	Retreated almost 1 600 m		Karma et al. (2003), UNEP and WGMS (2008)	Analyzed from newly published inventories of India, east Nepal, and Bhutan topographic maps and satellite images

Glacier or location	Period	Receding	Stable or Advancing	Source	Method of measurement
Imja Glacier	2001-2006	370 m		Karma et al. (2003), UNEP	Analyzed from newly published and WGMS inventories of India, east Nepal, and Bhutan topographic maps and satellite images (2008)
Karakoram glaciers	Not known		The observed downward trend in summer temperature and runoff is consistent with the observed thickening and expansion of Karakoram glaciers, in contrast to widespread decay and retreat in the eastern Himalayas. This suggests that the western Himalayas are showing a different response to global warming than other parts of the globe	Fowler and Archer (2006)	
KaraKoram Himalaya	Not known		More than 35 glaciers advancing, mid-glacier thickening in a dozen others, and a sudden increase in glacier surges	Hewitt (2009)	
Milam Glacier (Uttar Pradesh)	1909-1984	990 m retreat of snout; 13.2 m a year average retreat of glacier		Cruz et al. (2007)	Maps and Field Observation
Naimona'nyi Glacier in the Himalaya (Tibet)	1950-2004	No net accumulation of mass (ice) since at least 1950		Kehrwald et al. (2008)	Ice cores drilled from glaciers around the world generally contain horizons with elevated levels of beta radioactivity including 36Cl and 3H associated with atmospheric thermonuclear bomb testing in the 1950s and 1960s. Ice cores collected in 2006 from Naimona'nyi Glacier in the Himalaya (Tibet) lack these distinctive marker horizons
Northern Afghanistan		More than 50 per cent		Yablokov (2006), UNEP and WGMS (2008)	Remote Sensing
Pamirs		30-35 per cent		Yablokov, (2006) UNEP and WGMS (2008)	Remote sensing

Glacier or location	Period	Receding	Stable or Advancing	Source	Method of measurement
Pindari Glacier (Uttar Pradesh)	1845-1966	2 840 m retreat of snout; 135.2 m a year average retreat of glacier		Cruz et al. (2007)	Maps and Field Observation
Ponting Glacier (Uttar Pradesh)	1906-1957	262 m retreat of snout; 5.1 m a year average retreat of glacier		Cruz et al. (2007)	Maps and Field Observation
Spiti/Lahaul (Himachal Pradesh, India)	1999-2004	Calculations indicated that 915 km^2 of Himalayan glaciers of the test region thinned by an annual average of 0.85 m		IRD (2007)	By comparing the SRTM and SPOT5 topographies using stable non-glaciated areas around glaciers that researchers have been able to adjust for the deviations and superimpose the two digital field models. These comparisons gave the bases for a map of glacier elevation (and hence thickness) variations for altitude intervals of 100 m over the period 2000-2004
Siachin	Last 50 yrs		Not shown any remarkable retreat	Raina (2009) Bagla (2009)	
Su-lo Mountain, in the northeastern Tibetan Plateau, China	1966-1999	The total glacier area decreased from 492.9 km^2 in 1966 to 458.2 km^2 in 1999. The volume loss of the studied glaciers reached 1.4 km^3 from 1966 to 2000. This agrees with documented changes in other mountain glaciers of the whole Tibetan Plateau		Wang et al. (2008)	Topographic maps of 1:50 000 scales, aerial photographs taken in 1966, one Landsat image taken in 1999, and SRTM data from 2000 were used
Tien Shan	1900-2000	Glacier area is estimated to have decreased by 25-35 per cent		Podrezov et al. (2002), Kutuzov, S. (2005), Narama, et al. (2006), Bolch (2007), UNEP and WGMS (2008)	Obtained from the moraine positions, aerial photographs, and satellite images
Triloknath Glacier (Himachal Pradesh)	1969-1995	400 m retreat of snout; 15.4 m a year average retreat of glacier		Cruz et al. (2007)	Maps and Field Observation
Zemu Glacier (Sikkim)	1977-1984	194 m retreat of snout; 27.7 m a year average retreat of glacier		Cruz et al. (2007)	Maps and Field Observation

Table 4: Proportions of advancing and retreating glaciers in the High Asia in China in different stages. (Source- Yao et al. 2004)

Time	Number of Glaciers	Retreating Glaciers (%)	Advancing Glaciers (%)	Stable Glaciers (%)	Source
1950 -1970	116	53.44	30.17	16.37	Zhang et al. (1981), Ren 1988)
1970 -1980	224	44.2	26.3	29.5	Zhang et al. (1981), Ren (1988)
1980 -1990	612	90	10	0	Yao et al. (1991), Yao et al.(2004).
1990- 2004	612	95	5	0	Yao et al. (2004).

Armstrong et al. (2009a) caution:

> *It should be understood that the monitoring of the terminus location of a glacier is neither a complete nor a comprehensive assessment of total glacier condition or health. For example, if a glacier is noted to be retreating, this simply means that the ice volume at the terminus is melting faster than the rate at which ice is being supplied to that location by the dynamic movement of ice from further upslope in the system. On an annual basis, it is possible that a glacier could be gaining in total mass due to increasing amounts of snow arriving in the accumulation zone by precipitation, wind deposition and avalanching, while, at the same time, the terminus is retreating. Data that report glacier retreat describe only the conditions at the lowermost elevation of the glacier where the current climate does not support the extension, or even stability of the glacier. Thus, terminus data alone cannot comprehensively represent those conditions controlling the changes in volume and mass across the entire elevation range of a glacier system. And to put the Himalayan region in a global perspective, the elevation range of the glacier systems in this region is the greatest in the world.*

Figure 4: The elevation range of the glacier systems in this region is the greatest in the world

Figure 5: A glacial lake

Glacial Lakes

The shrinking of glaciers is accompanied by the formation of unstable glacial lakes that threaten downstream areas with outburst floods (UNEP 2007). Glacial Lake Outburst Floods (GLOF) are one of the most immediate and visibly dramatic effects of climate change in the Himalayan region. Glacial lakes are formed by meltwater, and many lakes in the Himalayas are full. Scientists and politicians are concerned that these 'brimming' lakes may overflow (outburst) and cause devastating floods (UNEP 2007). The frequency of the occurrence of GLOF events has increased in the second half of the 20th century, with an inevitable toll on lives, property, and infrastructure (WWF 2008).

Box 3 provides some observations that have been made about glacial lakes.

Box 3: Some quotes about glacial lakes

Some of its 25 dangerous lakes are not a hazard, but we found more that ICIMOD did not point out. Regardless of which lakes are risks now, the number will rise in the future, as glaciers continue to melt – Karma Toeb, Project's Glaciologist and Team Leader (Nayar 2009).

Nobody knows what will happen, taking into account all the changes in climate; the same situation may happen to any of the glaciers in Bhutan – Karma Toeb, Project's Glaciologist and Team Leader (Nayar 2009).

Although glacial lake bursts cause considerable damage in the Himalayas, an even bigger catastrophe would come from the disappearance of those very same glaciers, and the water they produce, which is predicted within the next few decades. That loss could significantly harm the 69 per cent of the Bhutanese population that relies on farming, mostly subsistence (Nayar 2009).

Figure 6: This NASA image shows the formation of numerous glacial lakes at the termini of receding glaciers in Bhutan-Himalaya. From: Retreat of glaciers since 1850. (NASA 2006, Wikipedia 2008; Image source: Jeffery Kargel, USGS/NASA/JPL/AGU)

Based primarily on anecdotal evidence, the percentage contribution of glacier ice melt to regional stream flow increases in an east to west direction across the Himalayas. As Armstrong et al. (2009a) note, however, both the precipitation and the total stream flow decrease when moving from the relatively wet monsoon climate of the east to the dry, more continental climate of the western Himalayas.

Causes of Glacial Change

Most scientists attribute the receding of the Himalaya glaciers to global warming. , Raina (2009), however, writes

> *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.*

Similarly, India's Environment Minister, Jairam Ramesh, states that "There is no conclusive scientific evidence to link global warming with what is happening in the Himalayan glaciers. (Although some glaciers are receding they were doing so at a rate that was not "historically alarming" (Ramesh 2009).

Rajinder Kumar Ganjoo, Glaciologist at the University of Jammu, India, contends that "If rising temperatures were the real cause for the retreat, then all ice masses across the Himalayas should be wasting away uniformly. At issue in scientific circles is how lengthy the response time is, and how it varies among glaciers" (Bagla 2009).

Others attribute the cause to pollution:

A Times of India headline declared "Black Carbon Major Cause of Global Warming" (Kumar 2009). Meitiv (2009) reports that

> *The article described the preliminary findings of a 5-year project to study the impacts of black carbon on global warming in the Indo-Gangetic Basin. The study, launched in 2007 under the auspices of the Indian Space Research Organization (ISRO), has already confirmed that "black carbon is (a) major cause of global warming…threatening to equal the impact of CO2 on melting snowpack and glaciers in the Himalayan region.*

Raina (2009) goes on to explain

> *An aerosol/ dust cover of 400gm/m*^{2} *—a thickness of about 2mm—has the maximum effect as far as melting of glaciers*

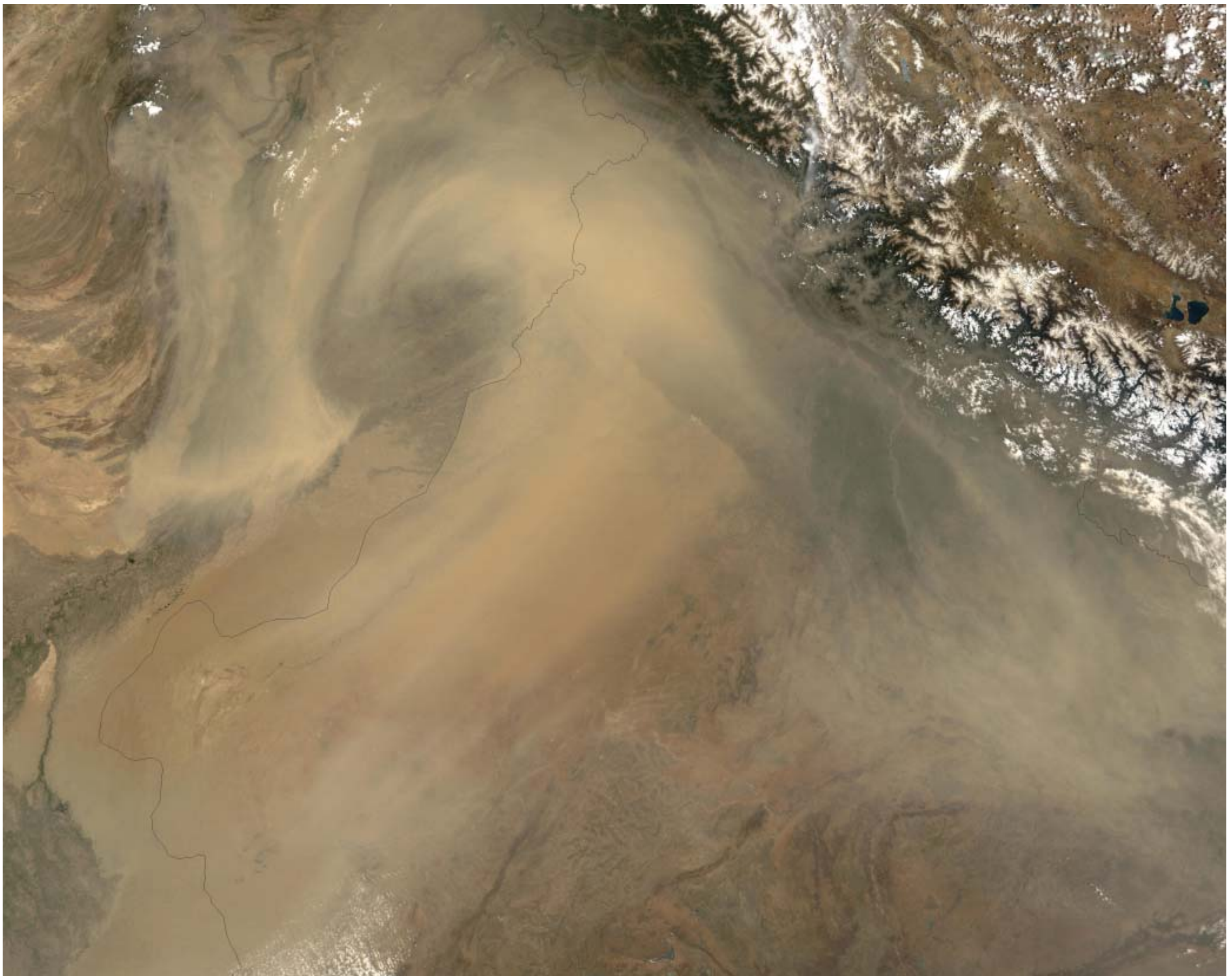


Figure 7: In this image, taken on 5 February 2006 by NASA's Aqua satellite, a pale band of haze covers northern India, just south of the Himalaya. Haze also intrudes into the skies of southern Nepal and Bangladesh. A study by UC researchers suggests that reducing air pollution could increase rice harvests in India. (Auffhammer et al. 2006).

Photo source:Jeff Schmaltz, Moderate Resolution Imaging Spectroradiometer Land Rapid Response Team at the NASA Goddard Space Flight Center .

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.

In reality, both may cause glaciers to retreat.

Figure 8: Thick clouds of desert dust were blowing over Pakistan (left) and India (right) at the foothills of the Himalaya Mountains on 9 June 2003. This image of the event was captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra satellite. The storm appears to be laying down a layer of dust on the snow-capped Himalayan peaks at top right. Red dots indicate active fire detections made by MODIS. Dust and debris may cover a glacier obscuring the ice below. (NASA, 2006) Photo Credit: Jeff Schmaltz, MODIS Rapid Response Team, NASA/GSFC.

Reasons for Differing Interpretations

There are a number of reasons for disagreement in statistics and interpretations, including the following:

- Different interpretations of what constitutes the Himalayan Region
- Different definitions and interpretations of what constitutes a glacier or parts of a glacier
- Measurements made at different times of the day, season, or year
- The use of different methods
- The use of different imagery resolutions
- Commission errors – counting something as a glacier or a part of a glacier when it is not (it may be a snow field or a frozen lake, for example)
- Double counting by two nations of a glacier that overlaps a national boundary
- Omission errors: overlooking a glacier because it is masked by debris that covers it or a part of it, or neglecting to count a transboundary glacier because of an assumption that the adjacent country has already included it in its inventory
- Observations made at different locations: glaciers in different parts of the Himalayas behave differently — east vs. west, centre vs. edge, etc.
- Observations made by different people with different perceptions

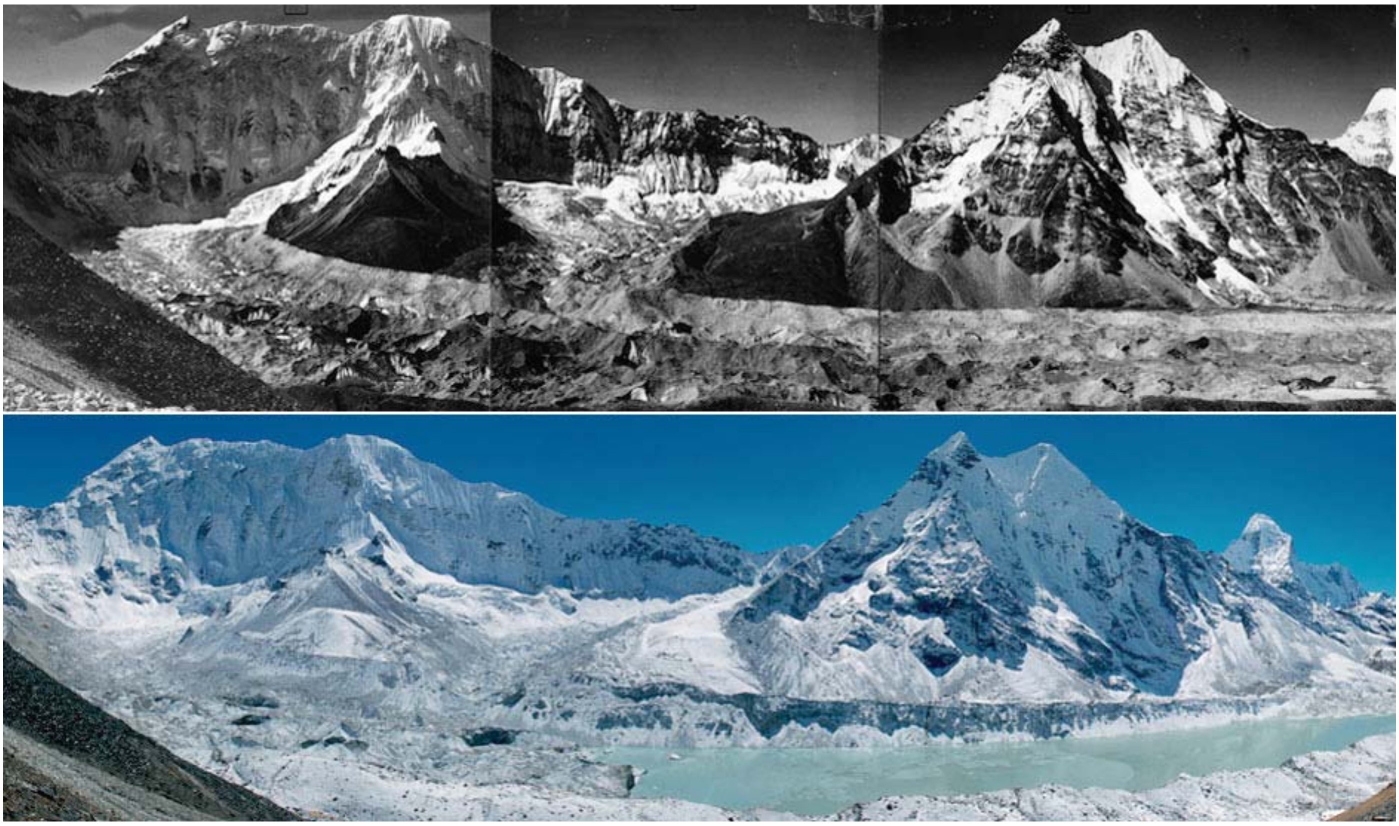
Other differences may relate to the limitations of remote sensing (WRRI 2006), which include the following:

- Non-availability of high-resolution data
- Cloud/shadow affect in RS data
- Field validation
- Manual interpretation vs. digital interpretation
- Limited climatic data, especially for high altitudes
- Estimation of ice reserves
- Lack of coordination among the institutions involved in glaciology
- Digitization of smaller lakes
- Individual variability in judgment
- Debris-covered glaciers

The lack of data also contributes to the disagreement. Compared to other glaciated areas, the Himalayan Region is data poor. This due to a number of reasons:

- Not sharing information
- Lack of access
- No means or staff to collect data
- Not deemed as important as other glaciated areas

Figure 9: A very deep layer of ice covered the Imja glacier in the 1950s (top photo). Over the next 50 years, small meltwater ponds continued to grow and merge, and by the mid 1970s had formed the Imja Lake. By 2007, the lake had grown to around 1km long. Photograph: Erwin Schneider/Alton Byers/The Mountain Institute (Carus 2009)



Box 4: Some quotes about data and research

Climate change is affecting the amount of snow and ice and rainfall patterns in the Himalayan region, but there is a severe lack of data needed to understand these processes – Pradeep Mool, ICIMOD (Dahal 2009).

There is no consistency in the data on the area glaciers cover in the Himalayas and this often confuses citizens – Pradeep Mool, ICIMOD (Dahal 2009).

There is no data on the annual snow precipitation and atmospheric temperature in Himalayas in general, even though Himalayan glaciers are an integral part of water supply to India – V.K. Raina, former Deputy Director General of the Geological Survey of India (Sinha 2009).

*They (the IPCC) were too quick to jump to conclusions on too little dat*a - John Shroder, Himalayan Glacier Specialist, the University of Nebraska, Omaha (Bagla 2009).

We have anecdotal evidence that glaciers may be receding, but we need precise and carefully vetted data, both through satellite imaging and ground surveys - Prime Minister Manmohan Singh (2009).

One reason is that there are far fewer data available compared with the Arctic and Antarctic, which have seen a far greater number of scientific expeditions to plumb their secrets. Although fieldwork there can be tough, the plateau offers the same physical isolation coupled with political challenges, at least for Western researchers (Qiu 2008).

The plateau's remoteness, high altitude and harsh weather conditions make any research on the region very challenging – Yao Tandong, Director of the Institute of Tibetan Plateau Research (Qiu 2008).

The lack of data has been worsened by hostility between ICIMOD's member countries — including India and Pakistan — who are reluctant to share data – (Cyranoski 2008).

Out of 9 575 glaciers in India, till date, research has been conducted only on about 50. Nearly 200 years data has shown that nothing abnormal has occurred in any of these glaciers – V.K. Raina, former Deputy Director General of the Geological Survey of India (Anand 2007).

Bhutan and Nepal do not have the technical and financial means to study the impact of climate change on their countries. Largely ignored in the international arena of high-tech science and overshadowed by their populous neighbours China and India, these least-developed countries struggle on their own – (Padma 2007).

There are few trained scientists or even a research station in Nepal to study this area of science. There are no research data available to help understand climate change in countries such as Nepal. Bhutan has the same problem – (Padma 2007).

The gaps in scientific manpower and research are acute – Doley Tshering, Officer for Climate Change, United Nation's Development Programme in Bhutan (Padma 2007).

There are only about a dozen scientists working on 9 575 glaciers in India under the aegis of the Geological Society of India – Anand (2007).

Himalayan glaciers and their mass balance are poorly sampled. For example, between 1977 and 1999, the average area surveyed each year on the field was 6.8 km^2 only. No direct mass balance measurement is available after 1999 – (Berthier et al. 2007).

We do need more extensive measurement of the Himalayan range but it is clear from satellite pictures what is happening – Rajendra Pachau, IPCC Chairman (Ramesh 2009).

There needs to be a lot of research on (Asia's) mountain glaciers. Truly, we know less about them than any other place on Earth – Glaciologist Lonnie G. Thompson, Ohio State University, Columbus (Bagla 2009).

We don't need to write the epitaph for the glaciers, but we need a concentrated scientific and policy focus on the Himalayan ecosystem since the truth is incredibly complex – Jairam Ramesh, India's Environment Minister (Bagla 2009).

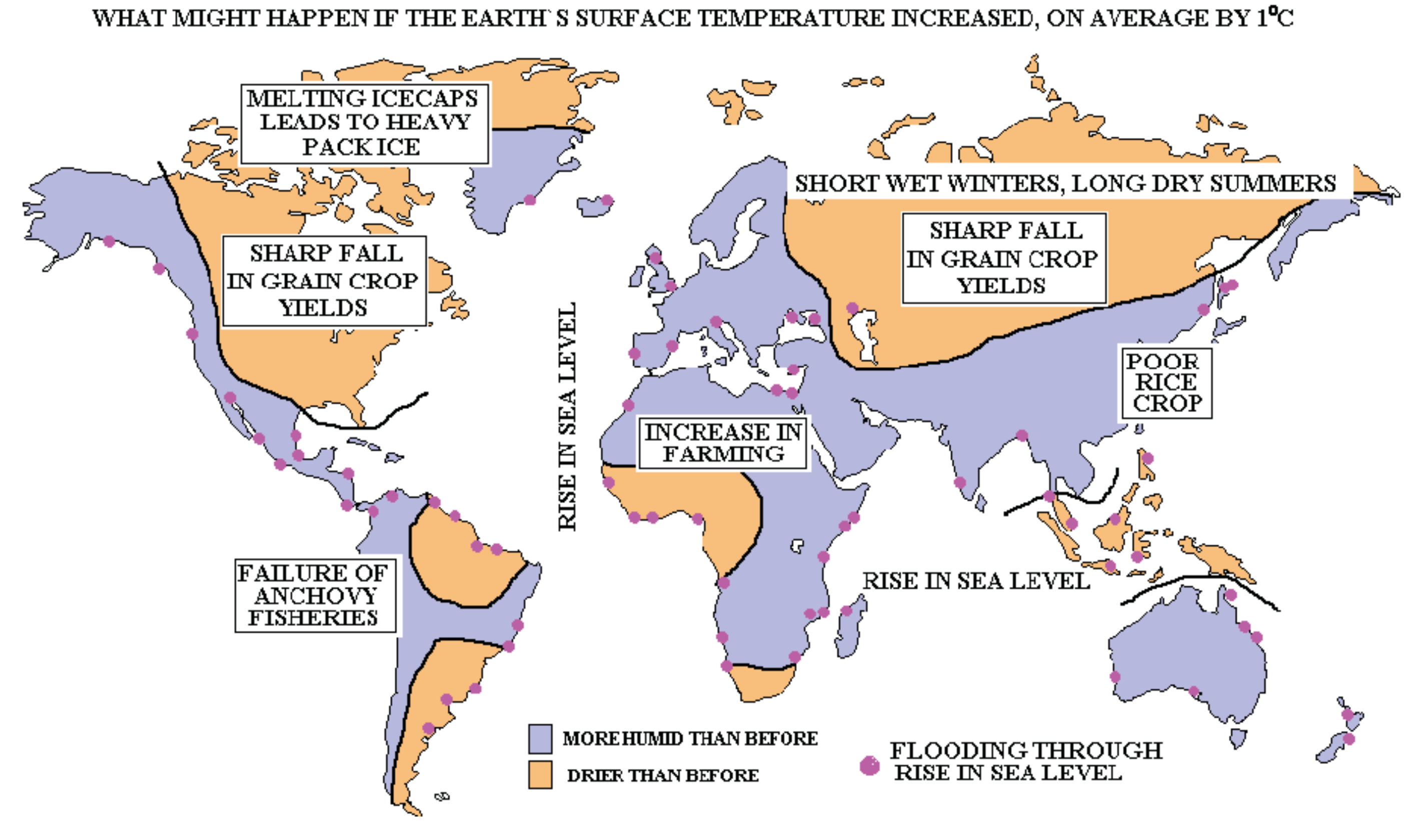


Figure 10: Global projections of changes due to global warming (Hobish 2009)

Future Impact of Climate Change

The World Bank (2008) projects the following:

- Glacier melting in the Himalayas is projected to increase flooding and will affect water resources within the next two to three decades
- Climate change will compound the pressures on natural resources and the environment due to rapid urbanization, industrialization, and economic development
- Crop yields could decrease up to 30 per cent in South Asia by the mid-21st century
- Mortality due to diarrhoea primarily associated with floods and droughts will rise in South Asia
- Sea-level rise will exacerbate inundation, storm surge, erosion, and other coastal hazards

The World Bank (2008) reports that the impacts of these changes on South Asia's poor community include the following:

- Decreased water availability and water quality in many arid and semiarid regions
- An increased risk of floods and droughts in many regions
- Reduction in water regulation in mountain habitats
- Decreases in reliability of hydropower and biomass production
- Increased incidence of waterborne diseases such as malaria, dengue, and cholera
- Increased damages and deaths caused by extreme weather events
- Decreased agricultural productivity
- Adverse impacts on fisheries
- Adverse effects on many ecological systems

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CHAPTER 2

Recent Trends in Tropospheric Temperature over the Himalayas and Summer Monsoon Rainfall over India

Himalayas and Monsoon

Fundamental to the onset of the Indian Summer Monsoon is the land-sea thermal gradient from the Indian Ocean to the Himalayas-Tibetan Plateau. The orography of the Himalayas-Tibetan Plateau (HTP), which acts as an elevated heat source, is crucial to the onset and strength of the monsoon, and sets this region apart from other tropical/sub-tropical regimes (Yanai et al., 1992; Webster et al., 1998). Warm air rising over the landmass throughout the troposphere, in response to the heating of the HTP, causes the inflow of moist air from the ocean towards the continent. Moreover, the Himalayas act as a barrier to the moisture-laden strong monsoon winds, resulting in heavy rainfall over South Asia that forms the bulk of the annual precipitation during each summer, from June through September. The importance of the seasonal heating of the HTP during pre-monsoon and early summer has long been recognized in influencing the intensity of the monsoon circulation and rainfall (Flohn, 1957).

Along with the monsoon rainfall, rivers originating from the glaciers provide water needed for agriculture which is the mainstay of economy of the South Asian countries. In addition, fresh water discharge from the rivers into the Bay of Bengal, and subsequently into the northern Indian Ocean, is important in regulating the oceanic nutrients production and salt budget (Tomczak and Godfrey, 1994).

In recent decades, South and East Asia have witnessed a dramatic increase in atmospheric pollution due to the growing population and energy demands, accompanied by rapid urbanization and industrialization. Together with the increasing concentrations of greenhouse gases, general circulation model (GCM) results suggest that absorbing aerosols have significantly caused warming of the lower troposphere over Asia (Ramanathan et al., 2007). In general, the global tropospheric warming, in recent decades, is recognized to be partly of anthropogenic origin as simulated by GCMs (Santer et al., 2000; Hansen et al., 2002). Consistent with model simulations, microwave satellite observations of free troposphere since 1979 have also shown an upward trend in the tropospheric temperatures (Santer et al., 2000; Mears et al., 2003; Fu et al., 2004). This document reports on recent changes in the Indian monsoon rainfall variability associated with the changing climate over South Asia indicated by increasing pollution, changes in tropospheric temperatures and snow cover changes based on several recent key published findings.

The influence of absorbing aerosols over these monsoon-dominated regions has been shown as potentially altering rainfall patterns (Menon et al., 2002). Mostly, through model simulations, recently, several studies have examined the role of aerosol absorption of sunlight in affecting monsoon circulation and rainfall variability over South Asia (Menon et al., 2002; Ramanathan et al., 2005; Lau et al., 2006; Meehl et al., 2008). Aerosol-induced surface dimming over the Indian Ocean results in less evaporation from the ocean surface, thereby reducing moisture inflow into South Asia which in turn causes weakening of the monsoon rainfall with prediction of frequent droughts over India (Figure 1). (Ramanathan et al., 2005). On the other hand, it has also been demonstrated that dust mixed with soot aerosols causes enhanced heating in the middle/upper troposphere, over northern India and the foothills of the Himalayas, leading the strengthening of the meridional tropospheric temperature gradient and resulting in the advancement of the monsoon rainfall in early summer (Lau et al., 2006).

In the context of rising global surface and tropospheric temperatures likely inducing changes in the Earth's hydrological cycle (Allen and Ingram 2002;

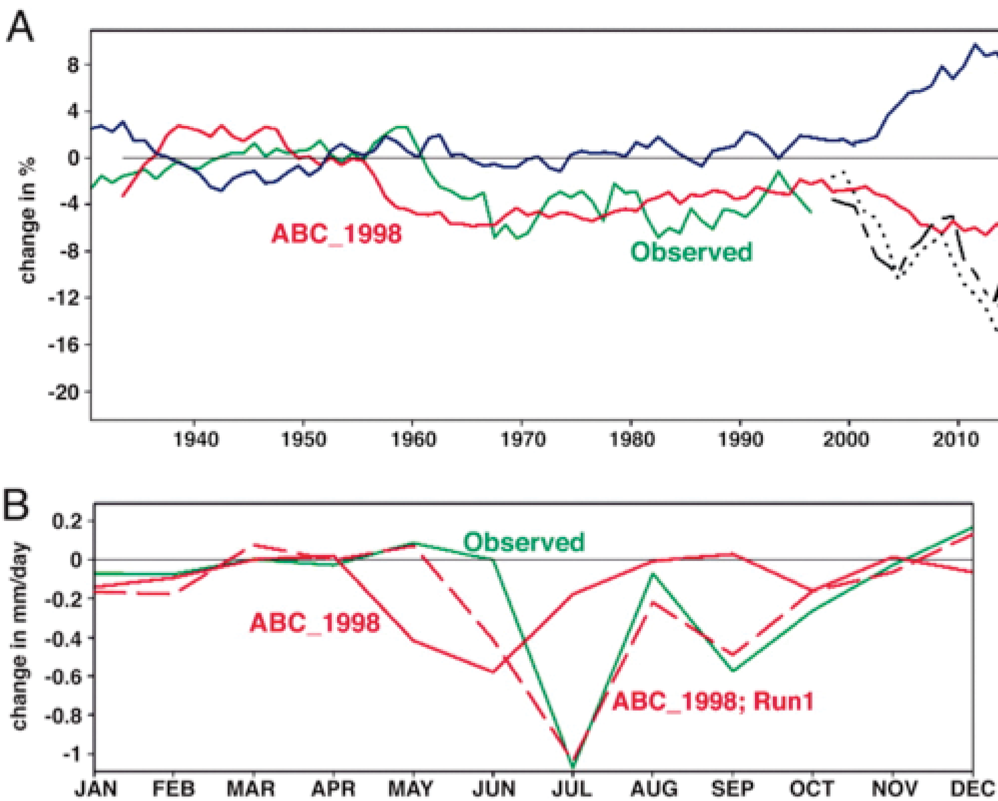
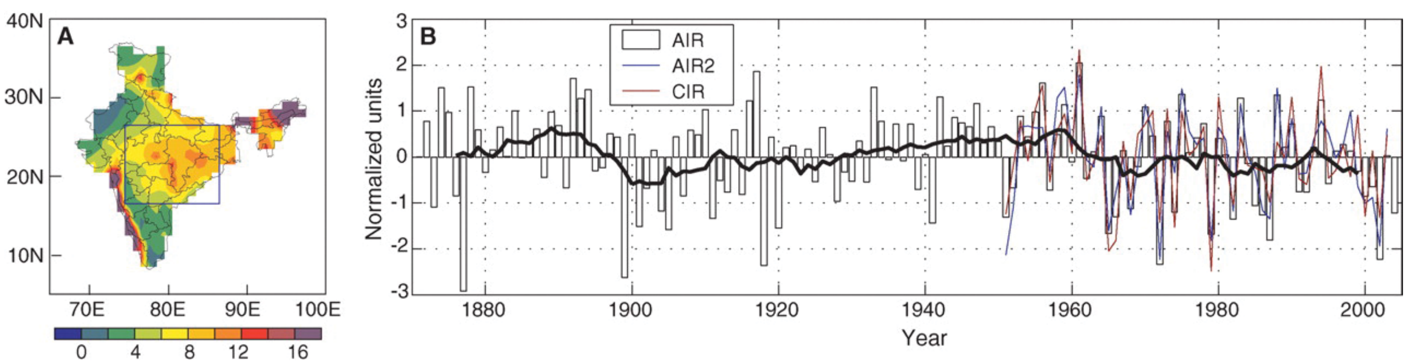


Figure 1. Rainfall trends. (A) Time series of observed and simulated summer (June to September) rainfall for India from observations and model simulations. The results are the percent deviation of the rainfall from the 1930–1960 average. The observational data are smoothed by an 11-year running mean averaging procedure. (B) Trend for 1930–2000 in monthly mean rainfall for India. (source: Ramanathan et al., 2007).

Held and Soden, 2006; Wentz et al., 2007) and in spite of the increasing trend of heavy rainfall events over India; albeit, the summer monsoon rainfall has been relatively stable in the past century (Figure 2) (Goswami et al., 2006). Vis-à-vis the strong control of seasonal heating over the HTP on South Asian monsoon dynamics and the regional hydrological cycle; and global climate change, we examine here tropospheric temperature trends using satellite-borne Microwave Sounding Unit (MSU) data (Mears et al., 2003; Fu et al., 2004) over the Indian Monsoon region from 1979 to 2007, and explore its implications to the recent monsoon rainfall variability.

Against the backdrop of increasing aerosol concentrations, recent studies have recognized the potential role of aerosols inducing changes in the monsoon circulation and rainfall over India. There are two major approaches in the recent literature that demonstrate these aerosol effects as documented in Lau et al., (2008), Gautam et al., (2009b).

Figure 2. (A) Climatological mean summer monsoon rainfall (mm/day). The box indicates the CI region used in our analysis. (B) Normalized (by the interannual standard deviation) JJAS AIR based on 306 stations (26) from 1871 to 2003 (bars). The mean is 84.9 cm, and the standard deviation is 8.4 cm. The solid black line represents an 11-year running mean indicating interdecadal variability but no trend. The AIR2 (blue) is the normalized seasonal mean AIR on the basis of the new gridded rainfall data (24). The seasonal mean and standard deviation are 94.0 cm and 9.1 cm, respectively. The CIR (red) is the normalized seasonal mean over CI on the basis of the gridded rainfall data set, the mean and the standard deviation of which are 69.5 cm and 11.2 cm, respectively Goswami et al., 2006).



Surface Dimming Effect: This mechanism proposed by Ramanathan et al. (2005) focuses on the northern Indian Ocean region where thick haze, consisting of dust, BC, sulfate, fly ash aerosols (referred to as Atmospheric Brown Clouds), is transported from South Asia towards the India Ocean. It has been shown by Satheesh and Ramanathan, (2000) that the widespread haze causes significant perturbations in the regional radiation budget with large reductions in the solar insolation at the ocean surface. The reduction of sunlight cuts the evaporation rates which further suppress convection from the ocean surface leading to reduced moisture transport towards the subcontinent during the peak monsoon season. This mechanism suggests the weakening of monsoon circulation and reduction of monsoon rainfall with the future possibility of frequent droughts.

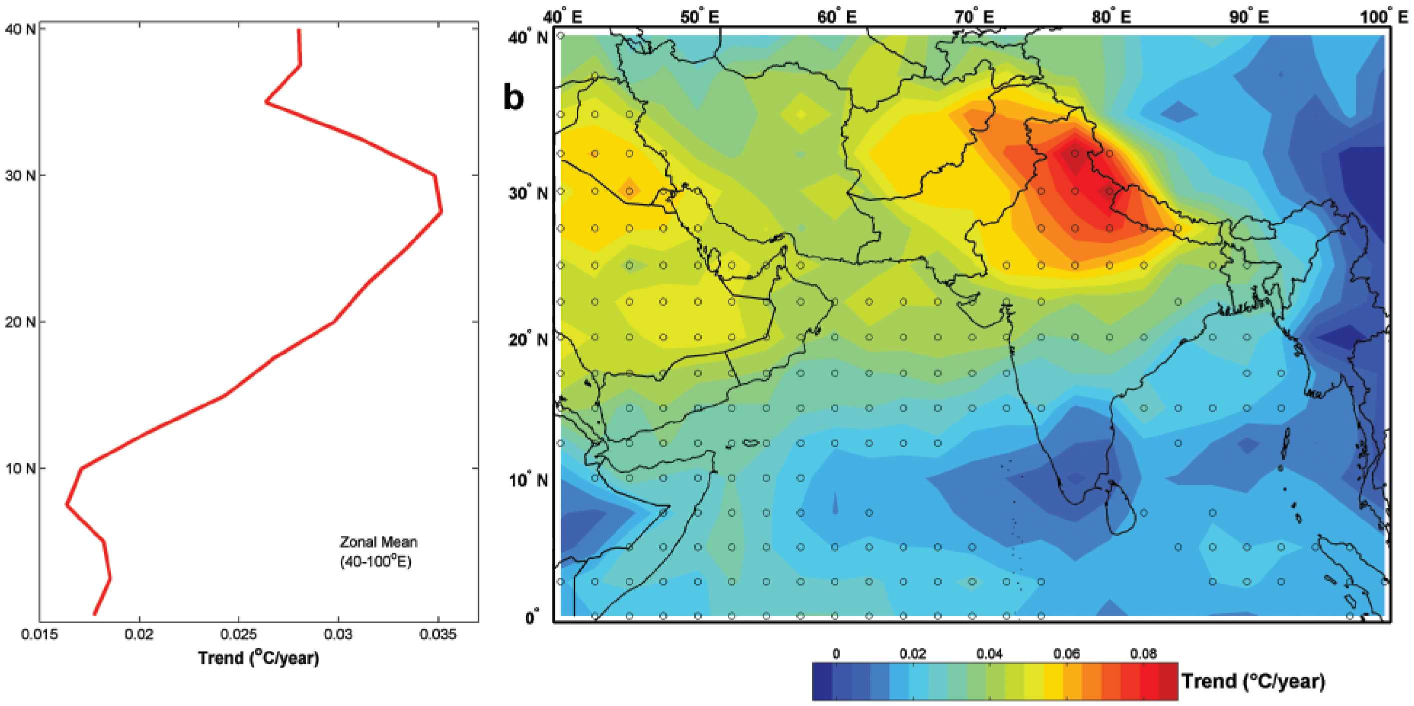
Elevated Heat Pump (EHP) Hypothesis: Lau et al. (2006a) proposed the EHP mechanism which rests on the heavy aerosol loading over northern India, primarily the IGP and over the foothills of the Himalayas, prior to the onset of the monsoon. Enhanced dust loading mixed with carbonaceous soot aerosols are vertically advected to elevated altitudes and pile up against the southern slopes of the Himalayas and cause significant warming in the middle and upper troposphere. The enhanced aerosol solar absorption creates a temperature anomaly which amplifies the overturning of the meridional circulation and thus causes to draw in more moisture from the Indian Ocean. This mechanism has been hypothesized in the advancement and intensification of the early summer monsoon.

Apart from the two proposed mechanisms, a key influence of aerosols on monsoon rainfall may take place through the modification of cloud properties such as cloud albedo, effective radius, liquid water path and so on (Kaufman and Fraser, 1997; Rosenfeld et al., 2001). Hygroscopic particles, such as sulfate aerosols, act as efficient cloud condensation nuclei (CCN), promote cloud formation and may cause enhancement in precipitation. In contrast, aerosols that are hydrophobic in nature and do not serve as good CCN, such as soot and dust, may act to suppress rainfall. However, such short-term aerosol indirect effects are more likely to come into play during the rainy period and are also dependent on the prevailing meteorological conditions.

Tropospheric Temperature Trends

Since 1979, the spaceborne Microwave Sounding Unit (MSU) has provided an unprecedented measure of global temperatures for several atmospheric layers from the lower troposphere to stratosphere. As most of the HTP stands over 4 km, tropospheric temperatures over the Himalayan region pertain to the mid-troposphere, corresponding to the 4-7 km atmospheric layer as recorded by the MSU. Gautam et al., (2009a) adopted the methodology of a previous study (Fu et al., 2004) by applying statistical combinations to different MSU channels in order to minimize the influence of stratospheric cooling on the tropospheric temperature signal. The data obtained are the brightness temperatures averaged for the mid-tropospheric temperatures (TMT) and the lower stratospheric

Figure 3. The zonal mean (40-100 ºE) latitudinal profile of mid-tropospheric temperature trend for the pre-monsoon period of March-April-May from 1979 to 2007 (Gautam et al., 2009a).



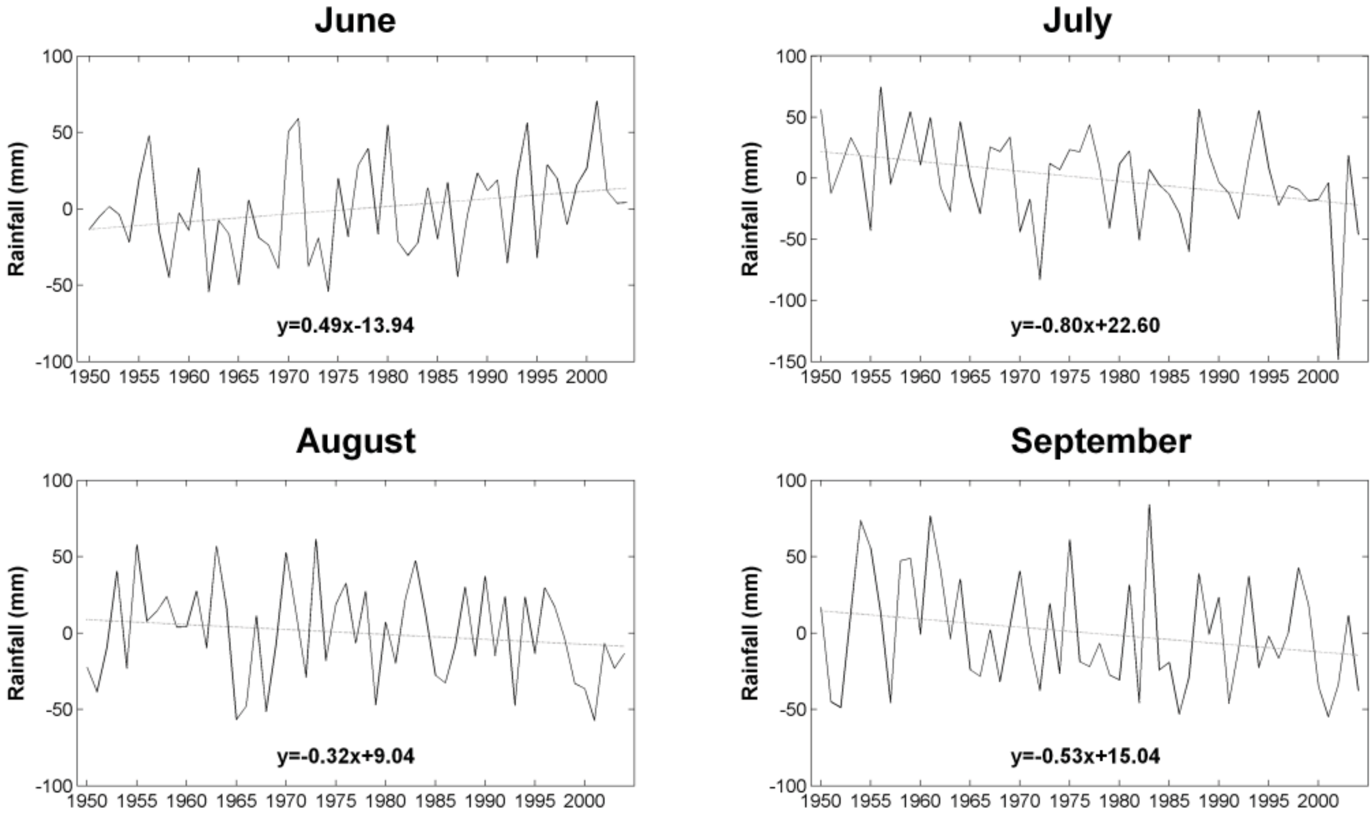


Figure 4. Time series and linear trends of monthly separated All India Monsoon Rainfall for June, July, August and September from 1979 to 2004. June rainfall exhibits a characteristic increasing trend, while all remaining monsoon months show a significant weakening trend in recent past decades (Gautam et al., 2009b).

temperatures (TLS) from the MSU data archive of Remote Sensing Systems (RSS) (http://www.ssmi.com) (Mears et al., 2003).

Figure 3 shows the zonal mean (40-100 ºE) latitudinal profile of mid-tropospheric temperature trend for the pre-monsoon period of March-April-May from 1979 to 2007 (Gautam et al., 2009a). A steep temperature gradient pattern is evident from the equatorial Indian Ocean to the South Asian landmass peaking around 30ºN. The Himalayan-Gangetic region is marked by the strongest positive trend resulting in a statistically-significant enhanced warming in the last three-decade period (Fig. 3). Spatial extent of the warming extends from the Himalayas to the western arid regions of Pakistan, Afghanistan, Iran and the Arabian Peninsula with appreciable warming also recorded over the Hindu-Kush Mountains. The northern Arabian Sea is also associated with a larger increase in tropospheric temperatures which is comparable to that of the arid landmass to its north. On the contrary, regions south of 10ºN, experience weak positive-neutral trends, especially over oceanic regions such as the Indian Ocean and the Bay of Bengal.

Apart from the emergence of the strengthened land-sea gradient, there is a sharp east-west pattern across the Tibetan Plateau (TP) and the Himalayan region. Most of the TP experiences relatively smaller (positive) warming trends compared to the strong western Himalayan warming. Only the region around 30ºN, 100ºE is marked by a weak cooling trend. Overall, there is a warming of 0.8 ºC averaged over the entire South Asian monsoon region during May (Gautam et al., 2009a).

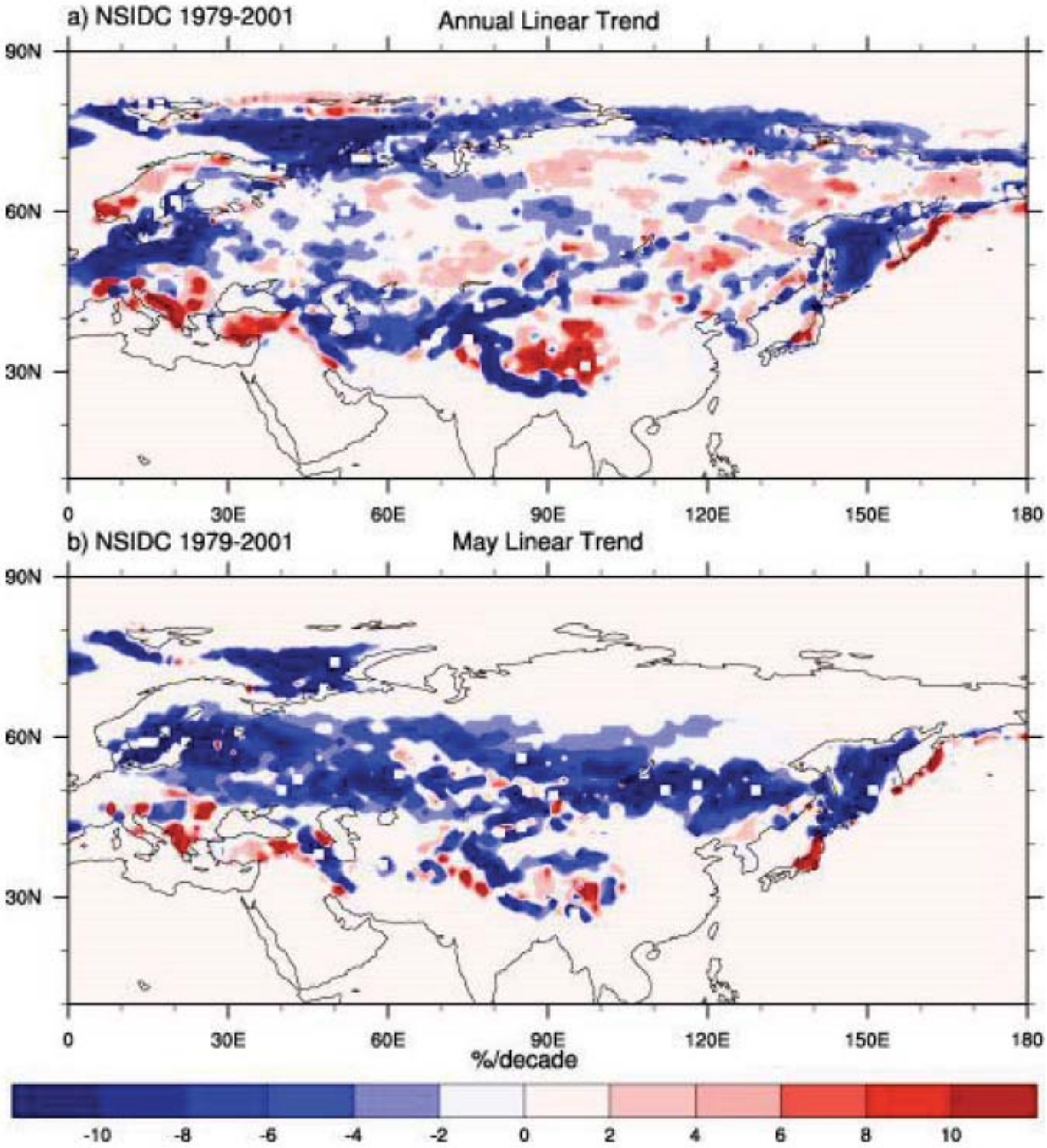
All-India Monsoon Rainfall

The seasonal mean monsoon rainfall, averaged over June-July-August-September (JJAS), shows some inter-decadal variability since 1871 but lacks a significant long-term trend (Fig. 2, Goswami et al., 2006). Since early 1900s there is an increasing trend of monsoon rainfall that exists until the late 1950s followed by a relatively stable period from 1970s to recent years. However, individual monsoon months reveal that the June rainfall has steadily increased in the past decades and is on the rise since 1950s (Fig. 4, Gautam et al., 2009b). The seasonal mean monsoon rainfall, averaged over June-July-August-September (JJAS), shows some inter-decadal variability since 1871 but lacks a significant long-term trend (Goswami et al., 2006). However, a closer look at the data, by separately analyzing individual months, reveals that the June rainfall has steadily increased in the recent past five-decade period (Fig. 4, see (Gautam et al., 2009b)). The all India June rainfall since 1950 has increased at a rate of 0.77 mm/year (with 94% confidence), which amounts to over 20% increase relative to the 1950–2004 mean June rainfall (~161 mm). As with the satellite tropospheric temperature data, there is an increasing trend in June rainfall over the Indian subcontinent since the late 1970s as well. A previous study also reported the strengthening of sea surface winds over the Arabian Sea during early summer monsoon period since 1997, observed using surface measurements (Goes et al., 2005).

The land-sea thermal gradient, and thus the monsoon circulation, is also governed by the Himalayan snow cover extent in spring and early summer. Since a substantial fraction of solar radiation is required for the melting of snow accompanied by less energy available for heating the underlying ground surface, therefore, in general, excessive snowfall results in colder surface temperatures (Barnett et al., 1989). Reduced snow cover, on the contrary, is considered to be responsible for stronger land-sea thermal gradient (Meehl, 1994). Concurrent with the warming trends reported here, a progressive decline in snow cover extent has been observed from satellite data over the HTP annually and in May as well since 1979 (Fig. 5, see Goes et al., (2005)). The observations that the tropospheric warming and the declining snow cover in May occur simultaneously suggests a plausible physical scenario for the recent increasing trend of June rainfall.

Henceforth, of the greatest relevance to the onset and intensity of the Indian summer monsoon is the land-sea thermal gradient from the equatorial Indian Ocean to the South Asian landmass which is due to the rapid pre-monsoon heating of the Himalayas-Tibetan Plateau compared to the relatively cooler Indian Ocean. Recent studies show that the early summer monsoon rainfall over India has strengthened in the past half

Figure 5. Annual linear snow cover trends (a) and (b) May (pre-southwest monsoon) linear snow cover trends expressed as % change per decade and based on a least-square linear fit to weekly gridded NSIDC Northern Hemisphere Snow Cover extent data from 1979 to 2001 (Goes et al., 2005).



century indicated by historical rainfall data. The steady increase in rainfall is led by enhanced and widespread pre-monsoon warming observed over the Himalayas and the subsequent strengthening of the land-sea thermal gradient as indicated in the longest available record of microwave satellite measurements of tropospheric temperatures from 1979-2007. Combined analysis of changes in tropospheric temperatures and summer monsoon rainfall in the past three decades, suggest the future possibility of an emerging rainfall pattern of a wetter monsoon over South Asia in early summer followed by a drier period. Together with the possible alterations to the monsoon dynamics on a seasonal-to-interannual time scales, the observed warming at higher elevations, if continues, may also have direct implications to the Himalayan glaciers and snowpacks and in turn the hydrological cycle over much of South Asia, which has received growing scientific attention (Barnett et al., 2005).

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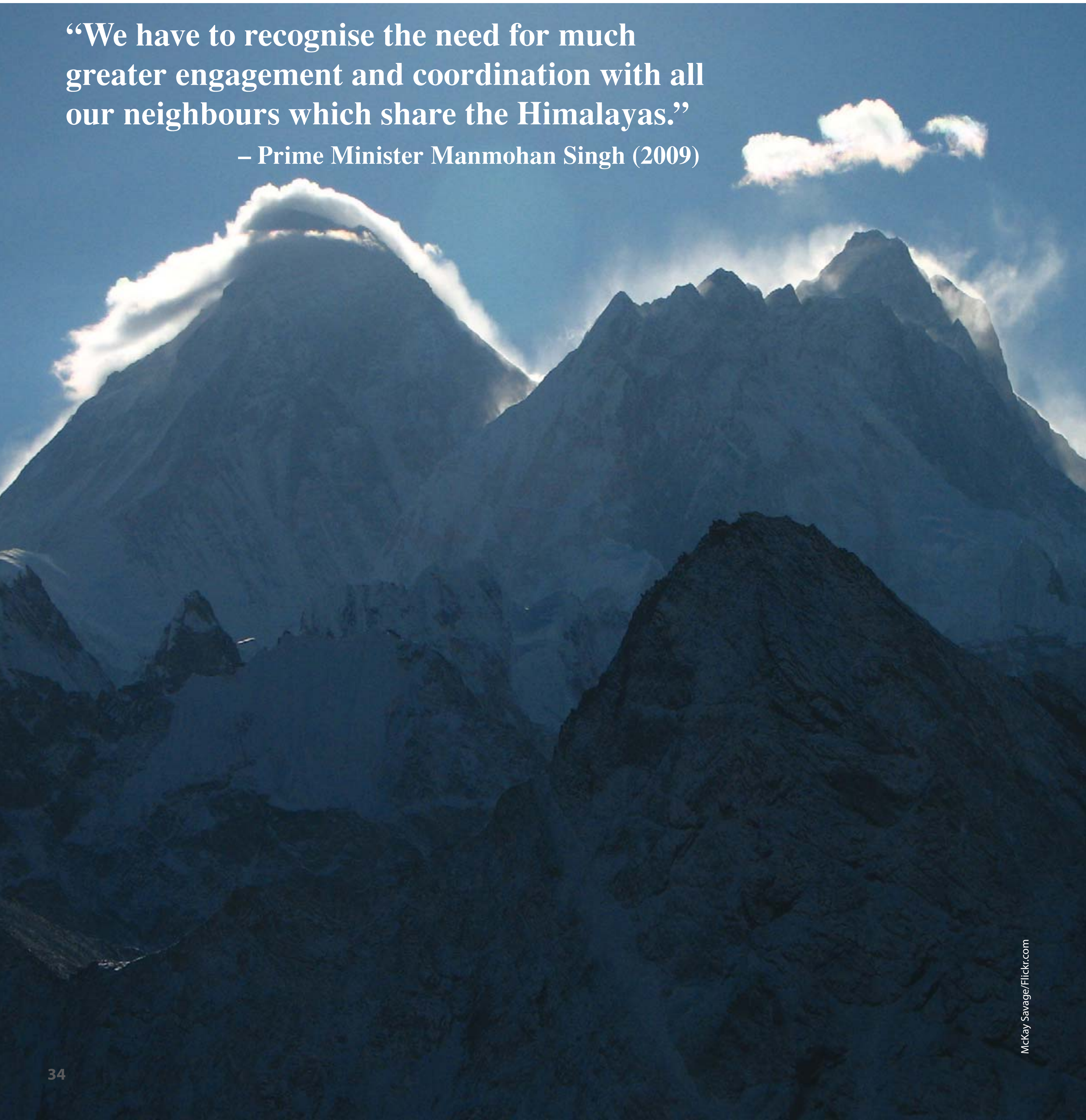
Epilogue

Many countries in the region lag in understanding and recognizing the broader scope of climate change and global warming, especially in relation to how it affects them and how they affect the change. The environmental causes and impacts do not respect boundaries between nations. To deal with the problems, international cooperation is needed. Nations, decision-makers, and the general public need to improve their understanding of the significance of change in light of sustainable development and other emerging global issues. To that end, one must first look at each country individually and create an awareness of what is taking place. Once that is done, one can develop actions to mitigate the environmental problems. In the words of the India Prime Minister, to quote: *"We have to recognise the need for much greater engagement and coordination with all our neighbours which share the Himalayas – Prime Minister Manmohan Singh (2009) "*



Annex 1: Agenda of the International Expert Workshop on "Emerging Issues in Climate Change"

Monday - December 28, 2009

9:30 – 10:30	Registration	
10:30 – 11:30	Opening Welcome - Institute of Green Economy, TERI University and Sharda University UNEP and Objectives of the meeting - Dr. Peter Gilruth Opening Remarks	
11:30 – 11:45	Tea/Coffee Break	
11:45 – 13:15	Session 1: State of Himalayan Glaciers and Snowpacks (Chair: Dr. Josefino C Comiso: Co-Chair: Gen. S.S. Sharma)	
Dr. Josefino C Comiso	NASA	"Satellite Observations of the State of the Cryosphere in the Northern Hemisphere"
Dr. Nikhil Chandavarkar	UN-Department of Economic and Social Affairs	"Melting Glaciers, Snowpacks and Sustainable Development in the Himalayas"
Dr. Murari Lal	Former Professor, IIT Delhi	"2007 IPCC Report at a Glance: Focus on Himalayas"
Dr. V. K. Raina	Former DDG, Geological Survey of India	"Let the Glacier Speak"
Dr. Manfred Buchroithner	Dresden University	"Examples of Glacier Changes in the Himalayas and Tibet"
Dr. Rajesh Kumar	Birla Institute of Technology	"Glaciers Snout Fluctuations: A case study of Gangotri and Kafani Glacier, Garhwal Himalaya"
Dr. R. K Ganjoo	University of Jammu	"Unfolding the Myth of Global Warming: Case Study of J&K Glaciers"
13:15 – 14:00	Lunch Break	
14:00 – 16:00	Session 2: Changing Climate over Himalayas and Impact on Glacier/Snowpacks (Continue)	
Dr. Walter Immerzeel	Future Water, Holland	"Will Climate change the Himalayan Water Towers"
Dr. Ruvey Midha	Resource Development Centre	"Glacier Fluctuation Studies in the Indian Himalaya – An Appraisal"
Dr. Rijan Bhakta Kayastha	Kathmandu University	"Changing Climate over Nepalese Himalayas and Impact on Glaciers"
Dr. A P Krishna	BIT, Ranchi	"Monitoring of Snow and Glacier cover for possible inferences on Climate Change Impacts"
Er. Gautam Rajkarnikar	Water and Energy Commission Secretariat	"The Impact of Climatic Variability on Water Resources of Mountain Region, Nepal"
Dr. A C Pandey	BIT, Ranchi	"Conflicting Signals of Glacier Response to Climate Warming in Great Himalayan Range(GHR) Jammu and Kashmir, India "
Dr. Syed Hasnain	TERI	"Short-lived Climate Forces affecting Himalayas-Tibetan Snow and Glacier"
16:00 – 16:15	Tea/Coffee Break	
16:15 – 18:00	Session 3: Impact of Climate Change on High Altitude Vegetation (Chair: Dr. P J Dilip Kumar, Co-Chair: Dr. Promode Kant)	
Dr Michael Maroschek	Institute of Silviculture, BOKU Vienna	"Mountain forests in a changing climate - A European perspective on impacts, vulnerability and adaptation in mountainous regions"
Dr. Mohinder Pal Singh	HFRI, Shimla	Title Awaited

Dr. Madhav Karki	ICIMOD	"Potential Impact on Monsoon and High Altitude Vegetation in the Himalayas-Tibetan Plateau"
Dr. Daizy Batish	Panjab University, Chandigarh	"Physiological and Biochemical Response of High-altitude Himalayan Trees in Response to Climatic Variations"
19:30	Dinner	

Tuesday - December 29, 2009

9:30	Address by Shri Jairam Ramesh, the Honorable Minister of Environment & Forests, Government of India	
10:00 – 10:15	Tea/Coffee Break	
10:15 – 13:00	Session 4: Atmospheric/Surface Temperature Trends and Atmospheric Pollution (Chair: Dr Ramesh Singh : Co Chair :Dr Manfred Buchroithner)	
Gen S S Sharma	Snow and Avalanche Study Establishment, Manali	"An overview of Temperature Trend and Snow Precipitation and Snow Cover Pattern of some important Remote Stations in Western Himalaya in the last three decades"
Dr. Ming Jing	National Climate Center, China	"Black Carbon in the Snow of Western China and its impacts due to the Radiative Forcing"
Dr. Jeffery S Deems	University of Colorado, USA	"Radiative and Hydrologic forcing by Modern dust deposition in Mountain Snow"
Dr. Zhiyuan Cong	Chinese Academy of Sciences	"Elemental and individual particle analysis of Atmospheric Aerosols from high Himalayas"
Dr. Ritesh Gautam	NASA	"Satellite Observations of Enhanced Tropospheric Warming over the Himalayan- Gangetic Region"
Dr. Jagdish Kuniyal	G.B Pant Institute of Himalayan Environment and Development	"Aerosols and Glaciers melting in the Northwestern Indian Himalaya"
Dr. M R Bhutiyani	College of Military, Pune	"Winter warming and its potential effects on variations in snowfall patterns over NW Himalaya"
Dr. A P Dimri	JNU	"Wintertime Climatic Trend Analysis over the Siachen Glacier"
Dr. Ramesh Singh	Chapman University, USA	"Dust, Anthropogenic Activities and Himalayan Snow"
13:00 – 14:00	Lunch Break	
14:00 – 15:15	Session 5: South Asian Monsoon Variability and Regional Hydrological Cycle response to and Coupled with Climate Change (Chair:Alan Robock : Co-Chair : V.K. Raina)	
Dr. Alan Robock	Rutgers University, USA	"Effects of Stratospheric Geo-Engineering on the South Asian Monsoon"
Dr. Bodo Bookhagen	University of California, Santa Barbara, USA	"Spatial and Seasonal Distribution of the Himalayan Hydrologic Budget"
Dr. Viju John	Hadley Centre, Met Office, UK	"Variability of Upper Tropospheric Humidity associated with Indian Summer Monsoon"
Dr. Pratap Singh	Hydro Tasmania Consulting, New Delhi	"Impact of Climate Change on Hydropower projects in the Himalayan region"
15:30 – 16:30	Final closing session: Moderator: Nikhil Chandavarkar	

Annex 2 : List of Participants

S. N.	Participant	Country/E-mail	Designation/Organization
International Organizations			
1. Dr Peter Gilruth	Peter.Gilruth@unep.org	Director of the Division of Early Warning and Assessment (DEWA), UNEP, Nairobi, Kenya	
2. Dr Subrata Sinha	subrata.sinha@unep.org	Regional Coordinator, Division of Early Warning and Assessment (DEWA), UNEP, Bangkok, Thailand	
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Acronyms

ADB	Asian Development Bank
AWS	Automatic Weather Stations (AWS)
CCN	Cloud Condensation Nuclei
CTA	Central Tibetan Administration
CTIC	China Tibet Information Center
EHP	Elevated Heat Pump
GCM	General Circulation Model
GLIMS	World Glacier Monitoring Centre/Global Land and Ice Monitoring System
GLOF	Glacial lake outburst flood (GLOF)
HTP	Himalayan Tibetan Plateau
ICIMOD	International Centre for Integrated Mountain Development
ICSI	International Commission for Snow and Ice
IPCC	Intergovernmental Panel on Climate Change
IRD	Institut de Recherche Pour le Développement
ISRO	Indian Space Research Organization
JJAS	June-July-August-September
MSU	Microwave Sounding Unit
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA/GSFC	National Aeronautics and Space Administration/Goddard Space Flight Center
TP	Tibetan Plateau
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WGHG	Working Group on Himalayan Glaciology
WGMS	World Glacier Monitoring Service
WRRI	Water Resources Research Institute
WWF	World Wide Fund

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