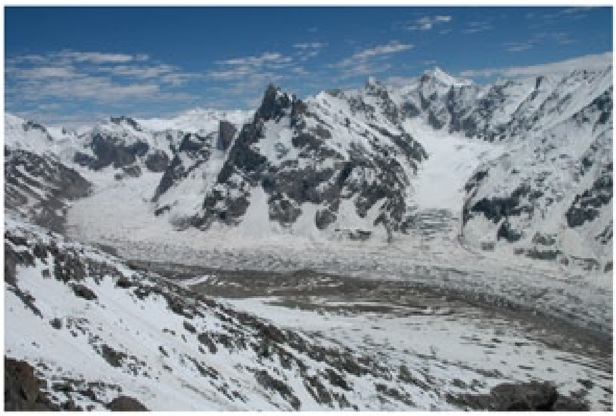
Understanding glacier changes

Kenneth Hewitt February 01, 2010

The impact of climate change on Himalayan glaciers is as complex as it is perilous. Kenneth Hewitt explores the hotly debated world of melting – and expanding – ice.



The upper Chiring-Panmah Glacier. Notice the prevalence of steep rock walls; the avalanches coming from them have left cones of snow at the base of all the slopes.
(Photograph/Kenneth Hewitt, June 2005)

Diverse dangers

Glaciers are quite sensitive to climate change and, recently, there have been many reports of major changes in the Himalaya and other parts of High Asia; mostly of glaciers retreating fast. Impacts of a range of glacier hazards, and on the reliability of water resources, are of concern at local, national and transnational scales. However, there is also a growing recognition that glacial conditions in the region are very diverse, and so are their responses to climate change.

There are some very different implications in different societal contexts, not least in relation to rapid socio-economic changes, water resource projects and security crises. The latter are often more urgent or immediate problems that disrupt or undermine peoples' capacities to adapt to environmental change. Such complexities are the focus of this article. The reality of climate change is not questioned, but some recent oversimplifications are, and claims about a narrow range of glacier hazards. In particular, unresolved problems of understanding high altitude glaciers and climate are emphasised, and the inadequacies of available information and monitoring. Recent evidence of glacier advances in the Karakoram Himalaya, and the author's work there, illustrate many of these complexities.

> *"One must qualify the notion that threats only arise from 'disappearing' glaciers or in proportion to the rate of reduction."*

Globally, most glaciers are reported to be diminishing more or less rapidly. Reports of "disappearing glaciers" have come from many parts of High Asia. However, this is not the case in the upper Indus and upper Yarkand River basins. Here, the glaciers have been holding their own for several decades and recently, in the Karakoram Himalaya, many have started thickening and advancing. Not only is this opposite to the broader picture for Eurasian glaciers, but also to what had been happening to Karakoram glaciers. Through most of the twentieth century they too diminished and retreated. There is no question that today's behaviour is a regionally distinct response to climate change. It may sound like good news, given the dominant lament for the loss of glaciers, but that too would be misleading. Advancing glaciers bring dangers as well.

Ablation zone conditions where annual ice losses are high: dust, dirt and scattered debris areas on Kaberi-Kondus Glacier, late June, at 4,000 metres above sea level.
(Photograph/Kenneth Hewitt 1998)

Of immediate concern are a number of glaciers on the Indus and Yarkand Rivers, whose past advances gave rise to large ice dams and catastrophic outburst floods. In the longer term, existing and planned water resource uses, dependent on glacier-fed streams or at risk from glacial floods and sedimentation, are of major concern. However, the largest challenges stem from inadequate information and monitoring, and limited scientific understanding of these high elevation glaciers. Misleading or exaggerated reports based on assumption rather than evidence are also a problem. Some high profile reports have suggested that the Indus basin is in imminent danger of losing its glaciers. Glacier hazards, notably "dangerous lakes" associated with retreating ice in other regions, have been assumed to be equally present in the Karakoram. The reports are simply wrong in this case.

Meanwhile, if the main trend in most of High Asia does seem to be glacier retreat, various lines of evidence show that it is occurring at very different rates in different mountain ranges, even within the same mountains. A 2006 survey of 5,020 glaciers in the mountains of western China and the Tibetan Plateau found widely differing rates of reduction. It also found 894 glaciers, about 18%, have advanced in recent decades. The jury is still out on a 2009 report from India, which questions the scale and reality of the extreme rates of retreat formerly reported for the Himalayas, and projections based on them.

None of this is to suggest that climate change is not a serious issue in the Karakoram. In every valley of the region farmers tell me the winters have grown shorter in the past couple of decades, there is less snow and more rain. They report an increase in windstorms and rain during summer. Formerly, clear, sunny weather in autumn was reliable and perfect for drying grain, fruit and winter fodder, and for post-harvest chores around the villages. Not any more. They report increasing problems with damp and mildew from insufficient drying days. Rain and wind threaten the harvest and damage buildings. These are, in fact, more immediate hazards for the mountain communities than anything that may be happening to the glaciers. This refers to the inhabited areas at lower elevations, where more, and more severe rainstorms have been reported in recent years, notably a disastrous storm on September 9, 1992. It triggered rockfalls and debris flows that damaged many villages, closed most roads and stranded tourists. Again, advancing glaciers are also a response to climate change – and are not necessarily good news.

Panmah Glacier accumulation zone, showing surrounding rock walls up to 2,500 metres high around the Latok Peaks, June 2005. (Photograph/Kenneth Hewitt, 2005)

Although there have been reports and discussions of Karakoram glaciers since the mid-nineteenth century, they have been patchy in space and time and of varying quality. The glaciers are not, and have never been, consistently monitored. Few glaciers anywhere in the inner Asian mountains meet the criteria of the World Glacier Monitoring Service, and hence have not been tracked by it. The cries of concern for these glaciers should at least highlight the need for more reliable data and a better grasp of climate-glacier interactions in the world's highest mountains.

The glacier cover of High Asia exceeds 110,000 square kilometres, the number of identifiable glaciers more than 50,000. There are major concentrations in about a dozen mountain ranges, forming watersheds of all the major rivers of the central, south and south-east Asian mainland. The Upper Indus and Yarkand basins have around 21,000 square kilometres of glaciers, the larger fraction in the Greater Karakoram, or about 16,500 square kilometres. Most of the biggest valley glaciers outside polar regions are found here. While there are more than 5,000 individual glaciers, just 12 make up almost half the ice cover. Melt waters from glacier basins comprise more than 40% of the average annual flows of the Indus and the Yarkand, with a potential to affect the lives of some millions of people downstream. While there was a roughly 10% reduction of the Karakoram ice cover in the first 60 years of the twentieth century, no significant reduction has occurred in recent decades and, as noted, many glaciers are undergoing advances.

One must qualify the notion that threats only arise from “disappearing” glaciers or in proportion to the rate of reduction. This is certainly a cause for concern, in itself or in what it implies about humanly induced atmospheric changes. But growing glaciers are not necessarily benign. In most glacierised mountains, certainly the Karakoram Himalaya, the worst consequences experienced in recent history came with the enlarged ice cover of the Little Ice Age: a period of several centuries, ending just over 100 years ago, when glaciers grew throughout the northern hemisphere. From those events come most of the stories and fears about glaciers recalled in Himalayan towns and villages. The considerable reduction of the glaciers observed between about 1910 and the 1960s was, in effect, removing ice stored in the Little Ice Age, a process that is not yet complete. Today's glaciers are larger than a few centuries ago. Meanwhile, the evidence of advances in the Karakoram not only indicates a different response here to changing climate. It raises the prospect of a return to the hazards of advancing ice not seen since the Little Ice Age.

Accounting for variety

Climate change is obviously having different consequences in different mountain areas of Asia. The situation in the Karakoram must represent some distinctive conditions. Three features of the regional environment seem critical. The first two relate to snowfall and the nourishment of these glaciers. They are intermediate in type between the summer accumulation (snowfall) glaciers of the greater Himalayas, and the winter accumulation glaciers of, say, the Caucasus and European Alps to the west. In each of the latter, more or less strong glacier retreat is reported. Second, the zone of maximum precipitation in the Karakoram is much higher than in these and most other mountain ranges. It is also entirely within the accumulation zones of the glaciers. This relates to the third factor, the exceptional elevations and, especially, elevation range of these ice masses.

The glaciers of large and intermediate size originate at very high altitudes and many of them descend much lower than elsewhere in the sub-tropics. Five glaciers span more than 5,000 metres in elevation, 15 over 4,500 metres and more than 30 over 3,000 metres. In the Hunza valleys of the central Karakoram, glacier termini advance below 2,300 metres above sea level.

Those on the north flank in the Yarkand drainage do not descend so low because the valleys are at greater elevations, but they include several descending more than 4, 000 metres, due to location in the very highest parts of the range around K2 (8,610 metres). All of the glaciers recently observed to be growing are in these high-relief basins. Of special interest, but poorly understood, is how elevation and topography interact with the regional climatic influences to determine the behaviour of the glaciers.

The regional climate of this south-western part of the Inner Asian mountains comes under the influence of three different, seasonally varying, weather systems. First, the winter half of the year is dominated by a westerly or “sub-Mediterranean” circulation. Second, in summer, moisture comes from the Indian Ocean to the south and the climate becomes “sub-monsoonal”. Third, inner Asian high-pressure systems, especially involving the Tibetan Plateau, interact with the other two systems to affect storm paths and the incidence of clear weather. The last is critical, since direct solar radiation is responsible for 80% to 90% of melting on the glaciers.

Global climate change is expected to alter the absolute and relative roles of all three systems, a likely factor in recent developments that complicates forecasting of future glacier changes. Meanwhile, investigations on the glaciers at higher elevations have revealed how different conditions are from the valley weather stations – mostly below 3,000 metres above sea level – whose records had dominated climatic interpretations.

Station records from the inhabited areas of the Karakoram show two-thirds or more of precipitation occurs in winter, mainly February through May. The average annual precipitation in these valleys is 150 millimetres to 300 millimetres water equivalent – an arid or semi-arid environment with severe summer drought. However, a very different story emerged from our measurements on the glaciers in the 1980s. At elevations above 4,800 metres we found that snowfall amounts are roughly the same in summer and winter, with roughly equal amounts coming from the west and the Indian Ocean. Summer drought was not observed on the glaciers especially in their accumulation zones above 4,500 metres above sea level. Moreover, the zone of maximum precipitation turned out to be between 5,000 metres and 6,000 metres above sea level – much higher than in, say, the eastern Himalaya or any other reports from tropical mountains. Moreover, accumulation zone snowfall is equivalent to between 1,000 millimetres and 2,000 millimetres of water; far more moisture than the valley stations suggest. What is identified here is a powerful gradient in climatic conditions with elevation – a five- to 10-fold increase in precipitation from glacier termini around 2,500 metres above sea level, to where the snow falls that nourishes the glaciers. A recent, pioneering study based on satellite imagery – conducted by Bibi S Naz and colleagues at Purdue University in Indiana – suggests snowfall amounts and the extent of perennial snow cover have increased in the past couple of decades at high elevations in the Central Karakoram.

Vertical gradients also define key conditions for the melting of the glaciers, and their contribution to water supply. In fact, although many ice tongues descend much lower, the decisive conditions for melting occur between 3,800 metres and 4,800 metres above sea level. Here lie more than 80% of the ice surfaces where melting occurs in summer. Ablation conditions – under which ice melts – also identify complexities that arise with timing and seasonal rhythms as well as elevation. Nearly all the melting and water production of the glaciers occurs in just a few weeks of summer, when temperatures rise above zero and strong sunlight occurs. In turn, this explains why 70% to 80% of the flow of the upper Indus and Yarkand rivers occurs in six to 10 weeks of summer – usually in July and August – lagged until winter snow sitting on the ablation zone has melted away to expose the ice. Moreover, melting is very sensitive to summer cloud cover or storms. A sudden summer storm can shut down melting for days at a time. Just when and for how long rapid and extensive melting occurs varies greatly from week to week, and year to year. It is one of the most sensitive variables affected by climate change.

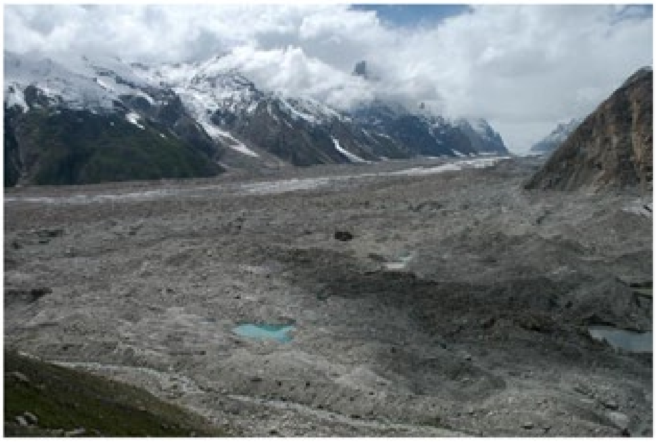
Another huge and poorly understood fact is that most Karakoram glaciers are largely or wholly avalanche-fed. The accumulation zone areas of these glaciers, above about 4,600 metres above sea level, are generally 70% to 80% steep rock walls. The larger part of high altitude snowfall in the region is on to these unstable slopes, and is avalanched more than 1,000 metres before incorporation into a glacier. It seems likely that changes in snowfall amounts, with season or in storm intensities, will alter the timing, temperature relations, and extent of avalanching. This can, in turn, affect glacier behaviour. The trouble is, there are no data or research to help predict what climate change does to this all-important part of the nourishment of the glaciers.

What can be said is that what happens between 3,800 metres and 7,000 metres above sea level is absolutely critical to the role of climate and climate change in glacier behaviour and survival. These are also the elevations where the reasons for the seemingly anomalous recent responses of Karakoram glaciers must be sought. However, it is here that the least research has been done. There are no permanent measuring stations or long-term monitoring. To recognise how unfortunate that is, we need to address changes that are, or may become, unusually threatening to human communities and activities.

Risks and responses

Glaciers and their immediate environs present many dangers for humans, such as crevasses and glacier mills into which one might fall, heavily crevassed ice falls, snow and ice avalanches from the side walls and, along the flanks, dumping of great boulders, ponding and floods from melt water. For these reasons, there are hardly ever permanent settlements on or right beside the ice. These are hazards mainly to mountaineers, hunters, travellers and military expeditions. The more serious dangers arise from processes in the glacial environment that may extend their impacts beyond existing glacial areas. The more serious tend to involve ponding of water that leads to glacial outburst floods, or releases that generate debris flows.

The risk of glacier lake outburst floods has received particular attention in other parts of the Himalaya, notably Bhutan, Nepal and Tibet. In Nepal, some 25 glacial lake outburst floods have been recorded since the 1930s, with especially destructive events in 1985 and 1991. Bhutan also has a number of dangerous lakes, one of which burst with disastrous consequences in 1994. Reports suggest all of these lakes and the triggers for outburst floods are related to climate warming and glacier retreat. There is also a history of such outburst floods from Karakoram glaciers. However, the problem here is also very different from that recently reported elsewhere in the Himalayas. In particular, the most serious threats involve, specifically, much larger impoundments by short-lived, unstable ice dams. Crucially, all recorded examples have been associated with advancing glaciers.


Heavily debris-covered ice, Panmah Glacier Central Karakoram, around 4,000 metres above sea level. Note that even the heaviest debris on active ice is rarely more than 2 metres thick. The relief of mounds and cones is almost entirely ice cored and the debris is constantly shifting around.
(Photograph/Kenneth Hewitt, June 2009)

In fact, the Karakoram presents two rather different groups of outburst floods. The most frequent are relatively local events. Collectively, they threaten dozens if not hundreds of small settlements in the higher valleys and examples occur in most years. They involve a wide variety of dam compositions, forms and outburst types, including ice-, moraine-, and mixed-barriers. Conversion of outburst floods into debris flows is quite common, usually the more severe risk. For the upper Indus, these are the only types of damaging outburst floods reported in the past several decades. Moreover, they occur whether glaciers are advancing, retreating and relatively stable. Conversely, the larger Karakoram dams involve impoundment of a main river valley by a relatively large tributary glacier. Most important, in the present context, these dams only form from a vigorous forward push of the ice.

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More than 60 glaciers of intermediate-to-large size (10 kilometres to 65 kilometres in length) have a history of advancing into and interfering with tributaries of the upper Indus and Yarkand rivers. Not all are known to have created actual dams, but at least 30 have done so and involved outburst floods of exceptional size and destructiveness. However, while there have been several large dams recently on the Shaksgam, on the Indus the last major ice dam was in 1933. "Major" refers to outburst floods that were large enough to register hundreds of kilometres downstream at the river gauge at Attock, where the river leaves the mountains.

The most urgent questions today involve some Karakoram valleys whose glaciers created ice dams and catastrophic outburst floods in the past and that are advancing right now. Will they impound the rivers again? Three locations require special attention; the Shaksgam, upper Shyok and Shimshal valleys.

The Shaksgam is a tributary of the upper Yarkand. According to satellite imagery, five glaciers that have formed ice dams in the past are advancing at present. One of them, the Kyagar, has created several recent dams. An outburst from the one in 1999 caused severe damages along the lower Yarkand River in Kashgar district. In the summer of 2009, Kyagar again impounded the river and a 3.5 kilometre-long lake was formed. Fortunately it drained slowly but was close to dimensions that have led to disastrous floods in the past. There were great difficulties in obtaining satellite coverage and scientists were unable to visit the site and monitor the lake so as to predict its behaviour. This raises serious issues about what would have happened if a large outburst had occurred, and what will happen in future cases. It seems a new impoundment will form at Kyagar in 2010, and the four other glaciers are across or entering the river and may impound it.

On the Indus, three glaciers in Shimshal and three on the upper Shyok, that have formed ice dams in the past, began advancing about a decade ago. They have not yet reached positions where a dam could form, but could do so quite soon. Historically, the most dangerous have been the Chong Khumdan and Kitchik Khumdan on the Shyok. In 2009, satellite imagery revealed a sudden and large increase in thickness of the Chong Khumdan, and advance of its terminus into the river. Between 1926 and 1932, this glacier formed a series of large ice dams. At least four outburst floods were reported that caused appreciable rises in the river 1,100 kilometres away at Attock. The 1929 event was the largest on record, and did great damage throughout the mountains and to the Indus Plains. The lake reached over 15 kilometres in length but drained in less than 24 hours. The Kitchik Khumdan also formed large ice dams in the nineteenth century, and its terminus is back in the river and has advanced across the river which passes beneath the ice. However, 2009 satellite imagery suggests it is beginning to waste back again. Conversely, its immediate neighbour the Aqtash Glacier which has also formed dams in the past advanced across the river in 2008 and 2009 and seems to be advancing very rapidly.

These glaciers highlight problems of security and the legacies of conflicts that exist in many parts of High Asia. They are in a militarised zone disputed by China, India and Pakistan. Apparently the Khumdan glaciers fall under the control of Chinese forces, but the dangers from the outburst floods are primarily in Indian and, especially, Pakistan-controlled areas. Given existing tensions, including the India-Pakistan "war" on the Siachen Glacier nearby, it is unclear how necessary studies, monitoring and warning systems can be set up.


The accumulation zone of Biafo Glacier near Hispar Pass (5,150 metres), showing the development of cornices along ridge lines due to wind action, avalanched steep walls and heavy build up of snow on gentler slopes.
(Photograph/Kenneth Hewitt, June 1999)

Other hazardous phenomena

The focus here has been on glaciers, but it needs emphasising there is a range of cold climate or cryosphere phenomena that may become hazardous through climate change. Communities, infrastructure and related activities confront changes in snowfall, snow-on-the-ground and permafrost, specifically ground ice. They will also be affected by changes in distribution and intensities of freeze-thaw, the quantities and timing of surface and ground waters and their quality (water temperatures, turbidity and dissolved matter, for instance).
The entire mountain area is covered by seasonal snowfall, varying in duration and depth with elevation. Its melting provides about half of stream flows in an average year. Permafrost – perennially frozen ground – at intermediate altitudes is much more extensive than glaciers and includes hundreds of ice-cored rock glaciers. Freeze-thaw cycles affect even larger areas, as do erosion and deposition forms created by snow avalanches. All of these are affected by climate change. Their responses interact physically, and in ways that modify the scope or significance of glacier-related risks.

Retreating glaciers and warming permafrost are associated with destabilised slopes. They can lead directly to landslides, or reduce the strength thresholds for, and the likelihood or size of, slope failures due to earthquakes or storms, which trigger most of the more destructive landslide events. For example, a dangerous landslide occurred on January 4, which blocked the Hunza River in the central Karakoram and probably involved destabilisation by changing moisture and temperature conditions in the slopes. The lake has already grown to 5.5 kilometres in length, forcing the evacuation of thousands of residents. Moreover, the lake behind a similar landslide dam in 1858, immediately upstream of the present one, lasted seven months then burst with catastrophic effects all the way to the Indus plains. Meanwhile, slopes exposed by reduced ice or snow cover may dry out and become useless. Conversely, some may also become vegetated and economically useful for timber, firewood, for pastoralists and even for cultivation.

The more immediate glacier hazards and response needs in the region involve communities and activities in the high mountains. Only the Andean highlands rival inner Asia in the numbers and diversity of settlements close to and at direct risk from glacier change. However, for the broader national and international contexts, the major issues raised concern water resources and their reliability.

Some caution is needed here. A commonplace of recent reports is to say that the lives and livelihoods of in excess of 1.5 billion people are critically dependent upon the glaciers in the headwaters of the largest Asian rivers. This is a misleading generalisation. Yes, such are the numbers of people living in river basins with tributaries coming from glacierised mountains. However, in most cases the glaciers are a tiny part of the river flows, notably in the most heavily populated areas of China, India and the south-east Asian mainland.

Snowfall affects much vaster areas than the glacier cover, and is more critical. For the vast majority of these populations, rainfall and ground waters are far more important than snowfall. Glacier change can have impacts on these other parts of the hydrological cycle or may compound changes in them, but the processes are mostly indirect and too poorly known to make such generalisations. Whether and how far there are significant risks for most of these populations, even from the “disappearing” glaciers’ scenario, is far from certain.

The Indus and Yarkand basins do involve large populations directly, or potentially, dependent on the glaciers. Even here, however, there have been exaggerated or misleading claims. Yes, glacier melt waters comprise more than one-third of the flow of the main stem of the Indus, snow and ice together providing over two-thirds. It has the largest ratio of melt water to population of any river, anywhere in the world. At the moment, however, nearly all the glacial melt water goes to the sea. It happens to coincide with the heavy monsoonal rains, making flooding the greater problem, and Pakistan lacks the capacity to store much or any of the melt waters at that time.

More exactly, the key roles of glacier melt waters have little to do with the total size of the ice cover, total melt water yields, or trends. Rather they turn upon demand in just a few weeks of the year and, in rare, extreme cases when the winter rains or monsoon are very weak, poorly timed, or fail. Even for Pakistan, the main dangers for the country as a whole are, therefore, potential rather than actual, and not so much in relation to glacier change as to planned and possible water resource developments. These seem to be being undertaken with inadequate understanding and assessment of how climate and glacier fluctuations will affect them.

This will become increasingly acute for all countries of the region and raise important transboundary concerns. There are the huge commitments being made now, to hydroelectric power, irrigation, urbanisation and other developments for which water from snow and ice will become increasingly crucial. More than 100 existing dams depend partly on glacial melt waters. Several hundred more, and some of great size, are under construction or planned for China, India, Pakistan, Nepal and Bhutan.

Given the present state of monitoring and scientific understanding, it is hard to believe any of these have adequate or accurate assessments of climate- and glacier-change impacts. For the Karakoram it is of singular concern to determine whether, as global warming continues, there will be a return to glacier retreat as some believe, or if the factors responsible for the present advances will intensify. Either way, there are serious implications for how communities in Pakistan, China and India, especially, are affected and need to respond.

The importance of climate change is not in doubt, but research and policies should be based on actual evidence. Where unavailable, that should be acknowledged, not – as has happened with glacier change in the Karakoram – simply replaced by supposition based on developments or models from elsewhere. Much of what is being said fails to recognise the patchiness of past research in space and time, and a near-total absence of glacier monitoring at elevations where the most critical ice and climate changes occur.

The limited evidence surely reflects, in part, the sheer scale, diversity and logistical difficulties of scientific work in much of the region. Now, as more resources become available to investigate these problems, it is important to identify what sorts of information are needed, where and how they can be best obtained. Science and information systems and regional cooperation need to address the complexity and diversity of the greater Himalayan region. Some practical suggestions being promoted by new programmes include the following:

* To set up improved monitoring systems that combine remotely sensed and automatic station measurements with ground control related to basic glaciological and hydrological research;

* To expand comprehensive, multi-disciplinary research that addresses environmental and cultural complexities in the region;

* To pursue regional cooperation in data sharing, risk and resource assessments; and

* To actively involve local communities in the mountains, so that their ecological knowledge and practical concerns inform understanding and help to shape appropriate development.

Kenneth Hewitt is professor emeritus in Geography and Environmental Studies and research associate at the Cold Regions Research Centre at Wilfrid Laurier University in Ontario, Canada.