DARKENING PEAKS

Glacier Retreat, Science, and Society

Edited by

Ben Orlove, Ellen Wiegandt,
and Brian H. Luckman

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Cover illustration: Piedras Blancas Glacier, Patagonia, Argentina. The glacier has diminished, its lower portion detached and calving into a newly formed lake. Photograph by Mariano Masiokas.

CONTENTS

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The immediate ancestor of this book is the Wengen-2004 International and Interdisciplinary Workshop on Mountain Glaciers and Society, held in Wengen in the Berner Oberland of Switzerland in October 2004. Its genesis was a session on glacier retreat held at the 2003 annual meeting of the American Anthropological Association in Chicago. We thank the participants of this session, especially Julie Cruikshank and Sarah Strauss, for raising questions that we felt would benefit from further exploration from an interdisciplinary perspective. The Wengen Workshops on Global Change Research provided an ideal setting to discuss these questions and others closely related to them. We are especially thankful to Martin Beniston, who has ably organized these meetings since 1995, for accepting the topic. Members of the steering committee of the 2004 workshop, particularly Harald Bugmann, Paolo Burlando, and Wilfried Haeberli, contributed to the success of the meeting, as did the proprietors and staff of the Hotel Regina, who provided us with an idyllic locale for our discussions. The Swiss National Science Foundation provided financial and institutional support to the conference, as did the Department of Geosciences of the University of Fribourg. The Association Montagne 2002 in the Valais, Switzerland, generously helped defray participant travel expenses. Chapter authors also deserve our appreciation for their willingness to revise the conference presentations, which were earlier versions of most of the chapters in this volume.

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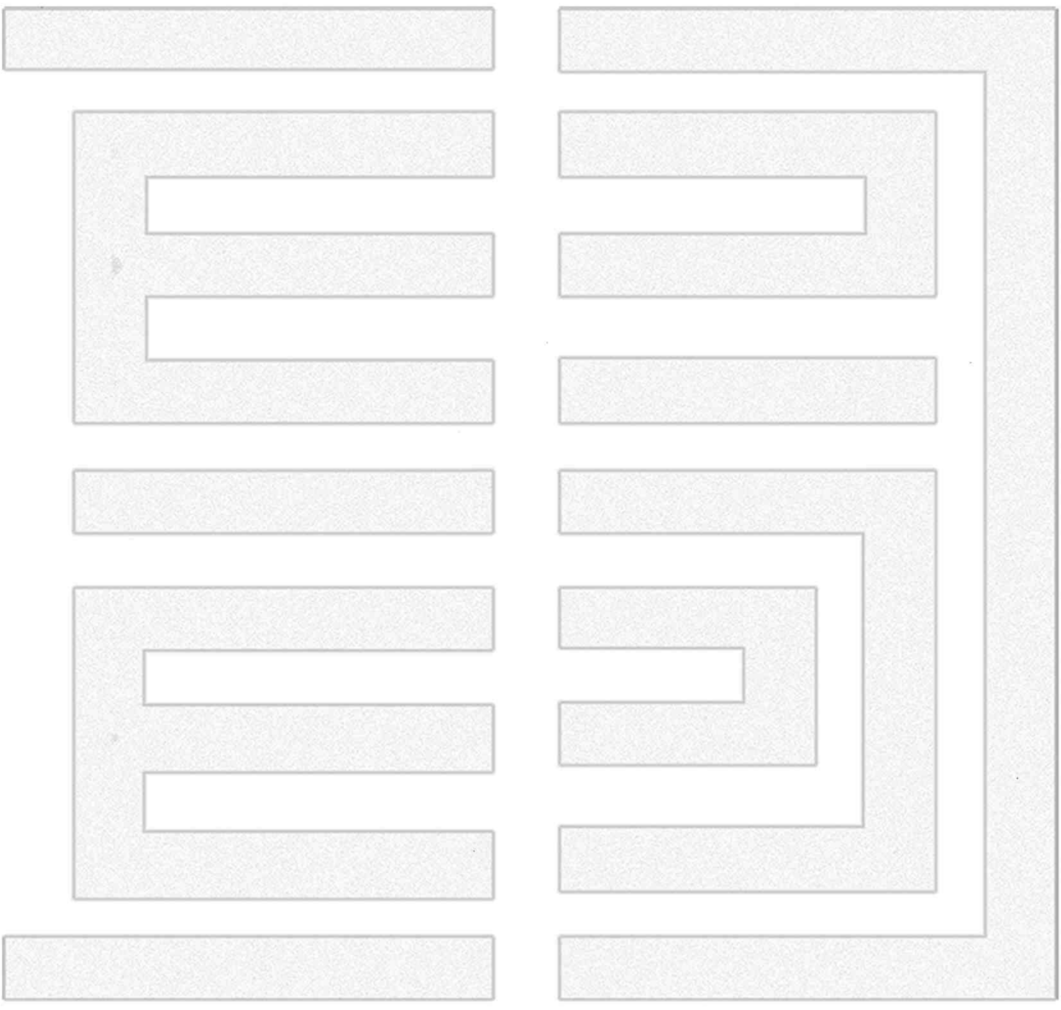
OVERVIEW

Glaciers in Science and Society



1

The Place of Glaciers in Natural and Cultural Landscapes

Ben Orlove, Ellen Wiegandt, and Brian H. Luckman

In the first half of the nineteenth century, glaciers taught us a great lesson about the earth. In the 1820s and 1830s, Swiss naturalists established the existence of the Ice Age. Their key insight was the fact that the small glaciers found at high elevations in mountainous regions were remnants of vast sheets of ice that once had covered large portions of the earth's surface. They combined many sources—Alpine villagers' intimate knowledge of mountain landscapes, earlier research by other geologists, and their own extensive explorations—to document the remote periods of the past, when areas that now are towns, fields, and forests had lain under miles of ice. Once they understood that this now-vanished ice had transformed the earth's surface, they were able to explain features such as the parallel scratches found on rock faces that were engraved by glaciers and the long walls of rocks, stretching across valleys, that were carried by glaciers. Later researchers traced multiple Ice Ages and linked them to the cyclical fluctuations in the earth's orbit. This first lesson, then, was of the dynamic quality of the earth. Geologists found common elements in the study of the ice sheets and other discoveries that were made around the same time, such as the formation of rocks from sediments deposited on the floor of the sea. They came to understand that the earth was immensely old and always changing. This first lesson faced many challenges, particularly from those who held to a literal interpretation of the Bible, but finally received broad acceptance.

Now, at the beginning of the twenty-first century, glaciers are teaching us a second lesson, one that may be even larger than the first and that certainly is more somber and more urgent. That lesson is of the susceptibility of the earth to human impacts. The nineteenth-century picture of an earth whose surface is continually being modified by very slow natural processes is being replaced by the image of a planet that is being altered by rapid processes caused by humans. Once again, glaciers are playing a major role in shaping our understanding of our planet, since the retreat of glaciers around the world is a clear and dramatic example of this vulnerability. This retreat has come to public attention only recently. Through the 1970s, glaciologists—the intellectual heirs of the early Swiss geologists—observed that some glaciers expanded and others shrank and spoke of glacial "fluctuations" rather than a coherent, unidirectional process. By the 1980s, though, they had noticed the consistency with which many glaciers in different regions were becoming smaller. Glacier retreat became headline news in 1991. In that year two hikers discovered Oetzi, a Bronze Age man who had died high in the Alps and whose body, soon covered with snow that turned into ice, had rested frozen for 5,000 years until melting ice exposed it to view. Another such ice man appeared at the edge of a receding glacier in Canada in 1999 and received the name Kwaday Dan Ts'inchi (Long Ago Person Found) from the indigenous people of the region. Other lines of evidence pointed in the same direction: the series of measurements, released in 1998, that documented the shrinkage of the glaciers for which Glacier National Park in Montana is famed; the announcement in 2001 that scientific models predicted the complete disappearance of the famous snows of Kilimanjaro by 2020; the dramatic melting of Alpine glaciers in the unusually warm European summer of 2003. It became clear that many of the glaciers that had seemed permanent features of the landscape for millennia will not survive for many decades. Geoscientists are finding common elements in the study of glaciers and other recent discoveries, such as the warming of Arctic regions and the rise of sea level. We are coming to understand that human impacts can be more significant than we had realized. This second lesson, like the first, is also facing many challenges, particularly from those with an unwavering trust in the power of technology to solve problems.

There will not be a third lesson, or, at least, it will not come for a very long time. Current research suggests that the addition of large amounts of greenhouse gases to the atmosphere will postpone any future glaciation by tens or hundreds of thousands of years (Berger and Loutre 2002; Archer and Ganopolski 2005; Cochelin, Mysak, and Wang 2006). Looking up at mountains on the horizons, future generations will see bare rock where we still see gleaming snow and ice; traveling to the high country itself, they will find the dry beds of streams that once were filled with meltwater. One crucial and cherished part of our world will be gone.

The nature, history, and consequences of these changes form the subject of this volume. Reduced to its essence, each of the major aspects of glacier retreat can be summarized by a single term. The first term, *perception*, evokes the ways in which people know glaciers and form mental images of them, whether by seeing them or by hearing about them from others. The second, *observation*, might seem to be virtually a synonym of the first, but we use it in the specific sense of scientific observation—the systematic collection of measurements of glaciers. These two terms provide the basis for the third, *trends*, which includes both the reconstruction of glacial dynamics in the past and the projection of these dynamics into the future, indicating the probable state of glaciers in coming decades and centuries. As the fourth term, *impacts*, suggests, people are affected by glacier retreat in a variety of ways. We identify the major areas where new dangers—and perhaps new opportunities—have emerged. We highlight the vulnerability and resilience of societies in the face of significant changes to their landscapes and livelihoods. The final term, *responses*, indicates the action that people take on the basis of their perceptions of these trends and of their impacts. These responses may include different forms of accommodation and adaptation, as well as the adoption of policies by government agencies.

To guide our broad overview of glacier issues, we present some concepts and basic terms in the field of glaciology. Glaciers occur in places where, over a period of time, winter snowfall amounts exceed summer melting, so that snow accumulates on the surface and is transformed to ice. Once it reaches a critical thickness (about 30 m) and density (about 0.85 g/cm^3), this ice can deform and move downslope under the influence of gravity, forming glaciers. The state of health of a glacier can be defined by its mass balance. When annual snow and ice accumulation exceeds the loss by melting and other processes such as the calving of icebergs, the glacier has a positive mass balance and increases in mass. When the snow and ice loss exceeds the mass gain, the glacier has a negative mass balance. Generally the headward part of the glacier (the accumulation area) has a net gain, and the lower part of the glacier (the ablation area) has a net loss. The line separating these two zones is the equilibrium line, and the equilibrium line altitude (ELA) is the elevation at which the net accumulation in a given year is zero. Glacier flow transfers ice from the accumulation area to replace ice lost from the ablation area. If loss at the toe exceeds replacement by downvalley flow, the position of the toe recedes upvalley (the glacier "retreats"); if the ice delivered to the toe exceeds melt on an annual basis, the glacier front advances. Generally, glaciers with a negative mass balance exhibit frontal recession, although they may also lose considerable mass by thinning without frontal recession. Direct measurement of mass balance is expensive and time-consuming, but crude estimates of mass balance may be obtained from inspection of the equilibrium line elevation at the end of the melt season: Glaciers with a positive mass balance have, on average, more than two-thirds of their total area above the equilibrium line; this fraction is known as the accumulation area ratio (AAR).

A significant portion of the earth's land surface, roughly one-tenth of the total area, is permanently covered with ice, but it is heavily concentrated in distant and uninhabited regions (Barry 2006). The Antarctic ice sheets hold most of this ice, about 85% of the total area. About two-thirds of the remaining 15% is located in the Greenland ice sheet. In other words, all the other glaciers make up only about 5% of the world's ice-covered area.

Nonetheless, these glaciers account for a significant area, 680,000 km^2 by a recent thorough estimate (Dyurgerov 2005). These, too, are concentrated in remote areas at high latitudes and elevations (Table 1.1). Over half of this area consists of glaciers located on islands near Antarctica and in the Arctic Ocean or on Antarctica and Greenland but not contiguous with the major ice sheets. Within Europe, about two-thirds of the glacierized area is in Iceland. Patagonia holds a similar proportion of South America's glaciers, and the bulk of them are located in the more remote South Patagonian icefield rather than in the North Patagonian icefield, closer to towns and roads. New Zealand's glaciers are concentrated in the distant southwestern corner of the less populated South Island. Despite their concentration in cold places where few or no people live, however, glaciers play an important role in human societies.

PERCEPTION OF GLACIERS AND GLACIAL PROCESSES

Two attributes of glaciers shape the ways in which human perceive them: They are visible, and they are subject to cultural framing. The first attribute is a simple one. As large, slow-moving objects, glaciers can be directly seen. Though this point may seem so obvious that it does not merit being mentioned, it is quite significant. There are many other environmental concerns that involve entities that cannot be seen by the naked human eye. One cannot gaze up into the sky and tell whether ozone thinning has taken place, nor can one feel whether one is exposed to harmful levels of radioactivity. Genetically modified crops cannot be distinguished from other crops simply by looking at them. However, a person who returns to a glacier after an absence of several decades or who compares photographs of it taken at different times can easily note glacier retreat.

The direct accessibility of glaciers to human vision has helped to make them a topic of personal and public concern. Moreover, many glaciers can be seen for long distances, as can be attested by the tourist-brochure photographs of gleaming peaks rising beyond fields and forests in the southern Andes or in the Alps or of Mt. Kilimanjaro standing high above the dry plains of East Africa. People have adopted glacierized peaks as icons of particular regions: Residents of the city of Seattle have a special

TABLE 1.1

Distribution of Glaciers in the World, ca. 2000

REGION	TOTALS AND SUBREGIONS	GLACIERIZED AREA (KM²)
World	Total	680,000
Europe	Total	17,800
	Alps	2,900
	Scandinavia	2,900
	Iceland	11,300
	West Caucasus	700
	Other	10
North Asia and Siberia	Total	3,500
Central Asia	Total	114,800
	Tien Shan	15,400
	Pamir	12,300
	Karakoram	16,600
	Himalaya	33,000
	Hindu Kush	3,200
	Other	34,300
Middle East	Total	830
	East Caucasus	780
	Other	50
Arctic islands	Total	315,000
	East Arctic islands	56,100
	West Arctic islands	36,700
	Canadian islands	151,800
	Greenland small glaciers	70,000
North America	Total	124,200
	Alaska	74,600
	Canada	49,000
	Other U.S.	530
	Mexico	10
South America	Total	25,000
	Patagonia	17,200
	Peru	1,800
	Other	6,000
New Zealand	Total	1,200
Sub-Antarctica	Total	77,000
	Sub-Antarctic islands	7,000
	Sub-Antarctic glaciers	70,000
Other	Total	9
	Africa	6
	New Guinea	3

NOTE: Figures include some rounding. Source: Dyurgerov (2005).

relationship with Mt. Rainier and will stop, when walking on a busy street, if the ordinarily cloudy skies clear and offer a view. The great height and pure whiteness of this mountain, featured on the city's Web site, evoke the natural beauty and abundant resources of the Pacific Northwest. At the center of the coat of arms of the Republic of Armenia is an image of Mt. Ararat, which now lies within Turkey but whose massive glacierized peak, visible from much of Armenia including the capital, Yerevan, serves as a symbol of the Armenian people and nation, of their greatness and of their indomitable will to survive.

However, not all glaciers capture the imagination. One may contrast the great fame of Kilimanjaro in Tanzania with the utter obscurity of the glaciers on Mts. Baker, Speke, and Stanley in the Ruwenzori Mountains of Uganda. First explored in 1906 by a team led by an Italian nobleman, they are less well known than Kilimanjaro, not only because they are somewhat smaller but also because they are much harder to view. In contrast to Kilimanjaro, a free-standing volcanic cone in an area of dry climate, these peaks lie behind other ridges in a moist region, almost constantly obscured by clouds. In other regions as well, some glaciers are seen only infrequently. Local residents in the Val Bavona in the Italian-speaking region of Switzerland only rarely view the nearby Basodino Glacier, even though it is the largest in the region (Madden 2003). It is difficult even to discern the glacier from the narrow and curved valley; over one-fifth of the valley's adult inhabitants have never seen it. No major ski facilities have been established in the high country above the valley, and therefore only the small number of men, less than one-tenth of the population, who work at a high-altitude hydroelectric power plant have any direct relation to the glacier or even see it on a regular basis.

Perception of glaciers does not rest on physical visibility alone. Cultural framing can also shape the ways in which glaciers are perceived, both by influencing the patterns of movement that can bring people close to them and by shaping their understandings (Knight 2004). Local populations in Uganda have generally considered the Ruwenzori Mountains unappealingly cold and damp. Even the Bakonjo people, who live closest to the peaks, identify themselves and are identified by others not with the peaks but with the forests of the lower and middle slopes, where they grow crops in clearings, gather wild plants, and maintain a series of shrines (Oryemoriga et al. 1995). Though the Batoro, one of the precolonial kingdoms that continued under British rule and after independence, have sought to impose their rule over this area and to tax its gardens, its rough terrain and its image as a wild, uncivilized place have supported the autonomy of the Bakonjo (Alnaes 1967, 1969; Cooke and Doornbos 1982; Horowitz 1977, 1881). Bakonjo men have occasionally obtained employment as porters and mountain guides, but this work is considered physically demanding and dangerous because of the possibility of angering the spirits that inhabit the high mountain zone (Busk 1954). If tourism brought foreign travelers more regularly to the glaciers, it might lead the local people to become more involved with them, but tourists coming to this region tend to visit the lakes and observe the wildlife in the lower, forested zones. In this case, cultural framing reinforces the limited physical visibility to keep the glaciers out of mind as well as out of sight.

In the Val Bavona, local residents may not see the nearby glacier, but they are quite conscious of glacier retreat and express concern about it. Over four-fifths of the people, including some who have never seen the Basodino Glacier, are aware that it is shrinking, since it is a topic of at least occasional conversation in the valley and those who see it often enough to notice the change have commented about it to others. Moreover, the glacier retreat has significance for them because they are generally concerned about climate change. The residents recognize other aspects of local climate change, such as drier summers, as well. They express their concern about its potential impacts elsewhere in Switzerland and throughout the world, but this concern stems from exposure to the national and international media. They are relatively untroubled by possible local repercussions such as the genuine risk that the reservoir of the power plant would receive insufficient inflow as glacier retreat continues. Nor do they attribute the increased number of rockfalls to glacier retreat, since the rockfalls that most affect them do not come from the area near the glacier. In the case of Val Bavona, then, cultural framing is influenced by global rather than local perceptions and leads to a greater level of awareness of the glacier than would result from its physical visibility alone.

Recent research thus confirms the variety of forms of cultural framing of glaciers. Cruikshank's work (2005) with the indigenous communities of the Yukon in Canada documents their frequent travel on glaciers, which they use as paths to cross the high ranges of the region in which they live. Cruikshank notes as well that they consider glaciers to be sentient beings who can observe and respond to human behavior. Native people express concern that white researchers will not demonstrate proper respect for the glaciers (by avoiding certain foods and ways of speaking), thus raising the risk of glacial surges. In this case, the local perceptions of glaciers come not only from the proximity that travel brings and the attentiveness required to avoid crevasses but also from the rich stock of stories that provide information about glacier movement in the past. Research with indigenous groups in the southern Peruvian highlands documents a long tradition of pilgrimage to a glacierized peak. In this region, native communities recognize spirits that live in the high mountains and make offerings and recite prayers to them. A glacierized peak, Sinakara, is the site of a pilgrimage that dates back to the eighteenth century (Sallnow 1987; Bolin 2001).The pilgrimage lasts several days and includes visits to a number of churches and chapels; one crucial element is the climb by costumed pilgrims to the glacier itself, where, until recently, they carved off blocks of ice, believed to have medicinal properties. The glacier itself was divided into different sections, each allocated to the pilgrims of a specific region. The retreat of the glacier has been a matter of great concern to the local people; their regular pattern of visiting ensures that they see the location and shifts of the glacial front, and the ritual significance of the travel leads them to pay close attention to it. Troubled by the thought that the mountain spirits are withdrawing the ice from them, they have resolved to stop cutting blocks from the glacier.

Cultural framing by these various indigenous groups thus influences both the ways people physically see the glacier and the ways they understand it, but it is by no means restricted to indigenous cultures and to earlier times. As Wolf and Orlove (this volume) show in their study of Mt. Shasta in California, many contemporary Americans attribute a kind of consciousness or awareness to the mountain itself. They note in particular the comments made by many locals that the mountain protects itself from encroachment by sending avalanches through current or proposed ski resorts, as it did in 1978 and 1995. In her ethnographic study of several German-speaking villages in the northern Italian province of Alto Adige, Jurt (2007) describes the economic importance of glaciers in this region heavily dependent on tourism. She notes that the villagers attribute the recession of the glaciers to many material factors, such as physical removal of surface ice and snow by skis and snowmobiles and the deleterious effect of disposing of rubbish by throwing it in crevasses. They also speak of the glaciers as being sentient; they comment that the numerous visitors "stören" (trouble, distress) the glaciers and that to avoid further retreat "man sollte sie in Ruhe lassen" (one should leave them [the glaciers] in peace).

Researchers have shown that these cultural framings of glaciers can change over time. Strauss (2003) documents the terrifying Swiss folktales that portrayed glaciers as physical sites of residence of souls of dead people, trapped in purgatory. There were stories as well of the villagers' ability to alter the glaciers through magical means. One such story told of a stranger who traveled to a valley and advised the residents to send a young maiden to the mountains at dawn;

if she removed a piece of ice from each of seven glaciers and assembled these pieces above the valley, a new glacier would form, increasing the flow in the local river.

These stories were ancient and conveyed fears of real hazards. During the nineteenth century, advancing glaciers increased the level of danger by blocking entire valleys, damming rivers to create lakes that burst out in devastating floods (Wiegandt and Lugon, this volume). Close attention to these developments led to more systematic observation of glaciers and ultimately contributed to the beginnings of the science of glaciology. Once glaciers began to be monitored regularly, the growing data sets allowed researchers to trace the movement of glaciers and to examine hypotheses to account for their shifts. The scientific observation of glaciers, deriving in part from the concerns of the populations living closest to them and in part from the interest of scholarly individuals and associations, is a new form of perception of glaciers.

OBSERVATION

The regular gathering of data about glaciers involves repeated and coordinated visits to particular glaciers, usually on a fixed schedule, and the systematic recording of their attributes. This observation is nearly always conducted in the context of scientific research, though it has significant premodern and prescientific antecedents. Cruikshank (2005) has recounted how Native peoples near the Yukon-Alaska border preserve stories describing the movement of the Lowell Glacier, including the advances that blocked the Alsek River to create lakes that accumulated behind the ice dam before bursting out in floods. In a similar vein, Quechua-speakers in highland Peru have visited a glacier in yearly pilgrimages, noting the shifting location of several tongues in relation to fixed features in the surrounding mountain landscape. Nonetheless, the stories remain largely oral and local and, as Cruikshank points out, require significant translation to be incorporated into the body of scientific knowledge.

Though measurements of glaciers had been made since the first half of the nineteenth century (Haeberli, this volume), it was not until near the close of that century that the modern systematic collection of data about glaciers began in Switzerland and Norway. The International Glacier Commission was established in 1894 and sought to coordinate the recording of the length and areas of glaciers (Radok 1997; Braithwaite 2002). The particular form of glacier monitoring reflected the nature of the groups involved: People living close to glaciers were often concerned about glacial hazards, while the members of national scientific communities and international scientific organizations were interested in understanding the motion and characteristics of glaciers and their history. In countries such as Switzerland and Norway, extensive monitoring is a measure of the importance of glaciers to the national identity, economy, and society. In Switzerland, densely populated valleys are exposed to glacier hazards, and major hydropower resources depend on the amount and timing of glacier meltwater. Cantonal forest services, natural-hazard managers, and university scientists work together to observe glacier dynamics. The mix of factors is similar in Norway, where the research has been conducted by national institutes, particularly those involved with polar exploration and with the extensively ice-covered archipelago of Svalbard, an international zone of whaling and coal mining over which Norway came to exercise a predominant role. The country's great pride in its accomplishments in ice-cap exploration (including the first crossing of the interior of Greenland and the first successful expedition to the South Pole) initially contributed to support for glacier research, though the national hydropower authority has played an increasingly important role (Andreassen et al., this volume). Glacier monitoring in Peru, by contrast, began several decades later. Disastrous floods, in which thousands of people died, directed attention to the monitoring of glacial lakes in the regions in which the risks of floods are greatest (Carey, this volume). Government services have sought to gather data on glaciers to assess stream flow in areas where glacial meltwater has high economic value as a source of hydropower and the supply of irrigation water to arid regions (Carey 2005).

Though glacier monitoring began over 100 years ago, its history has not been smooth (Macdougall 2004). Governments sometimes fail to provide steady funding, and the contribution of effort by local volunteers has similarly proved to be unreliable in a number of cases. For example, the Canadian government began an ambitious program of glacier inventory in the 1960s but abandoned it in the 1970s; it has yet to be resuscitated. International organizations were disrupted during the two world wars, and funding was often scanty in the intervening decades. Some expansion of glacier monitoring began after world war II, particularly with advances in mass balance studies. In contrast to earlier work, which concentrated on measuring the frontal positions of glaciers and their surface areas and lengths, this research examined the changes in volume of glaciers by measuring accumulation and ablation (Schytt 1962). Many such studies were set up during the International Hydrological Decade of 1965–74.

Glacier observation has expanded greatly in the past two decades (Knubel, Greenwood, and Wiegandt, this volume; Bowen 2005). The concern about global warming in the 1980s brought attention to glaciers as a valuable indicator of environmental change. The creation of the World Glacier Monitoring Service (WGMS) in 1986, centered at the University of Zurich and the Swiss Federal Institute of Technology, combined earlier organizations, systematized data collection, and extended it to new areas. The WGMS coordinates closely with the United Nations Environment Program, the United Nations Educational, Scientific, and Cultural Organization (UNESCO), and international bodies in the geosciences. The International Geosphere-Biosphere Program (IGBP), also founded in 1986, has vigorously promoted research linking glacial data with climate change. The data sets assembled by the WGMS have documented the dramatic glacier retreat around the world and have received specific mention in such major reports as the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report of 2007.

As glacier observation has become an increasing priority and attracted more funding, new techniques have allowed more efficient and detailed data gathering and analysis. These methods provide much better information than the aerial photographs, some dating back to the 1930s, which offered poor resolution and uneven coverage. New remote sensing methods have improved the collection of data on glacier area. Aircraft-based laser altimetry and satellite-based kinematic global positioning system (GPS) measurement allow mass balance to be studied by observing shifts in the height of glacial surfaces. The rapid advances in computational power permit analysis of the new data sets. New modeling techniques have led to better projections of glacial mass balance by integrating data on glacier area and elevation with meteorological data on temperature and precipitation and energy-input data from solar radiation at a high degree of spatial resolution (Paul et al., this volume). This modeling work has also led to assessments of the effects of different scenarios for climate change on hydrology in glacierized watersheds (Corripio, Purves, and Rivera, this volume; Schneeberger et al. 2003) and on changing hazards such as debris flows (Huggel et al. 2004).

TRENDS

Much of the current interest in glaciers rests on the linkages between trends in climate and trends in glacier extent (length, area, or volume). The consensus reported in the most recent IPCC report is that glaciers around the world are shrinking primarily because of global warming (Lemke et al. 2007). The linkage between glacier extent and temperature is not quite as direct and immediate as this account suggests. The effects of warming can be influenced by other variables such as topography and cloud