

THE EFFECTS OF GLOBAL WARMING ON MOUNTAINS

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Contents

1. Introduction
 2. Impacts of Global Warming on Natural Systems in Mountains
 - 2.1. Impacts on Hydrology
 - 2.2. Impacts on Mountain Cryosphere
 - 2.3. Impacts on Ecological Systems
 3. Impacts on Socioeconomic Systems
 - 3.1. Mountain Agriculture
 - 3.2. Tourism
 - 3.3. Hydropower and Other Commercial Activities
 4. Policy Response
- Glossary
Bibliography
Biographical Sketch

Summary

Mountain regions are characterized by sensitive ecosystems, enhanced occurrences of extreme weather events and natural catastrophes; they are also regions of conflicting interests between economic development and environmental conservation. Once regarded as hostile and economically nonviable regions, mountains have in the latter part of the twentieth century attracted major economic investments for tourism, hydropower, and communication routes. In the context of climate change, significant perturbations can be expected to natural systems and these will inevitably have an influence on the economy of mountainous regions. Global change will probably exacerbate the present conflictual situation between environmental and economic interests.

Examples of systems in mountain areas which could be significantly perturbed by abrupt climate change, in particular hypothesized global warming, are summarized in this chapter. Particular attention is given to both the natural environment and socioeconomic factors.

1. Introduction

Few assessments of the impacts of environmental change in general, and climatic change in particular, have been conducted in mountain regions, as opposed to other biomes such as tropical rain forests, coastal zones, high-latitude, or arid areas. This is mainly because mountain orography is often too poorly represented in global or regional

climate models for meaningful projections to be applied to the impacts sector, although recent progress in high-resolution models is leading to an improved situation. There is also a significant lack of comprehensive multidisciplinary data for impact studies, which is one of the prerequisites for case studies of impacts on natural or socioeconomic systems. In addition, the complexity of physical, ecological, and social systems in mountains, and their mutual interdependency, pose significant problems for assessment, particularly because there is often little or no quantification of the value of mountains in monetary terms.

The complexity of mountain systems presents major problems for assessing the potential impacts of environmental change. This applies to assessments of changes in both biophysical systems and societal systems, particularly because many of the most valuable products of mountain regions are not easily quantified in monetary terms. Tourism, which is an increasingly important component of mountain economies around the world, represents an economic sector that, in contrast to agriculture or forestry, is closely linked to other aspects of mountain economies and is not a “stand-alone” sector. A further consideration is that few mountain regions can be described comprehensively, because of the heterogeneity of the available data for climatic, biological, or socioeconomic impact assessments.

Because of the diversity of mountain economies, from the exclusively tourist-based ones to those characterized by subsistence agriculture, no single impacts study will adequately represent the range of potential socioeconomic responses to climate change. A case-by-case approach is therefore essential to understand how, for example, mountain agriculture may change in Bolivia, tourism may change in Switzerland, or hydropower resources may be impacted in New Zealand.

Despite these severe constraints, it is possible to assess to a certain extent the manner in which environmental change may impact various biogeophysical systems, either based on climate model scenarios or on a “what if” approach, which determines the sensitivity and vulnerability of a system to a hypothetical change or range of plausible changes.

2. Impacts of Global Warming on Natural Systems in Mountains

2.1 Impacts on Hydrology

Because mountains are the source region for over 50% of the globe’s rivers, the impacts of climatic change on hydrology are likely to have significant repercussions, not only in the mountains themselves but also in populated lowland regions that depend on mountain water resources for domestic, agricultural, and industrial purposes. Hydrological systems are controlled by soil moisture, which also largely determines the distribution of ecosystems, groundwater recharge, and runoff; the latter two factors sustain river flow and can lead to floods (see *Effects of Global Warming on Water Resources and Supplies*). These controls are themselves governed by climate, and hence any shifts in temperature and precipitation will have significant impacts on water. Increased temperatures will lead to higher rates of evaporation, a greater proportion of liquid precipitation compared to solid precipitation; these physical mechanisms, associated with potential changes in precipitation amount and seasonality, will affect

soil moisture, groundwater reserves, and the frequency of flood or drought episodes.

According to recent estimates, the global annual water demand is likely to increase from 4130 km³ in 1990 to 5190 km³ in 2020, if present consumption patterns are sustained. Because of the increasing population, the additional demand will be accompanied by a sharp decline in water availability per capita. While a consumption of 1000 m³ of water per year and per capita is considered a standard for “well-being” in the industrialized world, projections of annual water availability per capita by the early twenty-first century are 210 m³ for North Africa, 700 m³ for Central Asia and Kazakhstan, and 1100 m³ for southern Asia. This trend is declining in all parts of the world, including those that are considered to have ample water resources. This in turn has prompted the need for a more rational approach to the conservation and use of what is probably the most vital single resource for humankind. An additional source of concern is that mountains have long been considered as an exclusive source of water for the lowland populations. The new initiatives are aimed at conservation and distribution of water within the mountains of the developing world so that mountain people, in particular women, can avoid spending a large part of their working lives merely carrying drinking water for their families.

Against this backdrop of social problems, it is obvious that water resources will come under increasing pressure in a changing global environment. Significant changes in climatic conditions will affect demand, supply and water quality. In regions that are currently sensitive to water stress (arid and semiarid mountain regions), any shortfalls in water supply will enhance competition for water use for a wide range of economic, social, and environmental applications. In the future, such competition will be sharpened as a result of larger populations, which will lead to heightened demand for irrigation and perhaps also industrialization, at the expense of drinking water. It would be difficult to assume that present-day water-supply and consumption patterns will continue in the face of increasing population pressures, water pollution, land degradation, and climatic change. Events in recent history may provide useful guidelines for developing such strategies.

Projections of changes in precipitation patterns are tenuous in general circulation models (GCMs), even those operating at high spatial resolution, because rainfall and snowfall are difficult variables to simulate, compared to temperature. A number of assessments of the potential impacts of climate change on water resources, including snowfall and storage, have been conducted at a variety of spatial scales for most mountain regions. Investigations in the United States and elsewhere have concluded that in many cases, it is difficult to find changes in annual river flows in response to climatic change, but that seasonality changes are often detected.

In Latin America, which accounts for 35% of global non-cryosphere freshwater, the impacts of climate change are expected to occur in the more arid regions of the continent, which are often associated with the rain-shadow influences of the Andes ranges. Shifts in water demands will depend on population growth, industrial expansion, and agricultural potential. In many countries of the region, water availability is expected to decline, which is likely to generate potential for international conflicts. The Intergovernmental Panel on Climate Change (IPCC) estimates that water availability per

capita and per annum will decrease from 4750 m³ in 1990 to 2100 m³ in Mexico by 2025, without any change in climate, that is, due to population and economic growth. Based on several GCM simulations, projected shifts in precipitation in a warmer climate yield a range of 1740 to 2010 m³. For Peru, the respective set of figures are 1860 m³, 880 m³ resulting from demography alone, and 690–1020 m³ with climatic change, figure that are close to or below the minimum requirements for “well-being” (see *The Intergovernmental Panel on Climate Change*).

Water resources in tropical Asia are very sensitive to tropical cyclones and fluctuations in their trajectories and intensity. The dominant effect of the monsoon may be perturbed in a changing climate. Average runoff in the Ganges, for example, is more than six times that of the dry season. As elsewhere in the world, water resources will become increasingly vulnerable to increasing population growth, urbanization, industrial development, and agriculture. An impacts assessment study for a number of Himalayan basins contributing to the Ganges has shown that changes in the mean runoff in different sub-basins ranged from 27 to 116% in a climate forced by a doubling of carbon dioxide (CO₂) concentrations relative to their preindustrial levels. The sensitivity of basins to climate change was seen to be greater in the drier catchments than in the wetter ones. However, water demand is greatest in the dry season in India, and demand cannot be met by supply in this season. Shifts in the timing and intensity of the monsoon, and the manner in which the Himalayan range intercepts the available precipitable water content of the atmosphere, will have major impacts on the timing and amount of runoff in river basins such as the Ganges, the Brahmaputra, or the Irrawaddy. The amplification or weakening of the monsoon circulations would indirectly impact upon agriculture and fisheries, freshwater supply, storage capacity, and salinity control.

2.2 Impacts on Mountain Cryosphere

Changes in the mountain cryosphere will have a number of indirect consequences. In terms of water supply, changes in seasonal snow pack and glacier melt will influence discharge rates and timing in rivers that originate in mountains. In terms of tourism, the negative impacts of lack of snow in winter, and the perception of landscape changes in the absence of glaciers and snow, may deter tourists from coming to certain mountain regions.

In most temperate mountain regions, the snow pack is close to its melting point, so it is very sensitive to changes in temperature. As warming progresses in the future, the current regions of snow precipitation will increasingly experience precipitation in the form of rain. For every degree Celsius increase in temperature, the snowline rises by about 150 m; as a result, less snow will accumulate at low elevations than today, while there could be greater snow accumulation above the freezing level because of increased precipitation in some regions. Shifts in snow pack duration and amount as a consequence of sustained changes in climate will be crucial to water availability for hydrological basins.

Glaciers are possibly the system most sensitive to climatic change, because any changes in the ratio of accumulation to ablation of snow and ice, which are dependent on temperature and precipitation, will trigger glacier mass wasting. Glacier behavior thus

provides some of the clearest signals of ongoing warming trends related to the enhanced greenhouse effect. A number of studies, in the European Alps in particular, suggest that current glacier retreat is now beyond the range of natural variability as recorded during the Holocene.

The effects of temperature and precipitation changes on glaciers are complex and vary by location. In polar latitudes and at very high altitudes of mid-latitudes, atmospheric warming does not directly lead to mass loss through melting and runoff but to ice warming. In areas of temperate ice which predominate at lower latitudes or altitudes, atmospheric warming can directly impact the mass and geometry of glaciers. Empirical and energy-balance models indicate that up to 50% of existing mountain glacier mass could disappear by the year 2100 if global warming scenarios indeed occur. The smaller the glacier, the faster it will respond to changes in climate. With an upward shift of up to 300 m in the equilibrium line between net ablation and net accumulation, the reduction in ice thickness of temperate glaciers could reach 2 m per year. As a result, many glaciers in temperate mountain regions would lose most of their mass within decades.

Impacts studies for different mountain regions of the globe confirm these projections. In East Africa, for example, the Lewis and Gregory glaciers on Mount Kenya have been in constant regression since the late nineteenth century. Should this trend continue as expected in the twenty-first century, there would be very little permanent ice left in this region within the next 100 years. Similarly, photographic evidence from the nineteenth century shows that the snowline has risen from 4100 m to more than 4700 m today. These changes in ice extent and in the snowline altitude have had important geo-ecological effects, leading to shifts in vegetation belts and to the fragmentation of previously continuous forest formations. Enhancement of the warming signal in these regions would lead to the disappearance of significant snow and ice surfaces. In northwest China, projected changes in precipitation and temperature over the twenty-first century are likely to lead to the disappearance of one-fifth of glacier surfaces in this region.

A consequence of increased glacier mass ablation in coming decades is that there will be enhanced runoff as the ice disappears; this extra runoff could persist for a few decades to a few centuries, according to the size of the melting glaciers. Use could be made of this resource in terms of hydropower or irrigation in the interim period until the glaciers disappear completely. Runoff from glaciers in Asia could triple in volume by the middle of the twenty-first century in response to global warming as projected by the IPCC.

Permafrost will also respond to climatic change, although investigations of mountain permafrost are not extensive and monitoring is confined essentially to the European Alps. Evidence from borehole profiles in permafrost helps to determine the rate and magnitude of temperature changes; permafrost temperatures are increasing at an annual rate of 0.1 °C, reflecting the particularly strong warming signal in the Alps since the 1980s. It is difficult to interpret changes in permafrost, as the amount of permafrost in any particular region depends on regional geomorphologic characteristics, soil and geology, exposure to weather elements, seasonal precipitation and temperature, and the

amount and duration of the snow pack. This latter parameter significantly controls perennially frozen surfaces, because snow insulates the ground surface and suppresses the propagation of cold temperatures into the soil which are favorable to permafrost. Changes in just one of the controls on permafrost, such as temperature, need to be viewed in the larger context of the other controls on this element of the cryosphere.

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Biographical Sketch

Martin Beniston was born in 1953. He completed his university education in the UK, France, and Switzerland, and has worked since 1978 in the fields of atmospheric and climate modeling in France,

Germany, and Switzerland. He has been active in the scientific and policy arenas of climatic change, and was one of the vice-chairpersons of the Intergovernmental Panel on Climate Change (IPCC) from 1993 to 1997. He is currently professor of physical geography and head of department at the University of Fribourg in Switzerland.

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