# Mountains and Climate Change

## From Understanding to Action

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# Contents

# Foreword

Mountains are among the regions most sensitive to climate change. Some of the most visible indicators of climate change come from mountain areas, such as the widespread retreat of glaciers that has been observed from polar to tropical regions in recent decades. The sensitive position of mountain areas has been clearly highlighted by the IPCC in its latest report in 2007.

Mountains provide freshwater to half of the world's population and are home to half of all global biodiversity hotspots. Mountains are also important areas for recreation in an increasingly urbanized world. This raises crucial questions: How will these vital services be affected by climate change? Will mountain areas continue to provide the same amount of freshwater as they have in the past? What will be the magnitude and the impact of climate change in mountains and their adjacent lowlands? Where will the changes take place and who will be most affected?

The present publication aims to create awareness about potential changes and related challenges for global development. It shows that not all is doom and gloom by presenting nascent and promising initiatives at the local, national, and international level. These endeavors attempt both to face the challenges presented by climate change and to take advantage of emerging opportunities wherever possible.

Switzerland is often seen as a mountain country par excellence. The Swiss Agency for Development and Cooperation SDC has supported the development of mountain regions worldwide since the early days of its involvement in international development cooperation. Many of SDC's first programmes were anchored in mountainous countries. Mountain regions and their development have thus retained an important position in our engagement with development up to the present day.

Together with its partners, SDC has supported regional and global initiatives to strengthen the position of mountains on the international agenda. Prominent examples include the creation of Chapter 13 on mountains in Agenda 21, adopted at the Earth Summit in Rio in 1992; engagement within the UN Commission on Sustainable Development (CSD) and the related resolutions on mountains in 2007 and 2009; support for the International Year of Mountains IYM 2002 and the establishment of the International Mountain Partnership initiative in the wake of the World Summit for Sustainable Development in Johannesburg 2002.

Dear readers: The present publication, prepared on the occasion of the United Nations Framework Convention on Climate Change UNFCCC 2009 in Copenhagen, underscores Switzerland's commitment to sustainable mountain development. It is my hope that it will help raise awareness about the key role played by mountain regions in global development. May it also promote practical action in the face of the manifold challenges and the probable opportunities that climate change presents for mountain regions in an ever faster changing world.

Martin Dahinden
Director General
Swiss Agency for Development and Cooperation

# 1 Climate Change in Mountains

S. Kummer

# Climate Change in Mountains

## The global context

Man-made greenhouse gas emissions are expected to lead to average global warming in the period 1990-2100 of between 1.1 and 6.4°C, depending on the global release of greenhouse gas emissions.

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Swiss Academy of Sciences, Bern, Switzerland

Pamir from the air (D. Maselli)

This warming will not be uniform but will vary considerably between different regions. In general, it will be greater over land and in high northern latitudes. The most robust precipitation projections are for increases in the monsoon regions and in middle and high latitudes, and a decrease in the subtropics. The area of snow cover will decrease in general, while snowfall may increase in regions with very cold temperatures such as high mountains. Most glaciers and ice caps will lose mass or disappear in the long term.

Figures 1.2 and 1.3 show the regional distribution of temperature and precipitation changes and the position of principal mountain regions. While most mountain areas are in regions of medium to high temperature change, changes in precipitation vary considerably for different mountain areas.

## Climate change: Mountain specificities

Climate change is a reality today, and some of the best evidence such as melting glaciers comes from mountain areas. Many scientists believe that the changes occurring in mountain ecosystems may provide an early glimpse of what could come to pass in lowland environments, and that mountains thus act as early warning systems.

Mountains exist in many regions of the world. They occupy very different positions on the globe and they differ in shape, extension, altitude, vegetation cover, and climate regime. They will therefore be affected differently by climate change. However, they share some common features relating to climate change:

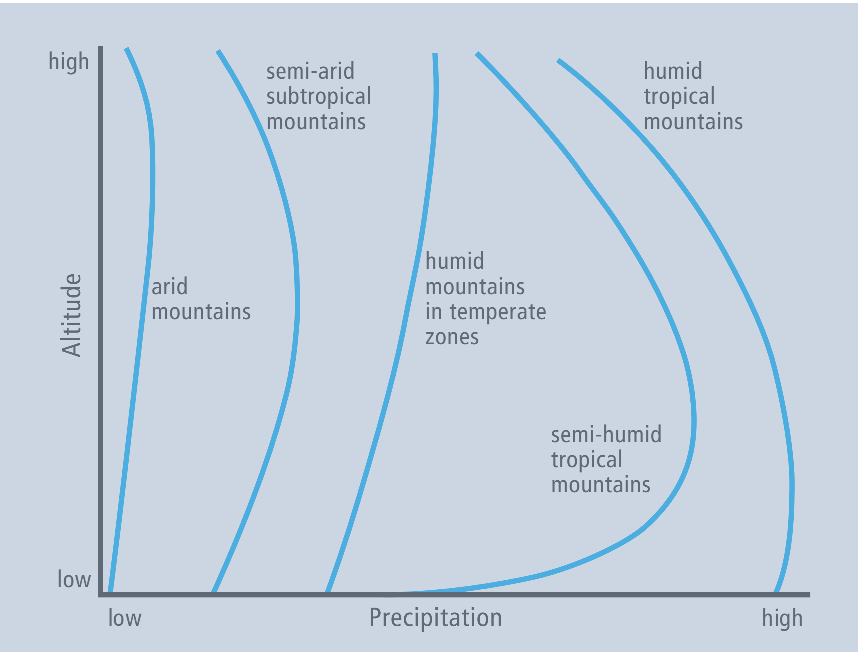
Firstly, mountain areas have a marked and complex topography and so their climates vary considerably over short distances (Figure 1.1). Climate change projections are therefore difficult to make. Unfortunately, reliable long-term and high-altitude records of mountain climate which allow verification of regional climate models exist for only a very few areas such as the European Alps.

Secondly, temperature changes with altitude. The impacts of a warmer climate are different for different elevations. Areas at the snow line or freezing line will be affected particularly heavily, as they might undergo a shift from mainly snow-covered to mainly snow-free. For example, every degree Celsius increase in temperature will cause the snow line to rise on average by about 150 m, and even more at lower elevations. In such regions precipitation will change from snow to rain. The decrease in snow cover will lead to an above-average warming of mountains, because snow-free surfaces absorb much more radiation than snow-covered surfaces.

Thirdly, melting of glaciers and permafrost will trigger the release of loose rock and soil and exacerbate the danger of rockfall, debris flows, and mud flows. A specific risk is the build-up of glacial lakes and the threat of lake outbursts, which could result in destruction of property and death.

Fourthly, mountains themselves play a major role in influencing regional and global climates. They act as barriers for wind flow, which induces enhanced precipitation on the windward side, and reduced precipitation and warmer temperatures on the leeward side. Changes in atmospheric wind flow patterns may induce large and locally varying precipitation responses in mountain areas, which could be much stronger than average regional climate change (IPCC 2007a). For example, model simulations show that in Scandinavian mountains, enhanced westerly wind flow might induce up to a 70% increase in precipitation, while average warming without changes in wind flows would lead to an increase in precipitation of up to only 20%.

Overall, model simulations of climate change in mountain areas are very difficult because existing climate models do not yet adequately represent complex topography and its effects on climate. This lack of more precise, regional models concerns the largest mountain massifs in the world including the Andes, the Hindu Kush-Himalaya, and Central Asia. As a result, the magnitude of projected changes in temperature and precipitation still differs greatly between models, for extremes as well as for mean values.




Precipitation increases with altitude due to uplift of air masses and condensation - the main reason for the role of mountains as water towers of the world (see Chapter 2). Precipitation maxima vary and occur at different altitudes in different mountain regions of the world (Richter 1996).

Figure 1.1: Altitudinal gradients of precipitation in different mountain regions of the world.

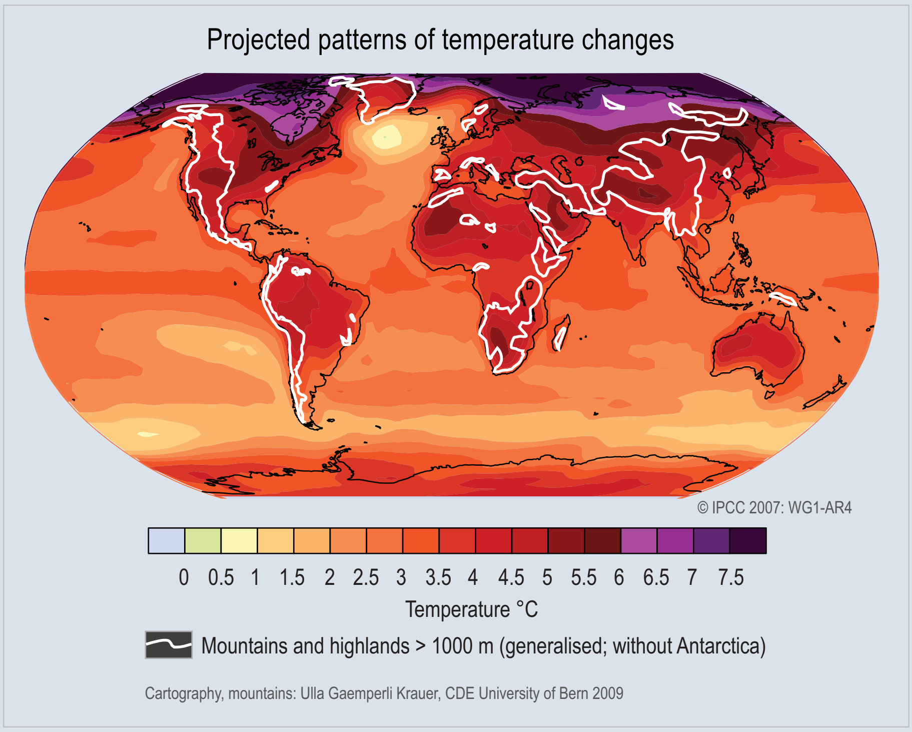



Figure 1.2: Changes in temperature at the end of the 21st century compared to 1990 for a high greenhouse gas emission scenario. White contours depict important mountain regions. (adapted from IPCC 2007, Fig. WGI-SPM-6)

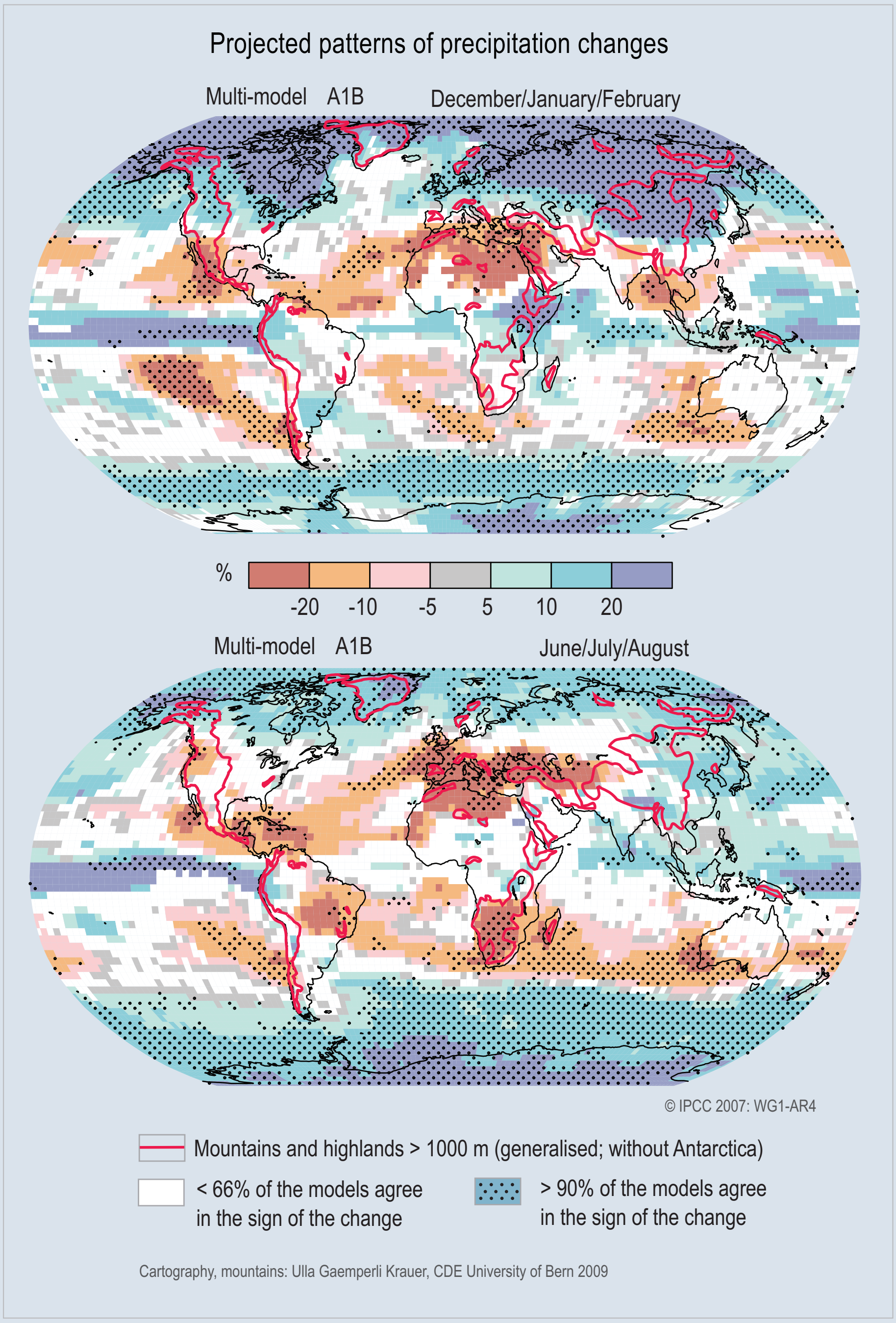



Figure 1.3: Relative changes in precipitation (in %) at the end of the 21st century relative to 1990 for a medium greenhouse gas emission scenario in the Northern Hemisphere in winter (left) and summer (bottom). Purple contours depict important mountain regions. (adapted from IPCC 2007, Fig. WGI-SPM-7) 1

## Regional climate projections for mountain regions

**Andes**

Annual precipitation is likely to decrease in the southern Andes, with relative changes being the greatest from June to August. For the rest of the Andes, future precipitation changes will depend heavily on changes in El Niño patterns, which are poorly understood at present. A recent regional climate model study for the tropical Andes shows more warming at higher elevations and an increase in interannual temperature variability for scenarios with greater global warming (Urrutia and Vuille 2009). Glaciers in many parts of the tropical Andes may disappear over the next few decades, which could entail severe problems in water supply – in Peru, for example, 10 million residents of Lima depend on freshwater from the Andes.

**Rocky Mountains**

Higher elevation sites in the Rocky Mountains have experienced a threefold increase in warming compared to the global average during the last few decades. Climate models show above-average warming with the greatest warming at high latitudes from December to February, and from June to August in the mid-latitudes. Annual mean precipitation will increase, except in the South, but precipitation is influenced by El Niño and the North Atlantic Oscillation, for which predictions are uncertain. There will be earlier snowmelt in spring and a shift from snowfall to rainfall, particularly at middle and lower altitudes. Moreover, the incidence of forest wildfires has increased significantly in recent decades; this is closely associated with increased spring and summer temperatures and with earlier spring snowmelt (Westerling et al 2006).

**Hindu Kush-Himalaya**

As the largest high-elevation land mass in the world, the Himalaya-Tibet massif plays an important role in global climate and climate change. Warming is predicted to be well above the global average, which can be seen even in global climate projections (see Fig. 1.2). Many climate models project that monsoonal flows will weaken, which would lead to a precipitation decrease. However, it seems probable that this effect is more than offset by enhanced water transport due to greater moisture in warmer air. Model projections show an increase of precipitation in December, January and February. These projections are uncertain, as they depend on poorly known changes in the monsoon regime and El Niño patterns.

**European Alps**

In general, Europe has shown a greater warming trend since 1979 compared to the global mean, and the trends in mountainous regions are still higher (Böhm et al 2001). Regional climate projections indicate warming of about 1.5 times the global average, with greater warming in summer. Precipitation is projected to decrease in summer and on an annual average, and to increase in winter. General warming is expected to lead to an upward shift of the glacier equilibrium line by between 60 to 140 m per °C temperature increase (Oerlemans 2003), along with a substantial glacier retreat during the 21st century. The duration of snow cover is expected to decrease by several weeks for each degree C of warming at middle elevations in the Alps region.

# 2 Mountain Waters

Tarfala Valley, Lapland, Sweden (D. Viviroli)

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Bruno Schädler, Rolf Weingartner
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# Water Towers in a Changing World

**Mountain waters, a key resource for development**

Mountains are the water towers of the world. They provide freshwater to half of the world's population for irrigation, industry, domestic use and hydropower. But mountains are also among the regions most sensitive to climate change.

Lake Ladtjojaure, Sweden (D. Viviroli)

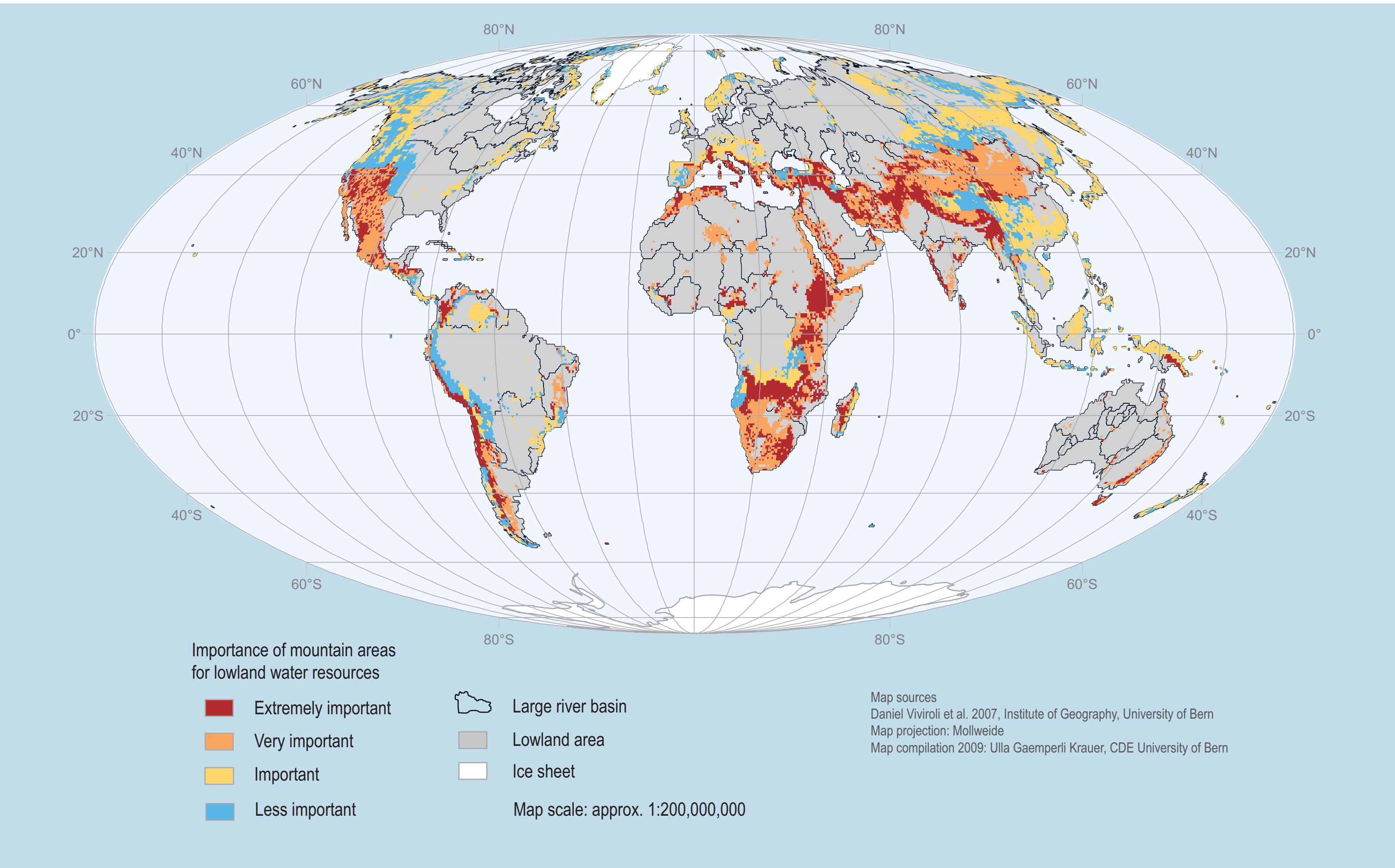
Global assessments of mountain water resources are challenging owing to the limited data available. An initial comprehensive global overview was recently created based on a set of global maps at a resolution of 50 × 50 $km^2$ (Figure 2.1; Viviroli et al 2007). Analysis of this overview shows that even in temperate climates, which are relatively water-abundant, mountains deliver about twice as much runoff per unit area as lowlands. In arid zones, mountains provide as much as 7 times more runoff than lowlands; in these dry water-scarce zones, mountains frequently contribute as much as 90% or more to the total runoff of a river basin (Figure 2.2, Viviroli et al 2003). The importance of mountains is particularly pronounced in subtropical regions with a high variability of precipitation, especially if they depend on a single rainy season. Cases in point are the countries of monsoon Asia, such as India and Pakistan, as well as Southeast Asia and southern China, where about 1.3 billion people or close to 20% of the global population depend on mountain waters from the Himalaya, Karakoram, and Tien Shan massifs and from Tibet. Other large mountain systems critically important for water supply are the Rocky Mountains, the Andes, the mountains of the Middle East, the Atlas Mountains, and the mountains of South Africa. In addition, a number of regional 'water towers' found on each continent play a key role. In East Africa, for example, Mount Kenya is the only source of freshwater for over 7 million people.

## Implications of climate change

Temperature and precipitation in the form of rainfall and snow largely determine the hydrological cycle, including runoff. Changes in these factors will thus impact freshwater supplies from mountain areas and have implications for water availability in the lowlands. Snow cover is particularly sensitive, as it reacts quickly to changes in temperature. In a warmer world, a smaller fraction of winter precipitation will fall as snow, and the melting of winter snow will occur earlier in spring. This will lead to a shift of the seasonal runoff maximum to winter and early spring. At present, the seasonal maximum occurs in summer and autumn, when demand in the surrounding lowlands is highest. Where no sufficient storage capacities are available, much of the winter runoff will flow directly to the oceans. Such changes in seasonal maxima, predicted by the IPCC with high confidence, have already been observed in some regions such as the Rocky Mountains and the European Alps. Their future impacts are likely to be severe, since more than one billion people, or one-sixth of the earth's population, rely on snow-melt dominated runoff for their water supply (Barnett et al 2005). To this the impact of shrinking glaciers will be added, which is more limited to mountain regions but has the potential to jeopardise large irrigation systems that rely on glacier melt runoff, such as those found in the mountains and forelands of the Andes. Regions where the water supply is dominated by snow and glacier melt, such as the Hindu Kush-Himalaya and the Rocky Mountains, will also be highly vulnerable, particularly where water systems are already over-allocated, as in the Western US (e.g. Columbia River) and Canada. Although adaptation of these systems appears to be possible by building up infrastructure such as dams, this will be expensive; moreover, it will have unknown impacts on societies and ecosystems downstream.

Changes in water availability due to climate change are taking place at a time when pressure on water resources for irrigation and food production, industrialisation and urbanisation is increasing. The effect will be the greatest in semi-arid regions and in the monsoon belts, especially during seasonal deficits which have been covered by water supply from mountains until now. These changes will give new impetus to the construction of dams and water transfer systems. India and China, for example, are planning or already implementing large interbasin schemes to transfer water to water-scarce regions, the effects of which are difficult to anticipate. If these two schemes are realised, more than two billion people will depend on water originating in the Hindu Kush-Himalaya.

Figure 2.1: Importance of mountains as "Water Towers" of the world (Viviroli et al 2007).



## The way forward

Projections of climate change and its impacts remain a challenge due to the highly non-linear interactions of the relevant factors. This is especially true for mountain regions with their marked topography, which is not well reflected in present climate models. Mountains can alter atmospheric circulation and hence rainfall patterns and snow cover beyond current predictions and over large areas, for example in the Hindu Kush-Himalaya region, where the interplay of the Indian summer monsoon and the winter westerlies over Tibet is little understood. In light of such knowledge gaps, global climate models and predictions of future freshwater supplies are subject to great uncertainty.

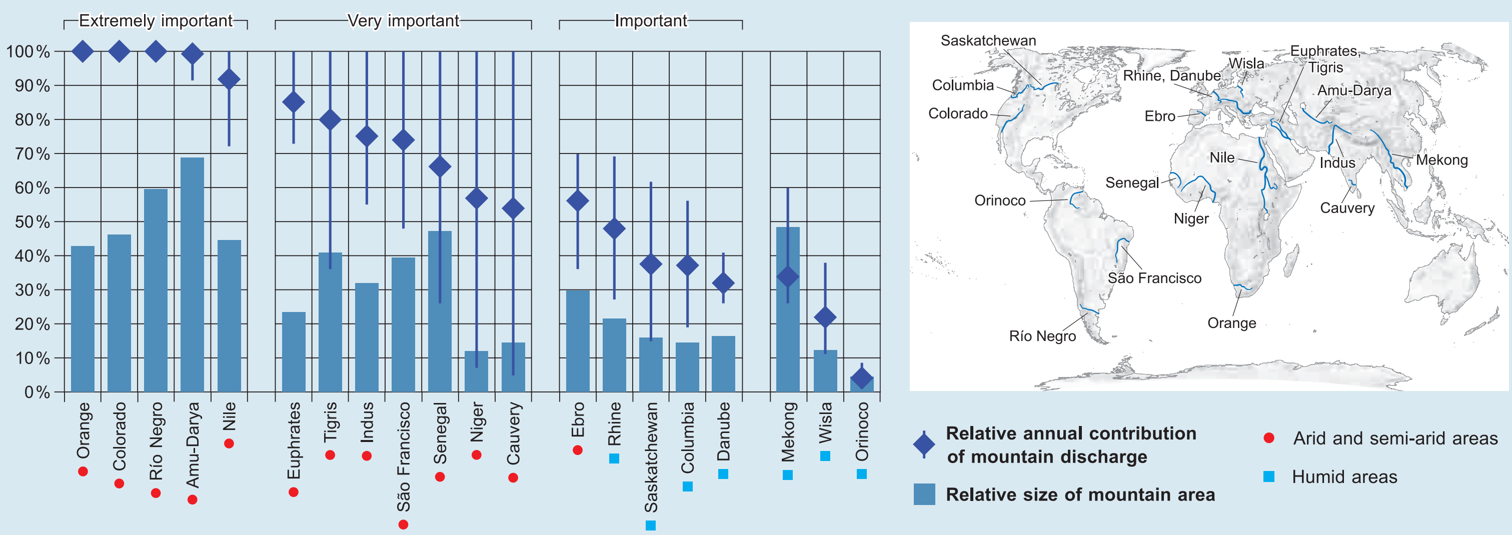
In a world of growing water scarcity, it is urgent that we improve our knowledge of present and future mountain water resources and freshwater supplies. This necessitates investment in long-term high-altitude observatories, especially in mountain areas in the developing world, where they are few and far between; the current trend of closing down monitoring networks due to high operating costs must thus be reversed. While monitoring is essential, it is not enough. Public access to data

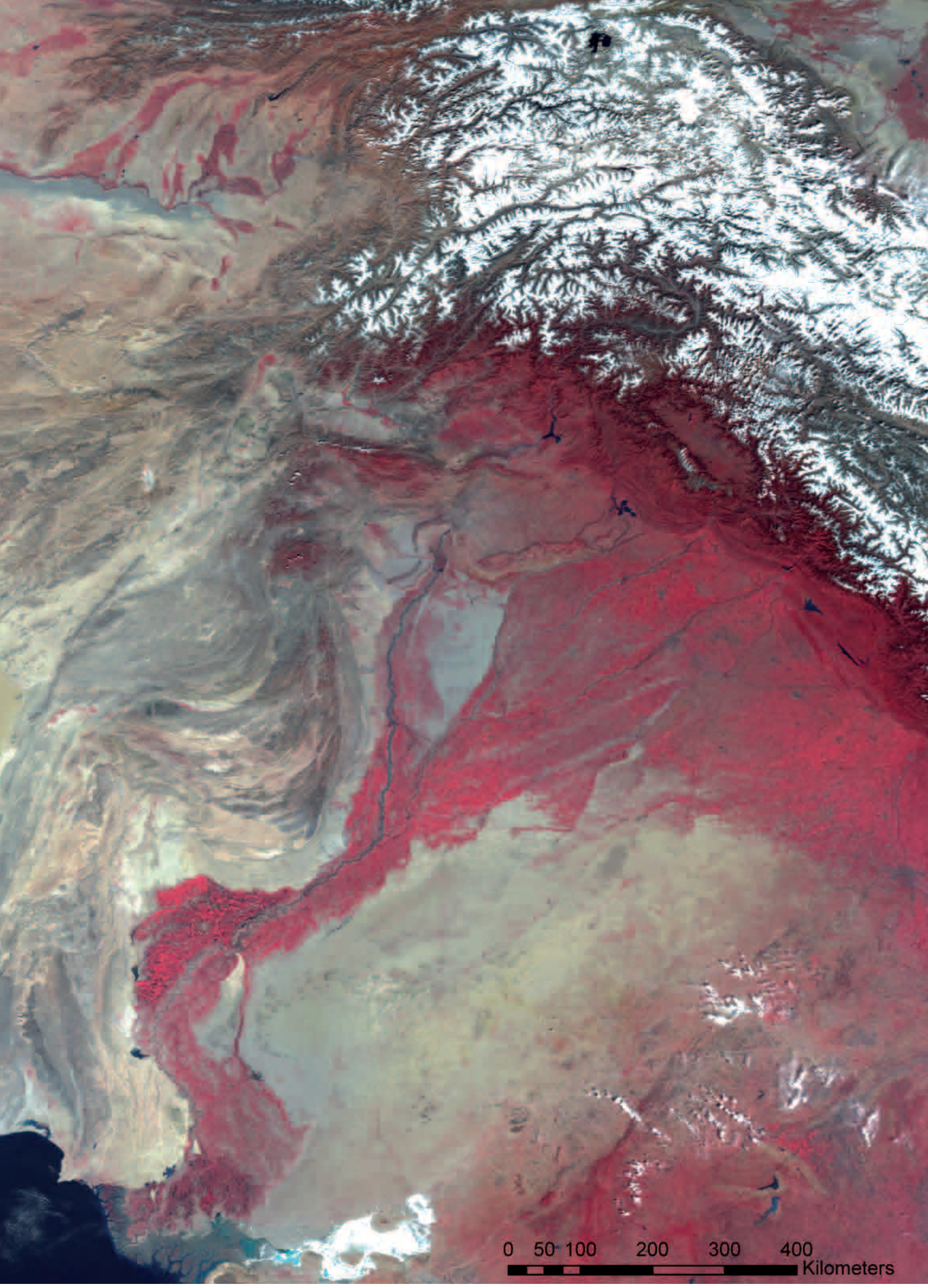
### Mountain waters on the global agenda

The importance of mountains in their role as headwaters and sources of water for the often densely populated surrounding lowlands has long been recognised by the scientific community. Since the 1992 Rio Earth Summit, this importance has increasingly become the focus of political attention, even more so during the International Year of Mountains in 2002 and the subsequent International Year of Freshwater in 2003. The Intergovernmental Panel on Climate Change (IPCC) stated in 2007 that mountain regions will be particularly affected by climate change, and that changes in the water cycle can already be observed in these regions.

In 2008, the UN General Assembly adopted Resolution 62/196 on Sustainable Mountain Development, stating that "The UN General Assembly notes with appreciation that a growing network of governments, organizations, major groups and individuals around the world recognize the importance of the sustainable development of mountain regions for poverty eradication, and recognizes the global importance of mountains as the source of most of the Earth's freshwater [...]".

Figure 2.2: Contribution of mountain area to total discharge, and size of mountain area as compared to total basin area for selected rivers world-wide (Viviroli et al 2003).







Left: This false colour infrared satellite image shows the Indus Basin in Pakistan. The irrigated area (in red) is one of the largest in the world. It ensures the country's food supply and generates 23% of its GDP. 80% of the waters that feed the basin are provided by seasonal snow and ice melt in the Hindu Kush-Himalaya mountains (in white at the top of the image). Source: NASA/GSFC, MODIS rapid response/1.10.2002

on water resources, where they exist, must be improved and current restrictions imposed for strategic reasons must be removed. Investment in infrastructure, technology, and international collaboration, as well as a shift in water management from the supply side to the demand side, will be necessary in order to share future water supplies from mountain areas equitably and sustainably.

### Vulnerability of snowmelt-dominated regions to climate change

"Geographic areas where snowmelt hydrology dominates the water cycle are expected to be especially vulnerable to climate change because a warming climate, which is projected with high certainty for the twenty-first century, directly affects the seasonality of runoff, generally shifting runoff from the warm season to the cool season." Adam et al 2009.

# European Alps: A Water Tower of Continental Europe

In the European Alps, melting of snow and ice produces high, reliable discharge in summer, supported by low evaporation due to high elevation. This discharge levels out the more variable runoff that forms at lower altitudes, where precipitation is more irregular.

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Goescheneralp, Switzerland (D. Viviroli)

As a result, the mountainous sections of the four main rivers, the Rhine, Danube, Po and Rhone, contribute about twice as much runoff as would be expected on the basis of their surface area. In the summer months, their contribution to overall discharge is even greater, reaching 80% in the case of the Po (see Table 2.1). Where international cooperative water management is concerned, the Rhine River basin is exemplary: Since the 1950s, the International Commission for the Protection of the Rhine (ICRP) has successfully coordinated the actions of nine countries, as well as the European Commission, with respect to sustainable development, water quality, flood prevention, and protection. The ICRP has served as a model for other large river basins, and similar approaches are urgently recommended for other transboundary rivers. With regard to climate change, the ICPR initiated a scenario study on future water resources and changing flow regimes in 2007. Based on the results, adjustment strategies for integrated water management in the River Rhine basin will be proposed.

Table2.1: Freshwater contribution of the European Alps to total discharge of the four major Alpine rivers.

| River | Mean annual contribution from mountain area to total discharge | Maximum monthly contribution from mountain area in summer (Jun-Aug) | Share of mountain area in total basin area |
|---|---|---|---|
| Danube | 26% | 36% | 10% |
| Po | 53% | 80% | 35% |
| Rhine | 34% | 52% | 15% |
| Rhone | 41% | 69% | 23% |

# Water and Climate Change in the Tropical Andes

As glaciers are melting away in the tropical Andes, water regulation and storage capacity may shift to other areas such as mountain wetlands in the *Páramos* and *Punas*. These high-altitude landscapes with their moors and lakes are very vulnerable to human perturbation including land cover change, pollution, and destructive recreation.

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CIP-CONDESAN, Lima, Peru

Pàramo near Cuenca, Ecuador (W. Buytaert)

Their management and use is thus increasingly important, but also delicate as it has to strike a balance between safeguarding water supply for downstream regions while securing economic benefits for local communities. The *Proyecto Páramo Andino* has taken up this task with funds from the Global Environment Facility (GEF). Implementation was started in 2006 by CONDESAN with the support of governments, research institutions, local NGOs, and the population. The project has sites in Venezuela, Colombia, Ecuador, and Peru. An important component is participatory environmental monitoring, including data collection on precipitation and river flow, which helps farmers improve irrigation schedules and water supply systems. Such data are also essential for negotiating compensation for environmental services, which can help diversify local incomes and make farmers more resilient to the anticipated effects of climate change.

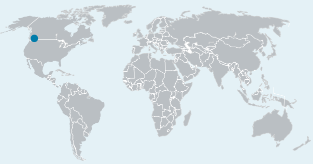
In other areas, farmers have become active on their own initiative. A striking example can be found in the basin of the Laguna de Fúquene in Colombia, which is inhabited by about 115,000 people: The potential threats of climate change have prompted farmer communities to join forces to make current water resources more resilient to potential future changes. Without government support, they have raised money to buy crucial wetlands, reforest degraded areas, and decrease water loss in canals and pipe systems. Awareness campaigns encourage households to reduce their water consumption.

# Climate Change Action in the Columbia Basin in Canada

The Columbia River in western North America originates in British Columbia, Canada, and flows into the Pacific Ocean in Oregon, USA. The river is 2000 km long and has more than 40 major hydropower stations that produce most of the electricity for the Pacific North-West.

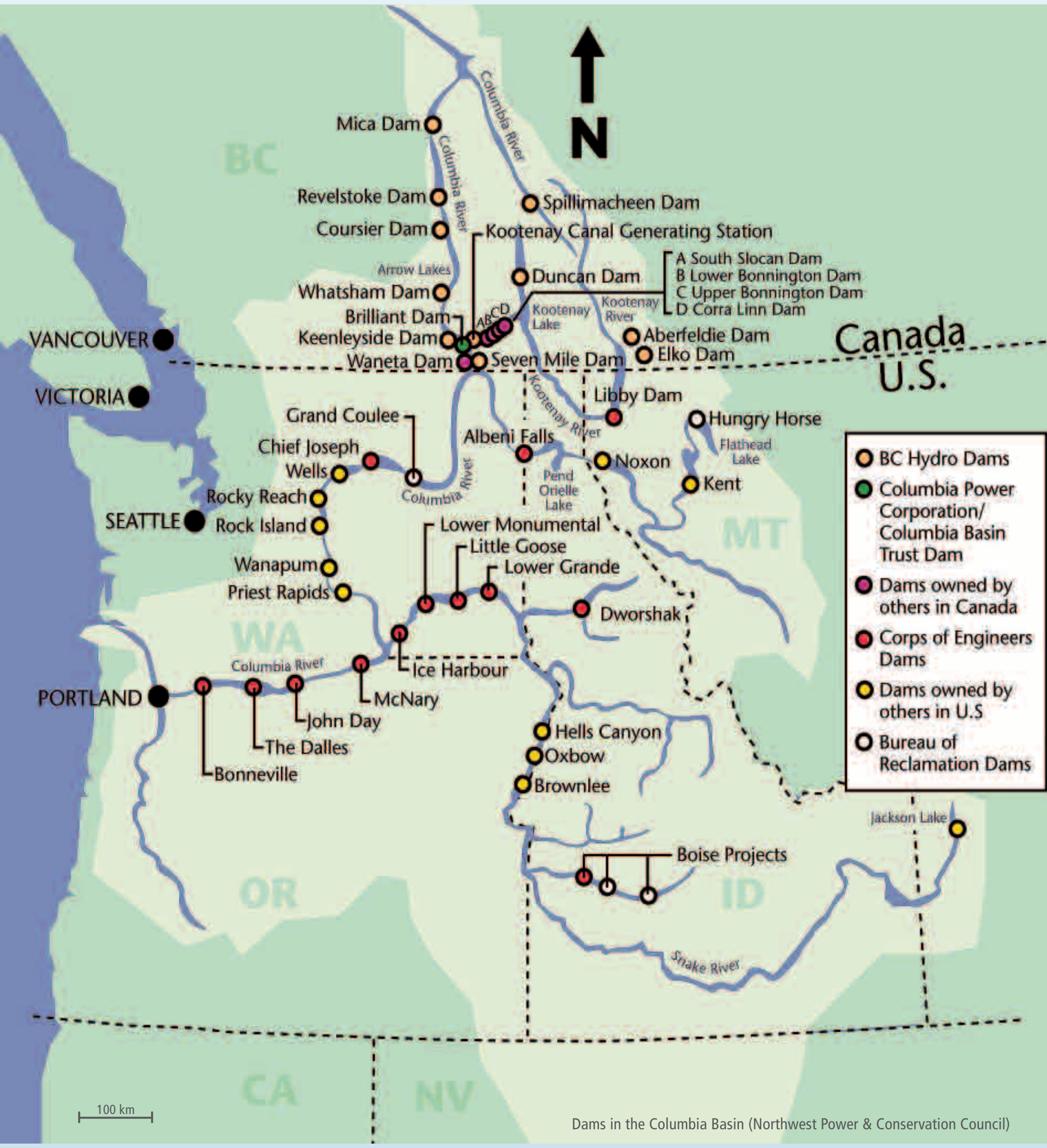
Hans Schreier
University of British Columbia, Vancouver
Kindy Gosal
Columbia Basin Trust, Golden B. C.
Canada

Waneta Dam (Columbia Basin Trust)



The Canadian portion covers 15% of the total watershed but provides approximately 40% of the total annual stream flow. In 1964 Canada and the USA ratified the Columbia River Treaty (CRT), a unique bi-lateral water management agreement that dealt with water storage for optimisation of power production and flood control on the entire Columbia River system. The centrepiece of the Treaty was the creation of three major water storage dams in Canada. In return, the US as the downstream nation agreed to compensate Canada as the upstream nation for the service of water storage for flood protection and hydropower generation. The Treaty provides that after 60 years either party may consider its termination or re-negotiation. Thus the agreement will come up for renewal in 2024, provided that 10 years' prior notice is given by either party in 2014.

No one was aware of climate change in 1964. In recent years, however, concerns have been expressed about the implications of global warming for the basin's hydrology and the resultant vulnerabilities of the system's services. Given concerns about glacial recession, changes in snow cover, possible shifts in streamflow regimes and higher rainfall and runoff variability, the Columbia Basin Trust (CBT) has initiated an aggressive climate change-related research, adaptation and mitigation strategy with a specific focus on community involvement. Since 2006, the following major programmes have been put in place:




Dams in the Columbia Basin (Northwest Power & Conservation Council)

Mica Dam (Columbia Basin Trust)

1. Climate-related research to understand predicted hydrologic changes in the Canadian Columbia Basin;
2. Development of a community watershed network that focuses on water quality monitoring and stream rehabilitation. 12 community teams have been trained to produce scientifically sound datasets on stream flow, water quality and ecosystem health;
3. A water-smart initiative to aggressively pursue water conservation practices for domestic, recreational and industrial use, with the aim of reducing water consumption within the basin by 20% by 2015;
4. Development of climate change adaptation strategies for mountain communities. This project started in 2007 with two mountain communities. The aim was to develop a methodology that can be used to identify the risks faced by increased climatic variability. A multi-stakeholder process was used to determine and prioritise the risks and to develop protective measures to minimize possible impacts. In 2009 two additional communities and one regional district were chosen to engage in a similar process, and it is anticipated that by 2014 all mountain communities in the basin will have Climate Change Adaptation Plans in place.
5. An innovative program was also initiated to monitor carbon emissions and reduce the local government corporate carbon footprint in each of the 25 municipalities and 3 Regional Districts in the Basin.

The Columbia Basin Trust has taken the lead in supporting community-based initiatives that have a large public education component, involve academic institutions and researchers, engage community volunteers, and assist municipal governments in putting climate adaptation and mitigation efforts into action.

# 3 Mountain Glaciers

Ellesmere Island (J. Noetzli)

# Mountain Glaciers: On Thin Ice

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## Mountain glaciers as key indicators of climate change

Mountain glaciers are the most visible sign of global climate change; everybody can see their development and qualitatively understand the main processes involved: snowfall and melting as a result of weather conditions.

Chopicalqui, Peru (E. Hegglin)

Glaciers can be found in, and compared across, all latitudes – from the equator to the poles. Mountain glaciers are therefore key indicators in global climate observation systems.

Glaciers have been observed in an internationally coordinated way for more than a century (Haeberli 2006). The results from data collected around the world are not at all comforting and the perspectives for the near future even less so: Evidence of accelerated glacier shrinkage at a global scale is becoming stronger. The average rate of thickness loss measured on 30 reference glaciers worldwide (Figure 3.1) has doubled since the year 2000 (Zemp et al 2009) compared with the period 1980-1999 (see Figure 3.2). The record loss in 1998 has already been exceeded three times in the 21st century, and the new record loss in 2006 was almost twice that of 1998. Satellite-based information confirms this trend and indicates even significantly higher losses in certain regions such as southern Alaska. Despite decadal regional and individual exceptions of glacier advance – for example, in the wetter parts of Norway, in New Zealand, and in the western Himalaya – rapid shrinkage dominates at a worldwide and centennial scale.

## Facts and figures on glacier retreat

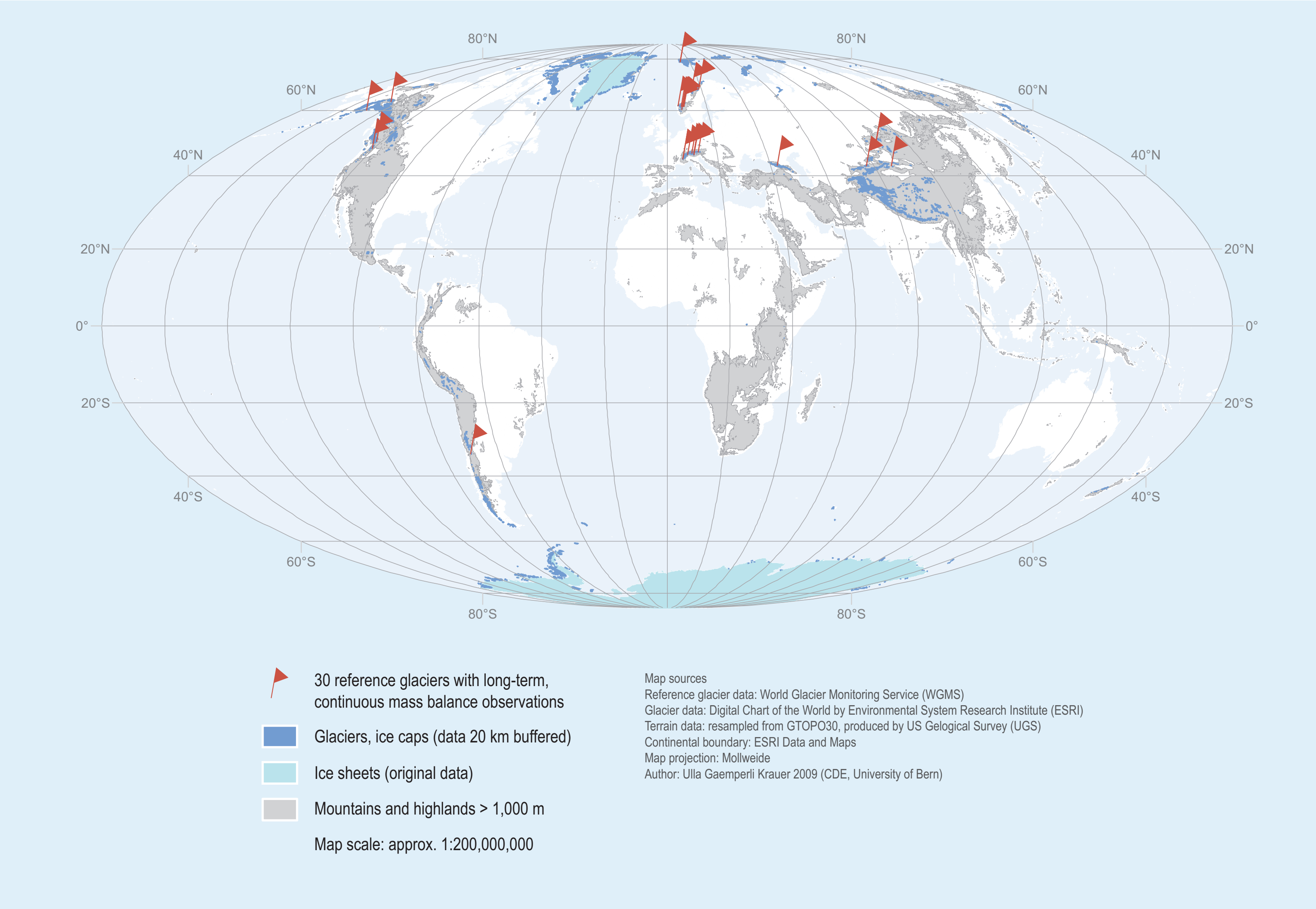
Measurements of changes in the length of glaciers constitute the main data collected during the initial phases of international glacier monitoring, which began in 1894. Information from such simple observations is extremely robust, and it leaves no doubt that today the shrinking of mountain glaciers is taking place at a global scale and at a rapid rate. The strikingly synchronous retreat in many parts of the world since the late 20th century may be unique; in many regions, glaciers have now been reduced close to their minimum extent during the climate optimums in the Holocene, i.e. in the past 10,000 years (Solomina et al 2008) – and in some places even beyond this.

Observations based on mass balance – i.e. the difference between income, which is snowfall, and expenditure, which is mostly melting – show that loss of ice is even taking place at a rate considerably faster than what could be expected from enhanced greenhouse effects alone. This means that self-reinforcing processes, especially due to decreasing reflectivity (albedo) from darkening glacier surfaces, retreating snowlines, and enhanced dust deposition from snow-free surrounding slopes have increasingly come into play (Oerlemans et al 2009, Paul et al 2005).

In recent years, glacier inventories based on satellite images and digital terrain information have opened new perspectives for documentation of the distribution of glaciers and ice caps and the ongoing changes affecting them. Computer models combining data from observed time series with satellite information make it possible to look at changes in larger glacier ensembles which extend over entire mountain regions. They show very clearly that even if global warming is limited to 2°C, small- to medium-size glaciers in many mountain ranges will most likely disappear already within the coming decades, with grave consequences for local hazard potential and water cycles. Large glaciers may develop extreme disequilibria and down waste or collapse rather than retreat, as is indeed being observed more and more frequently.

Techniques have also been developed to model the topography that will be uncovered by vanishing glaciers. This helps anticipate the formation of new lakes in local depressions of glacier beds that are becoming exposed. Such new lakes are fascinating and constitute an interesting new potential for hydropower production. They also replace some of the landscape attractiveness lost with disappearing glaciers. However, they constitute a growing hazard for flood waves and far-reaching debris flows caused by moraine breaching or by rock avalanches from de-glaciated slopes or slopes which contain degrading permafrost.

Figure 3.1: Global distribution of glaciers, ice caps and ice sheets as well as the locations of 30 reference glaciers with long-term continuous mass balance observations.



## The impacts of vanishing glaciers

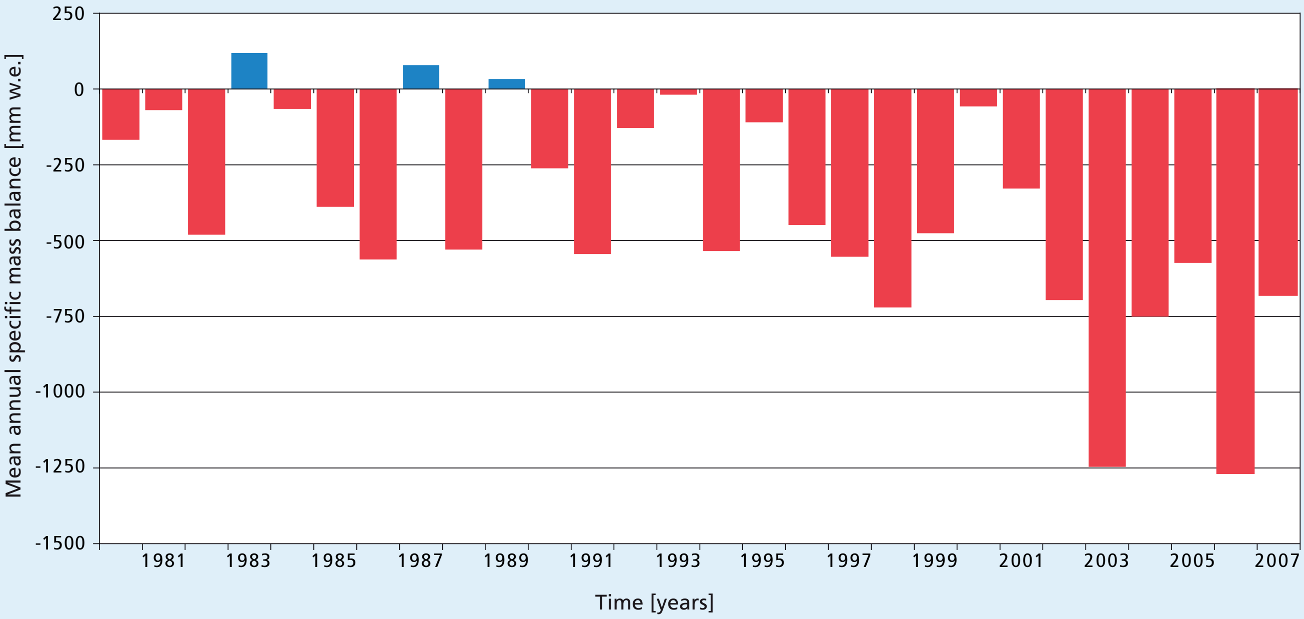
The most serious impact of vanishing mountain glaciers undoubtedly concerns the water cycle from regional to global scales. Glacier melting will probably dominate sea level rise during our century (Meier et al 2007) and the seasonality of runoff will dramatically change due to the combined effects of less snow storage, earlier snowmelt, and decreasing glacier melt. An estimated one billion people mainly in Asia, North and South America and Central and Southern Europe currently depend on snow and glacier meltwater during the dry season and may be affected by such changes (UNEP 2007). The lack of water during extended future droughts caused by changing snow and ice cover in high mountain ranges has the potential to seriously affect economies and livelihoods in general. Problems during the warm

### Global monitoring of glaciers

The United Nations Environment Programme (UNEP) and the World Glacier Monitoring Service (WGMS) recently issued a compilation and assessment of quantitative information on glaciers from long-term observations (WGMS 2008). Measurements include change in length, i.e. advance and retreat of glaciers; monitoring of mass balance; and observation based on spatial information technology such as satellite imagery and digital terrain information. For more information see:
http://www.grid.unep.ch/glaciers/

Additional links:
- Global Terrestrial Network for Glaciers (GTN-G; www.gtn-g.org)
- World Glacier Monitoring Service (WGMS; www.wgms.ch)
- US National Snow and Ice Data Centre (NSIDC; www.nsidc.org)
- Global Land Ice Measurement from Space initiative (GLIMS; www.glims.org)
- GlobGlacier project of the European Space Agency (www.globglacier.ch)

Figure 3.2: Evolution of annual glacier mass balance. Blue and red bars indicate ice gain and loss, respectively. The mass balance unit is millimeter water equivalent. Data from the World Glacier Monitoring Service.



Eiger Glacier, Switzerland in about 1900 (Courtesy of S. Nussbaumer)

Eiger Glacier, Switzerland in 2009 (S. Nussbaumer)

or dry season include fewer resources on the supply side, with longer-lasting discharge minima and low flow periods in rivers, lower lake and groundwater levels, higher water temperatures, perturbed aquatic systems and less power production, as well as increasing needs on the demand side for water for a growing population, urbanisation, industrialisation, irrigation, power production and fire fighting. The combined effect of lower supplies and increasing demands holds a potential for conflict. Together with higher air temperatures, increased evaporation and changing snow conditions, the vanishing of mountain glaciers could dramatically sharpen two fundamentally important questions: who owns the water and who will decide on the priorities for its use?

## Glaciers and ice caps by main regions*

| | |
|---|---|
| Arctic Islands (incl. Greenland) | 275,500 $km^2$ |
| North America | 124,000 $km^2$ |
| Antarctica | 77,000 $km^2$ |
| Central Asia | 62,000 $km^2$ |
| North Asia | 59,600 $km^2$ |
| Hindu Kush-Himalaya | 52,800 $km^2$ |
| South America | 25,500 $km^2$ |
| Europe (incl. Caucasus) | 6,725 $km^2$ |
| New Zealand | 1,160 $km^2$ |
| Africa | 6 $km^2$ |
| New Guinea | 3 $km^2$ |
| **Total** | **684,294 $km^2$** |

If all these glaciers and ice caps melted away, sea levels would rise by roughly half a meter (IPCC 2007). In addition, the complete melting of the Antarctic and Greenland ice sheets would result in sea level rises of 57 and 7 m, respectively.

* excluding the Antarctic and Greenland *ice sheets*.
Sources: Dyurgerov and Meier 2005, WGMS 2008.

# Tropical Glaciers of the Andes: Peru

While the largest glaciers in South America are found in Southern Chile and Argentina, the small glaciers in the dry tropical and subtropical Andes are critically important for freshwater storage and supply.

Marco Zapata
Unidad de Glaciologia
Audoridad Nacional del Agua (ANA)
Huaraz, Peru

Laguna Llaca (E. Hegglin)

The meltwater of the glaciers in the Peruvian Andes, for example, is used for multiple purposes such as domestic consumption, irrigation, hydropower generation (80% of total electricity produced in Peru) and mining operations, which play a vital role in the development of the country, especially the arid Pacific coast and Andean front ranges which contain 70% of the population, but comprise of only 1.8% of the totally available water resources of the country. About 70% of the tropical glaciers in the Andes are found in Peru, while the rest are in Bolivia, Ecuador and Colombia. Accelerated glacier retreat can be observed in all these countries. In 1970, the area covered by glaciers was 2041 $km^2$ in Peru, but only 1595 $km^2$ in 1997, a loss of 22% in only 27 years. Small glaciers disappeared completely. Moreover, glacier retreat has been accelerating. In Peru's Cordillera Blanca, for example, average retreat rates for six observed glacier fronts were 7 to 9 meters per year between 1948 and 1976, but have been about 20 meters per year since then. The vanishing of glaciers threatens regional water supply during the dry season in many large catchment areas, affecting thousands of people. A cooperative Swiss-Peruvian project on adaptation to climate change has recently been initiated in the Andes regions of Cusco and Apurímac. A remarkable collaboration between Peruvian and Swiss scientific institutions, non-governmental organizations focusing on practice and implementation, and the political level, is establishing the scientific basis of climate change impacts in this region and developing corresponding adaptation strategies with local communities. The project is active in the field of water resources, food security and disasters.

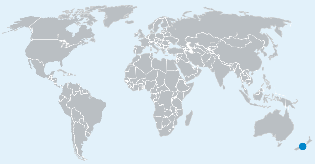
# Glaciers in the New Zealand Alps

The most recent maximum extent of New Zealand's glaciers occurred at the end of the Little Ice Age, which terminated near the end of the 19th century.

Trevor Chinn
Alpine Processes Consultancy
Lake Hawea
New Zealand

Proglacial lakes of Hooker and Mueller Glaciers, New Zealand (T. Chinn)

Since then, New Zealand experienced a modest warming of about 1°C, from about 1890 until the 1970s. A 61% volume loss in glaciers has been calculated for this period. After the mid 1980s, the fast response alpine glaciers gained mass and advanced noticeably. Since the beginning of the 21st century, the number of retreating glaciers has increased again. A net loss of ice volume between 1977 and 2005 of about 10% has been reported in recent studies, mostly from the largest glaciers. This loss will not have noticeable effects on water supplies, including hydropower generation and irrigation, as the glaciers lie in a very high precipitation zone. Locally, there may be dramatic changes to the tourist trade where some glaciers retreat from easy access.



# Glaciers in the European Alps

Historical documentation is especially rich in the European Alps. Glaciers there lost about half their total volume, or 0.5% per year, between 1850 and 1975. Another 25%, or 1% per year, of the remaining volume vanished between 1975 and 2000, and an additional 15 to 25%, or 2 to 3% per year, was lost in the first years of our century.

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World Glacier Monitoring Service (WGMS)
Geography Department
University of Zurich
Switzerland

Morteratsch Glacier, Switzerland (J. Alean)

The emergence of the roughly 5000-year-old body of the Oetztal iceman in 1991 clearly demonstrated to a worldwide public that conditions in the Alps had reached, if not exceeded in some places, the "warm" limits of climate variability since many millennia. 75% of the glacier area still existing in the period 1970–1990 is likely to disappear already with an increase in summer air temperature of 2.5 °C (Zemp et al 2006). The modelling shows that this loss is virtually independent of the scenario range in precipitation changes and might already become reality during the first half of our century (OcCC 2004).

Together with earlier snowmelt, such a dramatic reduction in glacier area will reduce water supplies in the late-summer seasons, which could seriously limit economic activity and worsen living conditions far beyond the Alps. Hydropower production from Alpine reservoirs, with its growing importance for covering short-term peak demands in the expanding European network, will also have to be fundamentally re-thought, with a view to storing water in wintertime and releasing it in summertime – the opposite of current practice. A project on hydropower, climate change and glaciers funded by the Federal Office for the Environment and *Forces Motrices Valaisannes*, a regional association of hydropower suppliers, has been initiated in Switzerland to investigate such questions. Serious threats from new lakes at the surfaces and margins of glaciers have emerged since the turn of the millennium in Italy, at the Italian/French border, and in Switzerland, necessitating remedial action by the authorities. The International Working Group on Glacier and Permafrost Hazards in Mountain Regions provides recommendations and guidance for such action.

# Glaciers in the Hindu Kush-Himalaya

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ICIMOD Kathmandu
Nepal

The Hindu Kush-Himalaya region is among those with the least available data on glaciers. Glacier retreat from Little Ice Age moraines is widespread. However, fluctuation series are extremely sparse (WGMS 2008) and do not allow for sound quantitative comparison of rates of change with other regions.

Bhutan's glaciers from space (ASTER satellite image)

Based on the few available mass balance measurements, a simplified model experiment shows the vanishing of a small clean-ice glacier, called AX010 in the Everest Region in Nepal, as the consequence of a rise in summer air temperature by 3 °C, neglecting variations in other climatic variables (Ageta and Kadota 1992). But the results for this glacier, with an elevation range from 4,950 to 5,360 m in 1978, cannot be applied to the entire Hindu Kush-Himalaya with its many debris-covered glacier tongues and accumulation areas reaching elevations above 8,000 m. The region is strongly underrepresented in terms of front variation and mass balance observations. There is thus an urgent need to improve the observational basis for glacier changes in the region, including climate records, so as to more safely assess the possible impacts of climate change.

Glacial lakes form where glaciers retreat. The threat of glacial lake outburst floods (GLOFs) with damaging effects in downstream areas is increasing. An inventory compiled by ICIMOD identified about 200 potentially dangerous glacial lakes in the Hindu Kush-Himalaya. Field investigations now underway will help understand how these lakes are formed and what risks they pose. At Tsho Rolpa glacial lake in Nepal, considered a hazard that required immediate attention, the lake level was artificially lowered by three meters, at a cost of USD 3 million, and an early warning system installed with the participation of the local population. Exchange of knowledge and experience with the Alpine countries to assess the evolution of glaciers and lakes and develop adaptation strategies has recently started.

# 4 Mountain Hazards

Mountain pastures, Central Asia (D. Maselli)

# Natural Hazards and Risk in Mountains: The Potential Impacts of Climate Change

Mountain regions are high-risk areas; hazards can cause damage, destruction, injury and death at any time. Cases in point are the Kashmir earthquake in Pakistan in 2005 that killed about 80,000 people, and the 1985 Armero mudflow in Colombia, triggered by a volcanic eruption, which claimed about 21,000 lives.

Christoph Marty
WSL Institute for Snow and Avalanche Research SLF
Davos, Switzerland

Mount Mayon, Philippines 2006 (M. N. Zimmermann)

Relief operations are often severely hampered because landslides and rockfall triggered by the earthquakes destroy access roads and other important infrastructure. As mountains are often located in tectonically active zones, susceptibility to earthquakes is higher than in other areas (Hewitt, 1997). In the Andes, for example, as much as 88% of the mountainous area is susceptible to destructive earthquakes (Table 4.1).

People have inhabited mountain regions for centuries, living with hazards and risks. Mountains are not necessarily more inhospitable than other environments, even though they pose specific challenges to people who live in mountain regions. Well-adapted mountain societies have often benefited from more diverse resources, greater security, and a healthier environment compared to surrounding lowland areas.

Earthquake in Kashmir, Pakistan (M. Schär)

Table 4.1: Percent of mountain area susceptible to destructive earthquakes.*

| Mountain areas in: | % |
|---|---|
| South America | 88 |
| Australasia and Southeast Asia | 71 |
| Eurasia | 61 |
| North and Central America | 45 |
| Africa | 27 |
| Greenland | 2 |
| Global average, all mountain areas | 55 |
| Global average, non-mountain areas | 36 |

*Level VIII or greater on the modified Mercalli scale (UNEP-WCMC 2002, Mountain Watch)

## Increasing susceptibility to disaster

However, there is growing scientific evidence that many mountain regions have become increasingly disaster-prone in recent decades, and that a disproportionally high number of natural disasters occur in mountain areas. Mountains are more frequently affected than other environments by destructive natural processes including earthquakes, volcanic eruptions, dam bursts or glacial lake outbursts. Moreover, other hazards such as avalanches and landslides occur almost exclusively in mountains.

### Natural hazards and disaster

A natural hazard in itself does not necessarily cause a disaster; a disaster results when a natural hazard impacts on a vulnerable, exposed or ill-prepared community. Disasters are therefore not purely the result of natural events, but the product of such events within the social, political and economic context in which they occur. In the developing world, one in 20 people was affected by a climate disaster between 2000 and 2004. In the OECD countries, the corresponding figure was one in 1500.
InfoResources 2/2009. Figures from International Disaster Database (www.cred.be)

In addition to relief and geology, human activity can also influence the impact of hazards. Destruction of mountain forests or inappropriate farming practices can accelerate erosion and expose land to the risk of landslides, floods and avalanches. Moreover, dams, roads or mining enterprises can be hazardous if not properly constructed and managed. Current migration from rural to urban areas and from higher to lower areas is a significant factor that has led to greater concentrations of population in valleys, increasing environmental degradation and vulnerability to large-scale disasters. Often, migration is linked to poverty, which by itself exposes people to higher risk, especially where access to safe housing and safe land is left unconsidered (UN/ISDR, 2002).

## Greater mountain hazards owing to climate change

The two most deadly natural hazards (earthquakes and volcanic eruptions) are not directly affected by global warming, but most mountain areas are subject to multiple other hazards and pressures. This is especially true for the northern and central Andes, the East African Rift, the Middle East, the Pamir, the Himalaya and the mountains of northern China (Figure 4.1). Globally, climate change is very likely to increase the pressure exerted by non-seismic hazards. Higher temperatures will enhance the hydrological cycle and it is predicted that they will alter rainfall patterns and intensity. In the mountain regions of South and Southeast Asia, for example, changing monsoon patterns, including increased severity and frequency of storms as projected by climate models, may threaten agricultural production, food security and the livelihoods of millions of people, and damage vital infrastructure. Accelerated river erosion can destabilise valley slopes, with dramatic effects where these slopes are saturated with water after prolonged intense rains.

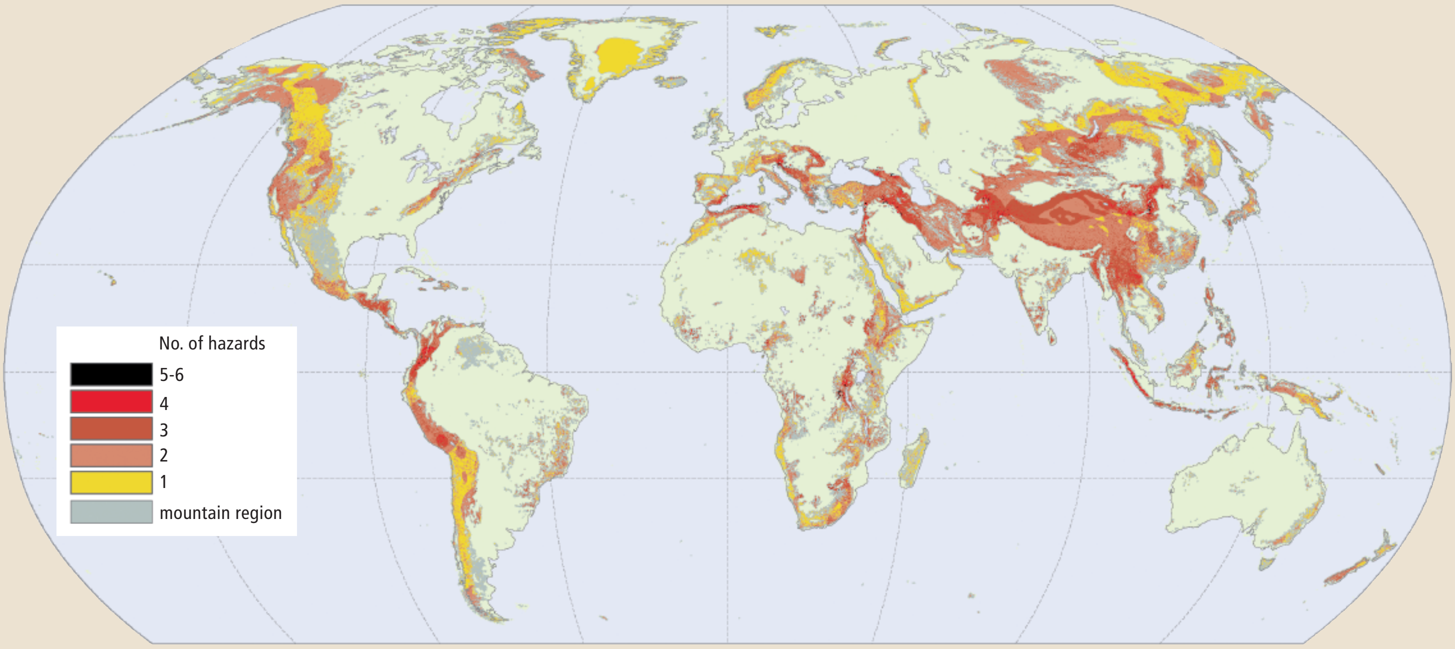
Effects will not be limited to changes in precipitation: Global warming reduces snow cover, melts away glaciers, and degrades permafrost (Bavay et al 2009). As vegetation development on such sites is a slow process, they may remain unprotected against erosion for decades or even centuries. As a result, slope failures, rockfall and debris flow will pose increasing threats to settlement and infrastruc-

Landslides triggered by the Wenchuan earthquake and by rainfall dot the landscape of Longmen Shan, China (O. Korup)

ture in many places (Beniston 2005). Moreover, prolonged periods of higher temperatures will transform areas already sensitive to fire, such as the coastal ranges of California or the Blue Mountains in Australia, into regions of sustained fire hazard and make others such as Tibet or Mongolia prone to desertification. Finally, global warming is likely to increase the incidence of insect-borne diseases at higher altitudes that were previously not affected by such health risks.

In conclusion, it can be said that casualties and damage due to hazards in mountain regions will increase irrespective of global warming, especially where populations are growing and infrastructure is developed at exposed locations. But climate change will definitely increase risk due to the fact that expected increases of heavy rainfall, heat waves, and glacier melt will amplify hazards in many mountains worldwide, and in areas where they have not been known in the past (Table 4.2). Adaptation strategies will need to adopt an integrative approach that covers the whole risk cycle from prevention to recovery. Possible entry points for factoring climate change into risk management include hazard mapping and spatial planning based on longer return periods of damaging events, coupled with risk monitoring and improved early warning systems (Lehning and Wilhelm 2006).

Figure 4.1: Map of mountain regions affected by multiple hazards.




Most mountain areas are affected by multiple hazards, which magnifies overall negative impacts. The hazards considered are earthquakes, fire, human conflict, suitability for rain-fed crops (drought), the future impact of infrastructure, and climate change (Map: Courtesy of UNEP-World Conservation Monitoring Centre, Mountain Watch 2002).

Desertification on grassland, Tibet (F.Graf)

Table 4.2: Climate change and the incidence of hazards in mountain regions.

| Hazard | Trend of expected change | Confidence in trend projection | Most affected regions | Economic importance |
|---|---|---|---|---|
| Seismic hazard | → | high | South America, Southeast Asia, North and Central America | very high |
| Snow avalanches | → | medium | Northern hemisphere, New Zealand | low |
| Droughts | ↗ | high | Africa, Caucasus, Eastern Himalaya | high |
| Landslides and mud flows | ↗ | high | Southeast Asia, Central and South America | medium |
| Glacier lake outburst flood | ↗ | high | All regions with valley glaciers | low |
| Floods | ↗ | medium | Asia, Africa, North America | high |
| Forest and bush fires | ↗ | medium | Africa, North and Central America, Eurasia | medium |
| Insect-borne diseases | ↗ | medium | Africa, Southern Asia, Central and South America | medium |

Ch.Marty 2009; based on IPCC (2007), Iyngararasan (2002), and UNEP-WCMC Mountain Watch (2002)

The table shows that climate change will increase the incidence of hazards in mountains with a medium to high level of confidence. This applies for 6 out of the 8 hazards identified, and in most mountain regions of the world. Economic impacts will be mostly medium to high, but may be disastrous in the regions concerned, depending on the type and severity of the hazard.

# A Regional Hot Spot Catalogue for Slope Stability Hazards in the Kyrgyz Tien Shan

Vulnerability to natural hazards in many developing countries and countries in transition depends greatly on the capacity to understand, respond to, and mitigate these adverse processes.

Oliver Korup
WSL Institute for Snow and
Avalanche Research SLF
Davos, Switzerland

River with deposits from landslides, Tien Shan (O. Korup)

Scientific networking and capacity building have been the focus of NATASHA, an EU-funded initiative to inaugurate an international and multidisciplinary Working Group on Natural Hazards in the Tien Shan Mountains of Central Asia. This initiative responded to the need to efficiently link mainly landslide research, integral risk management, and environmental protection through active cooperation among experts from Europe, Russia, and the Newly Independent States (NIS) of Central Asia. Together, they identified and ranked high-priority needs for research on slope instability threatening the region's population and infrastructure and compiled this vital information in a regional "Hot Spot" catalogue. The initiative helped disseminate previously unavailable research results between European, Russian and NIS researchers, while fostering the training of young scientists from the Central Asian region during an International Field Workshop, a Summer School, and an international exhibition.

Summer school participants (O. Korup)

# Snow Avalanches and Landslides in Iceland

Snow avalanches and landslides have caused many catastrophic accidents and severe economic losses in Iceland since the country was settled in the ninth century. Altogether more than 1000 people have been killed in avalanche and landslide accidents since then.

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WSL Institute for Snow and
Avalanche Research SLF
Davos, Switzerland

New avalanche defence, Siglufjördur, Iceland (St. Margreth)

Direct economic loss due to avalanches and landslides in Iceland in the 26-year period between 1974 and 2000 was about USD 41 million. Catastrophic avalanches in 1995, which killed 34 people in two towns and caused extensive economic damage, totally altered views of avalanche safety in Iceland. The Icelandic government has in the meantime decided to construct avalanche protection measures for hazard areas and/or to purchase endangered property in order to reduce the death toll and economic loss caused by avalanches. Future climate change could have an effect on the avalanche and landslide hazard situation in Iceland in the long run. Higher temperatures in future can be expected to result in fewer hazards, but increased winter precipitation and possible changes in storminess could have the opposite effect.

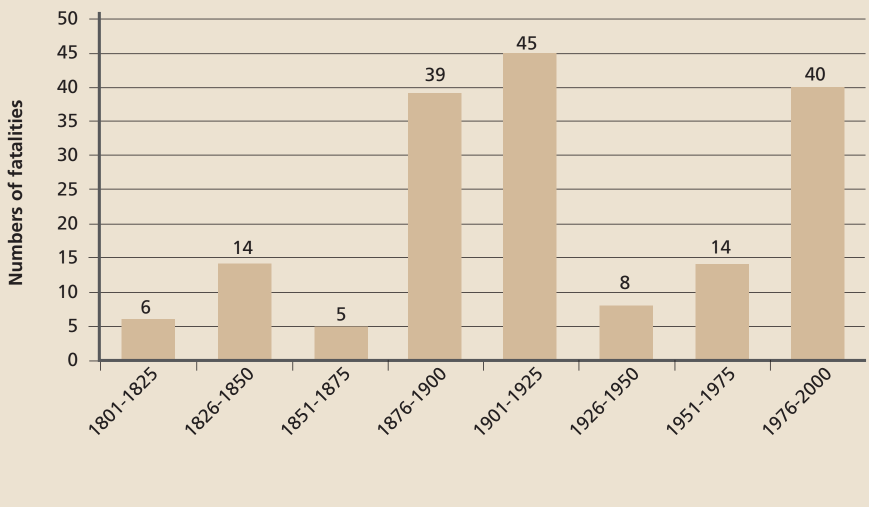


Figure 4.2: Iceland: Fatal avalanche accidents in populated areas in the period 1801-2000 (adopted from Jóhannesson and Arnalds, 2001).

# Swiss Alps: Climate Change and Permafrost

About 5 % of the land area of Switzerland consists of permafrost, i.e. permanently frozen ground. As this permafrost starts to melt due to warmer temperatures, the risk of debris flows from steep unfreezing slopes could increase considerably.

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WSL Institute for Snow and
Avalanche Research SLF
Davos, Switzerland

Snow nets and standard defence structures (downslope), Randa, Switzerland (M. Phillips)

Pontresina with protection dam, Switzerland (M. Phillips)

With a projected increase of more intense rainfall, such debris flows will affect areas further downslope. This new risk poses a threat to well-known tourist resorts in the European Alps and the Rocky Mountains. The Swiss alpine resort of Pontresina, for example, decided to respond to this hazard by building a large retention dam, 13 metres high and 460 metres long, for permanent protection, simultaneously addressing the long-term threat of avalanches. The dam cost USD 6 million as against estimated potential damage of USD 90 million. Flexible snow-nets are used nowadays to protect against avalanches instead of the standard more rigid avalanche defence structures, because they are better adapted to rockfall and creeping permafrost. They are also less costly to maintain than standard structures in such terrain.

# Programme on Climate Change Adaptation in Peru

In response to the high vulnerability of Peru's Andes region to climate change, the Peruvian Ministry of Environment, in collaboration with the Swiss Agency for Development and Cooperation (SDC), has initiated a programme on climate change adaptation (PACC – *Programa de Adaptación al Cambio Climático*) in the regions of Cusco and Apurimac.

Carmenza Robledo
Intercooperation
Bern, Switzerland

Christian Huggel
Geography Department, University of Zurich
Switzerland

Lenkiza Angulo
UC-PACC, Peru

Understanding the perceptions and coping strategies of women in Yanahuaylla, Cusco (C. Robledo)

The PACC focuses on three main thematic lines: water resources, food security and hydro-meteorological disasters. The human dimension is integrated throughout the programme for a better view of vulnerabilities to climate change and their impacts on poverty alleviation efforts. This strategy allows combining scientific and traditional knowledge into the PACC. For example, the perceptions of local communities about climate change and their coping strategies are included in the analysis and complemented by climate impact analyses that include a number of downscaled climate scenarios as a basis for impact studies.

The interdisciplinary and multi-actor setting of the PACC facilitates dialogue between the scientific community, implementing agencies, and policy-makers at national and international levels in a bid to find sustainable mechanisms for climate change adaptation.

Implementation of the PACC is facilitated and advised by a consortium of Swiss and Peruvian Non-Governmental Organisations, led by the provincial governments of Cusco and Apurimac. The programme is supported by scientific institutions in Peru and a Swiss scientific consortium.

The programme began its activities in February 2009. Up to now PACC has focused on creating a dialogue space for all stakeholders at different levels, increasing sensitivity and capacities among local stakeholders, initiating downscaling of climate modeling and identifying people's perceptions and coping strategies with regard to climate change.


# Mountain Biodiversity

Eucalyptus forest, Australia (Ch. Koerner)

# Biodiversity in Mountains: A Natural Heritage Threatened by Climate Change

Eva Spehn
Christian Koerner
Global Mountain Biodiversity Assessment
Basel, Switzerland

The world's mountains are focal points of global biodiversity, hosting about half of the world's biodiversity hotspots. This is due to the great diversity of habitats within short distances, which is a result of altitudinal gradients, changes in exposition, and varying geology and soils.

In the forests of Mount Kilimanjaro (Ch. Koerner)

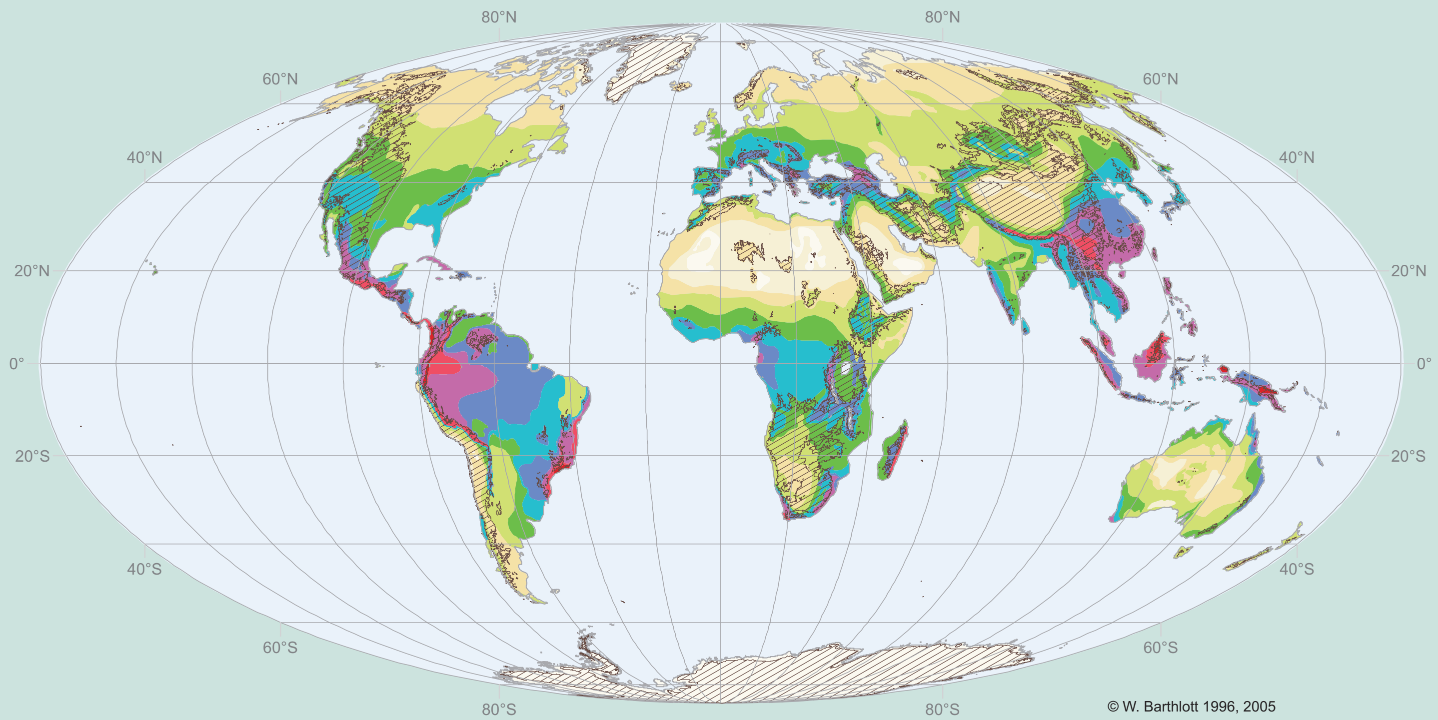
Mountains are also characterized by a high level of endemism, i.e. of plants and animals that occur nowhere else. Major centres of plant species diversity are in, or include, tropical and subtropical mountains: Costa Rica and Panama, the tropical eastern Andes, the subtropical Andes, the Atlantic forests in Brazil, the eastern Himalaya-Yunnan region, northern Borneo, New Guinea, and East Africa. For example, the mountains of tropical and subtropical America harbour over 90,000 species of flowering plants (Figure 5.1). Epiphytes such as mosses and ferns are an important component of this richness: Total moss diversity in the five tropical Andean mountain countries is estimated to be more than 7 times higher than diversity in the entire Amazon basin. Secondary centres of biodiversity are found in the Mediterranean mountains, the Rocky Mountains, the Alps, the Caucasus, and Central Asia. Mountains are also important centres of agro-biodiversity, with a great variety of locally adapted crops and livestock – an important genetic resource and an asset for assuring food security for a growing global population. Mountain biodiversity also supports the livelihoods of mountain and lowland populations by providing basic environmental services such as freshwater, timber, medicinal plants, and recreation for an increasingly urbanized world.

Mount Kinabalu (4101 m) in Sabah, Malaysia, is estimated to harbour over 4000 plant species, more than one-quarter of all the plant species in the United States of America.

## Climate change: a threat to mountain biodiversity

Mountain areas have been increasingly affected by loss of biodiversity due to expansion and intensification of land use. In recent decades, climate change has emerged as another threat to diversity. With higher temperatures predicted, habitats for organisms adapted to the cold will be curtailed. Species already inhabiting summit regions will be in a very difficult situation, because they can go nowhere else. Longer summers with a greater incidence of drought are expected in many mountain regions worldwide. The main issue is the speed of change: ongoing and expected climatic changes are much faster than what evolution and migration are commonly able to cope with, even though the pace of plant species moving uphill is quite rapid; in the Alps, for example, it has been about 10 m on average per decade during the past century. An acceleration has been reported recently. Uphill movement increases the total number of species in the upper belts. Rare species or those adapted to the cold may be outcompeted in the long term. Mountain ecosystems are also likely to be exposed to more extreme events such as intensive rainstorms, severe insect and disease outbreaks, longer fire seasons and more severe fires.

Figure 5.1: Global biodiversity and mountain regions: Number of species of vascular plants in a regional perspective (100x100 km).




Diversity Zones (DZ): Number of species per 10,000 km²

- DZ 1 (<100)
- DZ 2 (100 – 200)
- DZ 3 (200 – 500)
- DZ 4 (500 – 1000)
- DZ 5 (1000 – 1500)
- DZ 6 (1500 – 2000)
- DZ 7 (2000 – 3000)
- DZ 8 (3000 – 4000)
- DZ 9 (4000 – 5000)
- DZ 10 (> 5000)

Mountains and highlands > 1,000 m

Map scale: approx. 1:200,000,000

Map Source
W. Barthlott, G. Kier, H. Kreft, W. Küper, D. Rafiqpoor, & J. Mutke 2005, Nees Institute for Biodiversity of Plants, University of Bonn

Terrain data: resampled from GTOPO30, produced by US Gelogical Survey (UGS)
Continental boundary: ESRI Data and Maps

Map projection: Mollweide
Cartography, mountains: Ulla Gaemperli Krauer 2009 (CDE University of Bern)

Mount Sajama, Bolivia (Ch. Koerner)

## The need to reconcile conservation and development

Managing mountain biodiversity has increasingly been recognised as a global responsibility in recent decades. Globally, protected areas have increased sixfold to eightfold in the last 40 years, largely in mountain areas. Many of these are inhabited by local people. Climate change may further increase the pressure for more conservation as well as for more intensive resource use in mountains. Innovative concepts and approaches are thus required to reconcile biodiversity conservation with development. Not much time is left to reach the UN Millennium Development goal of reducing poverty and hunger by half by 2015, and even less time is left to reach the 2010 target to reduce the loss of biodiversity. Both are global commitments, but they are often conflicting goals in a concrete local and regional setting. One way of reconciling them is by engaging local people in the stewardship of their natural heritage, for example within the framework of conservation landscapes which include biodiversity sanctuaries within a pattern of agricultural land use. Conservation landscapes are increasingly recognized for their potential to maintain high levels of biodiversity in combination with intensive but diversified small-scale farming, where high population density inhibits the establishment or extension of protected areas. The Kigezi Highlands in Southwestern Uganda is such a conservation landscape. Despite intensive use and a population density of over 250 people per km$^2$, the agricultural production system supports biodiversity management based on a wide variety of crops and trees deliberately planted on farms. Many small-scale farming areas in Africa and in other parts of the world have the potential to become conservation landscapes owing to their diversified land use. Highly developed regions such as the Alps and, by contrast, mountain regions which are still in a natural or even pristine state – for example the Patagonian Andes – require different strategies such as creating protected areas or maintaining wilderness areas.

## Mountain forests

Between 1990 and 2000, the area of natural forest decreased by 6.8% in the tropics, while in temperate areas it expanded by 1.2%, mainly due to an increase in forest cover in the mountainous countries of Europe (FAO 2001). Natural mountain forests are important reservoirs of species and they are essential for the provision of key environmental services such as freshwater. They can reduce peak runoff and local flooding, although this effect decreases as the size of the watershed and its distance from a headwater area increase. Many of the world's largest cities, including New York, Jakarta, Tokyo, Mumbai, Rio de Janeiro, Los Angeles, Barcelona, Nairobi, Melbourne, Bogota, La Paz, and Mexico City rely on protected forests in their watershed for much of their freshwater supply.

Evergreen tropical cloud forests are the most fragile and most diminished parts of mountain forests, but they are very rich in endemic species, i.e. species that occur nowhere else. In Peru, for example, 30% of the 272 species of endemic mammals, birds and frogs are found in cloud forests. In Ecuador, 17,000 $km^2$ of tropical cloud forest contain 3400 vascular plant species – 300 more than in 70,000 $km^2$ of lowland Amazon forest. Cloud forests also harbour the wild relatives and sources of genetic diversity of important staple crops such as beans, potatoes and coffee. Moreover, montane cloud forests capture moisture from fog or clouds and thus add substantial amounts of water to the hydrological system. This is especially important in dry areas with frequent fog or cloud formation.

Cloud forest, Bolivia (E. Spehn)

# Conservation Corridors in the Hindu Kush-Himalaya

Conservation biology has demonstrated the usefulness of large habitats for maintaining larger populations with high genetic diversity. Such habitats provide connectivity, which assures the flow and movement of organisms across larger landscapes. These movements may be altered by climate change.

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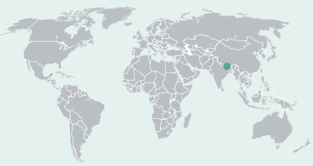
Bandana Shakya and
Eklabya Sharma
ICIMOD Kathmandu
Nepal

Kanchenjunga from Darjeeling, India (N. Chettri)



In mountains, connectivity across altitudinal gradients will be important for the movement of organisms. The International Centre for Integrated Mountain Development (ICIMOD) is therefore promoting the idea of establishing seven transboundary landscapes and four trans-Himalayan transects across the Hindu Kush-Himalaya region, which will extend from low- to high-altitude areas and from dry to wet areas, with the aim of improving connectivity within the landscapes and systematic environmental monitoring in the region. The transboundary landscapes are nested within the transects. One of these transboundary landscape projects is the Kanchenjunga Landscape, which is shared by India, Bhutan and Nepal. The regional cooperative framework for Kanchenjunga addresses the root causes of biodiversity loss in the landscape – habitat loss, fragmentation of the landscape, over-extraction of resources, uncontrolled tourism – in order to exploit complementarities between and coordination among the many actors engaged in biodiversity conservation. Community-based conservation projects are being implemented with a view to improving local livelihoods. The present framework enables the countries to develop an implementation plan in line with the national conservation agendas.

# Mountains, Climate Change, and Fire Hazard

Kilimanjaro is an icon of climate change due to its melting ice cap: Over the last century, rainfall has decreased by 30%, while temperatures have been rising since the 1970s. Another issue is the incidence of fire.

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View of Mount Kilimanjaro, Tanzania (Ch. Koerner)

The incidence of fire has increased, especially on the upper slopes, as the combined effect of climate change and human activities such as honey gathering and illicit logging. This has led to the destruction of 50 $km^2$ of montane cloud forest during the last three decades and a lowering of the tree line by 800 m. With the loss of the forest went one of its major environmental services, trapping water from clouds. The forest destroyed was by far more important for water supply to the densely populated lower slopes than the melting ice cap (Hemp 2005). A special fund was set up for fire fighting, to which various donors including environmental institutions and the private sector made contributions. A comprehensive development approach is now needed which includes effective patrolling of the endangered zones and an effective early warning system, and which considers the needs of a growing population (OECD 2003).

In dryer areas of the world, mountain regions are sensitive to fire. Increased frequency and intensity of fire has already been observed around the globe. Cases in point include the Bale Mountains in Ethiopia, the Blue Mountains of New South Wales in Australia, the Western Rocky Mountains, and the mountains on the fringes of the Mediterranean, which are likely to become regions of sustained fire hazard in future. As natural fires are quite rare at higher elevations, most natural highland vegetation is not specifically resistant to this hazard and is easily transformed when fires become more frequent as a result of climate change and human action, including arson. Burned areas are then normally poorer in species, particularly in forested areas, and are usually characterised by more widespread and common species.

# 6
# Food Security in Mountains

Irrigated terraces, Nepal (T. Hofer)

# Mountains, Climate Change and Food Security

## Food security in mountains

**For millions of mountain people, hunger and the threat of hunger are nothing new. Harsh climates and difficult, often inaccessible terrain combined with political and social marginality make many mountain people vulnerable to food shortages.**

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Mountain agriculture, Central Asia (D. Maselli

A 2003 FAO study indicated that of the 720 million people living in rural mountain areas worldwide, as many as 245 million, or one-third, are at risk of, or actually experiencing, hunger (Table 6.1). Today, this figure may be much higher, given the global economic situation and the recent crisis in soaring food prices.

The livelihood systems of rural mountain people are quite diversified. FAO has estimated that 78% of the world's mountain area is not suitable or is only marginally suitable for growing crops. Grazing and forestry are more adapted to mountain ecologies. In the recent past, many mountain communities have altered their agricultural practices to meet the demands of a wider market economy, often relying on a single cash crop for their livelihoods. As a result, indigenous knowledge about local foods and traditional agricultural practices has been eroded and agricultural diversity has declined. This has contributed to food insecurity and malnutrition in mountain areas.

Nutrition studies indicate that mountain populations suffer from high rates of micronutrient deficiencies. For example, inhabitants of the Andes, the Himalayas and mountain ranges in China are considered to be at highest risk of iodine deficiencies. In addition, data from the Himalaya and the Andes indicate a high prevalence of vitamin A deficiency. Hunger and micronutrient deficiencies are contributing factors to the significantly higher infant mortality rates in mountain regions.

## The threat posed by climate change

Until recently, economic, political and social changes such as globalisation and migration were taken to be the main drivers of change in mountains. Today, it is increasingly acknowledged that climate change and its consequences are likely to have similar or even greater impacts.

People living in mountain areas are used to the fact that the climate varies considerably from year to year, season to season and day to day at different altitudes, and even on slopes with different exposure. Traditional land-use systems have adapted to this variability, for instance, by growing sun-loving plants on the warmest slopes and moving livestock to graze on high summer pastures after the snow has melted. In the future, however, climate change may increase climate variability beyond the limits of past experience. For example, as glaciers disappear and snowlines move upwards, river flows are likely to change, and lack of water may become an increasing problem. Higher temperatures may also affect the health of both people and livestock; for instance, malaria is likely to continue moving to higher altitudes, as already reported from East Africa and the Andes. For wild plants and animals, a warmer climate may mean extinction as their habitat disappears. In summary, climate change will worsen the living conditions of mountain farmers who are already vulnerable and food insecure. Rural mountain communities dependent on agriculture in a fragile environment will face an immediate risk of increased crop failure and loss of livestock. As a result of all these trends, hunger and malnutrition will increase.

At the same time, climate change may bring regional and local benefits. In the mountains, higher temperatures could mean that trees produce higher yields of timber and that crops can be grown at higher altitudes, if water and soils are adequate. An extended growing season and accelerated soil decomposition, leading to better nutrient intake by trees and other plants as well as to increased growth and productivity, may be additional positive impacts of climate change. Notwithstanding, for many mountain areas in the South, present models predict that water availability will be lower and rainfall more erratic.

Farmers at work, Bolivia (S. L. Mathez-Stiefel)

Anti-Atlas, Morocco (T. Hofer)

Table 6.1: Rural mountain populations vulnerable to food insecurity (developing and transition countries) by region and altitude.

| Regions | Vulnerable mountain population (million people) | | | |
|---|---|---|---|---|
| | < 2500 m | 2500-4500 m | 4500 m and above | total |
| Asia and the Pacific | 126.1 | 10.8 | 3.1 | 140.0 |
| Latin America and the Caribbean | 23.8 | 8.9 | 0.2 | 32.9 |
| Near East and North Africa | 25.3 | 4.4 | 0.03 | 29.7 |
| Sub-Saharan Africa | 28.5 | 2.3 | 0 | 30.8 |
| Countries in transition | 10.7 | 0.5 | 0.02 | 11.2 |
| Total developing and transition countries | 214.4 | 26.9 | 3.3 | 244.6 |

FAO 2003

## The way forward

There is a growing body of adaptive action relating to climate change in mountains. In terms of climate change and food security, examples include:

- Review of land use plans and zoning, a crucial measure for both mountains and surrounding lowlands, as floods, landslides and avalanches are likely to become more severe and affect livelihood systems in areas so far considered safe;
- Adoption of a conservation-by-use philosophy and better integration of agriculture, livestock, forestry, aquaculture and local processing in order to help diversify income sources and make mountain food systems more resilient to climate change;
- Promotion of multifunctional, biodiverse and organic farming systems as well as localised, diversified food systems to improve food security in mountain areas facing climate change. Ecological and organic farming also reduce the demand for intensive irrigation while enhancing soil capacity in order to retain water and improve water quality. Finally, ecological and organic farming mitigate climate change by reducing greenhouse gas emissions and increasing carbon sequestration in plants and soils;

- Maintaining and enhancing the particularly high agro-biodiversity and cultural diversity in mountain areas which offer significant adaptation potential to respond to the challenges of climate change;
- Providing education and training in the nutritional value of locally grown and gathered food to mountain families and the providers of health and education services in mountain communities. This helps to ensure that mountain people remain healthy and are able to participate in the economic and social development of their communities and to find appropriate solutions to face the challenges of climate change;
- Promoting a supportive environment for the development of high-quality products and services from mountain areas as a means to improve livelihoods and protect mountain environments and encourage more active involvement by the private sector in all parts of the value chain for high-quality mountain products;
- Integrating local and indigenous environmental knowledge and practices in climate change adaptation and food security strategies. The diversity of cultures and knowledge systems in mountain areas must be taken account of in adapting to climate change, and be recognized and enhanced through public policy and investment;
- Fostering capacity building for all stakeholders in climate change processes and trends, mitigation and adaptation measures, and food security options in mountain regions, along with the establishment of appropriate extension services;
- Improving economic conditions and facilitating access to resources for mountain communities through mechanisms such as payment for environmental services.


Women group in action, Nepal (T. Hofer)

# Adapting Potatoes to Climate Change in the Andes

In Peru, the International Potato Center, the Ministry of Agriculture, local and indigenous producers, retailers, processors and supermarkets have worked together to develop and market a line of native potatoes in Lima, under the brand name *T'ikapapa*.

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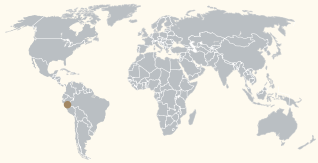
Market in Peru (S. L. Mathez-Stiefel)



As pest diseases and temperature increase owing to climate change, farmers are forced to move higher and higher up the mountains to avoid them. Peru is home to more than 2000 varieties of native potatoes, the vast majority of which are cultivated above 3800 metres, where other crops cannot grow. However, potato consumption has decreased in Peru, as consumer preferences have shifted to imported rice and noodles, and this has hurt the incomes of potato producers in food-insecure communities. *T'ikapapa* was established to boost income for Peruvian potato farmers and raise consumer awareness about the nutritional value of native potatoes. Also, the government has acted to reduce costly wheat imports by encouraging people to eat bread that includes potato flour, as potato cultivation can promote food security and alleviate poverty.

# Climate Risk Management in Nepal

In Nepal, climate change constitutes an additional threat to the already deprived rural population heavily engaged in agriculture. Increasing trends of extreme climate events and natural disasters due to climate change could undermine future food security.

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Terraced landscape, Nepal (T. Hofer)

Although the government of Nepal has constantly responded to climate risk impacts, a shift from reactive emergency response to proactive disaster risk management initiative is crucial in order to save agricultural livelihoods. In response to a request from the government of Nepal, FAO is implementing a Technical Cooperation Project to promote national and local capacities for disaster preparedness and climate risk management in the agricultural sector with the long-term goal of making the food system in Nepal more resilient to the impacts of climate change. The main project outputs include a) strengthening of technical and institutional capacity within the Department of Agriculture for disaster preparedness and climate risk management, and b) identification and demonstration of location-specific technologies for climate change adaptation and disaster risk management at community levels.

# Diversifying Incomes in India and Morocco

Diversifying income opportunities through the promotion of high-quality niche products is a key element in the development of strategies for improving food security in mountain areas in the context of climate change.

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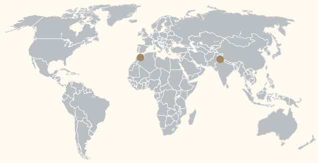
Saffron plant (T. Hofer)



Diversification of crops and livelihoods makes socio-economic systems more adaptive and responsive to environmental change, thus enhancing the resilience of rural mountain communities and their capacity to cope with climate change impacts. Through the Rawain Women's Cooperative Federation, 2800 women in India's Central Himalayan Region are employed by agricultural micro-enterprises. Knowledgeable in traditional agricultural practices, which use no chemical inputs, the women have been able to capitalize on the growing demand for organic produce. The federation is marketing 18 different types of traditional crops in Indian cities, including buckwheat, horse gram and foxtail millet.

In the Anti-Atlas region of Morocco, saffron, also known as "red gold", is a unique high-value mountain product. It is a key source of income for approximately 3000 smallholder farmers who harvest the saffron at the end of October, store it in safety boxes, and sell it on the market during the course of the year as family cash needs arise. An FAO/Mountain Partnership project was launched to support improved production, processing and marketing of saffron.

Village scene in Central Asia (D. Maselli)

# 7

# Migration and Mountains

On the move, Nepal (D. Maselli)

# Migration, Household Resource Allocation, and Climate Change

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Human migration occurs for many reasons. Some people move to marry or to continue their education; others move for political security or religious freedom. However, the single most important reason for migration is economic – labor migration.

Approach to Naryn, Kyrgyzstan (K. Anderson)

Labor migration has important effects on labor markets and household decision-making. It also has the potential to influence community development and alleviate pressure on local natural resources. Climate change can be a catalyst for migration; in primarily agricultural areas, it can impact the productivity of land and the viability of pastures, motivate migration, and alter consumption at home and abroad.

## People pushed and pulled

Economists use two theoretical approaches to explain labor migration. The first economic explanation for migration is often called the push-pull hypothesis. Economic factors in the origin country push workers into other markets, while economic factors in destination countries pull workers in. In this context, labor migration acts as a market-clearing mechanism. Suppose for example that global demand for energy is high, and energy-producing countries need more labor than is locally available. Wages in the energy sector are high and pull workers from other regions into these countries. In contrast, suppose the productivity of land in a mountain agricultural region is low, partly due to rising temperatures and inadequate rainfall. Income is low in this region relative to income in energy-producing regions; low wages push workers out of the mountain region into higher wage countries. In the global market over time, the movement of workers from low-wage to high-wage areas reduces regional disparities in wages, income, and employment; the labor market clears in the long run.

## Migration as a form of insurance

A second economic approach to migration is to view it as a form of insurance. Suppose that in one country income is volatile during the year or over time. In agricultural areas, income may be high during the harvest season and low during the winter; consumption patterns reflect this volatility in income. A family can smooth its consumption over time by saving or storing goods during the summer months and spending down savings in the winter, but without developed and safe institutions for saving, savings will not be adequate to compensate families during the difficult times. As an alternative, a family can use migration to protect itself from negative shocks to income and wealth. If the family sends someone to a more stable market for work, then during the downturn in the local economy, the family receives income support from abroad. In this way, consumption is smoothed over time, and the family gains the peace of mind of a stable, constant flow of income. Remittance flows from migrants do stabilize income over time in lower-income countries. Income stability encourages investment and planning for the future (Chami, Hakura, and Monteil 2009).

### A migrant's view

"There is not enough demand for skilled labor here. The government knows the problem but offers no support. There are opportunities for business here but we do not have starting capital. I need credit to buy new equipment, but I cannot get credit. Goods brought from China are cheaper and the competition is tough. I am looking for alternatives to make money but migration seems to be the best choice. So most likely I will have to migrate again; there is no opportunity here. I will have to go to Russia and earn money there. The wage rate here is not enough to repay the debt."

Skilled young craftsman from Badakshan, Tajikistan, working in construction in Russia.

Labor migrants in rural Badakshan, Tajikistan (K. Anderson)

New homes in migrant suburb of Bishkek, Kyrgyzstan (K. Anderson)

Changes in climate and changes in the environment contribute both to labor migration as a market-clearing mechanism and labor migration as insurance. People often move for environmental reasons. A natural disaster such as a hurricane, earthquake or tsunami destroys local capital, both physical and human; people leave for safer markets, but most eventually return to the same place. Climate change also contributes to labor migration. It has been cited as a cause of "desertification, soil erosion, deforestation, rising sea levels and the salinization of water resources" (Boncour, 2009). All of these factors contribute negatively to local productivity and income; migration is one way local populations can adjust to economic damage precipitated by climate change.

## Remittances and household resource allocation

In addition to the direct effects of labor migration on productivity, employment, and income in sending and receiving countries, migration has an important secondary effect on markets through remittances. Figure 7.1 shows the increasing importance of remittances in low-income countries. Between 1999 and 2008, official remittances increased from 3% to almost 7% of GDP. Worldwide, remittances have become an increasingly important source of foreign exchange.

The impact of remittance income on economic development depends on how the transfers are used in the short run and the long run. Remittance income can be used to support current consumption, reduce labor supply of family members, or finance investment. Remittance income can be invested in physical capital, livestock and land or in human capital through education, training and health. Investments in agriculture are directly linked to environmental concerns and may improve or exacerbate existing environmental problems. Community investments in infrastructure, if carefully developed, can lower the costs of energy and transport. Household and community human capital investments are generally expected to improve skill and knowledge and lead to more efficient allocation of resources within households, businesses, and communities.

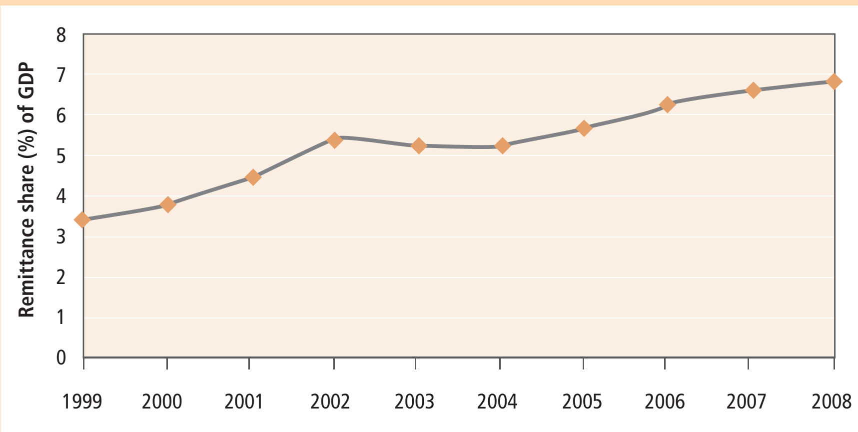
In general, remittances to lower income countries increase household income and reduce poverty; these effects are larger in the poorest households. A recent World Bank study estimated that between 1995 and 2004, one-fifth of the poverty reduction in Nepal was due to labor migration and remittances (Lokshin, Bontch-Osmolovski, and Glinskaya, 2007). Remittances are mostly spent on living expenses and often allow women, children and the elderly to reduce their hours of paid work. For children and younger women this means that remittances can motivate them to remain in school or to enter job training programs.

On the negative side, remittances cannot fully compensate for the lack of young workers in migrant communities. In some communities children are raised by grandparents because parents migrate for work; these children often exhibit more behavioral problems than other children and do worse in school. Remittance income is also frequently used for large celebrations such as funerals and weddings; while the payment may improve one's status in the community, it does little to develop skills, create jobs, or make the household more secure. Finally, remittance income has been used to purchase livestock in communities with inadequate pasture management and dwindling supplies of water. Short-run gains motivate the purchase of large animals; long-run planning is secondary.

## The relevance of climate change for migration

There are many ways in which climate change can affect economic performance. "Climate change is the mother of all externalities: larger, more complex, and more uncertain than any other environmental problem" (Tol 2009). Greenhouse gases are produced from many different sources – homes, farms, businesses, transport – and their effects are pervasive – agriculture, energy, health, labor productivity. Resource scarcity precipitated by climate change can motivate inter-regional conflict. The literature suggests that climate change has a negative impact on economic performance in the long run if temperatures continue to rise; estimates are in the range of 1-4% of GDP, the equivalent of over one year of economic growth. In low-income developing countries, the cost of climate change is more than double the world average. While the impact of climate change on labor productivity is not clearly documented in the literature, some argue that the impact may be "substantial." Low productivity precipitated by climate change keeps wages low in low-income, primarily agricultural countries, and encourages the most skilled workers to move to less affected markets. Income is remitted to sending communities and can help households adjust their consumption to better fit a changing environment.

Figure 7.1: Remittances into low income countries, 1999-2008 (World Development Indicators Database 2009).



# Migration from the Mountains of Central Asia

Remittances from migrants provide an important share of the income of the countries in Central Asia. For Tajikistan, official remittances and other external transfers accounted for 39 % of GDP in 2006, one of the highest figures in the world. 40% of households received remittances in cash or kind, with over 70% of the poorest households receiving transfers (Brown, Olimova, and Boboev, 2008).

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School built with remittances from village diaspora,Badakshan, Tajikistan (K. Anderson)

Migration significantly alters income, expenditure and investment patterns of households. A survey done in Kyrgyzstan in 2008 (Anderson and Qiyobekov, 2009) on monthly earnings abroad (primarily in Russia) found that education paid off in the labor market abroad. Monthly income was 20% lower for secondary school dropouts and 20% higher for the most highly educated workers in comparison to all other migrants in the sample. Legal registration was also important; income was 22% lower for workers without legal registration. Workers in the retail trade earned over 50% more than workers in other occupations. The average monthly income earned abroad was $635; the wealthiest migrant received $12,000 a month and was engaged in trade.

The survey also found that remittances significantly increased the proportion of family income that was allocated to living expenses. Remittances also led to more consumption of communication equipment such as TVs, radios, and cell phones and had no effect on entertainment, education, or other durables. However, migration history mattered. Expenditures on entertainment and savings fell with the duration of migration, but expenditures on education increased. Expenditures on all durable goods increased with the number of migration spells from the household. There was no negative effect of migration and remittances on relationships within the family or community.

Migrant family in Bishkek, Kyrgyzstan (K. Anderson)

The effect of migration on the local environment is difficult to assess, and the available data do not offer a clear answer. The literature suggests that climate change has had a significant negative impact on productivity, particularly in low-income countries. Emigration can offset this negative effect of climate change by giving households more occupational and location choice; individuals can move from low productivity agricultural areas to higher productivity urban areas and improve the economic well-being of their households at home and their communities. In addition, remittance income can also be an effective tool to combat the negative impact of climate change. Remittances increase household income and lower poverty; if remittances are used to purchase more efficient durable goods and housing, then migrant households better adapt to resource scarcity and climate change in their own communities. However, there are costs to long-term migration. Rural households are highly likely to invest in livestock with remittance income, and the combination of increasing livestock numbers and unsustainable pasture management can lead to pasture degradation (Schoch 2009). In addition, as the most able workers and their families leave the community, communities may be less willing and able to effect changes that would streamline community response to the pressures of climate change. Policy initiatives can help mitigate the negative effects of migration on communities by encouraging sustainable investment, education, good management, and support from a diverse diaspora.

# Mountains and Climate Change

## A Global Concern

Mountains in Mongolia (E. Gabathuler)

# Mountains and Climate Change: A Global Concern

Mountains are among the regions most affected by climate change, and some of the clearest evidence, such as the shrinkage of glaciers, comes from mountain areas. As the present publication shows, the implications of climate change in mountains will reach far beyond mountain areas: Climate change in mountains is a global concern.

## Mountains: a key concern on the global climate change agenda

Mountains provide freshwater to half of the world's population. Climate change will affect the availability of water. In many cases, this will mean less water when it is most needed (Chapters 2 and 3 in the present publication). Regions with the most mountain land are also the regions where mountain water for surrounding lowlands is most important – including the countries across the Eurasian continent from the Middle East to China, the Andean countries, the Nile Basin, and western North America (Map page 69). Also, many countries with less mountain land critically depend on mountain waters for specific regions or uses. Climate change in mountains will thus have important implications for irrigation, urbanization and industrialization, and hydropower generation. This will mean using water more efficiently, increasing storage capacities, and establishing, or re-visiting, institutional arrangements for sharing water equitably within and between nations.

Mountain areas are typically exposed to multiple hazards. Climate change is likely to increase this exposure, as extreme events such as storms, landslides, avalanches, and rockfalls are likely to become more common and more intense in mountain areas (Chapter 4), threatening both livelihoods and infrastructure. Hazards cannot be prevented, but mountain regions can be supported in managing the risks emanating from these hazards. This support begins with preparedness and ends with recovery; key ideas include effective early warning systems, land use zoning, and strategies for intervention.

Half of the global biodiversity hotspots are in mountain regions. They are an important global heritage that is being threatened by climate change and human action (Chapter 5). Impressive achievements have been made in safeguarding this heritage; protected areas have been the fastest growing land use category in recent decades, especially in mountains. While mountain biodiversity is thus increasingly seen as a global common good by many, local communities who directly depend on its services must be included in stewardship of this valuable resource. Mountain communities should see more tangible benefits from conservation efforts than has been the case in the past. Payment for Environmental Services is a way to achieve this aim.

Mountains are home to about 10% of the global population. The large majority of mountain people live in developing countries. One third of them are food-insecure, a high proportion in global comparison (Chapters 6 and 7). Mountains are often limited-choice environments due to harsh living conditions and a marginal position in terms of economic integration and political decision-making. External support is needed in order to reduce poverty levels. As temperatures rise, however, climate change might hold prospects for mountain agriculture – for crops previously not grown or limited to lower altitudes – provided that water, land, labour and capital through credit schemes or remittances from migrants are available to exploit such opportunities, and that access to markets is assured.

## The importance of moving beyond climate change

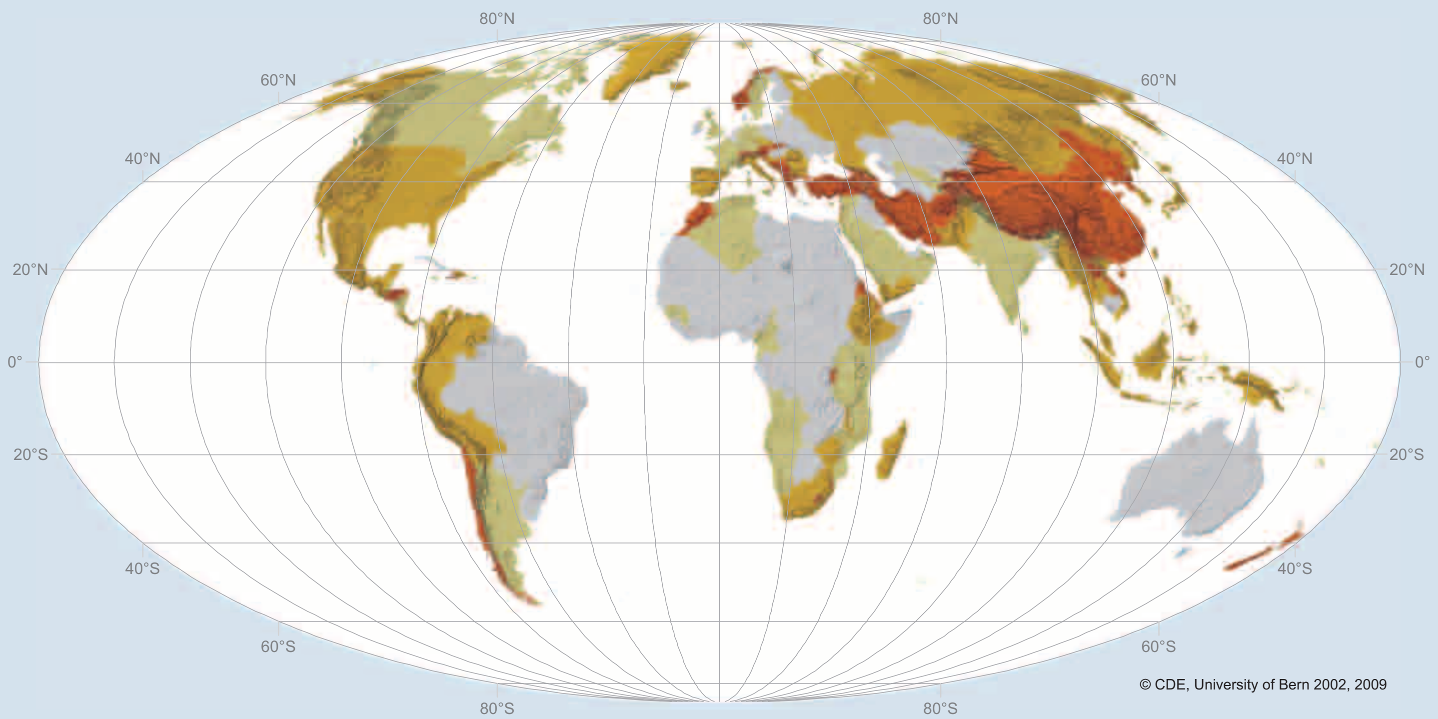
Much recent and current debate on adaptive capacity and vulnerability has been driven by the climate change agenda, but understanding the multidimensional nature of drivers of change, responses and feedback mechanisms is essential. This also applies to mountain regions, which are exposed to a wide range of mainly external drivers of change, including political, economic, and socio-cultural forces. Climate change action must therefore be embedded into a more general framework as provided, for example, by the concept of sustainable development. Any such framework will have to take note of the great diversity of mountain development contexts relating to environment, people, economies and cultures (Map below). Specific and tailored strategies will therefore be needed when it comes to climate change action. Human factors such as governance need to be considered in order to avoid simplistic projections about the impacts of climate change.

## Managing climate change in mountains: a huge externality

Many mountain countries, especially those with a high percentage of mountain territory, are developing countries with lower levels of industrialization, and many are smaller nations (Map below). For these countries, adaptation is the main answer; they are far less the cause of the problem than they are the victims when it comes to climate change. For them, this change is a huge externality that will mean substantial additional costs in future. As adaptive measures are designed and implemented, the involvement of mountain populations is a must, as they have important knowledge and will be among those most directly affected by climate change and remedial action. As the case studies collected in the present publication show, the involvement of local people is increasingly becoming a reality.

Adaptation will have to be supported by mitigating measures that address the root causes of climate change: the emission of greenhouse gases and other substances that cause global warming. The involvement of economic and population centres

Map of the countries of the world and their mountain areas.





Percentage of mountainous area per country

- 0 – 10 %
- 10 – 25 %
- 25 – 50 %
- 50 – 100 %

Map scale: approx. 1:200,000,000

Map Source
Terrain data: resampled from GTOPO30, produced by US Gelogical Survey (UGS)
Administrative: ESRI Data and Maps
Map projection: Mollweide
Map authors: Sebastian Eugster, Hans Hurni, Albrecht Ehrensperger, Thomas Kohler and Kristina Imbach 2002 (CDE, University of Bern)
Map compilation 2009: Ulla Gaemperli Krauer (CDE, University of Bern)

outside mountain regions in industrialized, emerging and developing economies will be critical for achieving a tangible reduction of these emissions, as a major share of the greenhouse gases are released in these areas. Some of the largest emissions of greenhouse gases come from countries with a significant proportion of mountain areas, such as China, the US, and Russia (Map page 69).

## The way forward

**At the global level:** Chapter 13 of Agenda 21, with its focus on mountain areas, as well as the UN Framework Convention on Climate Change and its Clean Development Mechanism (CDM), provide frameworks for concrete action to tackle the drivers of climate change and to mitigate its impact. It is hoped that the UN Climate Change Conference in Copenhagen in 2009 will be a starting point for strengthening these mechanisms. As many mountain countries are smaller developing nations, they have not benefited much from the CDM programme and the carbon market, due to institutional constraints and the complexity of accessing funds. This requires urgent re-examination. Mountains and money do not easily come together. Technological, financial, and institutional support for development in mountain countries thus need be strengthened. Mechanisms for coordinating and extending such support include the Global Environment Facility (GEF), the National Adaptation Programmes for Action (NAPA), and the Global Climate Change Alliance of the EU, to mention but a few mechanisms already in place.

**At the national and regional levels:** Many countries have established national focal points and regional bodies for managing climate change and have carried out impact assessments to determine how climate change is likely to affect them. However, progress on mainstreaming climate change adaptation has been limited, especially in relation to key development concepts such as poverty reduction policies, land use planning and zoning, and national development strategies. There is a growing number of Payment for Environmental Services (PES) programmes with proven track records in industrialized and developing countries. PES relating to watershed management, water regulation for hydropower and irrigation, biodiversity conservation, and hazard prevention are a means for ensuring that mountain communities can benefit from the implementation of measures to maintain environmental services that are important for lowland areas and their large population centres. Many of the efforts made to date in climate change adaptation are generic. Proven practices that could be upscaled are as yet lacking. Documentation and lessons learnt will thus be crucial for establishing a body of sound experience tailored to the specific needs of mountain regions.

**The importance of research:** The research community has a responsibility to sensitize policy-makers and the public about climate change in mountains and its implications in wider highland-lowland interactive development contexts. Research should also focus on designing integrated mitigation and adaptation measures. Given the paucity of reliable and long-term data on mountain climates and resources, especially in countries of the South and East, there is a need to establish long-term observatories and monitoring mechanisms that will allow more accurate projections of climate change, more precise assessment of impacts, and documentation of existing adaptation strategies in and beyond mountain regions. For the research and education communities, capacity development and transdisciplinary approaches will be important components of all these activities.

Now is the time for action in addressing climate change issues in mountains. This could help transform currently perceived problems into opportunities for a better future in mountain regions and in the many lowland areas that depend on their services.

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## 1 Climate Change in Mountains


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"By three methods we may learn wisdom:
first, by reflection, which is noblest;
second, by imitation, which is easiest;
and third, by experience, which is the most bitter."

Confucius

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**Mountains and Climate Change: A Global Concern**

Mountain Focus Group, CDE, University of Bern; Switzerland
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Mountains are among the regions most affected by climate change. The implications of climate change will reach far beyond mountain areas, as the contributions in the present publication prepared for the UN Climate Change Conference in Copenhagen in 2009 show. Themes discussed are water, glaciers and permafrost, hazards, biodiversity, food security, and migration. The case studies included show that concrete adaptive action has been taken in many mountain areas of the world. The publication concludes with a series of recommendations for sustainable mountain development in the face of climate change.

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