

Editorial

Climate change impacts on mountain glaciers and permafrost

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Due to their proximity to melting conditions under terrestrial conditions, mountain glaciers and permafrost are particularly sensitive to climate changes. In fact, the Intergovernmental Panel on Climate Change (IPCC) recognizes glaciers as the best terrestrial indicator of climate change, due both to their sensitivity to climatic variations and the clear visibility of glacier growth and shrinkage to the public (McCarthy et al., 2001). Mountain and lowland permafrost are similarly sensitive to climate changes because of their strong dependency on climatic conditions at the ground–atmosphere interface and the subsurface ice often involved (e.g., Osterkamp and Romanovsky, 1999; Harris et al., 2001). However, much less is known about the response of permafrost to changes in boundary conditions due to the wide variety of surface and ground conditions, and the complex interplay of the processes involved. Permafrost reacts in a much delayed and attenuated way to climatic changes compared to glaciers. Thus, both glaciers and permafrost together make up a key set of targets for monitoring climate change and its impact on terrestrial systems in cold regions (WMO, 1997; Haeberli et al., 2002). Glaciers constitute a straightforward and clearly visible indicator, permafrost a long-term and invisible one.

The evidence for current glacier retreat in most mountain regions of the world becomes continuously clearer and more detailed. New modelling of glacier response to climate change for the European Alps quantifies expected changes in the spatial distribution of glaciers as a response to temperature and precipitation trends, and predicts drastic losses of ice area and volume with future expected trends in temperature and precipitation (Zemp et al., 2007—this issue). For New Zealand, in general it turns out that climate sensitivity and past glacier changes are even larger than in Europe and that the strongest impact is observed on glaciers in the more humid parts of New Zealand (Hoelzle et al.,

2007—this issue). In Alaska, 98% of the glaciers examined in a sweeping study of hundreds of glaciers in eleven mountain ranges show thinning, retreating, or both (Molnia, 2007—this issue). A case study in Peru documents glacier area loss in a section of the Cordillera Blanca on the order of 10% between the 1960s and 2003 (Raup et al., 2007—this issue). Another study shows area loss on the order of 30% for the last decades for a section of the Tien Shan and examines the connection to temperature and precipitation observations (Bolch, 2007—this issue). Even the actual extinction of small glaciers in specific sites, as shown by Delgado et al. (2007—this issue) for the glaciers on Popocatepetl Volcano (Mexico), must be considered by now.

Significantly less numerous and more complex to interpret are the indications of permafrost changes due to climatic forcing. First of all, borehole temperature series point to marked changes in the ground thermal conditions (not covered in this issue). However, parameters other than the directly-measured ground temperatures also hint marked permafrost changes. Kääb et al. (2007—this issue), for instance, found a recent significant increase in rock-glacier speed in the Swiss Alps, possibly related to atmospheric warming in the region.

Mountain glaciers and permafrost are key scientific indicators for global and regional climate variation. However, understanding glacier and permafrost changes is equally important due to their impact on human life and nature through their crucial influence on the water cycle in cold mountains and their surrounding lowlands, due to their influence on landscape evolution and tourism, and – in this issue of particular concern – due to glacier- and permafrost-related hazards. Chiarle et al. (2007—this issue) show in how various and numerous ways glacier and permafrost changes recently caused natural hazards and disasters in the Italian, French and

Swiss Alps. Especially critical is the availability of large quantities of unconsolidated, unvegetated sediments as a consequence of general glacier retreat and permafrost degradation. In the Himalayas and Canada, great concern comes from supraglacial and moraine-dammed lakes occurrence, caused by general glacier retreat since the Little Ice Age ended, because of their potential to breach catastrophically (Quincy et al., 2007—this issue; McKillop and Clague, 2007—this issue).

The rapid shrinkage of mountain glaciers in many regions, the large uncertainty about permafrost response to climate change, and the urgent demand of detecting, anticipating, and reacting to historically un-preceded hazard situations in high mountains calls for adaptation of established modelling and monitoring approaches, or development of new ones. The GLIMS project is the first initiative aiming at globally mapping and monitoring the outlines of Earth's glaciers, a task that is fundamentally supported by the advent of operational space-borne earth-observation-technologies (Bishop et al., 2004; Kargel et al., 2005). Such global project is only possible through sound and robust data retrieval and management systems (Raup et al., 2007—this issue). Established ways of remote sensing of glaciers (e.g., Bolch, 2007—this issue; Raup et al., 2007—this issue), however, will have to be reconsidered; examples include timing and distribution of repeat satellite data acquisitions, and parameters observed and analysed. Paul et al. (2007—this issue) investigate future glacier monitoring strategies which need to be established as a consequence of accelerated down-wasting of glaciers due to global change based on examples derived from the satellite-derived Swiss Glacier Inventory. The examples highlight the necessary adaptations and indicate how the basic geometry of glaciers already has changed during recent decades. D'Agata and Zanutta (2007—this issue) discuss an approach and the problems involved for compiling a large number of different digital elevation models from maps and airphotos in order to derive a series of high-resolution geometry changes for a debris-covered glacier tongue in the Italian Alps.

New monitoring and modelling methods have to be evaluated and combined with established ones for glacier and permafrost hazard detection and management. Space-borne microwave techniques, for instance, allow for retrieval of relevant parameters even under conditions of frequent cloud cover and difficult direct access to potential hazard source areas (Quincy et al., 2007—this issue). The statistical, remote-based approach developed by McKillop and Clague (2007—this issue) provides a more systematic and objective, quick and inexpensive method for making

first-order estimates of the probability of catastrophic draining of moraine-dammed lakes. Initial steps have been taken in order to model the potential response of permafrost to climate change. Kääb et al. (2007—this issue), for instance, expect accelerated deformation speed for creeping mountain permafrost, and a variety of local-scale expressions of such general trend. Totally new approaches have to be developed to couple global and regional climate models to permafrost models, in order to quantify the potential impact of climate change scenarios to perennially frozen ground. Salzmann et al. (2007—this issue) and Stendel et al. (2007—this issue) investigate the possibilities to downscale the output of Global and Regional Climate Models (GCM, RCM) as input to permafrost models. The authors conclude that despite many uncertainties and inaccuracies the approaches offer a promising perspective to evaluate climate change impact on high mountain and lowland permafrost sites.

The authors of this preface strongly believe that the new challenges that arise from the currently observed climate changes demand integrated cryospheric observation and modelling approaches of glaciers, permafrost and related impacts. Such work is greatly facilitated by new earth observation and geoinformatics technologies. Interdisciplinary collaboration between modelling and earth observation experts, field-oriented scientists, and practitioners is best suited to ensure a sound response to new requirements for the monitoring and modelling of mountain glaciers and permafrost, and related hazards. In this sense, the present special issue is hoped to give a wide, though by no means complete, overview of recent results from investigating climate change impacts on mountain glaciers and permafrost.

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A. Kääb*

*Department of Geosciences, University of Oslo,
P.O. Box 1047, Blindern, 0316 Oslo, Norway*

*Corresponding author. Tel.: +47 228 55812;
fax: +47 228 54215.

E-mail address: kacaeab@geo.uio.no.

M. Chiarle

*CNR-IRPI, Strada delle Cacce 73,
10135 Turin, Italy*

B. Raup

*NSIDC, 449 UCB, University of Colorado,
Boulder, CO 80309-0449, U.S.A.*

C. Schneider

*Department of Geography, RWTH Aachen University,
Templergraben 55, D-52056 Aachen, Germany*

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