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# Meeting of Minds

## Decision-Makers from Asian and Alpine Mountain Countries Sharing Policy Experiences in Regional Cooperation for Sustainable Mountain Development

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# 1.5 Climate Change and High-Mountain Regions – Adaptation Strategies for the Alps

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A general climate-change adaptation strategy for the Alps still has to be developed. In fact, it was only recently that the discussion about the necessity of adaptation to already unavoidable impacts of continued atmospheric warming started. The National Research Programme 61 on sustainable water management or the recently initiated transdisciplinary project on climate change and hydropower funded by energy producers and the Federal Office for the Environment (FOEN) are examples from Switzerland of ongoing initiatives. Possibilities and limitations of options concerning complex natural systems in conditions of growing disequilibrium must be critically reflected and many unknown aspects relating to the involved socio-economic side must be taken into account. This constitutes a more difficult challenge than often assumed, especially in view of the increasing rate of change and the corresponding reduction in the degrees of freedom for decision taking. High-mountain regions already now show strong effects from climate change impacts. They may, therefore, be seen as "pilot cases" with respect to comparable geo- and ecosystem changes likely to spread towards lower altitudes in the foreseeable future.

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Fig. 1: Steingletscher and Gwächtenhorn, Sustenpass, Swiss Alps. The Steinsee Lake in the foreground started to develop after the 1940s and as such is a clear consequence of atmospheric warming and glacier retreat during the 20th century. Newly formed lakes in high-mountain areas are interesting as tourist attractions and hydropower potentials but can also constitute serious hazards to downstream settlements and infrastructure.

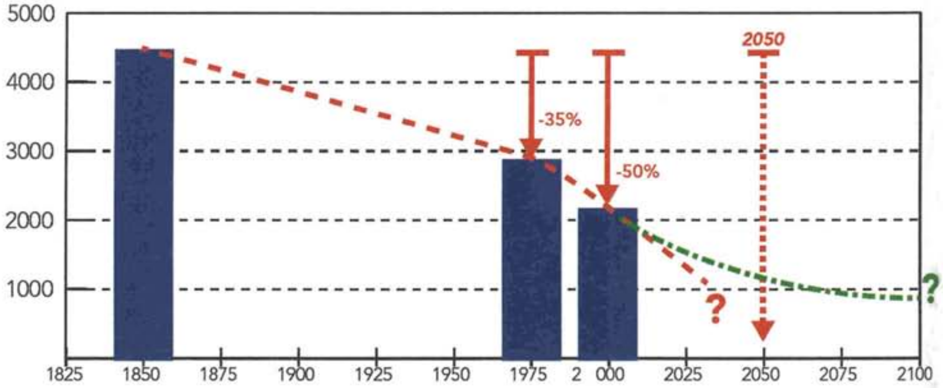
Photo: W. Haeberli 2009

Landscape, climate, society and infrastructure in high-mountain regions such as the Alps have been strikingly changing and continue to change at high if not accelerating rates (The Royal Swedish Academy of Sciences 2002). Environmental impacts from ongoing climate change on corresponding geo- and ecosystems are especially pronounced around and above timberline where effects related to snow and ice reflect increasing atmosphere/earth energy fluxes with extraordinary clarity (UNEP 2007). Snow and ice have very different characteristics and functions in high-mountain landscapes. Snow primarily depends on short-term weather conditions and constitutes a *"nervous interface"* with respect to processes and interactions between the atmosphere, the earth surface and living conditions for plants, animals, and humans. Glaciers, on the other hand, are *"safe indicators"* of integrated climatic changes. The global trend of shrinking glaciers is a key indication of worldwide and rapid changes in the complex climate system. Such changes also induce strong effects and long-term disequilibria within deep layers of perennially frozen slopes (permafrost), mainly found above the Alpine timberline. Due to the slow diffusion of heat in the ground, the response of permafrost – the "*invisible deep disturbance*" – to climate change involves a large inertia, but will continue for a very long time (centuries to millennia).

In the Alps, glaciers lost about half their total volume (roughly 0.5% per year) between 1850 and around 1975, another 20 to 25% (near 1% per year) of the remaining amount between 1975 and 2000, and some additional 15 to 25% (around 2 to 3% per year) since the turn of the millennium. During the 20th century, the warming of permafrost on mountain summits, due to atmospheric temperature rise, reached depths of more than 50 meters. Wide areas of loose morainic material on slopes have been exposed, the frequency of large-size rock avalanches from icy peaks increased and a number of new lakes have formed at various sites (Fig. 1), in cases constituting serious hazards to nearby settlements and infrastructure. Present-day ice, water and slope conditions at high elevations are different from conditions, which existed during the historical lifetime of Alpine villages and they are likely to soon change beyond the variability range of the Holocene, i.e. of the past about 10,000 years since the last Ice Age.

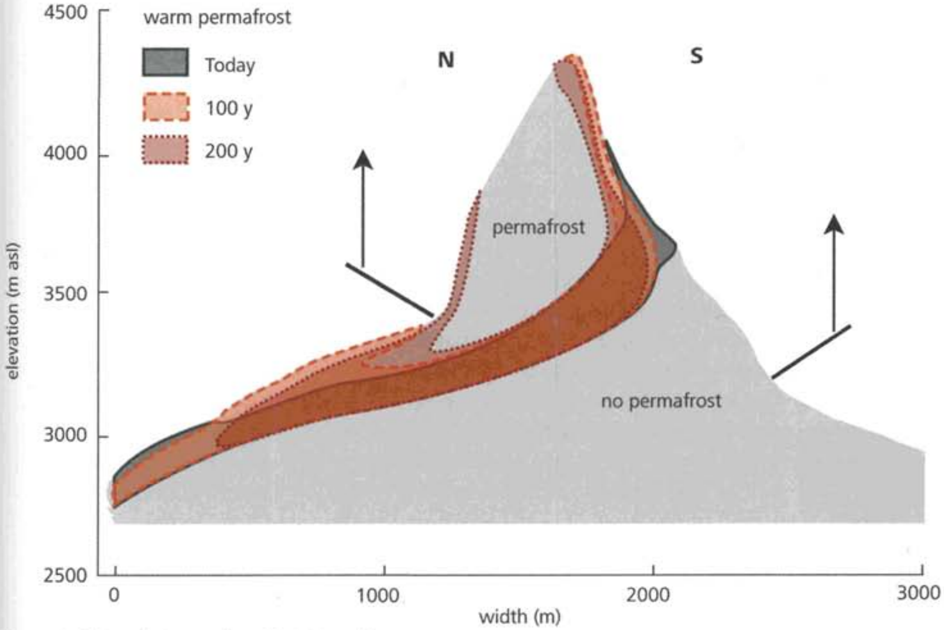
Atmospheric warming in the Alps has so far been stronger by about a factor of 2 than the global average. The envisaged limiting of the rise in global temperature by 2°C, therefore, most likely corresponds to a warming by about 4° in the Alps and comparable mid-latitude mountain ranges. Climate scenarios for the time horizon of 2050 in the Swiss Alps as simulated by using high-resolution (RCM) ensemble modelling indicate most likely changes in temperature/precipitation by about + 2°C / + 10% in winter and + 3°C / - 20% in summer. Such realistic climate-change scenarios for the Alps indicate that glaciers could largely disappear already within the coming decades (Fig. 2), and that increasing thermal anomalies are likely to affect permafrost down to 100 meters or more, causing deep thaw, penetration of water in ice-filled crack systems and, hence, reduced slope stability (Fig. 3) and increasing probability of large rock falls above timberline. Seasonal snow may become restricted to high altitudes and a few winter months, and many more new lakes are likely to form (Haeberli and Hohmann 2008).

Fig. 2: Development of glacier area in the European Alps. Most Alpine glaciers could disappear already within the coming decades



Accelerating rates of change could lead to increasingly difficult combinations of stresses involving growing levels of anthropogenic pressure, landscape alteration or the increasing vulnerability of infrastructure with respect to natural and economic hazards (Watson and Haeberli 2004). Climate-induced effects indeed seriously influence – already within the lifetime of our children – the landscape appearance, most natural hazards, the water cycle and the living conditions of plants and animals in high-mountain regions. The new lakes can be attractive for tourism and hydropower production. However, they also constitute serious hazard potentials as they come into existence in an increasingly destabilised environment. Dealing with such a combination of potentials and threats represents a scientific as well as economic and political challenge. A knowledge basis for assessing future developments must combine perspectives of geoscience (deglaciation, landscape evolution, lake characteristics, natural hazards) with hydraulic/hydrological aspects (retention capacity, flood protection, hydropower potential, sediment balance, ecological runoff regimes) and economic/touristic considerations (costs, benefits, perception, added value). The whole complex of questions must also be examined with respect to legal conditions (property, spatial planning, responsibility, liability, concessions, landscape protection).

Fig. 3: Model calculation for the Matterhorn-Permafrost. Different colors indicate occurrence of warm permafrost (0 to - 2°C) critical for slope stability at three time horizons (today, in 100 years, in 200 years); black arrows show occurrence of critically steep slopes. Over the coming centuries, combinations of critical slopes and critical permafrost conditions affect increasing parts of the mountain, rising from lower to higher elevations, first on warm (sunny) sides, later also on cold (shadow) sides.



Numerical simulation and graph: J. Noetzli.

Changes in local to regional natural hazards – especially relating to large rock falls from deep permafrost warming and to floods from newly forming lakes – must be assessed far beyond the historical-empirical knowledge basis and require integrated analyses of all involved phenomena and potential processes and process chains. Well-developed procedures and technologies exist and are available for use in other high-mountain regions as well (Huggel et al. 2004, Kääb et al. 2005). Problems of fresh-water resources involve regional to continental scales: the seasonality of runoff will dramatically change due to the combined effects of less snow storage in winter, earlier snowmelt in spring and reduced glacier melt in summer. Decreasing resources on the supply side in combination with increasing needs on the demand side will more and more affect economics and living conditions far beyond the Alps during increasingly frequent droughts in late summer (OcCC 2007, 2008). Operational aspects of power production from Alpine lake reservoirs with their growing importance for covering short-term peak demands in the expanding European energy network need complete rethinking (storage in wintertime, release in summertime?). A new science of growing disequilibria in complex ecosystems has to be developed. This requires integrated analysis and monitoring of important components in nature and society – an enormous challenge with progress in time having its limits.

Robust decisions with long-term perspectives must be taken to prevent threatening processes and to adapt to unavoidable changes. Enhanced awareness, transparent information and intensified transdisciplinary (policy-oriented) research are thereby key issues. Integrated geo-information systems combining data, models and scenarios will be increasingly needed to anticipate developments of complex geo-systems beyond the empirical knowledge basis from the past. Such geo-information systems primarily provide an overview of the available knowledge and understanding concerning the most important processes, subsystems and their potential interactions (cf. the case study in the Upper Engadin, eastern Swiss Alps, by Haeberli et al. 2007). As a consequence of often incomplete or even missing (spatiotemporal) information, they must apply relatively simple and robust models, which need examination by more sophisticated process-oriented models. They render the corresponding scientific reflection (assumptions, hypotheses, scenarios) transparent, quantify results in the space and time domain and indicate knowledge gaps. Perhaps most importantly, they demonstrate the usefulness of, and the need for, considering complex systems and longer time scales. However, they are – and will always be – far from perfect and need continuous development in view of ongoing rapid changes in nature, technology and scientific understanding. Models of abiotic subsystems such as snow and ice conditions, water supply or hazards from rock falls, debris flows, avalanches and floods are already well advanced and useful. Biotic subsystems, especially vegetation as related to climate change, ice vanishing and effects of grazing, are much more complicated and less well covered by robust spatial models applicable in high-mountain topography: an urgent research need. Regional capacity based on corresponding knowledge of the scientific background, of the technological potential and of the political relevance must be built up to manage, apply and continuously upgrade newly created geo-information systems. This requires close and uninterrupted collaboration between application-oriented scientific research, regional consulting and political planning.

Realistic visions are needed for regional adaptation and mitigation strategies with respect to heavy long-term impacts from global climate forcing and its constraints on the potential of sustainable development in high mountain areas. Such visions will soon make clear how difficult this task may be indeed, as successful adaptation not only requires a thorough understanding of the involved heavily deviated systems with all their complexities but also solidarity for harmonizing a multitude of goals and hopes diverging in space and time. This extraordinary challenge not only demonstrates the high priority, which must be attributed to this task: it also demonstrates the urgent need to slow down the warming trends with their increasingly dreadful consequences for cold mountain areas on earth.

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