GEOMORPHOLOGICAL IMPACT OF CLIMATE CHANGE ON ALPINE GLACIAL AND PERIGLACIAL AREAS

PROCESSES AND HAZARDS

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The glacial and periglacial environment is a sensitive indicator of climate change and it’s promptly reacting to global warming. In fact, several instability events which have been recently reported from the Alps can reasonably be considered as the first effects of the accelerated climate change, which is affecting not only the precipitation regime, but also the cryosphere structure. This work presents a review of geomorphological processes, distinguished by typology, that have been documented, mostly in the Italian Alps, since the beginning of the 21st century. The aim of the review is to discuss expected geomorphological impacts of climate change in high altitude mountains and related hazards.

RECENT INSTABILITY PROCESSES IN ALPINE GLACIAL AND PERIGLACIAL ENVIRONMENT

Lake growth at glacier margin. In the current period of marked glacier recession numerous lakes have appeared in the areas vacated by ice or on the glaciers themselves: once formed, lakes tend to expand due to thermokarst processes. During hot summer seasons 2003 and 2004, the Roche Melon Glacier lake (French Alps) reached a volume of ca. 600 000 m³ and a freeboard of just 15 cm: because of the risk posed to in case of lake outburst, French authorities decided the artificial lowering of lake stage (Fig. 1).

Debris flows. Debris flows seem to be increasing in frequency at the margins of glaciers, in part as a consequence of general glacier retreat and exposure of large quantities of unconsolidated, unvegetated, and sometimes ice-cored glacial sediments. A debris flow occurred in fair weather on 29 July 2005 in Val di Fosse (eastern Italian Alps): melt of a buried ice mass at 3000 m a.s.l. triggered a debris flow of 15 000 m³.

Paraglacial adjustment of moraines. Ice-core melting inside the LIA moraines or pressure reduction due to rapid glacier lowering can significantly modify the shape of the moraines. An impressive scar failure developed in the Locce frontal moraine (Monte Rosa), as a consequence of rapid exhaustion of a glacial surge which had extraordinarily increased the Belvedere Glacier thickness in the period 2001-2004 (Fig. 2).

High altitude rock falls/avalanches- Large rock and rock/ice avalanches occurred in high mountain in the Alps in the period 2004-2006 (e.g. Punta Thurwieser, Italy), while innumerable small sized rock falls occurred during the hot Summer of 2003 (e.g. Mont Blanc massif or Matterhorn). Due to their frequency (rock falls) or magnitude and long runout (rock avalanches), these events posed a significant threat to human activities.

Ice falls/avalanches. The degradation of the mountain slope glacial cover related with climate change has produced ice masses fragmentation, circulation of water at the ice-

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rock contact even at high elevation, lack of support at the foot of hanging glaciers. The ice-avalanche occurred on August 25, 2005 on the Monte Rosa East Face, which has experienced in the last few years a drastic decrease in glaciation, is one of the largest (over 1 M m$^3$) ever recorded in the Italian Alps.

*Glacier change.* The large part of glaciers shows enhanced volume and area reduction, as confirmed by glacier mass balances (10-15 cm of ice melted per day during the hot summer 2003). The most commonly reported changes are: glacial front retreat of tens of meters/year, increase in debris cover, development of large hollows on glacier surface, glacier fragmentation, enhanced glacial flow. The most impressive cases are represented by recent evolution of the Brenva, Invergnan and Belvedere glaciers, NW Italy.

**ARISING PROBLEMS AND HAZARD IMPLICATIONS**

Landscape evolution in glacial and periglacial areas has significant socio-economic and environmental impacts: i) reduction of water resources due to glacier shrinkage; ii) difficulties for tourism (change or disappearance of well-known landscapes; desertion of summer sky resorts on glacier; vanishing of classic climbing routes on ice); iii) increase of natural instability and related hazards (enhanced rock fall hazard along climbing routes previously considered safe; stability problems at high altitude structures, like mountain huts, due to permafrost degradation; hazardous conditions for people, buildings and infrastructure in areas prone to rock/ice avalanches or glacial outbursts).

**CONCLUDING REMARKS**

The availability of a larger number of case records will allow, in the next future, to outline reliable scenarios for geomorphological evolution in glacial and periglacial areas under changing climate, and related problems and hazards. On the other hand, emergency conditions faced in some critical occasions gave the opportunity of testing modern investigation techniques in extreme environments. In any case, the velocity of climate change and the observation that changes in glacier and permafrost equilibrium are shifting beyond historical knowledge require a careful and continuous monitoring of ongoing and potential processes, in order to define adaptation and mitigation strategies. The Interreg Alcotra Project PermaDataRoc (aimed at investigating the relation between permafrost degradation and high mountain rockwall instability), to which the authors participate, goes in this direction.

![Fig. 1: The Roche Melon Lake in 2001](image1)

![Fig. 2: Failure scar in the Locce frontal moraine (spring 2006)](image2)

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