Geophysical Research Abstracts
Vol. 17, EGU2015-8807, 2015
EGU General Assembly 2015

Risk assessment of mountain infrastructure destabilization in the French Alps

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In the current context of imbalance of geosystems in connection with the rising air temperature for several decades, high mountain environments are especially affected by the shrinkage of glaciers and the permafrost degradation which can trigger slope movements in the rock slopes (rockfall, rock avalanches) or in superficial deposits (slides, rock glacier rupture, thermokarst). These processes generate a risk of direct destabilization for high mountain infrastructure (huts, cable-cars...) in addition to indirect risks for people and infrastructure located on the path of moving rock masses. We here focus on the direct risk of infrastructure destabilization due to permafrost degradation and/or glacier shrinkage in the French Alps.
To help preventing these risks, an inventory of all the infrastructure was carried out with a GIS using different data layers among which the Alpine Permafrost Index Map and inventories of the French Alps glaciers in 2006-2009, 1967-1971 and at the end of the Little Ice Age. 1769 infrastructures have been identified in areas likely characterized by permafrost and/or possibly affected by glacier shrinkage.
An index of risk of destabilization has been built to identify and to rank infrastructure at risk. This theoretical risk index includes a characterization of hazards and a diagnosis of the vulnerability. The value of hazard is dependent on passive factors (topography, lithology, geomorphological context...) and on so-considered active factors (thermal state of the permafrost, and changing constraints on slopes related to glacier shrinkage). The diagnosis of vulnerability has meanwhile been established by combining the level of potential damage to the exposed elements with their operational and financial values. The combination of hazard and vulnerability determines a degree of risk of infrastructure destabilization (from low to very high). Field work and several inventories of infrastructure damages were used to validate it.
The application of this risk index for infrastructure in the French Alps indicates 999 infrastructures potentially at risk, among 0.2 % are characterized by a very high risk and 4.4 % by a high risk of destabilization. The risk unequally affects massifs: 55 % of the infrastructure at risk are in the Vanoise massif (Savoie) due to the large number of high-altitude ski resorts in this area. The Mont-Blanc massif (Haute-Savoie) includes only 6.5 % of the infrastructure at risk. Furthermore, 71 % of the exposed infrastructure are ski-lifts.