Geophysical Research Abstracts
Vol. 15, EGU2013-10123, 2013
EGU General Assembly 2013

Rockfall hazard in high mountain areas increased by the current atmospheric warming

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The study of rockfall (volume > 100 m3) in high mountains is essential to understand landscape evolution and to evaluate natural hazard. The number of rockfalls seems actually to rise in the European Alps, while vulnerability is increasing from high elevation areas (e.g. cable cars, huts) to valley floors (e.g. urbanization, transport).
Recent rockfalls from high-Alpine steep rockwalls are hypothesized to be a consequence of the climate change through the warming of the permafrost. Given the lack of systematic data on rockfall, this relationship has however remained difficult to assess despite few evidences including laboratory tests and temperature measurements indicating permafrost degradation, while the increase of rockfall frequency and magnitude remained conjectural.
Here we analyse several inventories of rockfalls acquired in the Mont Blanc massif (France and Italy) by innovative methods in order to characterize the rockfall triggering conditions and to emphasize the role of permafrost:
(i) In two sectors of the massif (Drus and Aiguilles de Chamonix), a comparison of photographs from the end of the Little Ice Age to 2011, combined with field geomorphological data, allowed the identification of more than 50 rockfalls during this period, ranging in volume from 500 to 265,000 m3.
(ii) A network of local observers (guides, hut keepers, mountaineers) allowed the documentation of all rockfalls occurred in 2007 (n = 45), 2008 (22), 2009 (72), 2010 (47) and 2011 (65) in the central part of the Mont Blanc massif, ranging in volume from 100 to 43,000 m3. Furthermore, 182 rockfalls were identified at the end of the 2003 Summer heatwave through the analysis of a satellite image of the whole massif.
A strong correlation between the rockfall occurrences and the hottest periods at the time scales of the century and the year strengthens the hypothesis of the relationship between permafrost degradation and rockfall at high elevation. Moreover, (i) modelling suggests the presence of permafrost in nearly all affected rockwalls; (ii) massive ice was observed in at least 40 scars during the period 2007-2011; and (iii) different other elements (e.g. mean elevation of the detachment zones, topography prone to permafrost degradation) support the permafrost degradation as the main triggering factor of rockfall.