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Large mass movements from glacierized and permafrost affected mountain regions: an analysis of potential climate-change related alteration of magnitude-frequency characteristics based on recent events

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Large mass movements from glacierized and permafrost affected mountain regions of the order of 10ˆ6 to 10ˆ8 m3 have usually been regarded as episodic events and have often been neglected for hazard assessments though there is potential for disasters with thousands of people killed. Evidence from events in recent years indicate, however, that such large mass movements may be more frequent under certain conditions. Glacier and permafrost are temperature-sensitive systems. The currently experienced atmospheric warming may provoke an increased activity of large glacial mass movements due to altered thermo-mechanical conditions, and, as a consequence, reduced stability of large ice-rock masses. To better understand the frequency-magnitude aspects, impacts and hazards of large mass movements from glacial environments on populated areas, we analyze large ice-rock avalanches from several mountain regions around the world in recent years in terms of failure, flow and propagation mechanisms, and monitoring methods. The majority of events originated from large glacierized high-mountain walls in permafrost and thermo-mechanically critical stability conditions. The most important events considered here include the 2002 Kolka ice-rock avalanche in the Caucasus which marks the largest historically documented ice avalanche. It started as a large slide in a steep glacierized high-mountain wall, entrained significant volumes of the Kolka glacier, rushed down as a $>$ 10ˆ8 m3 avalanche, and caused the death of more than 100 people. In similar conditions, one of the largest ice avalanches in the Alps in the last 100 years occurred in 2005 in the Monte Rosa region. Further evidence of recent large ice-rock avalanches comes from

Alaska. In 2005, a 5 * 10^7 m3 avalanche initiated in the steep south face of Mount Steller, Chugach Mountains. On Iliamna volcano, Cook Inlet region, an extraordinary series of ice-rock avalanches in the order of 10^7 m3 with return periods of about 4 years has recently been documented back for more than 20 years, and thus provides an excellent opportunity to study such kind of mass movements. Thermal disturbance due to volcanic activity may be used to investigate possible analogues in relation with climate-change effects. Satellite-derived thermal data and seismic records were analyzed to better understand avalanche failure. We show that the delicate stability equilibrium in steep glacier and permafrost terrain is sensitive to disturbance such as related to climate change or volcanic activity. Disturbed equilibrium may result in large mass movements. Currently experienced, often dramatic reduction in glacier extent and permafrost distribution has the potential to alter frequency and magnitude of mass movements from glacial environments. In terms of impacts and hazards, it is furthermore important to consider that ice-rock avalanches can transform into more mobile flows due to friction-related ice melting and thus affect populated areas in greater distance than commonly assumed.