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Impacts of climate change on hazardous processes in high mountains

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High mountains are prone to hazardous surface processes, including landslides, snow and ice avalanches, debris flows, and floods. These processes are conditioned both directly and indirectly by climate. The most studied climatically induced change in the high-mountain environment in the recent past has been the retreat of glaciers. Today, the areal extent of glaciers in many mountain ranges less than two-thirds what it was in the late 1800s, and the total area of glaciers in the European Alps is forecast to decrease another 20-50% by 2050. Outburst floods from lakes dammed by glaciers or unstable moraines are commonly a result of such glacier retreat. In the past century these floods have caused disasters in many high-mountain regions of the world. New, potentially unstable lakes will likely form as glaciers continue to retreat in the 21st century will likely.

Rock slopes can fail after they have been steepened by glacial erosion or debuttressed following glacier retreat. Although it may take centuries or even longer for a slope to fail following glacier retreat, recent landslides demonstrate that some slopes can respond within a few decades or less. Evidence of warming and degradation of mountain permafrost and attendant slope instability has emerged from recent studies in the European Alps and other mountain regions. Most documented slope failure are small, but several rock and ice avalanches with volumes of 30 to over 100 million m3 have occurred in the past decade. The response of bedrock temperatures to surface warming through thermal conduction will be slow, but warming will eventually penetrate to considerable depths in steep rock slopes. Other heat transport processes such as advection, however, may induce warming of bedrock at much faster rates. Latent heat effects from refreezing melt water can amplify the increase in air temperature in firn and ice. At higher temperatures, more ice melts and the strength of the remaining ice is lower; as a result, the frequency and perhaps size of ice avalanches may increase. Permafrost thaw may also increase both the frequency and magnitude of debris flows. The base of the active layer is a barrier to groundwater infiltration and can cause overlying non-frozen sediment to become saturated. Snow cover can also affect debris flow activity by supplying additional water to the soil, increasing pore water pressure, and initiating failure.

Other important factors in triggering debris flows are the spatial and temporal patterns of precipitation, the intensity and duration of rainfall, and antecedent rainfall. Debris flows from volcanoes (lahars) can be particularly large and hazardous. Lahars produced by volcanic eruptions on glacier-clad Nevado del Huila volcano in Colombia in 2007 and 2008 were the largest, rapid mass flows on Earth in recent years. Volcanoes in the tropics are particularly susceptible to torrential rainfall associated with tropical cyclones, and such events are projected to increase through this century. The impact of future, large, explosive, volcanic eruptions may also be exacerbated by an increase in extreme precipitation events, by providing an effective means of transferring large volumes of unconsolidated ash and pyroclastic flow debris from the flanks of volcanoes into downstream areas, as happened, for example, after the 1991 Pinatubo eruption in the Philippines. Large-scale ice loss on volcanoes reduces the load on the crust and uppermost mantle, facilitating of the rise of more magma into the crust and allowing magma to reach the surface more easily. Widespread uplift is currently occurring in response to thinning of Vatnajökull Ice Cap in Iceland and is expected to cause a future increase in volcanic activity. Future ice-mass loss on glaciated volcanoes, notably in Iceland, Alaska, Kamchatka, the Cascade Range in the northwest USA, and the Andes, could lead to eruptions, either as a consequence of reduced load pressures on magma chambers or through increased magma–water interaction. Additionally, the potential for edifice lateral collapse could be enhanced due to loss of support previously provided by ice or to elevated pore-water pressures arising from meltwater.