Glacier sensitivity to climate change: observations and modeling

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Glacier Sensitivity to Climate

A suite of general circulation model simulations and a glacier equilibrium line altitude model are used to test the sensitivity of Asian glaciers to climate changes at the Last Glacial Maximum (21 ka) and mid-Holocene (6 ka) [1,2]. The model simulations provide a test of glacier sensitivity to changes in climate boundary conditions. The results show that glacier sensitivity is strongly dependent upon the accumulation setting. In particular, the high accumulation regions of the southeastern Himalaya are most sensitive to changes in temperature and least sensitive to changes in precipitation. The reverse is true in the dry, interior plateau.

The intermodal differences for both 21 ka and 6 ka highlight regions where climate model uncertainty is greatest [3]. In particular, the southeastern Himalaya is a region where intermodel variability in temperature is extremely high, yet few paleoclimate proxies and glacier studies are available to help constrain the models. This is a region where paleoclimate and glacier reconstructions can provide crucial information for global and regional climate modelling efforts.

Southeastern Himalaya: Bhutan

Glacier retreat in the Himalayas impacts societies in the most densely populated area on earth by affecting river-discharge, hydro-energy and agricultural production, and glacial lake outburst flood potential. Bhutan sits in the bulls-eye of highest accumulation, where glacier sensitivity to temperature is greatest, and where there is a severe modern and paleo-climate data gap. Bhutan is therefore a region of potential scientific importance. In addition, Bhutan is representative of the potential societal impacts of glacier changes. Here we present quantitative predictions for glacier area and meltwater flux changes in Bhutan. Based on gridded climate data and a simple glacier melt model, our results show that Bhutan's glaciers lag behind the climate forcing considerably. Under the conservative scenario of an additional 1°C warming, about half of Bhutan's glaciers would disappear and the meltwater flux would drop to 20% of today's value. Even with no additional warming, almost 20% of the glaciated area would vanish and the meltwater flux would drop by 50%.

The results of the Bhutan study highlight the need to decrease uncertainty in glacier sensitivity to climate change. Given the transient nature of current climate and glacier systems, quantifying glacier sensitivity will rely heavily on well-documented glacier and climate histories. These longer term records are critical to quantifying the non-stationarity of glacier sensitivity, placing recent glacier and climate changes into context of longer term patterns, and validating both glacier and climate models.

[1] Rupper and Roe (2008) *J. of Climate* **21**, 5384-5401. [2] Rupper *et al.* (2009) *Quaternary Res.* **72**, 337-346. [3] Rupper and Koppes (2010) *IOP Earth and Environmental Science*. doi:10.1088/1755-1315/9/1/012009.

Mantle signals in olivine phenocrysts in arc volcanics

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Volcanism is fed by crustal storage reservoirs recharged ultimately with mantle-derived primitive melts. In particular withinin arc magmatic systems the nearly ubiquitous processes of mixing, hybridization, and crystallization combine to obscure the diversity of melts from the mantle. Isotope and trace element ratios of volcanic rocks and melt inclusions may help to reveal mantle inputs, but we explore here an alternative approach that uses trace element zonation in primitive olivines. Such zonation patterns both record the diversity of primary melts and provide a mechanism to constrain the timescales of mantle recharge and magma ascent through the entire crustal column.

Laser ablation-ICPMS and electron microprobe traverses provide extensive datasets of major and trace element zonation profiles in large populations of olivine (n>100). We focus here on Irazú volcano, in Costa Rica, as a typical strato-volcano from a continental arc, but we have extended our approach to other arc volcanic systems (Volcano A and West Mata in Tonga and Los Hornitos in Chile). The hybrid basaltic andesites that erupted from Irazú in 1963-65 bear abundant, primitive olivine crystals (up to 70 % of olivines include zones of >Fo88). Ni zonation varies within individual crystals by more than 500 ppm at nearly constant, high Fo content (>Fo88), recording the mixing of different mantle melts. The overall range of Ni in these magnesian olivines (2000-4000 ppm) is consistent with pyroxenitic and peridotitic mantle sources. Zonation profiles can be modeled by diffusive re-equilibration of Ni following a mixing event that sometimes creates a reversal (increase) in Ni. We calculate mixing time scales for these near-primary olivine phenocrysts that range from seven months to five years, accounting for anisotropic elemental diffusion in olivine (lattice orientation with respect to diffusion direction determined by electron backscattered diffraction). These short timescales are on the order of the duration of the eruption itself, providing new evidence for recharge of melts directly from the mantle, feeding on-going andesite eruptions at large stratovolcanoes. As the mixing of these distinct mantle melts occurs at least below the Moho (~ 35 km beneath Irazú), we can calculate average ascent rates of 10-100 m per day for magma to traverse the entire crustal column. Given that syn-eruptive ascent is likely very fast in the uppermost part of the magmatic column (typically from 5-10 km depth of the shallow magma chamber to the surface) we can infer that even in the lower and middle crust average ascent rates are >10 m per day. These rates are relevant to real-time geophysical observations of volcanic plumbing systems from the mantle to the surface.