Part II: Cryospheric changes

Mountain glaciers, snow cover and permafrost may be the best icons for global climate change. They are exquisitely emblematic of the balance between heat and cold on the planet. Glaciers and snow are crucial water reservoirs throughout the world, damping the variation in water supply over the course of a year. Snow and ice are not however always boons. The annual cycles of freezing and thawing, of deposition and ablation create local hazards while the on-going loss of glacial ice contributes significantly to rising sea levels. Glaciers, snow cover and permafrost mediate many of our concerns arising from climate change.

In the first contribution, *Haeberli* presents a broad overview of glacial monitoring throughout the world He explains the necessity of a tiered observing system based on focused energy and mass balance measurements within a broader context of glacial size and even presence/disappearance data. He notes data gaps in both the Andes and the Himalayas but holds out hope in the form of more complete data from remote sensing.

The increasing loss of glacial mass worldwide leads *Dyurgenov* to highlight the potential extinction of mountain glaciers. These losses account for an important fraction of the rise in mean sea level. Advances in technology offer some hope that important data on large and poorly sampled glaciers might still be gathered in these times of shrinking budgets.

The next three papers focus on tropical glaciers. *Kaser et al.* remind us that a glacier is a completely physical system, the mass of which is an immediate result of energy exchange and mass inputs. While in the mid-latitudes, temperature tends to dominate the mass balance equation, in tropical regions other meteorological variables such as humidity, cloudiness and precipitation are equally important. Their observations regarding Kilimanjaro, an important media story, are very thought provoking. *Francou et al.* focus on glaciers in the tropical Andes. Here they find that the ongoing loss of glacial mass is explained largely through changes occurring in the wet season, particularly as those seasons are themselves changed by ENSO. *Mark* and *Seltzer* examine the historical records and the likely impacts of glacial recession in the Peruvian Andes. They emphasize changes associated with lower precipitation and higher influx of radiation. And while high rates of recession have occurred in the past, the present rates will have significant hydrologic impacts on drier western slope economies.

The next two papers examine how climate change may affect the hazards in mountain areas mediated by permafrost, snow and glaciers. *Harris* focuses on permafrost and notes that even slight warming can lead to very large changes in the extent of frozen soil and rock with considerable increases in the risk of slope failure. *Kääb et al.* look at a wider range of potential hazards, including glacial lake outbursts, floods, glacial surges and slope failures, as well as yet more destructive combinations of events. Both papers recommend broad geographic assessment of hazards with spatial modeling in GIS coupled with more detailed site specific analysis or laboratory experiments.

Martin and *Etchevers* estimate the impacts of climate change on snow cover in the French Alps. Climate change could lead to a considerable shortening of the period of snow cover, with great impacts on the skiing industry as well as on timing and amount of water in major Alpine rivers. Impacts on avalanche hazard are much harder to predict as these are associated with extreme weather events, which are difficult to predict in climate change scenarios.

Finally *Hock et al.* examine how climate change will drive discharge from mountain glaciers. They emphasize that discharge responds at a variety of time scales related to both energy balances and extents of glaciation in the watershed. While the physics of melting have been studied extensively, much less is known about the routing of melt water through the glacier, key to understanding discharge at shorter diurnal and seasonal time frames.