An assessment of contemporary glacier fluctuations in Nepal's Khumbu Himal using repeat photography

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A preliminary study of glacial fluctuations in Sagarmatha (Mt Everest) National Park, Nepal was undertaken in Oct–Nov 2007 using repeat photography. Photographs from scientific and cartographic expeditions to the upper Imja Khola region ca. 1950 were replicated in order to derive a better, empirically-based understanding of what changes had occurred in the region's glaciers during the past half century. Over 40 distinct panoramas were replicated which demonstrated the (a) complete loss of certain small (< 0.5 km^2), clean glaciers (C-Type) between approximately 5400–5500 masl, (b) the retreat of larger (>0.5 km^2) clean glaciers by as much as 50 percent of the ca. 1955 volumes at elevations ranging from approximately 5500–5600 masl, (c) the formation of new and potentially dangerous glacial lakes that had been debris covered glaciers (D-Type) in the 1950s, and (d) the ablation of most of the D-Type glaciers re-photographed. The findings support and complement those of recent investigations based almost entirely on remote sensing and computer modelling. However, detailed, on-the-ground field studies of potential climate change impacts on the people and environments of the Mt. Everest region are disturbingly absent. I suggest that only by systematically combining field and laboratory-based investigations will we acquire the tools to enable us to identify the real threats, non-threats, and ways in which local people can adapt and reduce vulnerabilities to climate change.

EDITOR'S NOTE This preliminary report on a study of Himalayan glaciers has been released without peer review in order to share important findings. A detailed report will be forthcoming.

Between 1955 and 1963, the Austrian climber and cartographer Erwin Schneider completed a terrestrial photogrammetric survey of the mountain valleys to the south and west of Mt Everest (Schneider 1963, Byers 2005) which resulted in the beautiful 1:50,000 map of Khumbu Himal, first published in 1965 (Arbeitsgemeinschaft für Vergleichende Hochgebirgsforschung 1999). In 1956, an eight-month study of the region's glaciers was conducted by the Swiss glaciologist Fritz Müller (Müller 1958) following his participation as scientific leader to the successful 1956 Swiss Everest expedition. Both efforts resulted in the production of thousands of oblique black and white photographs of the Khumbu's cultural, physical, and high altitude landscapes. Half a century later, these photographs are now of immense value to our understanding of contemporary impacts of climate change on the world's highest mountain landscapes, especially when combined with other analytical tools such as remote sensing, computer modeling, GIS, and field-based biophysical and social science studies.

Over the years, I have replicated many of Schneider's 1955–1963 landscape photographs of the lower Khumbu valleys (3,200–4,200 meters above sea level, masl) in an effort to better understand contemporary landscape change processes and their prospective causes (Byers 1987a, 1987b, 1987c, 1996, 1997, 2003, 2005). However, it was not until 2002 that, thanks to Jack D Ives, I came into possession of hundreds of historic photographs of glaciers and high altitude landscapes from the Müller archives (see postscript). In October–November 2007, I spent 30 days in the upper Imja Khola watershed of the Sagarmatha (Mt Everest) National Park relocating the photopoints from which Müller and Schneider took their photographs, and then re-photographing the landscapes, in order to derive a better, empirically-based understanding of what changes had occurred in the region's glaciers during the past half century.

I conducted my field work in the upper Imja Khola region between 12 October and 12 November, 2007. I used a Nikon D-80 with Bogen tripod and Manfrotto 3039 head. I recorded locations and altitudes using a Garmin Summit GPS, and also noted other attributes such as date, time, and aspect. I shot the photographs using aperture priority at 15° and 30° intervals, and subsequently stitched individual frames into complete panoramas using Adobe Photoshop. I was able to replicate more than forty panoramas and hundreds of individual photographs. In this paper, I present four pairs of original and replicate images together with a discussion of preliminary results and recommendations.

Preliminary results

Four photo-pairs are presented as Plates 1 through 4, taken in the upper Imja Khola watershed at approximately 86° 50' E and 27° 53' N. The earlier of each pair was taken by Fritz Müller in 1956; the Schneider panoramas and photographs will be

Plate 1. The lower Khumbu Glacier in 1956 (top, Plate 1a; photograph taken by Fritz Müller), and in 2007 (bottom, Plate 1b), revealing very slight change in the lower tongue

presented in future publications. **Plates 1a** and **1b** illustrate that, superficially at least, and despite recent dramatic claims to the contrary, the lower tongue of the Khumbu Glacier has changed very slightly over the last 50 years. In contrast, the small Pokhalde Glacier (**Plate 2**) has entirely disappeared over the same period. **Plates 3** and **4** illustrate the pronounced retreat and collapse of the lower tongue of the Imja Glacier. This development introduces an associated phenomenon, i.e., the creation of moraine-dammed lakes (Imja Lake) in the frontal zones of retreating glaciers. In turn, this raises the prospect of glacial lake outburst floods (GLOFs, also known as *jökulhlaups*, the Icelandic term, Iceland being the country where systematic study of glacier outburst floods began almost 100 years ago).

Plate 1a shows the lower Khumbu Glacier as it appeared to Fritz Müller in 1956, taken from Awi Peak (5245 m) north of Dugla (4620 m), and **Plate 1b** is the 2007 replicate. When Muller took his first photograph, he, and most other glaciologists, would have been thinking about the likelihood of a recurrence of the 'Little Ice Age' rather than prospects for a widespread glacier melt-down. The lower glacier appears to have changed very little. Close examination, however, will reveal several recently-formed melt-water ponds among the boulders which constitute a nearly complete surface moraine. Two points must be borne in mind. First, a very thick cover of surface debris (as occurs on a "D-type" glacier) will insulate a glacier surface and so protect it from higher air temperatures. On the contrary, a thin debris cover will accelerate surface melting as heat due to solar insolation of the relatively dark debris is transferred to the ice below. Second, the lower Khumbu Glacier receives its supply of ice from one of the world's highest accumulation areas, i.e., the Western Cwm. At this extreme altitude, an increase of a few degrees in mean temperature has little impact on the rate of snow-melt. Furthermore, the ice supply to the lower tongue cascades down the precipitous and rapidly moving Khumbu icefall as it discharges from the Western Cwm on Mt Everest.

On the other hand, the Pokhalde Glacier (**Plates 2a** and **2b**), as it appears from just below the Kongma La pass (5535 m), has entirely disappeared since it was photographed by Müller in 1956. It is virtually the opposite extreme of the Khumbu Glacier – small total area and relatively low altitude accumulation zone. Furthermore, it had no conspicuous cover of surface debris and so could be classified as a 'clean' ("C-type") glacier. The same inferred explanation (disappearance on account of the current global warming) is used to explain the disappearance of many small glaciers in Glacier National Park, USA. This pattern is also characteristic of the European Alps and many other mountain regions. As mentioned, altitude has also played a role in the

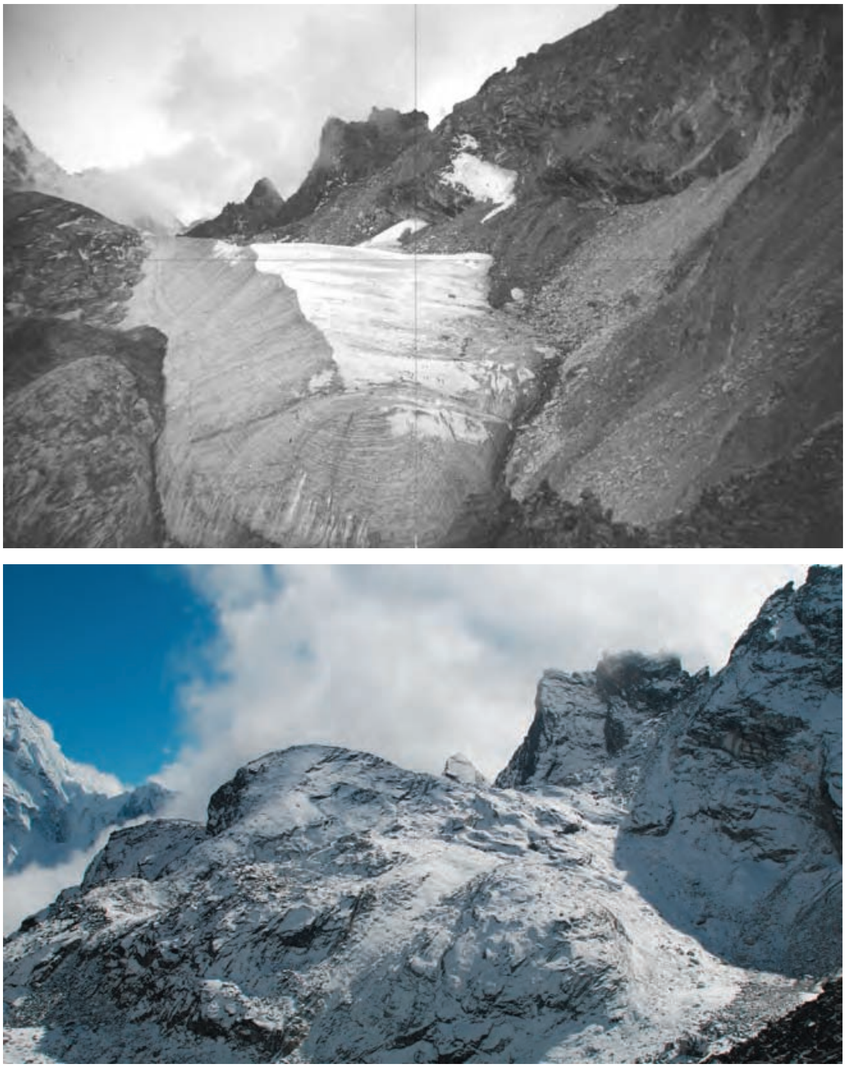

Plate 2. Pokhalde Glacier in 1956 (top, Plate 2a; photograph taken by Fritz Müller), and in 2007 (bottom, Plate 2b) when it completely disappeared

disappearance and/or retreat of small C-type glaciers in the Khumbu, with the zone between approximately 5400 and 5600 masl being the most heavily affected because of its warmer overall conditions. Within this range, I observed the entire disappearance of one C-type glacier (i.e., Pokhalde), the retreat by half of three C-type glaciers on the Jobo Lhaptsan (6440 masl) ridge toward Cho La, and upward retreat of dozens of ice sheets on most glaciated slopes re-photographed.

In one sense, Imja Glacier (**Plates 3** and **4**), as seen from a point above Amphu lake (Plates 3a and 3b) and again from the upper slopes of Island Peak (**Plates 4a** and **4b**), falls between the two extremes. It is a large glacier fed by two vigorous upper tributaries. A detailed study of Imja Lake and Glacier was initiated by the United Nations University (UNU) mountain hazards mapping program in 1983. The lake is totally absent in Müller's 1956 photograph, although a few small melt-ponds can be detected, comparable to those showing on the lower Khumbu Glacier today. Imja Lake only became of significance to UNU research when the late Dr Brad Washburn made available to the research team air photographs that he obtained in the course of producing the National Geographic Society's superlative 1:50,000 map of the Everest region.

The UNU identification of Imja Lake – we can't say "discovery," as its presence was previously known to the local Sherpas – coincided with the initial study of the glacial lake outburst from Dig Tsho, also in the Khumbu, in 1985. This occurred towards the end of UNU's mapping of mountain hazards in the area and facilitated one of the earliest on-the-ground post-facto analyses of such an event in Nepal, and discussion of its implications (Ives 1986, Vuichard and Zimmermann 1986). Thereafter a systematic collection of 'old' photographs was initiated and a series of expeditions to study Imja Lake was launched (Watanabe et al. 1994, 1995).

Interest in the Imja Lake continues to accelerate as a result of its rapid growth (WWF 2005, Bajracharya et al. 2007), relative ease of access, proximity to the popular trekking peak objective Island Peak, and the fact that it is located at the foot of Mt Everest, one of the world's most powerful media draws. Based on temporal series of satellite images from 1962 to 2006 combined with some field verification data, Bajracharya et al. report that the lake increased in area from 0.82 km^2 in 2001 to 0.94 km^2 in 2006, with the glacier currently receding at the rate of 74 m/yr. The lake increased in length from 1,647 m to 2,017 m during the same period, exhibiting an average depth of 41.6 m in 2002 that contains 35.8 million m^3 of water. They report that during the past six years, 34 major lakes appear to be growing in the Khumbu, and 24 new lakes have appeared, 12 of which are classified as "dangerous." They advocate early warning systems as the most cost-effective means of dealing with the risk of glacial lake outburst, and in fact a Japanese team installed a video cam to monitor lake levels in November of 2007. In May of 2008, Asian Trekking and the International Centre for Integrated Mountain Development (ICIMOD) are planning an "EcoEverest Expedition" designed in part to raise awareness of the potential problems associated with proliferation and expansion of glacial lakes as a result of climate change.

Discussion

Over 40 distinct panoramas were replicated which demonstrated, among other phenomena to be described in forthcoming papers, the (a) complete loss of certain small (<0.5 km^2), clean glaciers (C-Type) between approximately 5400–5500 masl, (b) the retreat of larger (>0.5 km^2) clean glaciers by as much as 50 percent of the ca. 1955 volumes at elevations ranging from approximately 5500–5600 masl, (c) the formation of new and potentially dangerous glacial lakes that had been debris covered glaciers (D-Type) in the 1950s, and (d) the ablation of most of the D-Type glaciers re-photographed. The findings support and complement those of Bajracharya et al. (2007), and illustrate the advantage of combining remote sensing and computer modeling with thorough and systematic field verification. However, detailed, on-the-ground field studies of potential climate change impacts on the people and environments of the mountain world – on water, agriculture, safety, glacial lakes, tourism – are disturbingly absent, and all too frequently substituted with well meaning, but frequently erroneous and sensationalistic reports based entirely on anecdotal evidence alone. For example, I found the terminus of the Khumbu glacier to be exactly where it was 50 years ago, despite stories heard in Kathmandu to the effect that it had receded by 5 km; and the "glacial lake outburst" in Kunde village reported on the Internet last summer was in fact a centuries-old torrent that floods at least once every several decades; there are no glacial lakes on Khumbui Yul La, the peak that rises above Kunde. My informal interviews with Sherpa informants suggest that a wide range of opinions exists regarding the impacts, or lack of impact, of climate change, and I can find no systematic studies that have attempted to determine what *local people* think. More than ever, we now need to emulate the thorough work of Müller and Schneider half a century ago, with on-the-ground field studies by mountain geographers, anthropologists, glaciologists, and social scientists with those of the laboratory. Only by combining both field and laboratory results, especially in collaboration with local people, will we have the tools that enable us to identify the real threats, non-threats, and ways in which local people can adapt and reduce vulnerabilities to climate change.

I also suggest that much more field-based analysis of glacial lakes in general is needed in the Khumbu and elsewhere in the Himalaya. For example, some have argued that controlled breaching of dangerous lakes is too expensive, and that early warning systems are the only practical solution. Yet, Peruvian engineers, for example, have over 45 years of experience in the successful control of glacial lakes in the Cordillera Blanca region of Peru (Byers 2000). This experience needs to be reviewed for possible adaptation to conditions in Nepal. Cost is clearly *not* prohibitive if dozens of lakes have been controlled in another developing country such as Peru. Regardless, the savings of lives, land, and infrastructure that could result from an outburst would appear to dwarf the expense of its prevention. Early warning systems, although potentially a viable component of GLOF management, provide only a brief opportunity to get out of the path of destruction for those lucky enough to hear them, and do little for the hundreds of farmers, porters, and trekkers who may be on the trail between villages when the

Plates 3. Imja Glacier, as seen from a point above Amphu lake in 1956 (top, Plate 3a, photograph by Fritz Müller) and in 2007 (bottom, Plate 3b) show pronounced retreat and collapse of the lower tongue of the glacier and formation of new melt-ponds

Plates 4. Imja Glacier, as seen from the upper slopes of Island Peak in 1956 (top, Plate 4a, photograph by Fritz Müller) and in 2007 (bottom, Plate 4b) show pronounced retreat and collapse of the lower tongue of the glacier and formation of new melt-ponds

outburst occurs. Likewise, classifying a lake as "dangerous" based on remotely-sensed size and volume alone does not take into account the more frequent causes of lake outbursts, such as catastrophic ice fall (e.g., as with the Langmoche flood), earthquake, or natural failure of the terminal moraine dam. Much uncertainty in these regards could be removed through the development and implementation of more thorough ground verification methods, followed by the implementation of controlled breaching and early warning systems where indicated.

Conclusion

The photographs compared here, and the dozens of other replicate panoramas that I took in order to highlight change over a 50-year period, represent only a tiny fraction of those remaining in the Müller/Schneider archives. More work is planned for the future in partnership with ICIMOD's Decision Support System (DSS) project, The Mountain Institute, and the American Alpine Club. This should provide a database to facilitate more objective assessment of changes that are occurring in the Khumbu, as well as development of a model applicable to other mountain regions of the world. In this way a more reliable basis can be built for the formulation of policies promoting adaptation to change as well as mitigation of disasters. The paper is also intended to encourage the incorporation of more field-based studies of the biophysical and human aspects of climate change in the mountains in order to realistically understand its impacts on peoples' lives, livelihoods, and safety.

Postscript (by Jack D Ives)

The preservation of Fritz Müller's 1956 photographs is a saga in its own right. Fritz formed the scientific 'team' on the successful Swiss Everest-Lhotse expedition of 1956. He stayed behind to continue his glaciological and permafrost studies after the climbers had departed for home. He remained for nine months at altitudes in excess of 5,000 metres – a non-indigenous record for the time [see note]. Afterwards he divided his energies as professor of geography between McGill University (Montreal), and ETH (Zurich). During this time he initiated and led a series of expeditions to Axel Heiberg Island in Canada's High Arctic (the island's largest ice cap is named in his honor). He also campaigned against what he perceived as reckless development of hydroelectric facilities in the Swiss Alps. It was while haranguing news reporters on the Rhonegletscher that he suffered a fatal heart attack in 1980, at the age of 54. In the confusion that followed his tragic death most of his photographic collection was lost. A single box of photographs was salvaged by one of his doctoral students, Dr Konrad Stefan, and brought to Boulder, Colorado. Koni presented the box to me, knowing that I had begun to focus my UNU activities on the Khumbu Himal. Inspection revealed that there were no negatives (apparently they had been inadvertently destroyed) and that most of the prints were 35mm contacts. Remarkably, the Imja Glacier photographs were amongst the very few that had been enlarged (to about 12 by 20 cm). Recently, Alton Byers was able to utilize the rapidly developing digital technology to enlarge and enhance many of the other contact prints. He is currently planning major photo exhibits featuring the comparative panoramas at the American Alpine Club's Brad Washburn Mountaineering Museum, Golden, Colorado; and in celebration of the 25th anniversary of ICIMOD in Kathmandu.

I present the story of the Müller photographs here in the hopes that it will encourage similar efforts to retrieve, restore, and utilize historic photographs. It is also meant to be a tribute to one of the most effective and imaginative Swiss-Canadian glaciologists I have ever known, Professor Fritz Müller.

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Note (from postscript)

One of my prized pieces of personal memorabilia is a postcard sent to me by Fritz from the South Col. It includes the official Swiss expedition diagram of the Everest group with Fritz's annotations to the following effect: he apologizes for not having had time before his departure for Nepal to assist me with my doctoral dissertation saying that, at least, I can claim it all as my own work; he goes on to say that, after struggling with his permafrost studies and after drilling holes in the Khumbu icefall for movement stakes, he needed a rest break; this he obtained by joining a party of Sherpas to carry a load to the South Col. I last saw Fritz on the Rhonegetscher just two years before his death in the same place.