The Snows of Kilimanjaro*: A critical comment on Numerical Simulations of the Role of Land Surface Conditions on the Climate of Mt. Kilimanjaro Region

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Widespread retreat of glaciers and ice caps is one of the clearest visible indications of the effects of climate change. The IPCC Fourth Assessment Report estimated that between 1990 and 2003, there was an average global loss of mass from glaciers and ice caps (excluding the ice sheets of Antarctica and Greenland) of 280 ± 79 billion tonnes per year (Gt/yr). This mass loss has contributed an average of 0.77 ± 0.22 mm/yr to sea level rise (Lemke et al., 2007). Glaciers and ice caps are retreating in all regions of Earth, including the tropics, where they have shrunk from a maximum in the mid-19th century, generally following the global trend. The wastage of tropical glaciers, including those on Mt. Kilimanjaro, East Africa (30°4'S, 37°21'E), has been strong since the 1970s and, as in other mountain ranges, the smallest glaciers are more strongly affected.

However, the images published on the front cover of CLIVAR Exchanges (No. 47; Vol 13#4, Heuser and Semazzi, 2008) give a very wrong impression of the magnitude of the retreat of glaciers on Mt. Kilimanjaro. These images of Kilimanjaro's highest peak, Kibo (5893 m), in February 1993 and February 2000 merely show changes in the transient snow cover – not the glaciers. These images originally appeared on the NASA Earth Observatory website (http://earthobservatory.nasa.gov/IOTD/view.php?id=3054) on December 20, 2002 and have been frequently misinterpreted. The caption on this NASA website was modified in 2005 to make it clearer that the images cannot be used as an indication of the rate of the loss of ice.

Neither of the images allows identification of the perennial

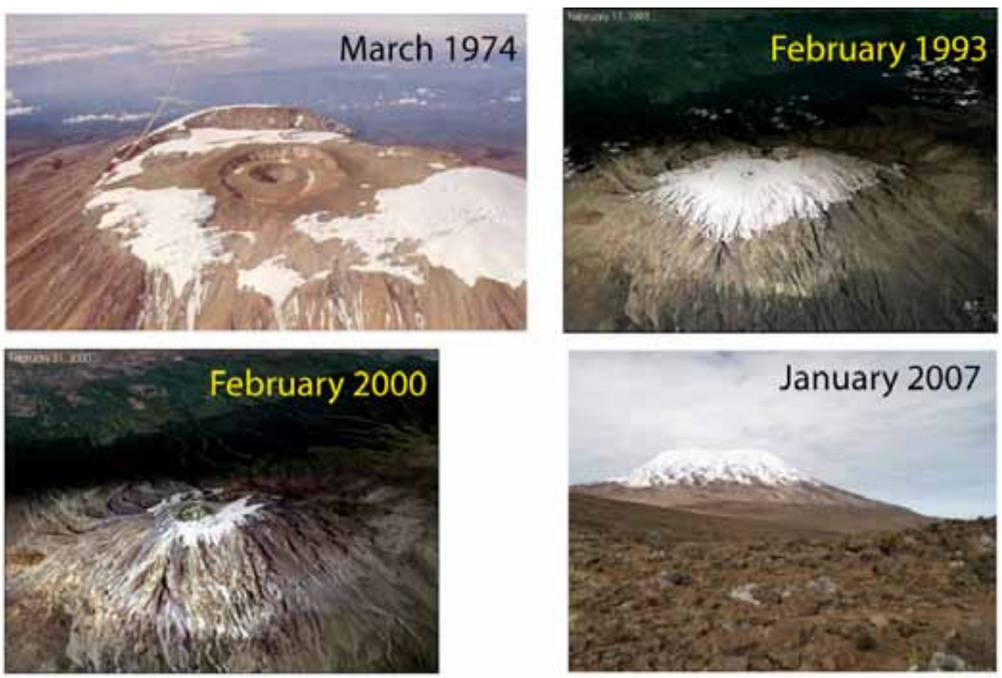

Figure 1: Ice and snow cover on Kibo in 1974, 1993, 2002, and 2007, each at the end of the so-called East African Short Rains. Pictures from Hastenrath (1984) upper left; NASA Earth Observatory (http://earthobservatory.nasa.gov/IOTD/view.php?id=3054) upper right and lower left, and G. Kaser, lower right.

**The title of this note unashamedly copies that of Ernest Hemmingway's short story. Hemingway's famous story has elevated the symbolism of Kilimanjaro and its glaciers as a key indicator of anthropogenic climate change. But his heroic symbol of a frozen leopard near the summit of the mountain might also be considered as a symbol of human perseverance and invention in the face of the environmental problems that we create for ourselves.*

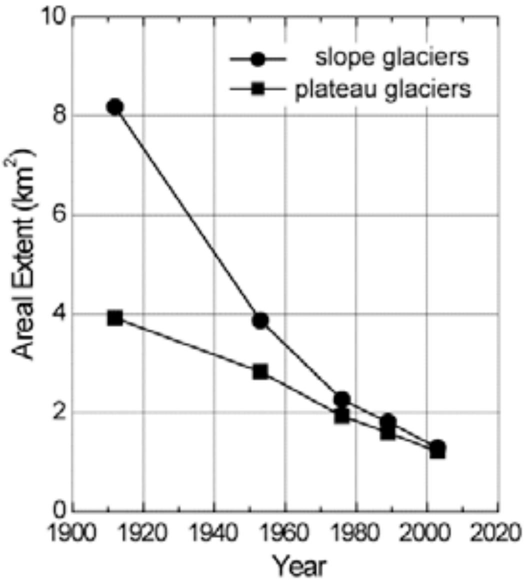

Figure 2: Change of areal extent of Kibo glaciers between 1912 and 2003. Modified from Cullen et al., (2006)

ice (glacier) extent. The 1993 image shows the entire mountain covered with snow roughly to the limit of the little ice age glacier extent, while even in the 2000 image only about 60 – 70 % of the white surface is perennial ice, the rest being snow. Snow cover on Kibo (as well as on the second highest Kilimanjaro peak, Mawenzi) stems either from a single isolated precipitation event or from a series of events during the "short rains" (October, November, December) and during the "long rains" (March, April, May). The snow cover can persist from a couple of hours to more than a year. For example, portions of the exceptionally heavy snow cover in January 2007 (up to 0.9 m measured on the Northern Ice Field) lasted beyond February 2008. If snow and ice are not clearly distinguished, a very false indication of glacier changes may be derived. The image series in Figure 1, for example, falsely suggests spectacular 'glacier expansion' up to Little Ice Age extents between 1974 and 1993 and again between 2000 and 2007. The actual glacier surface area, as carefully analysed and presented by Cullen et al. (2006), show a fairly steady monotonic retreat (Figure 2).

There are two different glacier regimes on Kibo that lead to different rates of decrease in glacier area (Figure 2). The plateau glaciers are too shallow for much ice deformation to occur and are bedded on horizontal surfaces that exclude basal sliding; the slope glaciers are frozen to the bed and move only slowly by deformation (Cullen et al., 2006). Changes in surface area of the plateau ice are exclusively due to the retreat of the vertical ice walls that are exposed either to the south or the north. Their retreat is mainly driven by solar radiation during the respective dry seasons (Kaser et al., 2004; Mölg et al., 2003). Changes to both plateau and slope glaciers reflect a long period of dry climate that probably started in the 1880s (Cullen et al., 2006; Kaser et al., 2004; Mölg et al., 2008; Mölg et al., 2003). Seasonal and inter-annual variability in snowfall frequency and amount affect the annual mass balance of both horizontal and inclined ice surfaces (Cullen et al., 2007; Mölg et al., 2008; Mölg and Hardy, 2004) but have no impact on the extent of the plateau glaciers which is exclusively determined by the retreat of the vertical walls. It has also been shown that precipitation anomalies over the Kilimanjaro region correlate significantly with the Indian Ocean Dipole (Mölg et al., 2006) and that the drivers of the anomalies have a large spatial scale.

Heuser and Semazzi (2008) used a high resolution atmospheric model to investigate how changes to land surface conditions in the region surrounding Mt. Kilimanjaro might modify precipitation. Although the retreat of the glaciers of Kilimanjaro was not the main focus of their study they do claim that "our modelling results support our hypothesis that the response of precipitation to land use change is significantly greater than that of temperature, and therefore a more likely factor for modulating the glacial volume over the Kilimanjaro summit". The specific studies of Kilimanjaro glacier changes cited above do not support this conclusion.

Heuser and Semazzi (2008) claim that the main mass loss on Kilimanjaro is due to sublimation. Although this is correct for the horizontal and slope glacier surfaces in the highest glacier regions (Mölg and Hardy, 2004; Mölg et al. 2008), it is not for ablation neither in the terminal regions of slope glaciers nor on the vertical walls that dominate the shrinkage of the plateau ice. For the latter, about 80% of ablation occurs by melting driven by the micro-meteorological conditions, even though air temperatures never reach the melting point. The dry season increase in sunlight does not primarily govern the turbulent latent heat flux between the ice and the atmosphere as claimed by Heuser and Semazzi (2008), but does provide energy to the surface that, if combined with a lack of turbulent heat loss (no wind), leads to melting (Kuhn, 1987). Melting often occurs on the vertical ice walls (Kaser et al., 2004; Mölg et al., 2003).

Finally, Hemp (2005) shows that forest fires have caused a decrease in mountain forest south of Mt. Kilimanjaro, but this is not impacted by glacier recession. The decrease of forest area does decrease the amount of precipitation that is captured from fog (Hemp, 2005), and this has a larger impact on the hydrology of the Mt. Kilimanjaro region than glacier changes.

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