HISTORICAL TRENDS OF AFRICAN GLACIER DYNAMICS

What does scientific research reveal about the snows of Kilimanjaro?
Kilimanjaro, the highest free-standing mountain in the world, was long renowned for its summit glaciers, immortalized by Ernest Hemingway in his famous short story "The Snows of Kilimanjaro." Over the first few years of the current century, its disappearing summit ice fields were once again made famous, this time by political luminaries such as Al Gore, Hillary Clinton and John McCain, who cited them as unmistakable evidence of the deleterious consequences of human-induced global warming. On the floor of the U.S. Senate during debate on Senate Bill 139 back in 2004, for example, Arizona Senator John McCain called this attribution not only a fact, but a fact "that cannot be refuted by any scientist." Then in subsequent debate on the same bill, former New York Senator Hillary Clinton echoed Senator McCain's sentiments. Displaying a set of photos taken from the same vantage point in 1970 and 1999 - the first depicting "a 20-foot-high glacier" and the second "only a trace of ice" - she said that in those pictures "we have evidence in the most dramatic way possible of the effects of 29 years of global warming." Nevertheless, and in spite of the absolute certitude with which the two senators expressed their views on the subject - which allowed for no "wiggle room" whatsoever - scientific analyses have shown both of them to be as wrong as they could possibly be.

Modern glacier recession on Kilimanjaro began around 1880, approximately the same time the planet began to recover from the several-hundred-year cold spell of the Little Ice Age. As a result, a number of people have declared that the ice fields retreated because of the rising temperatures, encouraged in this contention by a few reports in the scientific literature that promoted the same scenario (Alverson et al., 2001; Irion, 2001; Thompson et al., 2002). This view of the subject, however, is
"highly simplified," in the words of Molg et al. (2003a), who went on to demonstrate that it is also just plain wrong.

The trio of glaciologists began their analysis of the topic by reviewing some pertinent facts about the historic, climatic and geographic context of the long-term retreat of the Kilimanjaro ice fields. They noted, first of all, that "glacierization in East Africa is limited to three massifs close to the equator: Kilimanjaro (Tanzania, Kenya), Mount Kenya (Kenya), and Rwenzori (Zaire, Uganda)," all three of which sites experienced strong ice field recession over the past century or more. In that part of the world, however, they report "there is no evidence of a sudden change in temperature at the end of the 19th century (Hastenrath, 2001)," and that "East African long-term temperature records of the 20th century show diverse trends and do not exhibit a uniform warming signal (King'uyu et al., 2000; Hay et al., 2002)." Moreover, with respect to Kilimanjaro, they say that "since February 2000 an automatic weather station has operated on a horizontal glacier surface at the summit's Northern Icefield," and that "monthly mean air temperatures only vary slightly around the annual mean of -7.1°C, and air temperatures [measured by ventilated sensors, e.g., Georges and Kaser (2002)] never rise above the freezing point," which makes it pretty difficult to understand how ice could melt under such conditions.

So what caused the ice fields of Kilimanjaro to recede so steadily for so many years? Citing "historical accounts of lake levels (Hastenrath, 1984; Nicholson and Yin, 2001), wind and current observations in the Indian Ocean and their relationship to East African rainfall (Hastenrath, 2001), water balance models of lakes (Nicholson and Yin, 2001), and paleolimnological data (Verschuren et al., 2000)," Molg et al. (2003a) say "all data indicate that modern East African climate experienced an abrupt and marked drop in air humidity around 1880," and they add that the resultant "strong reduction in precipitation at the end of the 19th century is the main reason for modern glacier recession in East Africa," as it considerably reduces glacier mass balance accumulation, as has been demonstrated for the region by Kruss (1983) and Hastenrath (1984). In addition, they note that "increased incoming shortwave radiation due to decreases in cloudiness - both effects of the drier climatic conditions - plays a decisive role for glacier retreat by increasing ablation, as demonstrated for Mount Kenya and Rwenzori (Kruss and Hastenrath, 1987; Molg et al., 2003b)."

In further investigating this phenomenon, Molg et al. (2003a) applied a radiation model to an idealized representation of the 1880 ice cap of Kilimanjaro, calculating the spatial extent and geometry of the ice cap for a number of subsequent points in time and finding that "the basic evolution in spatial distribution of ice bodies on the summit is modeled well." The model they used, which specifically addresses the unique configuration of the summit’s vertical ice walls, additionally provided, in their words, "a clear indication that solar radiation is the main climatic parameter governing and maintaining ice retreat on the mountain's summit plateau in the drier climate since ca. 1880." Consequently, Molg et al. (2003a) concluded that "modern glacier retreat on Kilimanjaro is much more complex than simply attributable to 'global warming only'." Indeed, they say it is "a process driven by a complex combination of changes in several different climatic parameters [e.g., Kruss, 1983; Kruss and Hastenrath, 1987; Hastenrath and Kruss, 1992; http://www.co2science.org/articles/V7/N6/EDIT.php.
Kaser and Georges, 1997; Wagnon et al., 2001; Kaser and Osmaston, 2002; Francou et al., 2003; Molg et al., 2003b], with humidity-related variables dominating this combination.

Also reviewing a wealth of data pertinent to the subject of African glaciers were Kaser et al. (2004), who similarly concluded that "changes in air humidity and atmospheric moisture content (e.g. Soden and Schroeder, 2000) seem to play an underestimated key role in tropical high-mountain climate (Broecker, 1997)."

Noting that all glaciers in equatorial East Africa exhibited strong recession trends over the past century, they report that "the dominant reasons for this strong recession in modern times are reduced precipitation (Kruss, 1983; Hastenrath, 1984; Kruss and Hastenrath, 1987; Kaser and Noggler, 1996) and increased availability of shortwave radiation due to decreases in cloudiness (Kruss and Hastenrath, 1987; Molg et al., 2003b)," both of which phenomena they relate to a dramatic drying of the regional atmosphere that occurred around 1880 and the ensuing dry climate that subsequently prevailed throughout the 20th century. Consequently, Kaser et al. likewise demonstrated that all relevant "observations and facts" clearly indicate that "climatological processes other than air temperature control the ice recession in a direct manner" on Kilimanjaro, and that "positive air temperatures have not contributed to the recession process on the summit," directly contradicting Irion (2002) and Thompson et al. (2002), who, in their words, see the recession of Kilimanjaro's glaciers as "a direct consequence solely of increased air temperature."

In a contemporaneous study of the ice fields of Kilimanjaro, Molg and Hardy (2004) derived an energy balance for the horizontal surface of the glacier that comprises the northern ice field of Kibo - the only one of the East African massif's three peaks that is presently glaciated - based on data obtained from an automated weather station. This work revealed, in their words, that "the main energy exchange at the glacier-atmosphere interface results from the terms accounting for net radiation, governed by the variation in net shortwave radiation," which is controlled by surface albedo and, thus, precipitation variability, which determines the reflective characteristics of the glacier's surface. Much less significant, according to the two researchers, is the temperature-driven turbulent exchange of sensible heat, which they say "remains considerably smaller and of little importance."

Molg and Hardy therefore went on to conclude that "modern glacier retreat on Kilimanjaro and in East Africa in general [was] initiated by a drastic reduction in precipitation at the end of the

---

Modern glacier retreat on Kilimanjaro is much more complex than simply attributable to 'global warming only'. It is a process driven by a complex combination of changes in several different climatic parameters with humidity-related variables dominating this combination.

---

nineteenth century (Hastenrath, 1984, 2001; Kaser et al., 2004)," and that reduced accumulation and increased ablation have "maintained the retreat until the present (Molg et al., 2003a)." Buttressing their findings is the fact, as they report it, that "detailed analyses of glacier retreat in the global tropics uniformly reveal that changes in climate variables related to air humidity prevail in controlling the modern retreat [e.g., Kaser and Georges (1997) for the Peruvian Cordillera Blanca and Francou et al. (2003) for the Bolivian Cordillera Real (both South American Andes); Kruss (1983), Kruss and Hastenrath (1987), and Hastenrath (1995) for Mount Kenya (East Africa); and Molg et al. (2003b) for the Rwenzori massif (East Africa)]." Hence, the take-home message of their study is essentially the same as that of Kaser et al. (2004): "positive air temperatures have not contributed to the recession process on the summit."

The next group of researchers to study Kilimanjaro’s glaciers was Cullen et al. (2006), who found that "all ice bodies on Kilimanjaro have retreated drastically between 1912-2003," but they also note that the highest glacial recession rates on Kilimanjaro "occurred in the first part of the 20th century, with the most recent retreat rates (1989-2003) smaller than in any other interval [italics added]." In addition, they say that no temperature trends over the period 1948-2005 have been observed at the approximate height of the Kilimanjaro glaciers, but that there has been a small decrease in the region’s specific humidity over this period.

In terms of why glacier retreat on Kilimanjaro was so dramatic over the 20th century, the six researchers note that for the mountain’s plateau glaciers, there is no alternative for them "other than to continuously retreat once their vertical margins are exposed to solar radiation," which appears to have happened sometime in the latter part of the 19th century. They also say, in this regard, that the "vertical wall retreat that governs the retreat of plateau glaciers is irreversible, and changes in 20th century climate have not altered their continuous demise." Consequently, the 20th-century retreat of Kilimanjaro’s plateau glaciers is a long-term response to what could well be termed "relict climate change" that likely occurred in the late 19th century.

In the case of the mountain’s slope glaciers, Cullen et al. say that their rapid recession in the first part of the 20th century clearly shows they "were drastically out of equilibrium," which they take as evidence that the glaciers "were responding to a large prior [italics added] shift in climate." In addition, they report that "no footprint of multidecadal changes in areal extent of slope glaciers to fluctuations in 20th century climate is observed, but their ongoing demise does suggest they are still out of equilibrium," and in this regard they add that their continuing but decelerating demise could be helped along by the continuous slow decline in the air’s specific humidity. Consequently, in light of all the facts they present, Cullen et al. confidently conclude that the glaciers of Kilimanjaro "are merely remnants of a past climate rather than sensitive indicators of 20th century climate change."

Next to contribute to the growing knowledge of African glacial dynamics was Mote and Kaser (2007), who presented a review of the comprehensive field work that has been conducted over the past twenty years on tropical glaciers in general - and those of Mount Kilimanjaro in

---

4 http://www.co2science.org/articles/V9/N38/EDIT.php.
5 http://www.co2science.org/articles/V10/N36/EDIT.php.
particular - in which one of them (Kaser) was intimately involved, writing within the context of current concerns over possible CO$_2$-induced global warming.

The two researchers begin by stating "there is scant evidence ... of a direct connection between current global climate trends and the shrinking of the ice cap atop Kilimanjaro in tropical East Africa, despite its new role as a climate-change poster child," particularly as portrayed in the film *An Inconvenient Truth* by Al Gore. In fact, they say that "warming fails spectacularly to explain the behavior of the glaciers and plateau ice on Africa's Kilimanjaro massif ... and to a lesser extent other tropical glaciers."

With respect to what has actually been observed atop Kilimanjaro and what has caused the shrinking of its fabled ice cap, observations suggest that between 1880 and 2003, there was a shrinkage of almost 90% in the ice-covered area of Kilimanjaro; but Mote and Kaser note that "much of that decline [66%] had already taken place by 1953," confirming the earlier work of Cullen *et al.* (2006). This "pacing of change," in the words of the two researchers, "is at odds with the pace of temperature changes globally." In fact, at the closest point of reanalysis temperature data availability in the vicinity of Kilimanjaro's peak, they say "there seems to be no trend since the late 1950s." Consequently, and based on a long list of other observations, the two researchers ascribe the long-term wasting away of ice on Kilimanjaro "to a combination of factors other than warming air - chiefly a drying of the surrounding air that reduced accumulation and increased ablation."

Next to weigh in on the subject was *Duane et al.* (2008), who collected temperature and relative humidity readings 1.5 meters above ground level at 11,600 hourly intervals at seven locations over an elevation range of 3,910 meters on the southwestern side of Kilimanjaro between September 2004 and January 2006, after which they determined the implications of their data for the shrinking ice fields atop the mountain. Results indicated that temperatures remained well below freezing at their uppermost measurement site, so that "patterns of cloud cover and humidity are central to

---

understanding glacier-climate interactions" at the ice fields. In this regard, they further state that "nearly all of the moisture in the atmosphere at the higher levels of the mountain is brought up from lower elevations through the mechanism of the montane thermal circulation," and that their data point strongly "to the lower slopes of Kilimanjaro as a moisture source for both the snows that feed the summit glaciers and the clouds that impact their surface energy balance." They also say their data suggest there is a "net export of moisture out of the forest zone (upslope) during the daylight hours," noting that "it could be that land-use changes in the forest zone as a result of deforestation have reduced the efficiency of this moisture supply to the higher reaches of the mountain."

Stating that their work shows "the importance of moisture transport upslope to the summit of Kilimanjaro," Duane et al. thus come down on the side of the many other researchers who have concluded, in their words, that "the reasons for the rapid decline in Kilimanjaro's glaciers are not primarily due to increased air temperatures, but a lack of precipitation."

Finally, based on their review of a compilation of all available information on present-day phenomena that control the glaciers on Kilimanjaro, and after what the five researchers describe as "a careful glaciological evaluation," Kaser et al. (2010) concluded that "minor changes in thickness have no impact on the changing surface area of the tabular plateau glaciers," while noting that "plateau glacier area decrease has been strikingly constant over the twentieth century," and that "ablation rates of the ice walls are [also] persistently constant." In addition, their analyses suggest that the mountain's plateau ice "may have come and gone repeatedly throughout the Holocene," and that the reduction of plateau ice in modern times "is controlled by the absence of sustained regional wet periods rather than changes in local air temperature on the peak of Kilimanjaro." This latter point was discussed previously by Mote and Kaser (2007) who reported that "the historical records available suggest that the large ice cap described by Victorian-era explorers was more likely the product of an unusually wet period than of cooler global temperatures," which lead them to an interesting hypothesis about Kilimanjaro's future.

"Imagine," say the two researchers, "a scenario in which the atmosphere around Kilimanjaro were to warm occasionally above 0 degrees," so that "sensible and infrared heating of the ice surface would gradually erode the sharp corners of the ice cap [and] gentler slopes would quickly develop." If precipitation increased simultaneously, as is typically predicted by most

---

7 http://www.co2science.org/articles/V14/N2/EDIT.php.
climate models, they say that "snow could accumulate on the slopes and permit the ice cap to grow," which scenario leads them to the ultimate conclusion that, "ironically, substantial global warming accompanied by an increase in precipitation might be one way to save Kilimanjaro's ice." Alternatively, or concurrently, Mote and Kaser suggest that "substantially increased snowfall, like the 2006-07 snows, could blanket the dark ash surface so thickly that the snow would not sublimate entirely before the next wet season," and that "once initiated, such a change could [also] allow the ice sheet to grow."

Whatever the future holds, one thing is clear in the present -- the scientific, political and theatrical rushes to judgment that have elevated Kilimanjaro's predicted demise by CO₂-induced global warming to iconic status are misguided and incorrect, as shown by the evidence presented above.

REFERENCES


Cover photo of Mount Kilimanjaro provided by wallpapers5.com.