Workshop on the use of automatic measuring systems on glaciers

Extended abstracts and recommendations

IASC Workshop, 23-26 March 2011,
Pontresina (Switzerland)

Institute for Marine and Atmospheric Research,
Utrecht University, the Netherlands

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High-elevation weather stations on glaciers in the Tropics - 2011 update

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Climate measurements continue at automated weather stations (AWS) on Quelccaya Ice Cap, Perú and on Kilimanjaro's Northern Ice Field (Tanzania). Situated on flat surfaces at the glacier's highest elevations (5680 m and 5775 m, resp.), these locations were selected to represent what are now - or once were - tropical glacier accumulation zones. The AWS began operating in August 2003 and February 2000, respectively, to provide a better understanding of processes by which ice cores record climate (e.g. Hardy *et al.*, 2003); long ice-core records have been developed from both sites (Thompson *et al.*, 1985, 2002), and limited mass balance studies are on-going.

Figure 1. AWS on Quelccaya (left) and Kilimanjaro (right; stations are adjacent to one another). The Quelccaya tower and one of those on Kilimanjaro are custom, modular designs of aluminum tubing and structural fittings. Recently, radiation shields compatible with the U.S. Climate Reference Network (USCRN) began operating at both sites, visible in images as large white disks with vertical tubes beneath; these house 3 PRTs each to measure temperature and a Vaisala HMT337 for humidity measurement.

AWS instrumentation is similar at the two sites, as shown in Figure 1 and detailed elsewhere (Thompson *et al.*, 2002; Link). However, the tower designs differ considerably, due to contrasting mass balance regimes in recent years. For example, the average net mass balance (w.e.) for 2005-2010 at Quelccaya AWS was ∼+0.8 m, in contrast to ∼-0.24 m over the same time interval at Kilimanjaro AWS. Consequently, to maintain a relative constancy of measurement heights, we lowered the entire Kilimanjaro tower 4 times due ablation, and have extended the Quelccaya station by 12 m due accumulation. This experience underscores the reality that AWS tower design must be adapted to the mass balance regime in which it is located. An initial evaluation of each station's performance was provided at the 2004 AWS Workshop in Pontresina (Hardy *et al.*, 2004).

The Quelccaya and Kilimanjaro sites are at similar elevations, yet measurements reveal important differences in climate. The magnitude of precipitation at Quelccaya, for example, is 4-6 times greater and delivered during one wet season. A more-variable, bimodal precipitation pattern predominates on Kilimanjaro. Also, the Quelccaya site is warmer, with aspirated air temperature typically rising above freezing on more than 100 days per year; Kilimanjaro air temperature remains below freezing. An extended dry season occurs at both sites, during which the mean relative humidity averages 63 and 44 percent, respectively. As a result of these differing climates, the resolution and fidelity of environmental history records from the ice cores also differs considerably (cf., Thompson *et al.*, 1985, 2006, 2002; Kaser *et al.*, 2010).

Issues, challenges, and lessons learned

An abundance of challenges are inherent in all unattended measurements on glaciers, as discussed by Box *et al.* (2004). These include adapting to a surface height which is often changing constantly, meeting power requirements despite riming and snowfall, keeping the tower plumb, and for researchers, simply functioning at high elevation during visits. A broad range of solutions to common and unique challenges are presented in this volume and in the 2004 proceedings.

The following are some of the lessons learned in successfully operating AWS on Quelccaya and Kilimanjaro. The list begins with what might be considered minor-yet-crucial details, and expands in scope toward broader issues.

1. Structural slip-on fittings (e.g., Hollaender Manufacturing) have proven to be strong and reliable. In combination with aluminum tubing, modular towers can be built to accommodate a broad range of uses and mass balance regimes (note extensive use at both stations, in Fig. 1).
2. A supplemental enclosure or "junction box" allows extra sensor wire to be neatly contained, minimizing cable damage, riming, and the temptation to purchase excessively-short cables.

3. "Air terminals" (see Fig. 1) may help to prevent electrostatic problems. At Quelccaya these have proven robust enough to endure frequent riming, although their effectiveness remains anecdotal (i.e., not proven). In a similar situation at Sajama and Illimani AWS without terminals, electrostatic discharge was a considerable problem.
4. Helpful ideas on ultrasonic snow sensors are provided by Box *et al.* (2004). On Kilimanjaro and Quelccaya, annually changing the transducer has often reduced measurement noise. Both stations utilize identical sensors on opposite sides of the tower, improving data continuity and reducing the influence of small-scale transient anomalies (e.g., snow drifts).
5. At any glacier station, a compelling reason may develop to continue operating the station beyond a relatively-short research interval of several years. For example, the typical research period may inadequately characterize climate variability in some locations, or the initial measurements may reveal unanticipated findings. Designing for an extension of time or measurement scope may prove easy and cost effective, should either become warranted.
6. In some environments, such as at the summit of Quelccaya Ice Cap, thin-film capacitive humidity sensors are not compatible with part-time mechanical aspiration. To save power at the Quelccaya and Kilimanjaro stations, one radiation shield is aspirated prior to each measurement for 2 of every 10 minutes. Under certain radiation, temperature and humidity conditions, water is hypothesized to exist on the sensor when the fan is not operating; ice crystals then apparently grow when the fan is switched on and colder air is introduced over the sensor. It appears that these crystals cause physical damage to the sensor, reducing its surface area and causing a measurement offset (1999, 2009 pers. comm. from Vaisala and Rotronic Instruments, resp.).
7. Air temperature and humidity measurements are difficult over high-elevation, high-albedo surfaces such as glaciers, due to large, diurnally-variable radiation receipt from above and below. Vapor pressure calculations rely upon both. To optimize measurement accuracy, use a shield for which radiation errors over snow and ice are well characterized. If resources permit, replicate air temperature measurements may be valuable, especially if the site permits mechanical aspiration; often sites which present extreme radiation loading (e.g., Kilimanjaro) are also optimal locations for solar power to operate fans. Replicate measurements permit intercomparison studies, and will likely yield a more accurate representation of true temperature and humidity.
8. Instrument calibration is an essential element of measurement accuracy, especially for trend analysis. The need for calibration is especially acute at infrequently-visited AWS in extreme environments. Yet, instrument calibration at glacier stations is fraught with difficulty, as discussed by Box *et al.* (2004) freshly-calibrated sensors to the site, removing the existing and re-wiring in the new sensor, and then conducting a post-deployment calibration of the sensors taken out. At Quelc-

caya and Kilimanjaro AWS, temperature and humidity sensors are nominally replaced on an annual basis. Although the Pt100 RTD temperature sensor (platinum resistance temperature detector) has remained very stable, the capacitive-type humidity sensor has commonly drifted by ±2-5 percent between calibrations, and more serious shifts of 15-20 percent have been found on several occasions (see lesson #6, above). Without calibration, these changes could have been overlooked, possibly even with replicate measurements.

Finally, field notes and photographs during each visit provide essential documentation that data analysis will rely upon. Our lists of fieldwork objectives are typically long, even overly-ambitious, yet should never compromise careful metadata collection.

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