Integrated glacier monitoring strategies: comments on a recent correspondence

In a recent correspondence to the *Journal of Glaciology*, Lüthi and others (2008) commented on our paper concerning integrated monitoring concepts for large glacier ensembles (Haeberli and others, 2007b). Their thoughts provide perspectives on several aspects but seem to miss the following essential points in our paper:

1. Mass balance measured at individual points can indeed provide more direct information than values which are inter- and extrapolated for entire glaciers. The interest in corresponding point information is growing in connection with distributed mass- and energy-balance modelling. We also fully agree that seasonal mass-balance determinations are of high value with respect to process understanding and numerical model development. The point made in our paper, however, concerns (1) the *relation* of point measurements to the mass balance of *entire glaciers*, (2) the need for regular *calibration* of the resulting glacier mass-balance values using independent measurements such as repeated geodetic/photogrammetric surveys and (3) the *comparability* with other components of the described integrated monitoring strategy (area/volume/length change and inventory data). The problem with lacking or infrequent calibration becomes obvious in the case of Silvretta glacier, Swiss Alps: recent remapping revealed (cf. Huss and others, 2008a) that the mass-balance values reported for this glacier during the past 25 years have been far too positive and must now be corrected by a value (several decimeters w.e. a^{-1}) which roughly corresponds to characteristic loss rates of mountain glaciers during the 20th century.

2. Our statement concerning the long-term snow-pit observations at Claridenfirn, Switzerland – the full data series for 1915–2000 was published by the World Glacier Monitoring Service (WGMS) in a chapter on index measurements (WGMS, 2005) – appears in a later paragraph and concerns the use of information from avalanching (i.e. dry-calving) glaciers for estimating the volume change of large glacier ensembles. The argument that the stable geometry of avalanching glaciers makes point observations on them especially suitable for studying climate-change effects is a different question and would be generally valid for many points near the upper end of glaciers if effects of snowdrift near mountain ridges and elevation changes due to mass balance and flow were adequately documented. The question nevertheless remains open as to why such observations should be made outside the regular mass-balance network rather than on nearby glaciers of the regular network, which are unaffected by avalanching or other disturbances (e.g. heavy debris cover, lake formation, surging). In any case, a well-reflected scientific concept should accompany long-term series of index point information as published in the *Fluctuations of glaciers* series of WGMS.

3. Of course, ablation tends to have a maximum at the terminus of a glacier. Even this maximum, however, can approach zero. This is the case where *overall glacier slope* approaches zero, causing the difference in elevation and hence in mass balance between the equilibrium line and the highest/lowest point on a glacier to decrease towards zero. The slope dependence of response times as documented with the parameterization scheme for glacier inventory data developed by Haeberli and Hoelzle (1995) relates to such reflections (note that this parameterization scheme considers mass turnover, flow and average driving stress to be a function of vertical glacier extent).

4. Statistical relations between measured area and measured thickness of glaciers have been used for decades to estimate volumes of unmeasured glaciers. Our paper acknowledges this fact but suggests that full use be made of the widely available *three-dimensional-information* in detailed glacier inventories and of digital elevation models in order to calculate slope-dependent thickness variability. Corresponding approaches have been applied in modelling exercises (see Hoelzle and others (2007) for inventory data on a large glacier ensemble or Huss and others (2008b) for a local case study) and offer more and better possibilities than using planar (area) information only. The comparably poor performance of methods that calculate glacier volume from area only has already been demonstrated by Driedger and Kennard (1986).

5. The main problem with the often used statistical correlations between measured area and calculated volume of glaciers, that is the correlation between a variable (area) with itself (area in volume), concerns the unrealistically high correlation coefficients (e.g. Radić and others (2007) give $r^2 = 0.999$) caused by the inherent autocorrelation and the related suppression of the large scatter in the measured data. This scatter ($\sim\pm$20–30% around the mean) becomes evident in statistically more reasonable relations between measured glacier area and measured glacier thickness. The suggestion of Lüthi and others (2008) to use volume/area relations for 'approximate calculation of ice-volume change from measured glacier area change' implies that two highly uncertain glacier volume estimates are differenced or, in other words, that thickness changes of glaciers are related to the roughly *estimated* glacier bed rather than to the *measured* glacier surface. With the example of the nearly unchanged mean thickness of Rhonegletscher, Switzerland, during its historical retreat and the related scaling exponent γ close to 1, Lüthi and others (2008) demonstrate that (1) a problem exists with the volume/area scaling approach (in addition to the statistical autocorrelation), and (2) the method of calculating *total volume* from measured volume change (surface mass balance) over measured changes in glacier area, as mentioned by Haeberli and others (2007a), is indeed a reasonable approach.

6. A primary goal of internationally coordinated data collections with full referencing of all data sources (e.g. Haeberli and others 2005, 2007a and earlier WGMS volumes) is to facilitate access to and referencing of uniformly formatted, standardized/calibrated and user-friendly information. Referencing international data services is a standard procedure in the field of climate-related environmental monitoring; it helps to save working time and journal space. The suggestion that original data sources always be cited rather than (or in addition to?) corresponding international databases is not

in keeping with the primary goal. Even though understandable in principle, it introduces an often prohibitive complication for data analysis work and publication. The Swiss glaciological reports mentioned by Lüthi and others (2008) for instance, were repeatedly published tardily, in some cases taking >10 years. The creation of the WGMS database aims to avoid these problems and various other difficulties.

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