Different mass balances for climatic and hydrologic applications

A fundamental and well-recognized difficulty in glaciology is to interpret balance series in terms of climate. It occurs because balance is determined not only by climate, but also by changes in glacier shape and size. As Haeberli and others (2003) clearly put it, '... comparison between present-day and past values of [glacier-wide] mass balance must take into account area changes which have occurred in the meantime.' Surface elevation changes are significant as well. Elsberg and others (2001) proposed a solution to this problem, the determination of a type of balance that is independent of these changes (the 'reference-surface' or 'climatic' balance), and thus is amenable to direct interpretation in terms of climate. However, W. Haeberli (personal communication, 2003) and M. Meier (personal communication, 2001) have pointed out to us that the Elsberg paper is perceived to be too complicated for use in actual balance programs. The purpose of this note is (1) to point out that it is actually straightforward to determine the reference-surface balance, and (2) to argue that both this and the conventional balance should be reported in measurement programs.

It is true that the Elsberg paper does not give enough emphasis to a key point: the reference-surface balance is usually considerably easier to determine than the conventional one. The paper is complex largely because it also addresses the conventional balance problem and reconciliation of the results of glaciological and repeat mapping measurement methods. These facts of life deserve more recognition.

A simple example illustrates the concept of two distinct balances. Consider the determination of a glacier-wide annual balance series. Suppose that each year one measures a curve of balance vs elevation (assuming that such a curve exists uniquely), and then integrates its product with the area–elevation distribution function as determined from some topographic map. If the same map is used year after year, one obtains the reference-surface glacier-wide balance series directly, the series that would exist had the glacier not undergone area and elevation changes. Therefore this series is amenable to direct climatic interpretation. The reference surface is that described by the map chosen. If the map is updated annually, or the less direct methods outlined in the Elsberg paper are used, one obtains the conventional balance series. This represents the actual mass change of the glacier and is therefore more useful for hydrologic applications in engineering or in sea-level change, for example. Thus we have two balances, a 'climatic' one and a 'hydrologic' one.

The relative difficulty in determining the two balances will depend upon how a particular balance program is conducted, but usually the conventional balance will be the more difficult because it requires more mapping. In the above example the conventional balance requires annual updates to the topographic map, as compared with none at all for the reference-surface balance. However, it is worth emphasizing that for both balances the elevations of the measurement stakes must be measured annually. It is easy to imagine a balance program in which no map updating leads, unknowingly, to a reported balance which is actually the reference-surface one, but a more common scenario is that infrequent map updating or interpolation between maps, and lack of surface-elevation measurements at stakes lead to a reported balance which is neither the conventional nor the reference-surface one. Whether this is a problem is difficult to ascertain from the reporting procedure. Implementing the concepts addressed here would produce not only the reference-surface balance, but in some cases an improved version of the conventional one as well. In our opinion, programs should report both balances and most can do so with the resources already in hand. Also, correct series of both balances should be produced as far back as possible, ideally to the beginning of the measurement programs.

This requires a little additional work but has been easy for three glaciers in North America. Over an approximately 30 year interval the cumulative reference-surface balance is more negative than the conventional one by about 16% on South Cascade, 22% on Gulkana and 3% on Wolverine if one chooses the original surface to be the reference one (Elsberg and others, 2001; Cox, 2002, table C4; Cox, unpublished data). The difference for South Cascade and Gulkana Glaciers is increasing rapidly as the difference between the actual and reference surfaces increases. The difference for Wolverine is small because the glacier has changed relatively little.

The concept of a reference-surface balance is applicable to both glacier-wide annual and seasonal balances. Also, a balance series measured at a map point can be corrected for the elevation difference between the actual and reference surfaces. Finally, the glacier-wide reference-surface balance is a useful interface between climate and glacier dynamics in simple models of glacier response to climate (e.g. Harrison and others, 2003).

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