Correspondence

The Editor,
Journal of Glaciology

SIR,

Comments on "The use of planimetric surface area in glacier mass-balance calculations: a potential source of errors" by Jacobsen and Theakstone

Two of the major conclusions of this paper are: (1) the true area of a glacier surface is not the same as the area of its projection onto a horizontal plane (the planimetric area), and (2) the true surface area should be used in computing average mass balance from point measurements. The first statement is correct but trivial, because it follows from the most basic trigonometry that an element of planimetric area can be obtained from an element of surface area by multiplication with the cosine of the local surface slope angle. The second statement is incorrect if the point measurements are made in the vertical direction, which to our knowledge is always the case, whether one uses poles, aircraft altimetry or even sequential mapping. Average mass or volume change is computed from these data by integration over the planimetric area, not the surface area, as outlined by Paterson (1994), for example. Use of the true surface area will lead to error in average mass balance which is on the order of 15% (depending upon the geometry), as the authors compute.

The point seems quite basic. We caution against the uncritical use of the results of this paper.

Geophysical Institute, University of Alaska, Fairbanks, Alaska 99775-7320, U.S.A.

BERNARD RABUS
WILLIAM D. HARRISON
KEITH A. ECHELMEYER

12 February 1996

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SIR,

Comments on "The use of planimetric surface area in glacier mass-balance calculations: a potential source of errors" by Jacobsen and Theakstone

Geo-information systems (GIS) provide "triangulation irregular network digital terrain models" (TIN DTMs) as routines for many purposes. These include the determination of "true" rough surface areas in order to improve the results one obtains from the traditional glaciological mass-balance method (Hoinkes, 1970), where mass and volume changes are obtained from point measurements which are extrapolated to areal values. (1) These "true" surface areas are not at all true, and (2) even if they were true, their use for the calculation of mass balance and related topics (e.g. energy balance) would be wrong by definition.

(1) The value of a rough surface area is mainly a function of scale, similar to the determination of the perimeter of an island. Zooming continuously into larger scales, it becomes longer and longer, even up to orders of magnitude (e.g. Penck, 1894). If Jacobsen and Theakstone (1995) went to even larger scales than 1:2000 they would obtain "true" areas which become larger than the projected area not only by 10–20%, but finally by orders of magnitude if the scale is chosen large enough. These rough surface areas are neither wrong nor true. However, it is impossible to define them exactly.

(2) If one looks at the calculation of the mass balance of a glacier along a longitudinal cross-section, one has to deal with the surface area of a rhombus which has two vertical and two inclined sides. The surface area of such a rhombus, corresponding to changes in the volume of a glacier, is calculated by multiplying the arithmetic mean of the vertical sides by the arithmetic mean of the horizontal projections of the inclined sides. Therefore, as long as specific mass- as well as energy-balance terms are measured vertically, they must be related to the horizontal projection of the corresponding surface area which is, moreover, well defined. Using mass-balance values and energy fluxes which are directed normal to the surface would again lead to a scale problem (normal to which surface with which inclination?), in addition to measuring problems, and would not improve the results objectively.

The problem of serac areas is well known but there is no realistic way to solve it. Not only for this reason it has to be noted that not every glacier is suitable for mass-balance studies, and "mass-balance glaciers" should be chosen very carefully (e.g. Østrem and Brugman, 1991, p. 9).

Institut für Geographie, Universität Innsbruck, Innrain 52, A-6020 Innsbruck, Austria

GEORG KASER

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SIR,

A reply to comments by G. Kaser on "The use of planimetric surface area in glacier mass-balance calculations: a potential source of errors" by Jacobsen and Theakstone

Dr Kaser makes three points in his comments on our paper: that surface area is a function of scale, and non-planimetric areas should not be used for calculations of mass balance and related topics; that mass-balance calculations involve a rhombus with two vertical and two inclined sides; and that "mass-balance glaciers" should be chosen carefully, to avoid those which are not "suitable". We consider that, in part, Dr Kaser's remarks illustrate the difference between what is theoretically ideal and what is the best that can be achieved in the real world.

We agree that surface area is scale-dependent. Indeed, we noted that "the true surface area is always larger than that which is calculated, even when a very accurate DTM is used, and the surface roughness, represented by the ratio of the planimetric area to the 'true' surface area, is lower than that actually present on the glacier" (Jacobsen and Theakstone, 1995). (We should, perhaps, have written "true" throughout our paper.) Nevertheless, we wish to emphasise that, in calculations relating to the use of water resources in glacierized areas, the best possible representation of the surface area on which snow accumulates, or from which ice melts, should be used. For example, if a metre of ice melts from a dome-shaped area several hundred metres in diameter, the resultant loss of volume is better calculated for engineering purposes by using the surface area of a hemisphere rather than that of a circle.

Whilst an element of planimetric area can be calculated from an element of surface area by multiplying the latter by the cosine of the local surface slope, the definition of the latter is limited by the detail which can be extracted from available maps. In drawing attention to the potential value of three-dimensional digital terrain models, we hoped to emphasise the degree to which, with modern techniques of surveying, it is possible to produce better maps of glaciers than those based on older methods. Thus, global positioning systems make it possible to acquire three-dimensional (elevation and geographical-coordinate) data from a very large number of points in a relatively short period (Hulbe and Whillans, 1994). The maps which can be produced from such data are much more accurate than those used previously. This is particularly the case for featureless areas, such as those parts of a glacier which are permanently covered by snow, for which there are inherent difficulties in plotting photogrammetric contours (Østrem, 1966). Within a GIS, the aspect and gradient of every triangular facet in a TIN DTM can be determined simply, and areas which are shaded by adjacent terrain for different solar elevations and azimuth can be identified. Such information *is* likely to be of value in energy-balance calculations, despite Dr Kaser's reservations. In computing the ablation and consequent discharge generated by energy inputs to the surface of a glacier where slopes are of different steepness and exposure, measurements of heat-balance components at a point on a horizontal surface cannot give results which relate to the entire glacier.

Whilst, in theory, the point values of ablation at stakes and snow depths determined by probing during mass-balance studies should be measured vertically, it is unusual for this to be done in practice. Ablation stakes almost invariably tilt, even if care is taken to ensure that they are vertical when first set in place. In mass-balance programmes, snow accumulation usually is determined by several hundred measurements, frequently made by an individual moving across the glacier on skis. In those circumstances, the measured depth is as likely to be normal to a gently inclined surface as vertical. Nice though it would be to convert all such field measurements to truly vertical values, it is unlikely that the results would justify the effort involved. In the *real* glaciological world, the theoretical rhombus does not feature!

Most glacier mass-balance programmes are carried out for a particular purpose. In Norway, hydropower planning is the basis for such investigations. However, few Norwegian glaciers possess an ideal textbook mass-balance geometry: more typical of areas in which glaciers play a significant role in the use of water resources are those, such as Nigardsbreen (Jostedalen), Engabreen (Svartisen) and Austre Okstindbreen (Okstindan), which are of the "plateau" type, with a steeper, often broken, section intervening between their higher and lower parts (Haakensen, 1995). It is on these glaciers, seracs and rough surfaces included, rather than on atypical "ideal" glaciers, that mass-balance measurements have been, and will continue to be, made by practical glaciologists. In making the most of their field data, they should endeavour to relate them to the best available representation of the actual form of the glacier surface. Here, digital terrain models *are* likely to provide more useful data than simple measures of planimetric area.

Department of Geography,
University of Manchester,
Manchester M13 9PL,
England

FRANK M. JACOBSEN
WILFRED H. THEAKSTONE

9 April 1996

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