SIR,

Reply to the comments of H. Slupetzky on "Mass balance of glaciers other than the ice sheets" by Cogley and Adams

We agree with nearly all the points made by Slupetzky. However, he writes that his indirect method of estimation of the mass balance of Stubacher Sonnblickkees, based on measurements of accumulation-area ratio (AAR), is "certainly as accurate as 'direct' mass-balance measurements". From information given by Slupetzky (1991) in connection with his equations 5 and 7, the standard error of his regression of mass balance B on AAR, measured concurrently from 1964 to 1980, is $\pm 118\ \mathrm{mm\,a^{-1}}$. The total error in his indirect estimate of B is the geometric sum (Cogley and others, 1996) of the standard error of the regression and the standard error of B. The latter is not given by Slupetzky (1991), but if we choose Cogley and Adams' (1998) nominal figure of $\pm 200\ \mathrm{mm\,a^{-1}}$ the total error in Slupetzky's indirect estimate is about $\pm 230\ \mathrm{mm\,a^{-1}}$ (that is, $\sqrt{200^2 + 118^2}$). Here we assume no correlation between errors in B and in AAR. If these measurement errors are correlated, the error in the indirect estimate will be greater (up to $\pm 318\ \mathrm{mm\,a^{-1}}$, the arithmetic sum of the errors).

In short, an indirect estimate of mass balance must in practice be less accurate than the direct measurements against which it is calibrated. Methods such as Slupetzky's serve vital functions, for example in regional extrapolation, and we did not mean to discount such work. But the uncertainty of the direct measurements is itself a serious problem. Cogley and others (1996) note that, quite apart from the systematic errors which they discuss, a tenfold reduction in random errors will be needed if climatically expectable trends are to be identified in mass-balance time series. Reducing the measurement errors, for example through better control of the biases and better calibration by periodic geodetic surveys, should be a more urgent priority than enlarging the global network of balance estimates in ways which risk blurring the distinction between measurement and inference.

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29 March 1999

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SIR,

Formation of supraglacial sediment accumulations on Kötlujökull, Iceland

In this journal, Näslund and Hassinen (1996) discussed the formation of supraglacial sediment accumulations on the snout of Kötlujökull, an 8 km wide, 15 km long southeasterly outlet glacier of the ice cap Mýrdalsjökull in south Iceland. As participants in the Nordic Course in Dynamic Geomorphology and Sedimentology at Mýrdalsjökull in August 1994, Näslund and Hassinen studied ice-cored sediment accumulations on the surface of the northeastern part of Kötlujökull. They found that the supraglacial sediments consist primarily of non-striated rounded boulders, gravel and sand; the roundness of the material and the absence of finer components were suggestive of esker sediments. Furthermore, they found remnants of water conduits at high elevations. The largest conduit observed was 12–15 m in diameter, and was exposed along a length of 40 m; higher up, the tunnel had collapsed due to ablation. Näslund and Hassinen combined these observations, and concluded that the large sediment accumulations were transported to the glacier surface by water flow within high-level conduits. This could have resulted from a jökulhlaup-like event, with much more meltwater present than usual; such an event could explain the large size of the conduits and the transportation of large amounts of coarse sediments.

During the past two decades, however, detailed studies (cf. Krüger, 1985, 1994, 1997; Aber and others, unpublished information, http://edcwww.cr.usgs.gov/pecora/aber/aberja.html) have shown that the sediment accumulations on the surface of Kötlujökull are more differentiated in texture and origin than reported by Näslund and Hassinen, and that the water-worked sediments were not transported to the ice surface by water flow, but currently emerge from debris bands and debris-laden thrust-planes. In the following, we will comment on the arguments of Näslund and Hassinen and present our alternative evidence.

Kötlujökull transports huge quantities of debris which melt out on the glacier surface from numerous debris bands and thrust-planes (Fig. 1a). Aerial photographs and Landsat multispectral scanner images demonstrate that the upper limit of dirt cover has migrated down-glacier. Analysis of satellite imagery (Aber and others, unpublished information) indicates movement of the 1918 tephra bed clearly in the outlet glacier; it migrated about 800–1200 m down-glacier during the period 1973–86 (60–90 $\mathrm{m\,a^{-1}}$). This compares with the 80 $\mathrm{m\,a^{-1}}$ average velocity determined by Krüger (1994) from aerial photographs for the period 1960–80. The northern part of the glacier, where the large sediment accumulations are situated, appears to have moved farther than the southern part. The dynamic behavior of this glacier is thought to reflect variations in volcanic heating and meltwater production in the caldera. The longitudinal compressive flow, being generated when the outlet glacier expands widely beyond its confining valley walls onto the extensive Mýrdalssandur plain, is responsible for intense deformation of the ice, which tends to fracture by shear in its terminal 1–1.5 km. Because the glacier is subject to longitudinal compressive flow, the snout area also displays radial crevasses reflecting transversal tensile stresses. The intense upward-directed thrusting of the ice mass has resulted in production

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