oblique view of the bottom and side of an ice block which was cut from the sheet of ice and placed on wooden panels. Since the ice was transparent, both the underside of the top surface and the worm-like channels can be clearly seen in the photograph. The thickness of the ice block was *c.* 10 cm.

In discussions with some of our colleagues on this matter, several interesting theories have been put forward to explain this curious melt pattern, although none has adequately explained the general regularity of the pattern nor the numerous thin channels through the ice. Can anyone, as a matter of general interest, propose a mechanism by which such a melt pattern may occur?

We should like to thank Patricia Grichen for taking the excellent photographs shown here.

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Sir,

Glacier energy balance and air temperature: comments on a paper by Dr M. Kuhn

In the study of the relationship between glacier ablation and atmospheric processes there seem to be two distinct approaches. In the first, the energy balance at the glacier surface is described explicitly in physical detail and the individual components are evaluated by careful and difficult measurement to assess their relative importance in the ablation process. A good example is by Ambach (1963). In the second approach, highly simplified relationships are postulated to relate the ablation, or more often the mass balance or run-off, to one or more selected meteorological elements or indices. Example of this approach using statistical methods are by Lang (1973) and Østrem (1973) whilst Hoinkes and Steinacker (1975[a], [b]) take a more intuitive approach. There need be no real conflict between the two approaches but supporters of the first often claim that the empirical coefficients derived from the second method are not governed by any "physical" law, for example LaChapelle (1965). On the other hand, supporters of the more empirical approach could accuse the others of being hopelessly Utopian as the energy balance method is too sophisticated for application to practical problems like the estimation of discharge from large glacierized areas.

The recent paper by Kuhn (1979) represents an admirable step towards the reconciliation of these two approaches, something also attempted less elegantly by Braithwaite (unpublished). Kuhn outlines the theoretical basis of the energy-balance approach in some detail and then derives a simple bulk-transfer relationship between air temperature and sensible heat flux. The relationship involves two variables T_a and T_0, which can be reduced to one by assuming that the surface temperature T_0 is 0°C, and all the other variables like the density of air, the friction velocity, the roughness length, and a function of stability are lumped together with the true constants (specific heat of air at constant pressure and Von Kármán's constant) into a new quantity α which is actually a parameter. The validity of this process rests upon the fact that some "variables" are less variable than others and can be treated as if they were constants as a first approximation. The purpose of my letter is first to point out a misconception in one of Kuhn's definitions and secondly to suggest an extrapolation of his conclusions, perhaps further than he would like.

Kuhn defines the T_a which appears in his equation (7) as the air temperature "that prevails at the level of the glacier but outside its thermal influence". However, from the integration of his flux-gradient relation (equation (6)), it seems that T_a is actually the air temperature that one would measure in a standard meteorological screen placed 1 to 2 m above the glacier surface. The air temperature at this level is already influenced by the glacier, as shown by several studies done on Axel Heiberg Island among others. For example, Müller and Roskin-Sharlin (1967) compared monthly mean air temperatures at the Base Camp on Axel Heiberg Island with those at approximately the same altitude on White Glacier at a distance of several kilometres and found a cooling effect. Ohmura (1972) discusses the finite-difference solution of a simplified thermodynamic equation which describes the advection of air from the Arctic Ocean over a stretch of tundra and then over a melting glacier. From a graph presented in Müller and others (1973) it can be seen that the solution involves progressive cooling of the air as it flows down-wind of the tundra–glacier edge where there is a sharp discontinuity in the sensible heat flux.

In Braithwaite (unpublished) the air temperature "at the level of the glacier but outside its thermal influence" was computed by interpolation of upper-air data at neighbouring weather stations (at a distance of 113 to 280 km respectively). These temperatures were treated as independent variables in regression models of temperatures at a number of local stations on and around White Glacier for several seasons. Once again the results confirmed the reality of the cooling effect which turns out to be surprisingly consistent for the different stations. I do not think that any of Kuhn's arguments are seriously affected by his misdefinition of T_a. However, if one tries to calculate glacier ablation from long-term records at unglacierized stations, account must be taken of the fact that the air is cooler over a glacier than at equivalent altitude in the free atmosphere as in Braithwaite and Müller (1976) or as quoted by Kotlyakov (1980).

My second point may be more controversial. According to Kuhn's equation (7) the sensible heat flux is approximately proportional to the air temperature T_a and he quotes a coefficient of 1.68 MJ m^{-2} d^{-1} deg^{-1} with an error of $\pm 14\%$. In its turn, ablation is proportional to the sensible heat flux (among others) so that a change in temperature of 1 deg should give a change in ablation rate of 5 mm water d^{-1} due to the change in sensible heat flux alone. Other components of the energy-balance equation will also depend upon temperature, particularly the terrestrial downward radiation. Differentiation of Kuhn's equation (4) with respect to temperature and assuming an effective emissivity of 0.7 yields a change in downward radiation of 0.28 MJ m^{-2} d^{-1} deg^{-1} which, in combination with the value for the sensible heat flux, would give a total change in ablation rate of about 5.9 mm water d^{-1} deg^{-1}. This figure is in reasonably good accord with values obtained by several authors for the empirical coefficient linking ablation to positive temperature sums (degree-day factors), for example: Zingg ([1952]) gives 4.5 mm d^{-1} deg^{-1}, Kasser (1959) quotes a range from 5.1 to 7.0, and Orheim (1970) reports values of 6.5 and 6.1 for two seasons.

Braithwaite (unpublished) has re-analysed energy balance data reported by Andrews (1964), Keeler (1964), Havens and others (1965), and Müller and Keeler (1969) and found a change in ablation rate of 6.3 mm water d^{-1} $deg^{-1} \pm 16\%$ by regression analysis. The corresponding bulk transfer coefficient (assuming logarithmic profiles) for sensible heat flux in Braithwaite (unpublished) was 1.44 MJ m^{-2} d^{-1} $deg^{-1} \pm 28\%$ compared to a corresponding unpublished value of 1.40 MJ m^{-2} d^{-1} deg^{-1} $\pm 13\%$ by regression. These values are both a little lower than Kuhn's. In three out of the four cases studied by Braithwaite (unpublished) there were also significant correlations between latent heat flux and temperature with a coefficient of 0.54 MJ m^{-2} d^{-1} $deg^{-1} \pm 58\%$ whilst the corresponding coefficient for net radiation was 0.20 MJ m^{-2} d^{-1} $deg^{-1} \pm 147\%$ (these unpublished values were calculated by regression analysis). The large variations within the four cases are noteworthy but the figures indicate roughly the relative importance of the three energy sources in contributing to the variation of ablation rate with temperature.

We must acknowledge the complexity of the energy balance at the glacier surface and the resulting impossibility of accurately assessing ablation with any simple climatic model. However this does not stop us looking for simple and useful models which are reasonable approximations. Kuhn (1979) has clearly demonstrated the physical basis of his bulk transfer coefficient and, if he will accept my comments here, he can also claim to have provided an explanation for the long-known approximate relation between ablation and air temperature. If he is still sceptical about this point I suggest that he calculate regression equations of ablation rates on temperature using the many available energy balance series from Austrian glaciers, some of which are unpublished or only briefly reported. Although I would expect considerable scatter in the results, depending upon synoptic conditions, etc., I would be surprised (and disappointed) if the majority of the slope values did not lie in the range 5 to 7 mm water d^{-1} deg^{-1}.

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