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2 m temperatures along melting mid-latitude glaciers, and implications for the sensitivity of the mass balance to variations in temperature

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ABSTRACT. In calculations of the variation in the 2 m temperature along glaciers, the lapse rate is generally assumed to be constant. This implies that the ratio of changes in the 2 m temperature above a glacier to changes in the temperature outside the thermal regime of that glacier ("climate sensitivity") is equal to 1. However, data collected during the ablation season on several mid-latitude glaciers show that this sensitivity is smaller than 1. The lowest measured value (0.3) was obtained on the tongue of the Pasterze, a glacier in Austria. The measured temperature distribution along the Pasterze cannot be described by a constant lapse rate either. However, there is almost a linear relationship between potential temperature and the distance along the glacier. This paper introduces a simple, analytical, thermodynamic glacier-wind model which can be applied to melting glaciers and which explains the observed "climate sensitivities" and temperature distributions much better than calculations based on a constant lapse rate.

This way of modelling the 2 m temperatures has implications for the sensitivity of the surface mass balance to atmospheric warming outside the thermal regime of the glacier. The magnitude of this sensitivity is computed with a surface energy-balance model applied to the Pasterze. When a constant lapse rate is used instead of the proposed glacier-wind model to compute changes in the 2 m temperature along the glacier, the negative change in mass balance due to 1 °C warming is overestimated by 22%.

1. INTRODUCTION

In calculations of the variation in the temperature just above the surface along glaciers, the lapse rate is generally assumed to be constant (e.g. Oerlemans and Hoogendoorn, 1989; Jóhannesson and others, 1995; a constant lapse rate means that the change in temperature with elevation is constant). This assumption is made both for melting and for frozen surfaces. There are two reasons for reconsidering this assumption as far as melting glaciers are concerned.

First, measurements made during the melt season above the Pasterze, a glacier in Austria, show that the variation in the 2 m temperature along the glacier cannot be explained in terms of a constant lapse rate. In fact, the relation between potential temperature and the distance along the glacier is found to be almost linear (see Greuell and others, in press).

Secondly, the assumption of a constant lapse rate causes a problem in the calculation of changes in ablation due to changes in atmospheric temperature. Ablation changes are generally calculated by means of surface energy-balance models (e.g. Oerlemans and Hoogendoorn, 1989; Oerlemans and Fortuin, 1992) or degree-day models (e.g. Hoinkes and others, 1968; Jóhannesson and others, 1995). In most cases these models are forced by the temperature just above the glacier surface, typically at 2 m. Consequently, a change in temperature is also imposed at this level. If the lapse rate is assumed to be constant, the temperature change does not vary along the glacier and is equal to the temperature change outside the thermal regime of the glacier. Therefore, temporal variations in the 2 m temperature above the glacier are equal to those recorded at climate stations, and future changes in the 2 m temperature above the glacier are equal to those predicted by global atmospheric models. However, these equalities are not correct with respect to melting glaciers. Whereas the temperature of the free atmosphere (the part of the atmosphere not affected by the underlying surface) above a melting glacier varies, the temperature of the surface itself remains constant at 0°C. The 2 m temperature is intermediate between the temperature in the free atmosphere and the fixed temperature of the surface, and therefore the change in the 2 m temperature is smaller than that in the free atmosphere. Consequently, if a constant lapse rate is used to compute 2 m temperatures above the glacier from temperatures recorded at climate stations or predicted by atmospheric models, the sensitivity of ablation to variations in atmospheric temperature will be overestimated

The ideal solution to this problem is to use the temperature outside the thermal influence of the glacier as forcing and to compute melt by coupling a melt model to a mesoscale atmospheric model. The latter should extend beyond the thermal influence of the glacier and resolve details of the structure of the boundary layer above the glacier. However, such an approach is computationally expensive, and appropriate models still have to be developed. This paper provides an alternative approach in the form of a simple thermodynamic model of the glacier wind.