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Interactive comment on "Application of a minimal glacier model to Hansbreen, Spitsbergen" *by* J. Oerlemans et al.

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General comments

This paper deals with a most important problem in present-day glaciology, - the response of a tidewater glacier to climate, - that entails the combined effects of:

a) an altitude–mass balance feedback (Böðvarsson, 1955; Weertman, 1961); - increased mass balance raises the glacier mean surface elevation (anything else being unchanged) and since the air temperature drops with height this implies a more positive mass balance and further growth of the glacier.

b) a tidewater glacier cycle comprising changes of the calving glacier terminus (advance and retreat) that are forced by factors additional to climatic influence. The rate of calving is the product of glacier dynamics driven by the glacier mass balance and flow induced thinning of the terminus controlled by glacier velocity (the stretching rate) and geometric changes in the terminal region as it changes position (Mercer, 1961; Reeh, 1968; Post, 1975; Meier and Post, 1987; Meier, 1997; Alley, 1991; Powell, 1991; Warren, 1991, 1992; Van der Veen, 1996, 2002, 2004; Fischer and Powell, 1998; Vieli et al., 2001, 2004; Rignot et al., 2003; Nick and Oerlemans, 2006; Vieli *et al*. 2001, 2004; Benn et al., 2007; Alley et al., 2008).

Evaluation of the response of tidewater glaciers to climate is crucial for the prediction of cryospheric response to climate forcing, and consequent sea level change.

The authors present a simple parameterized model of ice mechanism and fluxes (called minimal glacier model) that is aimed at describing the evolution of the bulk glacier dynamics (with no spatial resolution) on a large time scale; the mechanics of glacier flow are not described in detail by the glacier profile and the related velocity field. The mean ice thickness (integrated over the entire glacier) and the ice thickness at the glacier front are parameterized in terms of glacier length.

The change in glacier length is determined by the total change in the mass budget (surface balance and calving flux). Difference in climate, forcing the model, is simulated by lowering or raising uniformly the mass-balance distribution over the glacier (the equilibrium line altitude), the specific mass balance being a linear function of altitude.

The rate of iceberg calving (for annually averaged data) is assumed to be entirely determined by the water-depth at the floating terminus and the glacier length. The rate of calving is described by an empirical calving law where the calving rate is proportional to water depth (as suggested by e. g. Brown et al., 1982, 1983; Pelto and Warren, 1991, Funk and Röthlisberger, 1989).

The model is run by reconstructed climate history and calibrated by comparing the simulated and observed geometry (glacier length) of Hansbreen. An empirical calving rate parameter is adjusted to field observations.

The minimal model captures the behaviour of a tidewater glacier and can describe the combined effect of the two feedback processes (a and b above): one bifurcation of equilibrium states related to the height-mass-balance feedback of the climatic forcing and another connected to the coupling between the calving process and the bed profile (water depth). The model is able to simulate the full cycle of ice-free conditions, glacier terminus on land, tidewater glaciers terminus, and backward, - for Hansbreen in Svalbard which is situated in an over-deepened basin.

The subject of the paper is highly relevant to glaciology. The paper is scholarly written: clear text and figures, references to related work adequate, the discussion careful and reasonable, results appear to be realistic and conclusions substantial.

The main strength of the quasi-analytical minimal model is that it makes possible productive discussion of the long-time response of tidewater glaciers in terms of parameters as the equilibrium line and the glacier geometry (see Figure 8 in the manuscript). The general validity of the simple calving law can be questioned but most glaciologists would agree, anyway, that it is reasonable to assume that mass loss by calving is generally larger the deeper the water is at the glacier front. In my opinion the minimal-model-approach provides a valuable contribution to the ongoing exploration of tidewater glaciers at the same time as more sophisticated two- or three-dimensional numerical ice-flow models and improved calving laws have to be developed.

Although the minimal model has been described in previous publications (Oerlemans and Nick, 2005, 2006; Oerlemans, 2008) it is important to see it applied on the well-studied Hansbreen in Spitsbergen. The schematic representation of the Holocene evolution of Hansbreen is instructive.

I recommend this paper for publication subject to addressing minor specific points.

Specific points

p. 958, l. 2-4. The referenced paper by Pohjola et al. (2004 or 2002? See page 975,

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Fig. 5b) is missing in the References. The paper may be:

Pohjola, V.A., T .Martma, H. A. J. Meijer, J. C. Moore, E. Isaksson, R. Vaikmäe and R. S. W. van de Wal. 2002. Reconstruction of three centuries of annual accumulation rates based on the record of stable isotopes of water from Lomonosovfonna, Svalbard. Annals of Glaciology 35, 57-62.

The reference to Pohjola et al. (2004 or 2002) is said to support why the reconstructed variation in the equilibrium line altitude in the 20th century does not quite follow the air temperature in Spitsbergen; the explanation being an increased accumulation on glaciers in Spitsbergen in the second half of the 20th century, detected by analyses of stable isotopes of water from the ice cap Lomonosovfonna. I am still impressed by the successful tracing of geochemical and isotopic signals on that temperate ice cap.

Page 950, l. 21 and page 965, l. 10-12. I believe the estimate of 50 m is an educated guess but the point made about a considerable higher pre-LIA bed profile is important.

p. 956, l. 3. “is” is missing. “is the ice thickness”

Do you want to use both the words Spitsbergen and Svalbard, and do you expect the general reader to know the difference?

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