MODELLING THE MASS BALANCE OF THE NORTH POLAR ICE CAP ON MARS. K. G. Schmidt, *Center for Planetary Science, Juliane Maries Vej 30, DK-2100 Copenhagen OE, Denmark (kgs@gfy.ku.dk)*, S. L. Buchardt, *Department of Geophysics, University of Copenhagen*.

Introduction

The ice caps on Mars are believed to consist mostly of water ice, with large amounts of dust and possibly some CO_2 ice. The surface appears white along the horizontal and north-facing surfaces, while the steep south-facing scarps are dark due to dust and expose numerous horizontal layers that are believed to be related to climate changes on Mars. The northern ice cap has a maximum elevation of 3 km, an extent of around 1000 km, and a volume approximately half that of the Greenland ice cap [1].

On the northern ice cap of Mars, the mass balance pattern is much more complicated than on a terrestrial ice sheet. It is heavily influenced by the scarp distribution — accumulation occurs on the white areas of the ice cap and ablation occurs from the scarps. We construct a new model for the north polar ice cap on Mars with a parametrisation for a realistic mass balance in order to calculate flow velocities for the ice cap under the assumption of steady state.

The Model

The mass balance is primarily governed by the local geometry described by three physical parameters: The altitude, the latitude, and the slope of the surface. We propose a very simple model for the local net mass balance b that includes the effects of these parameters given by

$$b = \alpha \cdot r + \beta \cdot s(r) + \gamma \cdot h(r) \qquad (1)$$

where r is the radial distance from the centre of the ice cap, s is the local slope of the ice cap, h is the height of the ice cap, and α, β, and γ are tunable parameters. The mass balance b is positive when there is net accumulation and negative for net ablation. The distance from the centre of the ice cap r represents the latitudinal variation of the insolation — the longer from the pole, the more insolation, which gives a negative contribution to the net mass balance, hence α has a negative sign. The slope s is considered negative when the altitude decreases with the radial distance from the centre of the ice cap. A steeper equatorward slope will enhance the local insolation and therefore give a negative contribution to the net mass balance, whereas a poleward slope will protect the ice from sublimating away, hence β has a positive sign. The height of the ice cap h determines the annual average temperature. Even though there will likely fall more snow at lower altitudes and latitudes than at the centre of the ice cap, the snow is believed not to sublimate away completely near the centre, and therefore the height will have a positive effect on the net mass balance and γ has a positive sign.

We assume that the ice cap has the shape of an ideal plastic ice sheet. This is the usual assumption for terrestrial ice sheets [2]. In the model the ice cap is composed of a central white plain area with radius R_0, where only accumulation occurs. The area of this plain area is 20% of the area of the whole ice cap [3], which corresponds to a value of $R_0 = 220$ km for an ice cap with radius $R = 500$ km. Outside the plain area the surface of the ice cap consists of alternating scarps with steep slopes and white areas with slopes that are flatter than they would have been for an ideal plastic ice sheet.

The total net accumulation of an area north of a given r-value must be equal to the amount of ice moved by the horizontal velocity u through the surface area of the cylinder with height $h(r)$ and circumference $2\pi r$ for an ice sheet in mass balance. This gives

$$u(r) = \frac{\int_0^r 2\pi r \cdot b(r) dr}{h(r) \cdot 2\pi r} \qquad (2)$$

Results

The present accumulation rate on the white areas is $a = 10^{-3}\,\frac{\mathrm{m}}{\mathrm{yr}}$ and the ablation rate on the scarps is $A = -10^{-2}\,\frac{\mathrm{m}}{\mathrm{yr}}$ [4]. If the height of the ice cap is in the interval $h \in [0, 3]$ km then the minimum value of γ is $\gamma \sim a/H_0 = 10^{-3}\,\frac{\mathrm{m}}{\mathrm{yr}}/3\,\mathrm{km} \doteq 3.3 \cdot 10^{-7}\,\mathrm{yr}^{-1}$. The values of α and β can be estimated similarly.

Table 1: Values for the tunable parameters in equation 1 for present day conditions.

Parameter	Present day value
α	$-2 \cdot 10^{-9}\,\mathrm{yr}^{-1}$
β	$5.7 \cdot 10^{-2}\,\frac{\mathrm{m}}{\mathrm{yr}}$
γ	$3.3 \cdot 10^{-7}\,\mathrm{yr}^{-1}$

Inserting these values in the model gives negative flow velocities for most of the ice cap, which shows that the ice cap must be stagnant or receding as ice generally cannot flow uphill. Hence, our conclusion is that the ice cap today is not in mass balance.

We then investigate which values of α, β, and γ that will give a steady state ice sheet with the size of the present ice sheet. This may explain how a former mass balance must have been in order to build up the ice cap initially. We choose values for α, β, and γ that results in an ice cap in mass balance with a size similar to the observed. We define the radius of the ice cap to be the value of the radius r where the mean horizontal flow velocity becomes zero or negative. α and γ are chosen so that they maximise the ice cap extent and β is chosen somewhat arbitrarily so that the scarps have a significant effect on the ice cap mass balance.

Table 2: Values for the tunable parameters in equation 1 for an ice cap in mass balance.

Parameter	Mass balance value
α	$-5 \cdot 10^{-9}$ yr^{-1}
β	$1 \cdot 10^{-2}$ $\frac{\mathrm{m}}{\mathrm{yr}}$
γ	$1 \cdot 10^{-6}$ yr^{-1}

In figure 1 the local mass balance b and the mean horizontal velocity u versus r are shown for the values of α, β, and γ from the two tables.

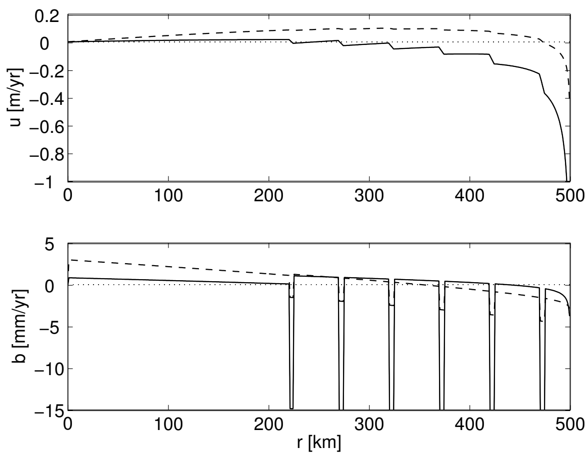

Figure 1: Comparison of horizontal flow velocity u (upper panel) and the net mass balance b (lower panel) as a function of the radial distance r from the north pole for two different sets of values for the tunable parameters α, β, and γ. The solid lines correspond to the present conditions (values for α, β, and γ given in table 1) and the dashed lines correspond to the values for an ice cap in mass balance (values for α, β, and γ given in table 2).

Discussion

For a decrease in α we expect an enhanced latitude effect, which means that the sublimation is more effective leading to a decreased net mass balance. Increasing γ enhances the altitude effect which gives higher accumulation in the central parts of the ice cap. The combination of the changes of these two parameters makes the slope of the net mass balance steeper. The steeper slope of the mass balance causes the velocity field to be more effective with higher velocities in order to keep up with the enhanced accumulation in the central parts and the enhanced sublimation near the edge of the ice cap.

Conclusion

The fact that the ice cap presently is stagnant or receding shows that the mass balance must have been different in earlier times in order to form the ice cap in the first place. We have seen that by changing the tunable parameters α, β, and γ it is possible for an ice cap in steady state to be of the same size as the present non-steady state ice cap. The difference between the mass balance calculated from the values in table 2 and the one for the present day values (table 1) is that b is a steeper function of r in the case of mass balance, which is equivalent to an enhanced accumulation at high altitude in the central parts of the ice cap and an enhanced ablation near the edges at lower elevations and latitudes. The enhanced ablation at lower latitudes could be caused by a stronger insolation, likely caused by a change in Mars' orbital parameters. The enhanced accumulation at high altitudes near the north pole could have been caused by a higher atmospheric content of water vapour, which might be a consequence of a stronger sublimation at lower latitudes. Changes in β correspond to a change in the sublimation from the scarps, which could also be caused by an insolation change.

References

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