

# SUBLIMATION OF WATER FROM THE NORTH POLAR CAP ON MARS.

C. S. Hvidberg, *Niels Bohr Institute for Astronomy, Physics and Geophysics, University of Copenhagen, Denmark (ch@gfy.ku.dk)*, H. J. Zwally, *NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.*

## Introduction:

The North polar cap on Mars is the largest known reservoir of H<sub>2</sub>O on Mars at present. The cap is thought to consist of water ice together with some dust and CO<sub>2</sub> ice [1]. It is formed by layers deposited through thousands of years. At present, the cap continues to interact with the water vapor in the atmosphere, and contribute to the water cycle with sublimation and deposition processes. What is the mass balance of the cap at present? What processes are actively contributing to accumulation and ablation of water ice? The present topography of the cap is a result of climatic conditions and erosional processes through time, and analyses of the topography may be a key to answer these questions.

We have analyzed Mars Orbiter Laser Altimeter (MOLA) topographic data from the North polar cap [2]. Assuming the cap consists of flowing water ice, we are using ice flow models to study relations between topography, flow, and mass balance. We have estimated the total sublimation of water from the cap during the northern summer. Our results are consistent with earlier estimates of water vapor in the atmosphere from Viking MAWD data [3].

## Topography of the North polar cap:

MOLA data show that the North Polar cap is circumpolar and rises 2800 meters above the surrounding terrain (Fig 1.). A characteristic feature of the cap is a system of troughs and scarps organized in a spiraling pattern around the pole. Horizontal or pole-facing areas appear white, and the steep (10-15°) scarps are south-west-facing and appear dark. It has been suggested that the cap accumulates ice along the horizontal areas, and loses ice by sublimation along the south-facing dark scarps [4,5]. The suggested alternating pattern of accumulation and ablation has been referred to as “accublation” [5].

## Models of the North polar cap of Mars:

Although the North Polar Cap on Mars is colder than any ice sheet on Earth, and gravity is around one third of that on Earth, the cap must flow due to gravity. Assuming the generally used ice flow laws may be extrapolated to the colder temperature regime on Mars, average flow velocities are small (i.e. in the order of mm per year [6]), but enhanced at scarps [7].

The model calculates the evolution of the polar cap in time. The polar cap is assumed to be axisymmetrical and to consist of flowing water ice. Topography along a MOLA track crossing the pole is assumed to represent the polar cap. Ice is assumed to

deform according to a power flow law with a temperature dependent rate factor [8,9]. Ice temperature is calculated from the heat flow equation. The model includes longitudinal stress gradients associated with the troughs. The model was developed for modeling terrestrial ice sheets [10], and its applications to the North polar cap of Mars has been documented [11].

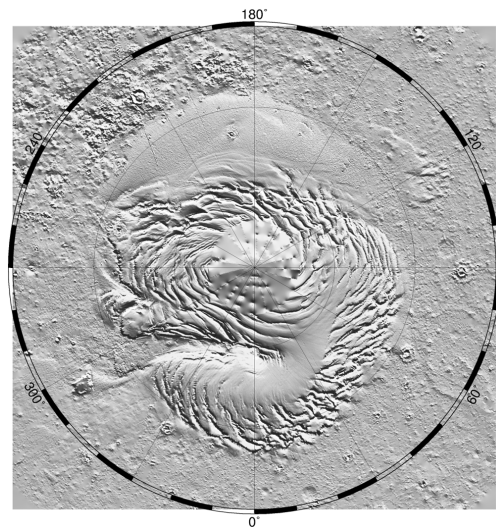


Figure 1. Shaded relief map of the North polar cap of Mars (image credit: NASA GSFC/MOLA Science Team)

Here, the model is used in two different modes: 1) To calculate the present flow from the present topography. This mode involves no assumption of accumulation or ablation. 2) To calculate how the cap would evolve in time. In this mode, the model assumes a pattern of accumulation and ablation, which governs the growth or shrinkage of the polar cap by time.

If accumulation and ablation is controlled by sublimation, they depend on surface slope as well as geographical position. For simplicity, it is assumed that they are functions of the surface slope only. North facing or horizontal surfaces are assumed to accumulate with a constant rate  $b$ , while south facing surfaces ablate. The ablation rate is assumed proportional to the surface slope with a constant proportionality factor  $C$ .

## Results: Ice flow and topography:

The characteristics of the spiraling troughs suggest that they were formed by sublimation. Is this

process active today? How fast would ice flow close the troughs? How much sublimation is needed to keep them open? We have used topography along several MOLA tracks to obtain a relation between the required sublimation rate to keep the troughs open, and the surface slope. Here, we refer to results from MOLA track #404, which follows the  $160^\circ$  E longitude.

*Ice flow would close the troughs.* If there is no ablation or accumulation, the polar cap flow slowly while it smooths. Deep troughs will close in the order of  $10^5$  to  $10^6$  years, most rapidly within the first tens of thousands of years, where the surface slopes are greatest. This suggests that the troughs are forming on time scales less than  $10^5$  years.

*Sublimation rates must exceed flow velocities.* We have evolved the cap by assuming patterns of accumulation and ablation. First, we assume that the deposition is 0.5 mm/year and  $C$  is determined in order to have an initial net mass balance along the flow line. With this pattern of accumulation and ablation, troughs migrate inward, while they smooth. The initial migration speed is in the order of cm/year. Sublimation rates are up to 5 mm/year at the steepest scarps. Troughs are closing in the order of  $10^5$  to  $10^6$  years.

We have calculated the present ice flow velocities from the present topography. Ice flow velocities are vanishing along the horizontal surfaces, but enhanced up to 5 cm/year at the steepest scarps. Sublimation rates must exceed ice flow velocities in order to keep the troughs open.

If sublimation rates are enhanced by a factor of 10 compared to the net mass balance, the troughs remain open in time. We use a deposition  $b$  as above, and the factor  $C$  at 10 times the value above. Troughs are migrating inward, while the steep slopes at the scarps are preserved. The migration speed is in order of tens of cm/year. Sublimation rates are 5 cm/year at the steepest scarps (Fig. 2).

*Estimated sublimation rates.* The sublimation rates found above equals the flow velocities at the scarps, and provide an estimate of the sublimation rates required to form the troughs observed at present.

#### Sublimation from the North polar cap:

Our analysis above shows: 1) The spiraling troughs are actively formed at present, -if not, ice flow would smooth out the troughs on short time scales. 2) The sublimation required to keep the troughs open, may be estimated from the surface slope.

We have used results from several MOLA tracks to determine the relation between required sublima-

tion and surface slope. We have used the MOLA topography to calculate the surface slope on the cap. We calculate the total sublimation North of  $80^\circ$ N to be in order of  $10^{11}$  to  $10^{12}$  kg per Martian year.

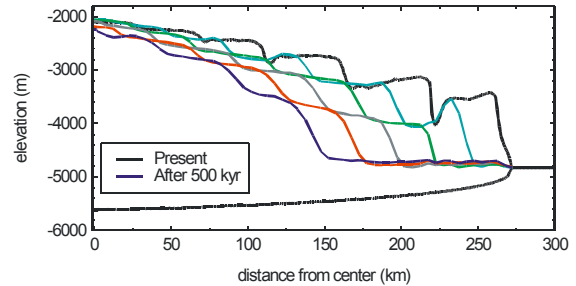


Figure 2. The surface is evolved in time assuming sublimation rates of up to 5 cm/year at the steepest scarps. The black line is the initial topography (MOLA topography along track #404). The surface is plotted every  $10^5$  years. Sublimation is sufficiently high to maintain the steep slopes at the scarps.

#### Discussion:

The estimated sublimation is a minimum estimate, because higher sublimation rates would also keep the troughs open. It is a mean annual value, but all sublimation occurs during the northern summer. Our estimate is sensitive to the assumed composition of the cap. A high dust content in the cap could make the ice stiffer than pure water ice. Stiffer ice would require smaller sublimation rates to keep the troughs open.

Haberle and Jakosky [3] studied sublimation and transport of water vapor in the atmosphere of Mars. Based on Viking MAWD data, they estimated the amount of water vapor entering the atmosphere in the northern hemisphere during the northern summer. Their estimate was a maximum estimate of  $7 \cdot 10^{11}$  kg. They also discussed how the atmosphere could transport this amount of water away from the cap.

In the northern summer, water may sublimate both from the North polar cap and from the northern lowlands, which were recently shown to contain large amounts of water beneath the surface [12]. However, a surface dust cover would protect subsurface ice from sublimating, e.g. as observed on terrestrial glaciers. The polar cap may thus be the dominant source of water vapor with its white surface and exposed ice deposits.

Our estimate of water sublimation from the cap is a new and completely independent estimate. The agreement with the estimate from Viking data is promising. The sublimation process may be well

understood, but our analysis also shows that the simple parameterization of accumulation and ablation from surface slope does not capture the mass balance processes fully. Water vapor may be recycled back to the cap, and wind may contribute to redistribution of material. We are continuing to study mass balance processes, in order to identify and quantify the important processes.

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