MODELLING THE EVOLUTION OF NORTH POLAR CAP OF MARS FOR RECENT PAST CLIMATE.

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Introduction

The time scale of about 10^5 years is an interesting one for the celestial mechanics of Mars. Orbital parameters of Mars undergo cyclic oscillations due to various dynamical influences [5]. Recent numerical integration of Solar System [3] showed that Mars' obliquity θ_o is rather chaotic and might have varied between $0^0 \leq \theta_o \leq 50^0$ or even greater during the past 10 Myr or more. Most striking change in the obliquity was observed in the recent past 5 Myr before present, when the value of θ_o reached 45^o. This obliquity period might have lead to very high ablation rates causing evaporation of the perennial North Polar Cap. We have studied the evolution and dynamics of the perennial North Polar Cap of Mars for past 5 Myr using an ice sheet model.

Model description

The ice sheet model SICOPOLIS used for this study was developed first for terrestrial application and then has been adapted to Mars' Polar Caps. It is a three dimensional, large scale, polythermal ice sheet model. External forcings for the model are given by mean annual surface temperatures at the surface, net surface mass balance and geothermal heat flux. The model domain is 1800 km × 1800 km square with its center located at the north pole. The grid resolution is 20 km in horizontal direction. The vertical resolution of the model is 51 points in the cold ice region and 11 points in the lithospheric column. There are also 11 points in vertical resolution if there exists temperate ice. For more details of the model see [4]

Surface temperatures are computed using radiative balance. For the radiative balance, insolation is calculated as daily mean insolatioan value at each grid point. Insolation is considered a function of orbital parameters and vernal equinox anomaly. Since this scheme is based on daily mean insolation value, it works well for polar day but fails for polar night or winter season. It fails because the assumption of radiative equlibrium is not valid during polar nights. During polar night atmospheric CO_2 condenses on the polar region. It is assumed that this condensation of atmospheric CO_2 keeps the surface temperatures at CO_2 condensation temperature.

For mass balance scheme, accumulation parameterization is based on Clausius-Clapeyron relation. The accumulation rate over the North Polar Cap is assumed proportional to the water vapour saturation pressure in the atmosphere. This gives the amount of precipitable water content available in the atmosphere for accumulation. The net mass balance i.e. accumulation - ablation rate is calculated using an equilibrium line concept, a widely used concept for terrestrial ice sheet. Equilibrium line is where the accumulation and ablation are in equilibrium, meaning net mass balance is zero. Equilibrium line is chosen close to the current ice margin. The region where accumulation is more than ablation is called the region of positive mass balance. This is the region where ice deposition takes place. The positive mass balance region lies between the pole and the equilibrium line. The region where ablation is higher than accumulation, it is a region of negative mass balance. This region lies equatorward side of the equilibrium line. An accumulation-ablation rate gradient is taken from pole towards the ice margin.

Evolution of the North Polar Cap

Taking into account the possibility of evaporation of the complete North Polar Cap, we consider an ice free initial condition 5 Myr before present. The cap is then allowed to build and to reach the present surface elevation. Present accumulation rate is adjusted such that the simulated ice cap reaches its current MOLA elevation (-1.95 km with respect to reference geoid) in 5 Myr. Simulations are driven by the climate forcing which are parameterized based on orbital parameters. Latest MARSIS instrument results [1] indicate that ice cap can not contain more than 2% of impurities. Hence 2% of dust is assumed to be present in total ice volume. Glen's flow law with stress exponent $n = 3$, which is common for terrestrial ice sheet, is used to describe ice flow. Geothermal heat flux from below the basal region is taken as 35 mWm^{-2}.

Results

The adjustment of accumulation rates such that North Polar Cap can be built within 5 Myr results with the accumulation rate of 0.2423 mm/a. The estimated rates for current accumulation vary in the range of 0.01-1.0 mm/a [2]. Hence the estimated value here can be considered realistic. Figure 1 top panel shows the variation of maximum ice flow velocities with time. The average values vary between 0.01 - 0.15 mm/a. It can be seen that ice flow starts almost 3 Myr after the simulation has started. This is related with the nonlinear power law and the ice volume. Glen's power law produces low strain rates for low stresses. Unless there is enough volume to produce stresses the ice flow does not start significantly. Figure 2 middle panel shows the ice volume during the simulation period. The ice flow starts significantly when the volume reaches about two third of its final value. Since the flow velocities are very low ice dynamics play minor role in the evolution of the cap.

It is seen in Figure 2 that topographic quantities like ice thickness, ice volume and elevation increases monotonically and the climates cycles are poorly represented. On the contrary thermodynamic quantities in Figure 1 show strong variations with climate cycles.

The middle panel in Figure 1 shows the maximum basal temperature. It is clearly seen that basal temperatures are below pressure melting. From the MARSIS observations [1] likely scenario for perennial North Polar Cap is of cold water ice layer thicker than 1 km. This supports the idea that there is no presence of melt water at the base of the cap. Our model results agree well with the MARSIS result for this.

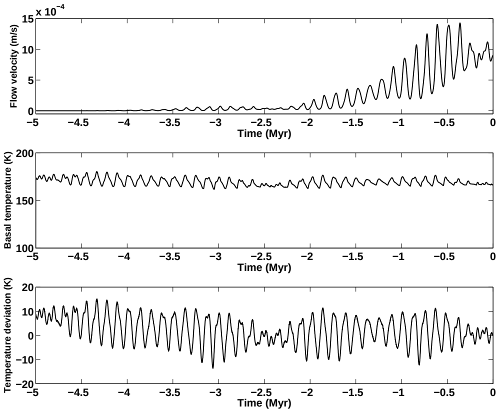

Figure 1: The top panel shows the variation of maximum ice flow velocities (m/s) during the simulation time. Zero indicates the present time and negative sign indicates the time before present (Myr). The middle panel shows the variation on maximum basal temperature (K) with respect to simulation time. The bottom panel shows the temperature anomaly (K) from the present surface temperature

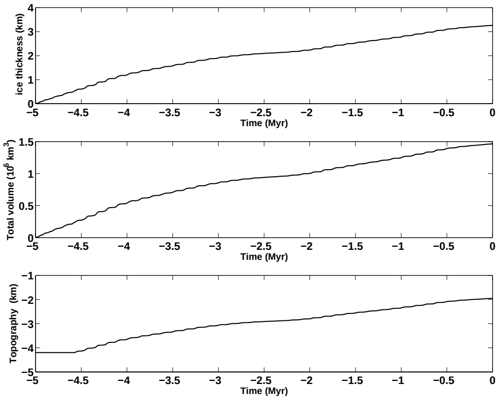

Figure 2: The top panel shows the variation of maximum ice thickness (km) during the simulation time. Zero indicates the present time and negative sign indicates the time before present (Myr). The middle panel shows the growth of ice cap volume (10^6 km^3) over time. The bottom panel shows surface topography variation with time. The surface topography is given with respect to reference geoid in kilometers

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