Note: This work is presented at COSPAR 2004 and has been already published in Greve and Mahajan 2005

The Evolution of the North Polar Ice Cap of Mars - Effect of dust content and ice rheology

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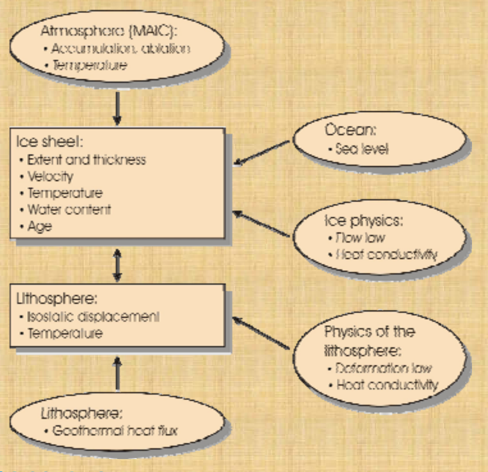
Abstract: The evolution and the dynamics of the north polar cap of Mars is simulated with the ice-sheet model SICOPOLIS. We consider a scenario with ice free initial condition. The north polar cap is then built up to its present shape driven by an obliquity and eccentricity cycle which is converted to a climate forcing (surface temperature and surface mass balance) with a simple parameterization module

The effects of different ice rheologies and different dust contents are investigated. The topography evolution is essentially independent of the ice dynamics due to the slow ice flow. Due to uncertainties associated with the ice rheology and the dust content, flow velocities can only be predicted within a range two orders of magnitude. For all cases, the computed basal temperature is far below pressure melting.

Introduction

The north polar cap of Mars consists of the residual cap and the underlying layered deposits. It is essentially centered around the geographic pole and rests in a topographic depression which occupies the large part of the northern hemisphere of the Mars. It is largely accepted that the cap consists mainly of water ice, however, the amount of mixed-in dust and CO_2 is not known. Currently the cap has an area of 10^6 km^2, a maximum thickness of 3-4 km and a volume of 1.2-1.7 x 10^6 km^3. The Mars surface topography is known very precisely due to Mars Orbiter Laser Altimeter (MOLA) on the Mars Global Surveyor (MGS) spacecraft.

Modelling approach



Ice-sheet model SICOPOLIS:
(SImulation COde for POLythermal Ice Sheets):

3-D dynamic and thermodynamic large scale polythermal ice-sheet model.
Ice as a non-linear, viscous (power-law), incompressible, heat conducting fluid.

Dust Content:

Quantitative information for the dust in polar ice is not available
For modeling purpose the density ρ and and heat conductivity κ of the ice dust mixture are computed as volume-fraction-weighted averages of the values of pure ice and crustal material

Ice rheology:

For terrestrial ice, the flow is prescribed in the form of power law.
strain rate produced ∝ (shear stress)^n

$$\dot{\varepsilon} \propto \sigma^n \quad \longrightarrow \quad \dot{\varepsilon} = E\,\frac{A(T')}{d^p}\,\sigma^{n-1}\,\mathbf{t}^D$$

ε = shear strain tensor
E = flow enhancement factor
A = flow rate factor
T´ = temperature at pressure melting point

σ = shear stress
n = power law exponant
t^D = Cauchy stress deviator
d = grain size
p = grain size exponant

Studies undertaken for model experiments:

Flow law	Power law exponent, n	Grain size, d (mm)	Grain size exponent, p	Dominating mechanism
Glen's	n=3	Independent of grain size	p=0	Dislocation creep mechanism
Durham	n=4	Independent of grain size	p=0	Dislocation creep mechanism
Goldsby and Kohlstedt	n=1.8	d= 1mm	p=1.4	Grain boundary sliding
Goldsby and Kohlstedt	n=1.8	d=10 mm	p=1.4	Grain boundary sliding

Simulation Set up:

Simulations are carried out with ice free initial conditions and run till simulated north polar cap reaches MOLA value of maximum surface elevation (-1.95 km)

Temperatures are derived from obliquity and eccentricity cycles

Present accumulation rate= 0.1 mm/a

Result:

Surface topography [km] for Glen's flow law after t_{build} = 13.79 Ma:

Measured present topography (MOLA) [km]

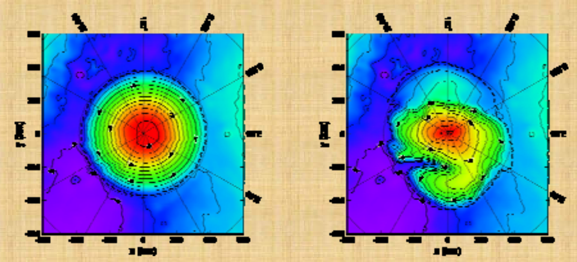


Fig.(a)

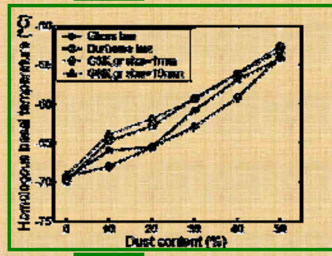


Fig.(a) Homologous basal temperature variation with dust content for different flow laws.

Fig.(b) Maximum surface velocity variation with dust content for different flow laws.

Fig(c) Build up time (time needed to build present NPC) variation with dust content for different flow laws.

Fig.(b)

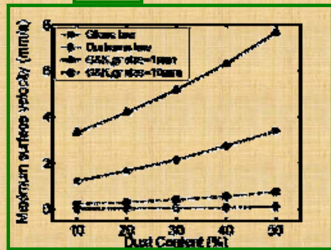
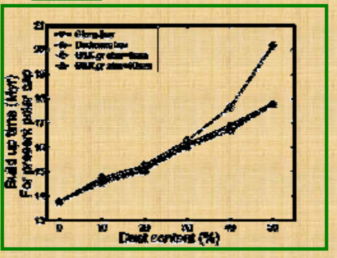


Fig.(a)



Discussion:

• Absolute flow velocities are very small as compared to terrestrial ice so internal ice dynamics plays minor role in topography evolution.

• Surface topography evolution is mainly controlled by mass balance.

• With increasing dust content, the time needed to build the cap also increases. Large dust content causes larger isostatic downward displacement of the underlying lithosphere, so more ice needs to be accumulated to reach present elevation (-1.95 km) of the cap.

• Basal temperature increases as amount of dust in the cap increases due to decreasing heat conductivity.

• Surface velocity increases with increasing dust content this is because of (i) increasing ice thickness producing larger driving stress (ii) increasing basal temperatures make ice soft though the direct effect should be hardening.

• For all cases, the computed basal temperature is far below pressure melting.

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