MARS ATMOSPHERE AND ICE SHEET MODELLING.

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Introduction

Like the earth, Mars has polar ice caps. From satellite observation we know that the Martian polar regions show structures, the so called polar layer deposits, which lead to the assumption of periodic climate changes of the polar caps. To understand how the layered deposits and the ice-caps evolve during Mars' strong orbit driven climate variations, numerical simulation of the involved physical systems atmosphere and ice-sheet are necessary. The climates at different orbit conditions are constructed with a General Circulation Model (GCM) of the Martian Atmosphere. To understand the behavior of the Martian ice caps at different climatic conditions a model is needed to simulate the ice physics. SICOPOLIS, a polythermal ice-sheet model, provides this capability, as can been seen in the studies Greve et al. (2004); Greve and Mahajan (2005); Greve (2005). This abstract presents the coupling the atmospheric model Mars Climate Simulator (MCS) with the polythermal ice-sheet model SICOPOLIS and some first results obtained with the coupled version.

Model description and Coupling

The Mars Climate Simulator is a spectral general circulation model of the Martian atmosphere. It simulates the atmospheric motions by integration of the primitive equations. Subscale processes are parameterized in simple numeric schemes. A large part of the properties of the models Mars Climate Simulator and SICOPOLIS is described in Segschneider et al. (2005) and Greve et al. (2004); Greve and Mahajan (2005); Greve (2005). Unlike the version described in Segschneider et al. (2005), the current version of Mars Climate Simulator now includes a hydrological cycle. The parametrization is mostly identical to that of the original Planet Simulator, an intermediate complexity GCM of the Earth's atmosphere from which the MCS was derived (Fraedrich et al., 2005a,b). The differences include for example a different treatment of saturation pressure: In Planet Simulator the saturation pressure of water vapor is calculated according to the Magnus-Teten-formula for water vapor over liquid water (Lunkeit et al., 2004; Lowe, 1977). Since liquid water does not currently exist on Mars the model has to be adjusted regarding this point. To account for this the saturation pressure is calculated with the Magnus-Teten-formula for water vapor over ice (Murray, 1967).

Mars Climate Simulator and SICOPOLIS are numerical models which operate on largely different spatial and timely scales. This would make a direct coupling of the two models both difficult and not very sensible, because the short term fluctuation of the atmosphere do not affect the ice. The development of the ice-sheet is driven by the longterm climate mean. This legitimates the choice to force the ice model with climatological means from the atmospheric model. SICOPOLIS has a horizontal resolution of 91×91 grid points at a distance of 20km. The grid is centered above the pole. The Mars Climate Simulator uses a Gaussian grid of 64×32 points. Along each circle of latitude the distance between two grid points is 5.625°. On Mars this corresponds to distances of 58km at 80° latitude and 114km at 70° latitude respectively. Along the meridians both the distance in degree and meter vary. Since the grid resolution of SICOPOLIS is much larger than that of the MCS, the boundary data from the MCS have to be interpolated for the use in SICOPOLIS and *vice versa*. There are several ways to do this (e.g., Press et al., 1992). In this case, a triangulation scheme as described by Cline and Renka (1984) is used.

Evolution of the north polar cap at different obliquities:

In an experiment which starts with the present NPC, we use annual means of 2m temperature, accumulation and ablation to force SICOPOLIS. The basis are data from three Mars Climate Simulator experiments with θ=25.2°, θ=15°, and θ=35° of obliquity. These experiments simulate the development of the NPC over the time-span of 25 million years. The three experiments give different growth rates of about 0.17 mm/a, 0.19 mm/a and 0.15 mm/a for the respective cases (Fig. 1). Different from SICOPOLIS experiments without Mars Climate Simulator (Greve et al., 2004), the SICOPOLIS runs from the present experiment show an ice-sheet that is not symmetric around the pole. Also the impact of different obliquity angles can clearly be seen:

At θ=15° the model results show the second highest but farest extending ice-sheet from the three integrations. At 112°W it reaches down to nearly 78°N and grows during the simulation period of 5 million years to a maximum height of about 400 m (Fig. 2 a). For θ=25.2° the ice-

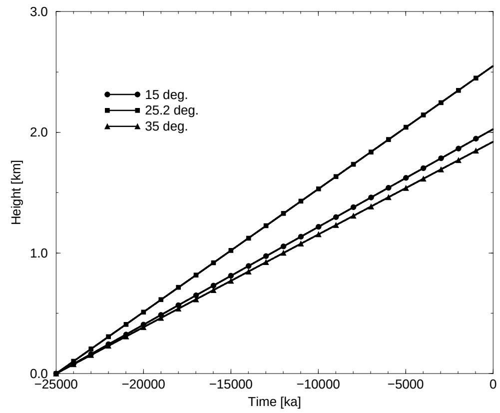
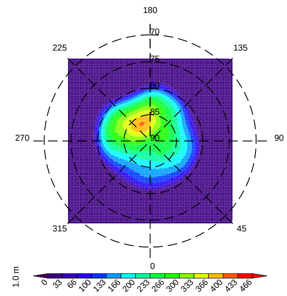


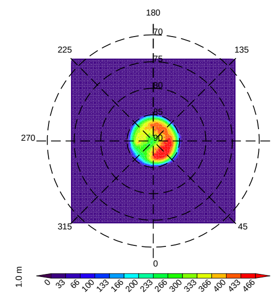
Figure 1: Maximum height of the NPC above starting level as a function of time BP resulting from the present topography start experiment

sheet extends southward to 85°N and so is a bit smaller than the actual one. After 5 million years it reaches a maximum height of ∼510m (Fig. 2 b). At θ=35° SICOPOLIS produces a very small ice cap that covers the pole down to 86°N and has a maximum height of just about 380 m (Fig. 2 c). In a second experiment the Mars Climate Simulator is started with no initial NPC. The orography underneath the present ice cap is estimated by interpolation with a scheme similar to that used for interpolation between the different model grids. The glacier mask is set to zero. Mars Climate Simulator is integrated with these boundary data with an obliquity of θ=25.2° for two model years. Of the two years only the second year is used for analysis. Figure 3 shows the 2m temperatures and precipitation – evaporation (P-E) for this experiment. The temperatures around the north pole are significantly higher than in an comparable experiment with a present NPC. The mass balance for the ground (P-E) is negative for the whole polar region. That implicates that at an obliquity of θ=25° no new perennial ice cap can be built. A comparison with the preexisting NPC experiment on the other hand, shows the growth of an already existing polar cap at the same obliquity.

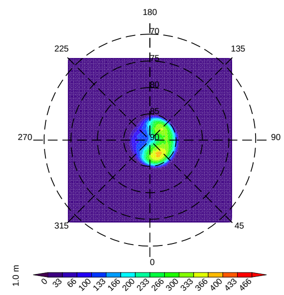
Further experiments with lower inclinations of the rotation axis can show at which critical obliquity value it is possible to build up a new polar cap. At an obliquity of θ=15° the model shows a new cap. The point of ‘critical’ obliquity θ_{crit} lies between 15° and 25.2°. To find this θ_{crit}, the obliquity range between θ=15° and θ=25.2° has been examined. We are using nested-intervals to check for θ_{crit}. In this way the ‘critical’ obliquity has been confined to $\theta_{crit} = 18° \pm 1.25°$. To estimate at which obliquity, if at all, an existing ice sheet vanishes, experiments with obliquities larger than θ=35 have to be



(a) $\theta = 15°$

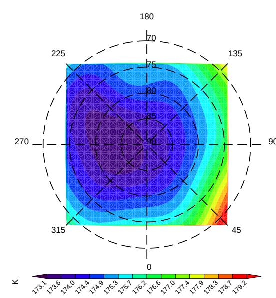


(b) $\theta = 25.2°$

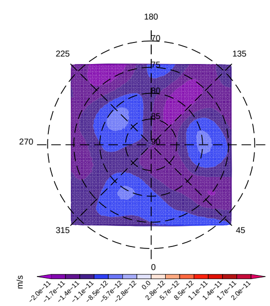


(c) $\theta = 35°$

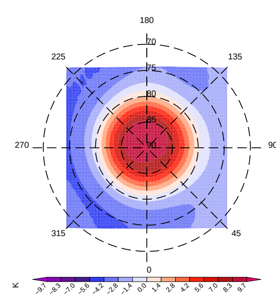
Figure 2: Height of the ice-sheet after 5 Ma, starting the integration from the present day topography



(a) 2m temperature



(b) P-E



(c) 2m temp. noice-ice

Figure 3: 2m temperature (a) and mass-balance (b) from the Mars Climate Simulator at the north pole in the ice-free start experiment at θ=25° and the 2m temperature difference between the ice-free and ice-cap experiment

conducted. These (at θ=45° and at θ=55°) however do not show a full depletion of the north polar cap.

Results

With the help of the coupled models, we have been able to show that the ice caps show different behavior at distinct obliquities. A strong inclination of the rotation axis leads to a strong ablation during the summer month through the higher insolation. This seemingly counterweights the increased polward transports of humidity in the warmer polar atmosphere. Further it was found that through the albedo feedback, it is easier to sustain an ice-cap at high obliquities than to create a new one. The model results show that an obliquity angle of no more than about 18° is needed to start the build-up of a new north polar cap.

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