A new model on the thermal behavior of the near surface layer on Mars and its implications for ground ice deposits in Gusev Crater. J. Helbert and J. Benkhoff, Department of Optical Information Sytems and Space System Technology, DLR, Rutherfordstrasse 2, 12489 Berlin, Gemany, joern.helbert@dlr.de

Introduction: : Most models used to investigate the thermal behavior of the Martian surface fall in three categories. The first category sees the surface only as a boundary condition for atmospheric models, a good example is the NASA Ames GCM [1] or the European Mars Climate Database [2,3]. These models usually study only the top layer of the surface, in general not deeper than 1m. The second category studies the surface on large scale both temporal and spatial. These models are for example used to study the effect of obliquity changes. They usually use a simplified structure of the subsurface with homogeneous thermo-physical properties and a very coarse grid laterally as well as on the surface. The third category studies the near surface layers down to a depth of about 100m. These models are ideally suited to study the stability of ground ice deposits reachable by future landing missions. However most of this models assume a very simplified subsurface structure. They assume that the underlying material has the same thermo-physical properties as the surface layer measured by MGS. A good example is the recent work by Mellon [4]. While all of this models produce valid results there have been concerns, that the simplified assumptions about the subsurface structure might influence the results significantly [5].

To address this concerns we have developed a new model for the thermal behavior of the Martian surface. The Berlin Mars near Surface Thermal model (BMST) is based on a standard model for cometary surfaces [6]. We have adapted this model to the conditions of the Martian surface. While most models used today for the near surface layer of Mars assume constant physical properties with depth, our model is based on a layered structure of the subsurface material, in which each layer can have different physical and thermo-physical properties. The recent result for the Polar layered deposit [7] and from the layering found for example in Maris Vallenaris [8], suggest that this is a more realistic representation of the Martian surface. The main features of the BMST are a high lateral resolution down to the centimeter range, the realistic treatment of the thermal properties of ice-rock mixtures, a detailed treatment of gas flux within the surface and into the atmosphere and a variable temporal resolution which allows to study daily as well as annual variations.

We have used this model already for studies of the Beagle 2 landing site [9] and the proposed MER landing site [10] both in Isdis Planitia.

The model: For this study we have assumed 50m thick surface layer composed of an initially homogeneous, porous, crystalline ice rock-dust mixture. This layer contains dust, rocks and two components of chemically different ices (H_2O, CO_2). We have used lower lateral resolution of only 10cm. The model solves the time-dependent mass and energy equations for the different volatiles simultaneously. Solar energy input varies due to orbital and rotational motion of the planet. Heat is transferred into the interior of the body by solid state heat conduction in the dust-rock-ice mixture (matrix) and by vapor flowing through the porous matrix. The gas flow from the sublimation fronts is driven by vapor pressure gradients. A dust layer (crust) on the surface is assumed in which all the volatiles are vaporized. The crust is initially very thin (one layer) and can grow because of inward migration of the sublimation fronts. The energy conservation equation for the porous, icy, dusty layer is (for detail see [6, 10])

$$\rho c \frac{\partial T}{\partial t} + \psi \rho_g c_g v \bullet \Delta T = \Delta \bullet \left(\kappa_m \Delta T \right) + \sum_{i=1}^{n} \Delta H_i q_i ,$$

where ΔH_i and q_i are the enthalpies of sublimation and the intrinsic mass release rate of vapor per unit volume of components i, respectively, κ_m is the thermal conductivity of the matrix, T is the temperature, t the time, ψ the porosity, ρ_g the mean gas density and v the mean velocity of the gas evaporating from deeper layers and streaming through the crust, and c and c_g the average specific heats of the matrix and of the gas at constant volume, respectively. The energy conservation equation for the crust is

$$\rho c \frac{\partial T}{\partial t} + \psi \rho_g c_g v \bullet \Delta T = \Delta \bullet \left(\kappa_d \Delta T \right)$$

where κ_d is the thermal conductivity of the dust crust. The surface temperature is calculated from the balance between the net incoming solar flux, losses from thermal reradiation, heat needed for sublimation or becoming free during condensation, and heat transport in and out of the shell

$$\frac{F_0 (1 A) \cos \zeta}{r^2} = \varepsilon \sigma T_s^4 + \kappa_d \Delta T_s |_{r = R_n} + \sum_{i=1}^{n} \Delta H Q_i .$$

In this equation A denotes the albedo, F_0 the solar constant, r the heliocentric distance in AU, ζ the local zenith angle of the Sun, ε the infrared emissivity, σ the Stefan Boltzmann constant, and T_s the surface temperature, and Q the gas release rate into the atmosphere at the surface. The latent heat L = ΔH is calculated from the Clausius Claperon equation

$$\frac{1}{P}\frac{\partial P}{\partial T} = \frac{L}{T^2 R}$$

where P is the saturation pressure. The conservation of mass in an n component system undergoing a phase change is given by the following equations:

$$\psi \frac{\partial \rho_g}{\partial t} + \Delta \bullet j_i = q_i,\ i = 1,\ 2,\ \bullet\bullet\bullet\ n,$$

where, for each component i, ρ_g is the density of the porous matrix and j the flux of gas. The internal gas production rate q is given by

$$q_i = \bar{c}_i \frac{\psi}{2a} (\rho_{sat_i} - \rho_{g_i}),$$

with c_i the mean thermal velocity of the gas molecules, ρ_{sat} the saturation density and a the radius of the pores.

Gusev crater: We have started a detailed study of Gusev Crater, one of the landing sites of the upcoming MER mission. We will present here some very first results of our study.

It has been suggested that Gusev Crater is the location of a paleolake [11-14] fed by Ma'adim Vallis, a 900km long fluvial system. Recent results from the GRS instrument on Mars Odyssey indicate that region around Gusev Crater shows an enrichment in Hydrogen in the soil, possibly indicating ground ice deposits within the upper 2m below the surface [15].

Thermo-physical properties of Gusev Crater: We have used MGS thermal inertia data [16] to construct maps of the thermal conductivity for the surface within Gusev Crater. Figure 1 shows a part of the floor of Gusev Crater surrounding the landing site. The targeted landing site and the lateral extension of the landing ellipse are marked on the map. The map has a resolution of 8 pixels per degree and is calculated from the map of thermal inertia I by

$$\kappa = \frac{I^2}{\rho c}$$

assuming for the density ρ=1500 kg m^{-3} and for the heat capacity c=795 Jkg^{-1} K^{-1} . These are typical values for fine sand assuming a basaltic composition.

The most striking feature of the map in Figure 1 are two areas showing high values for the thermal conducitivity. While the typical value is approximately 0.05 $WK^{-1}m^{-1}$ these two areas show values up to 0.14 $WK^{-1}m^{-1}$. In Figure 1 the contour line denotes a value of 0.1 $WK^{-1}m^{-1}$. The areas showing high thermal conductivity overlap with areas mapped morphological as etched terrain [18]. A likely interpretation is that the dust cover has been at least partly removed from the underlying base material. Comparison with MOC and recent THEMIS VIS images, confirms that the dust cover has only been removed in parts. Therefore the relatively coarse resolution of the thermal conductivity map gives only a lower limit for the thermal conductivity of the underlying material. As an estimate for the thermal conductivity of the base material we have assumed for this first study the maximum value of the thermal conductivity of T_c=0.14 $WK^{-1}m^{-1}$ observed in the high conductivity area. For the dust cover we have derived a medium value of T_c=0.05 $WK^{-1}m^{-1}$. The thermal conductivity of the base material might indicate sedimentary material, but this requires further studies.

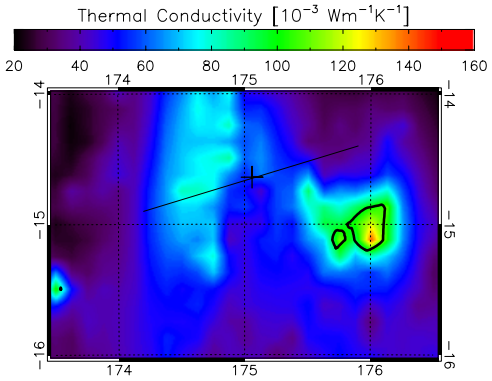

Figure 1 Thermal conductivity as derived from MGS thermal inertia measurements

Based on MGS data we have also derived a map of the albedo for the area surrounding the landing site shown in Figure 2. This map shows slightly higher albedo values for the high thermal conductivity area. However there seems to be no clear correlation between thermal conductivity and albedo. As a medium albedo for the area of the landing ellipse we have assumed a value of 24%.

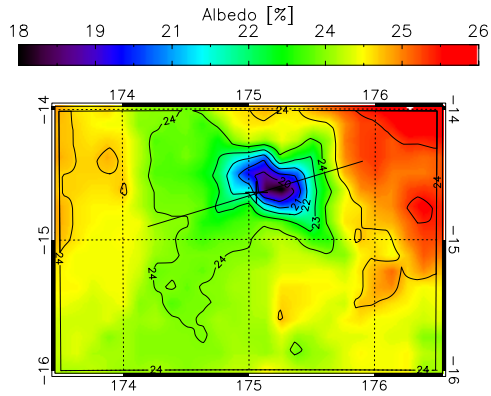

Figure 2 Albedo as derived from MGS TES measurements

Thermal modeling: We present here one example of the modeling we have studied for Gusev Crater.

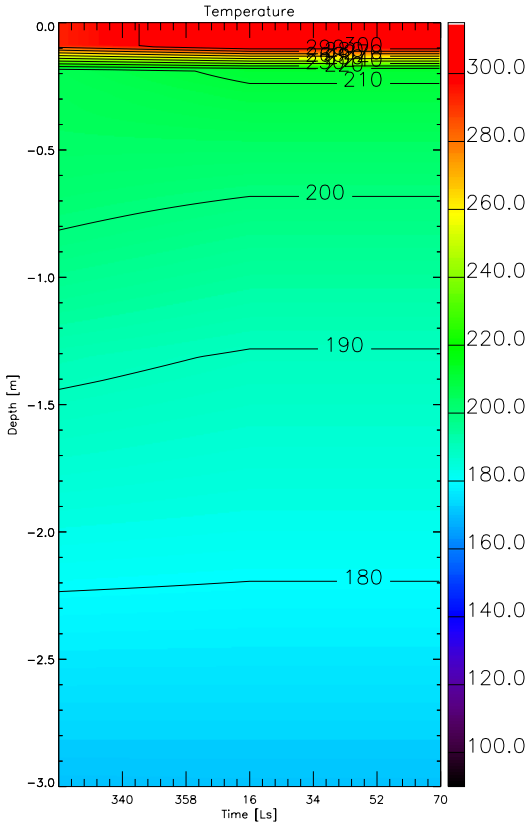

Figure 3 Temperature distribution in the subsurface for a layered subsurface structure

We have studied a two layered subsurface structure with a thin dust layer covering a 50m layer of a porous base material. For the thermal conductivity of the two layers the values derived above have been used. The base material has a porosity of 0.2 and a tortosity of 1.5. At the start of the modeling run the pores have been partly filled with water ice and CO_2 ice. The model has been run for 100 Mars orbits. At this time the model has reached a dynamically steady state. This means that annual cycles are repeated with little or no variatiations. Figure 2 shows the temperature distribution for the first 5m below the surface over a part of the annual cycle covering the activity period of the MER. The temperature gradient is very steep close to the surface. Within the first 30cm the temperature drops by almost 70K and the material below shows little variations over an annual cycle. The upper 10cm show temperatures variations of nearly 20K over the same time period. The material which will be sampled by the MER is therefore most likely modified by thermal erosion.

Stability of ground ice: The BMST allows not only to derive the temperature distribution in the subsurface, but calculates also the stability of ground ice deposits. Figure 4 shows the saturation of the subsurface with water ice. While the surface up to a depth of more than 1m is completely dessicated, starting at a depth of 1.5m the surface can hold up to 40% of ice. The ground ice deposit at this depth is stable over annual cycles. Possible frost deposits close to the surface forming on diurnal cycles are not shown in Figure 2 because for this modeling the time steps are approximately 2 sol.

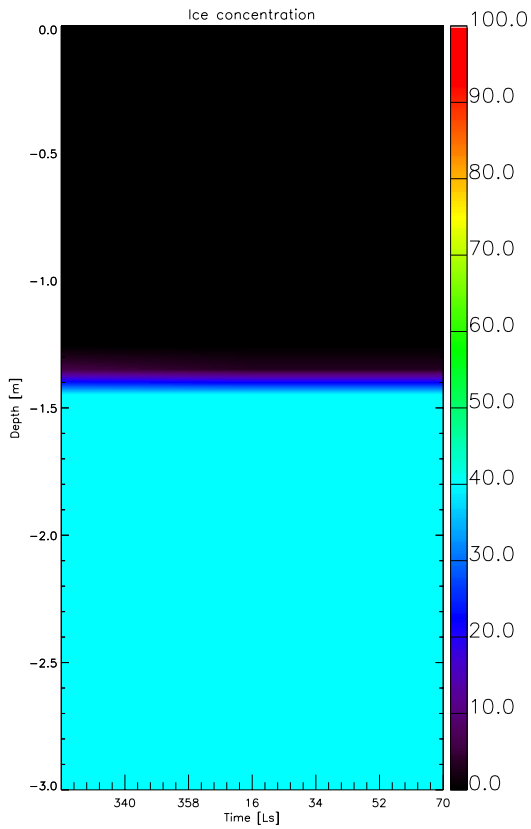

Figure 4 Saturation of the subsurface with ground ice

Our findings for the stability of ground ice deposits within the first 2m below the surface are in good agreement with the results from the Mars Odyssey Neutron Spectrometer as reported by Feldmann et al. [15]. The distribution map of hydrogen indicates an slight enrichment in the region of Gusev Crater. This enrichment seems stable over different seasons.

Conclusion: The newly developed model for the thermal behavior of the near surface layer has proven to be a useful tools in studying the MER landing site in Gusev Crater. The agreement with Mars Odyssey Neutron spectrometer data is encouraging.

Based on our first modeling results Gusev Crater might have ground ice deposits relatively close to the surface which are stable over long time periods.

Unfortunately the Mars Exploration Rover are not equipped with any instruments which will allow to access these ice deposits directly.

The location of Gusev Crater close to the surface might favor it as a landing site for a possible future drilling mission. The in-situ measurements of the MER in Gusev Crater will allow to improve the modeling and give better constraints on the subsurface structure and possible ground ice deposits.

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Additional Information: This work has been funded by the German Research Council (DFG) under grant number BE 1630/2.