Thermal modeling of the near surface layer at the Beagle 2 landing site in the Isidis Planitia region.

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Introduction: Beagle 2, the Lander of the ESA Mars Express mission, is scheduled to land in the Isidis Planitia basin in January 2004. The lander has a strong focus on exobiological studies. Therefore the prime question is, whether the landing site might provide an environment suitable for hosting exobiological activity. In order to address this question we have performed a number of studies modeling the near surface temperature distribution using the Mars Surface Layer Thermal Model (MaSLaTMo) recently developed in our group. This model includes a detailed treatment of the energy transfer into the surface, including energy transported by gas flux and energy used to sublimate and provided by recondensation of volatiles within the surface. It allows to study the thermal and physical properties of a near surface layer on Mars with a high spatial resolution.

Thermal model: We assume a 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). 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 (a few millimeters) 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 [1, 2])

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

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 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 $L = \Delta H$ 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 is the density of the porous matrix and j the flux of gas. The internal gas production rate q is given by

$$q_i = \overline{c_i} \;\; \frac{\psi}{2 \, a} \;\; (\rho_{sat_i} \; - \; \rho_i \;) ,$$

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

Thermal properties of the landing site: Data from the MGS thermal inertia measurements [4] have been used to construct a map of the thermal conductivity of the area surrounding the landing site as shown in Figure 1. 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 $\rho = 1500$ 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.

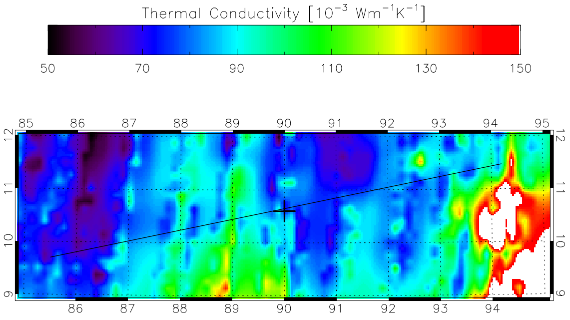

Figure 1 Map of the thermal conductivity constructed from thermal inertia measurements

For the landing site we derived a value for the thermal conductivity of $\kappa=0.1$ Wm^{-1}K^{-1} . This value varies by about 50% across the landing ellipse. The higher values at the southwest edge of the area shown in Figure 1 might indicate that this area is rockier.

From the albedo map obtained by the TES instrument [5] we derived an albedo of 22% for the landing site. Within the landing ellipse albedo values up to 25% are measured.

The thermal conductivity and albedo values and inspection of MOC images of the area lead to the conclusion that the surface in this area is covered by a fine dust layer on top of an unknown base material. The conclusion is in agreement with the finding of other author (see for example [6, 7]).

Thermal modeling: We present here one example of the modeling we have done for the Beagle 2 landing site. In this case we assumed for the base material a heat conductivity of $\kappa=0.5$ Wm^{-1}K^{-1} and a porosity of 0.1. These are typical values for a compact, sedimentary base material. This base material is covered by a dust crust with thermal properties as derived above. We modeled a 50 m layer at the surface for 20 Mars orbits. Figure 2 shows the resulting temperature distribution in the subsurface after 20 orbits for the proposed landing time of Beagle 2 in Martian early northern spring (LS 322° to 53°) [6].

In this case the surface reaches a maximum temperature of 300K during early summer. The temperature gradient within the surface is very steep for the first 10cm below the surface. In this shallow layer the temperature decreases by nearly 70K. Over an annual cycle the temperature in this layer changes by about 20K. Below 1.5m the temperature stays below 200K over an annual cycle. Under this conditions subsurface pore ice in diffuse contact with the atmosphere can be stable [8].

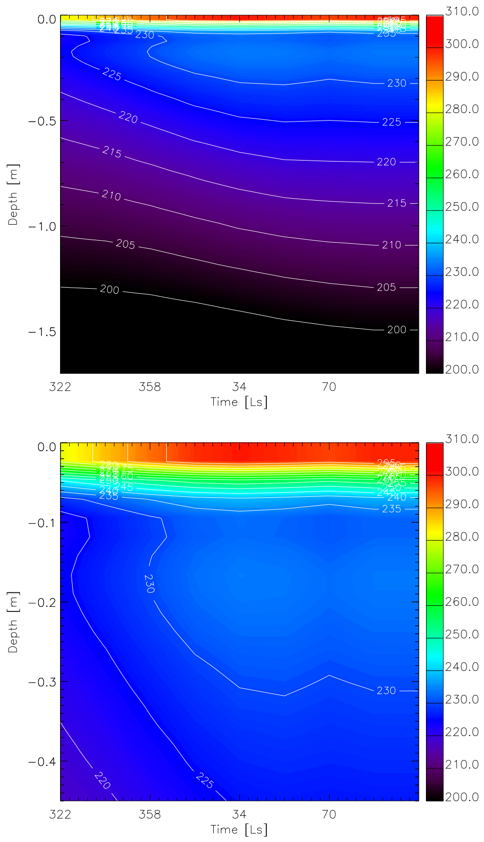

Figure 2 Upper panel: Temperature distribution to a depth of 1.70m **- Lower Panel:** Temperature distribution to a depth of 0.45m

Summary: The model we have developed for thermal modeling of the near surface layers on Mars allows a detailed study of the thermal properties of the surface material at the Beagle 2 landing site. This is of special interest for the inventory of volatiles. Based on the simple example presented here we might expected to find ground water ice in as little as 1.5 to 2m below the surface. A more refined analysis will allow to define further constraints.

References:

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