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Illumination conditions and thermal modeling for the Martian moon Phobos

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Abstract

We study the thermal conditions in the polar areas of the irregularly shaped Martian moon Phobos. As was previously discussed [10], we consider direct illumination by the Sun, eclipses by Mars, Mars shine, and single scattering of solar light by other surface areas of Phobos.

1. Introduction

In recent years the Martian moon Phobos was identified as a target by several planetary mission proposals [3–6]. With the current plans of the Japanese space agency JAXA to launch the sample return mission MMX (Martian Moon eXploration) [2] to the Martian satellites in 2024 there is increased interest in the evaluation of current data in preparation for this particular mission.

Thorough illumination and thermal studies are needed to plan in-orbit and landed missions. Phobos experiences the same seasons as Mars as it is orbiting in a near Mars-equatorial orbit with its rotational axis perpendicular to its orbit plane. Thus, in the polar regions during summer there are long periods of continuous illumination while in winter there are long periods of continuous shadowing. This makes these areas particularly interesting with respect to the question whether water ice might still exist below the surface and if yes, at what depths. Hence, this study focuses on the illumination conditions in the polar areas (above $+65°$/below $-65°$ latitude). The used methods are, of course, applicable for all areas on Phobos. Furthermore, the thermal environment is also an important aspect of mission planning when thinking of placing a probe onto the surface of Phobos.

2. Illumination

As a base for thermal modeling the illumination conditions on Phobos' surface were studied [10], using

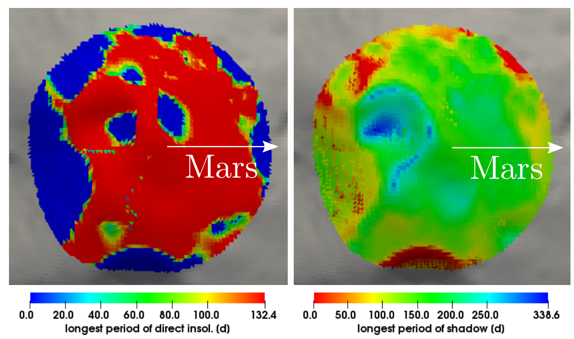

Figure 1: Longest period of uninterrupted direct solar insolation (left) and continuous shadow (right) for the North pole region (above 65° lat.).

a global shape model of Phobos [8], an updated rotational model [7], and the ephemerides model NOE-4-2015-b, having the least deviation in comparison to astrometric observations [9].

While computing the arriving direct solar flux, eclipses by Mars are taken into account. Respective simulations for the summer period show that areas in the North pole region are continuously illuminated by the Sun for up to 132 days, see Fig. 1. In the south pole region, continuous illumination periods spanning up to 109 days exist. Contrary, during winter, periods of up to 339 days with no direct solar flux were computed for the North pole region (Fig. 1) while even longer periods of 460 days without direct solar illumination were determined for the south pole region.

Phobos moves very close to Mars, so Mars shine, i.e. direct solar flux reflected by the Mars and thermal emissions by the Martian surface, have also be taken into account. Since Phobos moves in a bound rotation, one would expect that Mars shine does not play any role on the anti-Mars side, which is true for the North pole region. However, in the South pole region the anti-Mars side is situated a bit higher than the Mars side. Thus, almost the total Southern polar region can see at least a part of the Martian disk and receives Mars shine, see Fig. 2.

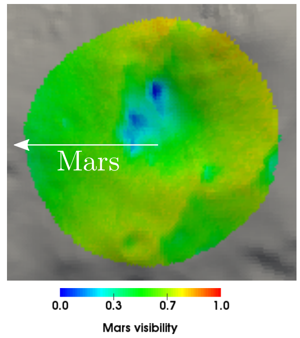

Figure 2: Fraction of the Martian disk that is visible from a given facet (South pole region).

Phobos' irregular shape causes reflection of incoming flux onto other parts of the surface. However, due to the low albedo of Phobos it is sufficient to consider only single-scattering contributions.

There are situations in which Mars shine and single-scattering are dominant. For example, during the winter period some areas in the southern polar region receive no direct solar flux for a long period of time, while Mars shine and single scattering can provide an incoming flux of 13 $\frac{\mathrm{W}}{\mathrm{m}^2}$ and 1.5 $\frac{\mathrm{W}}{\mathrm{m}^2}$, resp.

3. Thermal modeling

Based on the computed illumination data the surface temperature T of each facet of the shape model is computed via balance of energy,

$$F = \varepsilon\sigma T^4 - k \frac{\partial T}{\partial x}\Big|_{x=0}, \qquad (1)$$

where F denotes the total incoming flux consisting of direct solar flux, Mars shine and single-scattering of solar light on other areas of Phobos; ε is the thermal emissivity, σ the Stefan-Boltzmann constant and k is the thermal conductivity. The resulting temperature T is then used as the upper boundary condition for the 1-dimensional heat equation,

$$\varrho\, c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right), \qquad (2)$$

which is solved for each facet individually. Here ϱ and c_p denote the density and the heat capacity (per unit mass), resp. As a lower boundary condition it is assumed that the heat flux vanishes at the fivefold of the seasonal skin-depth D_{skin},

$$\frac{\partial T}{\partial x}\Big|_{5 \cdot D_{\mathrm{skin}}} = 0, \qquad (3)$$

defined by $D_{\mathrm{skin}} = \sqrt{\frac{kP}{\pi\, \varrho\, c_p}}$, where P denotes the orbital period of Mars. For each time step (1) and subsequently (2) are solved using as input the temperature that was obtained in the step before. As a starting point for the computation the perihelion passage of Mars is used and a homogeneous temperature of Phobos' surface is assumed. Below the surface the computation area is divided into intervals increasing with depth, leading to a high resolution for regions close to the surface, being more strongly influenced by diurnal variations in incoming flux, and a lower resolution for deeper layers.

4. Preliminary results and outlook

All contributions to the incoming flux are needed as input for thermal modeling. Mars shine and single-scattering can also provide contributions if no direct solar flux is available. Currently contributions by self-heating due to direct (and indirect) thermal radiation (see [1]) are considered. Preliminary results for thermal modeling will be reported at the meeting.

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