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Illumination Conditions in Phobos' Polar Areas

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Abstract

The illumination conditions in Phobos' polar areas are studied taking into account direct illumination by the Sun, eclipses by Mars and single scattering of solar light by other surface areas of Phobos. Developments to include the contribution of Mars' reflected energy are on the way.

1. Introduction

In recent years the Martian moon Phobos was identified as a target by several planetary mission proposals. Precise illumination and thermal models are critical information to plan landed missions and require careful analysis of direct solar irradiation and indirect contributions such as solar light reflected by Mars, thermal emissions from Mars and self-heating of Phobos' surface, i.e. direct thermal radiation emitted from the surrounding surface as well solar light and thermal radiation reflected by the neighborhood.

Phobos moves near the equatorial plane of Mars, with its rotational axis near-perpendicular to its orbit plane, resulting in strong variations of the solar irradiation and thus to seasons, just like on Mars.

This study focuses on the illumination conditions in Phobos' polar areas (above $+65°$/ below $-65°$ latitude) which are of interest to future landed missions. Illumination models from this study will also serve as a basis for a subsequent study of the thermal conditions.

2. Previous Work

Since detailed shape models were not available at the time, previous investigators [1], [2] used simple ellipsoid models to estimate Phobos' surface temperatures and heat transfer to subsurface layers at discrete surface points.

In addition to solar radiation and the effects of eclipses by Mars, reflected sunlight and thermal radiation from Mars were taken into account, which were demonstrated to cause an increased average temperature on the Mars-facing-side of Phobos in its synchronous rotation [1]. In contrast, [3] and [7] studied the direct incident solar flux for Phobos using a recent shape model [5]. Global charts of incident solar flux for certain fixed dates in different seasons [3] as well as average incident solar flux for a complete Martian year [7] were derived.

Figure 1: Phobos' Northern hemisphere. Left: SRC image H8870_0006 (ESA/DLR/FU Berlin (G. Neukum)). Right: Synthetic image.

3. Methods

The simulated illumination is based on the ephemerides model NOE-4-2015-b, having the least deviation in comparison to astrometric observations [6], a global shape model of Phobos comprising 274,874 facets [5], and an updated rotational model for Phobos [4]. The illumination of all facets within the North and South pole regions is modeled considering direct illumination by the Sun, eclipses by Mars and single scattering by neighboring surface areas.

To verify the quality of the input models, synthetic images, based on illumination and viewing geometry of original Super Resolution Channel (SRC) images taken by Mars Express were computed. These simulated images show excellent agreement with the originals. An example is provided in Fig. 1.

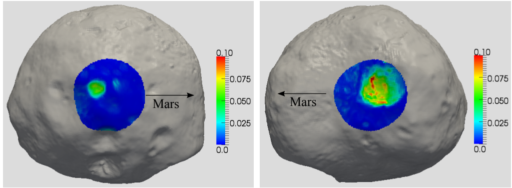

Figure 2: Total view factors for the North (left) and South (right) polar regions.

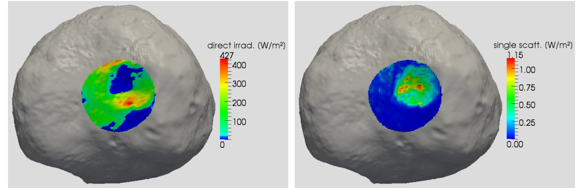

Figure 3: Direct solar irradiation (left) and single scattering (right) off other facets in $\frac{\mathrm{W}}{\mathrm{m}^2}$ for the Southern polar region at epoch 2018-06-22T23:10:00 (in Southern spring). Note the different scales of the color codes.

3.1. Direct illumination: Horizon method

For each facet the horizon is pre-computed and stored in a look-up table. At time intervals of currently 10 minutes azimuth and elevation of the Sun are computed and compared with the horizon line. Moreover, the percentage of the visible Sun disk is determined. The advantages of this method are a higher efficiency in the computing, compared to ray-tracing methods and a higher precision on the incoming solar flux rate.

3.2. Indirect Illumination: View factors

To include scattering by Phobos' surface onto other parts of Phobos the view factors F_{ij} indicating the fraction of flux radiated by facet j that reaches facet i are computed. Moreover, the total view factors

$$F_i = \sum_j F_{ij} \in [0, 1] \qquad (1)$$

were determined. A facet having a total view factor of 0 does not receive any irradiation from other facets while for a facet having a total view factor of 1 the field of view is completely filled by other facets of the surface. Note that we consider single-scattering only.

Fig. 2 shows the total view factors for the North and the South pole region. For the North pole region the maximum total view factor is 0.07, about half of what is found for the more concave-shaped South pole region, where the maximum value is 0.13. In both cases, such secondary irradiation is small when compared to direct insolation, but relevant for facets that are not directly illuminated, and would be in complete darkness without such scattered light.

4. Preliminary results and outlook

For both polar regions illumination maps for several time intervals ranging from a few seconds to a Martian year have been computed. During winter seasons, polar areas are in complete darkness, while in the summer, polar areas enjoy longer periods in full sunlight. During spring and fall, illumination is interrupted by frequent occultations by Mars. Certain areas (in particular South polar) frequently do not receive direct solar irradiation for several hours but are exposed to scattered light only. Fig. 3 exemplarily displays the contributions of direct solar irradiation and single scattering to the total irradiation for the Southern polar region at epoch 2018-06-22T23:10:00. Though these contributions are small, they might be relevant for future thermal modeling. The contribution of Mars-reflected solar light and thermal emissions by Mars' surface is currently considered and computed. Preliminary results will be reported at the meeting.

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