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The Martian Surface UV Environment: Theoretical Modelling and In-situ Measurements

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Abstract. The UV environment on planetary surfaces is of extreme importance in a wide range of scientific disciplines, from meteorological considerations to the viability of biological organisms. Presented here is theoretical modelling for the transmission of ultraviolet radiation (190-400nm) through the martian atmosphere for a variety of possible cases, resulting in surface spectra. Knowledge of the UV transmission gives insight into how significant dust presence on Mars interacts with incoming solar radiation, and also yields information on the effect of biologically damaging UV-C on organisms and organic products on the surface. Surface fluxes are calculated using a radiative transfer approximation, for a range of dust loading and ozone abundance. Effects of direct and diffuse illuminance are also highlighted.

In-situ measurements of the UV flux will be possible for the first time onboard the Beagle 2 probe, scheduled to land on Mars in 2003. The instrument will measure the flux at five passbands in the UV, and also measure the total UV dose between 200-400nm throughout the mission lifetime.

1. Introduction

The issue of the UV environment on Mars still remains a point of continued discussion, highlighting the need for direct measurement. The effects of short wave UV on biological systems and equipment materials can be extremely damaging and need to be accurately quantified. This can be achieved through atmospheric modelling, but in situ measurements are required for definitive results. No measurements from the surface of Mars have been taken to date, and the issue of the true surface flux remains to be investigated through instrumentation on a lander/rover type spacecraft. The Beagle 2 probe, set to arrive at Mars in 2003 onboard the ESA *Mars Express* spacecraft, offers the opportunity to conduct these in situ measurements for the first time. The instrument to perform this task is briefly described here.

To aid in the design of this instrument and begin assessing the impact of surface UV exposure, a theoretical model has been developed. Previous Mars UV investigation (Kuhn and Atreya 1979) has shown the existence of ultraviolet radiation orders of magnitude greater than experienced on Earth below 290nm. This biologically damaging part of the spectrum makes the investigation of Mars

UV a very important issue. This paper briefly covers the model used to calculate the UV spectrum at the surface, and results for particular situations. Also presented is a brief overview of the UV sensor to be flown on the Beagle 2 lander.

2. Theoretical Model

The UV environment at the martian surface can now be quickly and accurately predicted in a variety of conditions using a radiative transfer model. The solar input flux at Mars is correspondingly smaller than the terrestrial case due to the greater heliocentric distance, but the thinner less absorbing atmosphere of Mars creates a surface UV environment far more intense at shorter wavelengths when compared to the Earth. An approximation has been employed for the radiative transfer calculations to allow fast computation of the surface spectrum between 190-400nm. The calculation involves two steps, the determination of the direct transmission of UV followed by calculation of the diffuse component. Direct attenuation is calculated through consideration of absorption cross-sections, and diffuse illumination is calculated using radiative transfer theory. Inputs to the model are: latitude, time of day, areocentric longitude, surface pressure, dust optical depth and ozone abundance.

2.1. Direct Flux Calculation

The martian atmosphere is predominantly CO_2 with a mean surface pressure of about 6 mBar. The direct component of the illumination was calculated by consideration of the absorption cross-sections and column abundance of the various atmospheric gaseous components, and optical depth of the dust. The only significant absorbers in the UV relevant in the martian atmosphere are CO_2, O_3 and O_2, but for the radiative transfer calculations all martian gases were taken into account. The absorption is then calculated using Beer's Law exponential attenuation of incoming solar UV radiation from the top of the atmosphere.

2.2. Diffuse Flux Calculation

The presence of significant quantities of dust in the martian atmosphere makes the issue of diffuse light non-trivial. Optical depths due to dust can range from 0.1 ('clear') up to 4 (dust storm) throughout the martian year (Pollack et al. 1979). The scattering properties of the martian dust therefore need to be known to evaluate the degree of interaction with incoming solar UV, namely the single scattering albedo (w), the asymmetry factor (g) and extinction efficiency (Q_{ext}). Values for these properties were interpolated from the values of Ockert-Bell et al. (1997) in the UV range. The Delta-Eddington approximation (Joseph, Wiscombe, and Weinman 1976) for radiative transfer was then used to calculate the diffuse illumination created by scattering from dust, and to a lesser degree gas molecules.

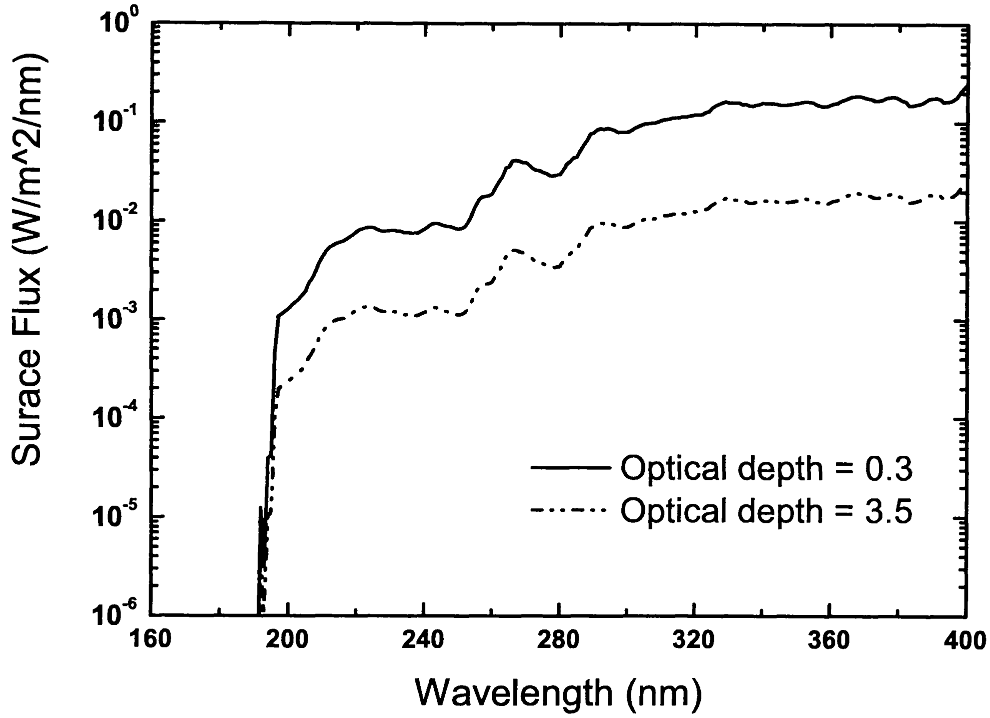

Figure 1. Model results for UV flux (direct and diffuse) at the martian surface for two extreme dust environments. Abundance of dust in the atmosphere is defined by the visible optical depth, i.e. an optical depth of 0.3 for a low dust situation, and an optical depth of 3.5 during periods of high dust levels in the atmosphere. This case is for an areocentric longitude of 180° (autumnal equinox) for a latitude of 30°N at local noon.

3. Results

Shown here are the results of the model for two particular scenarios where the dust loading in the atmosphere in the second case is significantly increased, i.e. in the event of a major dust storm. Figure 1 shows the transmission spectrum at the surface for a case where the dust loading increases from a nominal optical depth of 0.4 to 3.5.

It is immediately apparent that the presence of significant amounts of dust suspended in the martian atmosphere have a large impact on the total UV flux reaching the martian surface. This point is of interest, since the presence of significantly large amounts of dust in the martian atmosphere has been frequently observed (Pollack et al. 1979), and therefore cannot be disregarded. The curves retain the same spectral features, but the fluxes are simply attenuated to lower significantly lower values. In the biologically active UV-B (280-315nm) and UV-C ($<$ 280nm) regions, this change is highly important to the survival of any

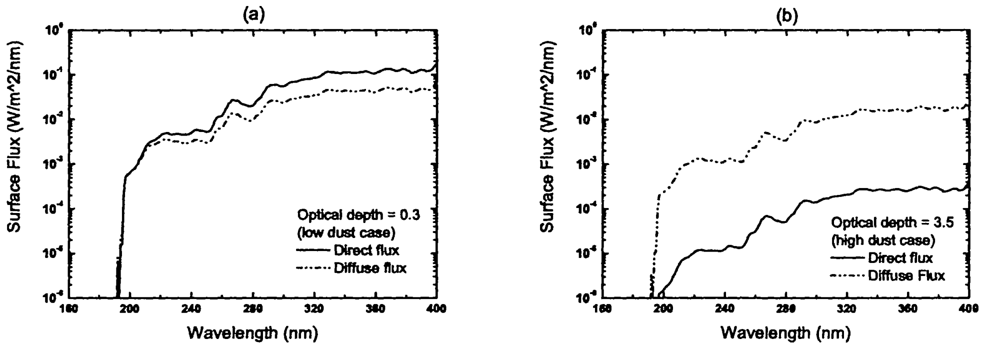

Figure 2. Results for the direct and diffuse contributions to transmitted flux for the same cases as Figure 1. (a) shows the low dust loading scenario with an optical depth of 0.3, and (b) is the high dust loading scenario, with an optical depth of 3.5.

micro-organisms at the surface. The attenuation of UV is not as large as would be expected if direct transmission was considered solely; the diffuse component permits a small but noticeable amount of UV even at extreme dust levels. The curve in Figure 1 for an optical depth of 3.5 is essentially pure diffuse radiation, the direct flux being almost completely attenuated. This effect is readily seen when the separate transmission components are considered, as shown in Figure 2. At low dust levels, the direct component provides greater input, whereas at high dust levels the diffuse component is dominant.

4. Experimental Investigation

The Beagle 2 probe will begin investigating the martian surface environment towards the end of 2003, and will carry a UV sensor to monitor the local radiation environment throughout the mission lifetime as part of an Environmental Sensor Suite (Towner et al. 2000). The sensor is a small instrument, with a total mass of only 20 grams. It will monitor flux levels across 5 different bandpasses of scientific interest using filtered UV sensitive diodes, centred around 210, 230, 250, 300 and 350 nm. A separate sensor will monitor the total UV dose between 200-400 nm. This sensor will operate for a nominal 180 sols (mission lifetime), monitoring diurnal and seasonal variations, as well as the option to monitor any local transient phenomenon such as the passing of a dust devil. These localised vortical columns of air carry dust into the martian atmosphere, and will be recognisable from the UV instrument readings as a step-wise decrease in signal, returning to ambient as the phenomenon passes out of the field of view.

5. Conclusions

The model presented here allows for the fast computation of the surface UV environment of present day Mars for a range of situations. The UV flux is seen to decrease by an order of magnitude for increasing dust levels such as the onset of a major martian dust storm, especially relevant for the survival of any organic species or proposed organisms at or near the surface of Mars. Instrumentation designed and developed using this model will form part of the Beagle 2 lander, which will measure directly the martian surface UV environment for the first time.

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