The Effect of UV Surface Flux Shielding By Spacecraft Geometries

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Introduction

Ultraviolet radiation travelling through the Martian atmosphere undergoes significantly less attenuation that would occur in the atmosphere of the Earth due to the lower abundance of ozone and lower atmospheric pressure (e.g. [1]). Surface chemistry, including the degradation of organic compounds, and the habitability of the surface of Mars is significantly effected by the amount of UV radiation incident on the surface. Small-scale surface geometries, such as overhangs and pits, can shield or partially shield the surface from UV and the effects of Martian surface features on the received intensity of UV have been quantitatively assessed in [2]. Spacecraft geometries could have similar effects and their influence on the ground and their undersides has yet to be investigated. In this poster, we describe a model and method used to examine the effects of idealized spacecraft geometries on the UV flux received by the ground and spacecraft underside in the vicinity of a given component, considering both shadowing and reflection effects from the spacecraft and reflection from the ground.

Project Aims

- Compute maps of UV energy received by the ground and underside of spacecraft components on Mars from the Sun, taking into account atmospheric scattering and absorption via a plane parallel radiative transfer code, shadowing and reflection from the spacecraft components, and reflection from the ground.
- Use these to quantitatively assess the effects of UV radiation on habitability and sterility of the spacecraft and ground in its vicinity on a variety of timescales.

Model Description and Components

- The Doubling and Adding code (D&A code, [3]), a plane parallel radiative transfer code, was used in a 3-level, 2 layer configuration to model the atmospheric scattering of incident Solar radiation and compute transmitted direct and diffuse fluxes.
- The models have been split into 6 wavelength regions, henceforth known as bands, due to scattering and absorption cross section variations. These are: UVA (315-400nm), UVB (280-315nm), and four UVC bands (260-280nm, 240-260 nm, 220-240 nm and 200-220nm). At wavelengths below 200nm, there is very little transmitted radiation due to extreme CO_2 absorption.
- Gaseous absorption due to CO_2, O_2 and in some models , O_3, is included according to: $\tau_{abs} = \bar{\sigma} n$, where $\bar{\sigma}$ is the average absorption cross-section across the band considered. The majority of the absorption cross-section data was obtained at 278 K. Typical τ_{abs} values are < 0.1
- Optical depth due to Rayleigh scattering in each band were computed according to the calculations of [4], using the refractive indices taken from [5].
- Aerosols are assumed to be mie scattering centres, with both spherical (parameters taken from [6]) and non-spherical (parameters taken from [7]) trialled.
- Aerosol optical depths were taken from [8]. These were assumed for the UVA band and the required abundances to produce these optical depths were calculated and used as input to UVB and UVC band models, allowing a consistent aerosol abundance with wavelength-dependent optical depth to be used. The variation in optical depth is minimal but non-zero across UVA-UVC.
- The ground is assumed to be a Hapke surface, with parameters taken from [6] and [7].
- Our model was verified by comparing to the results of the well-tested model of [6] at a variety of optical depths and the results agree well (Fig. 1).
- Sun paths at various rover locations at 10° Ls intervals were computed using the well-tested Mars24 algorithm of [9] (Fig. 2). These sunpaths were used as input to the D&A code and the total energy per square metre per sol received by the flat, unobstructed ground over the course of a year were calculated (Fig. 3).
- Spacecraft components were simulated initially as flat plates, vertical and horizontal, building up to a box on or floating above the ground being used as an idealized rover body.
- Shadowing and received flux on the surface was calculated assuming that the radiance maps outputted from the D&A code as a function of azimuth and zenith angle represented a grid of parallel vector fields originating at the given azimuth and zenith angles with magnitude equal to the radiance at that point in the map. Each vector field magnitude was corrected for solid angle of emission, the cosine angle with the normal of the incident surface and receiving area to give energy received by the surface from that single vector field per second.
- Shadows were cast from idealized spacecraft components and those regions in shadow were assumed to receive zero energy from the vector field being considered. This was repeated for every diffuse and direct point in the radiance maps and the results summed to give a map of energy received by the ground at a single instance in time (Fig. 4 & 5).
- Lambertian reflection from spacecraft components was included assuming a constant albedo (Fig. 6 & 7, assumed albedo=0.5).

Results and future work

- Maps of received UV energy per square metre per sol received by the ground in the vicinity of idealized spacecraft components have been computed, including shadowing and reflection effects of the spacecraft at a variety of Ls. Fig. 8 shows an example map in the vicinity of an idealized rover body on the ground at Ls 230 at the MER Opportunity landing site.
- Ground reflection must now be included to examine the incident UV energy on the underside of the spacecraft.
- Additional complexity of the idealized component shapes will increase the accuracy and realism of these models, allowing us to more reliably examine the effects of UV insolation.

Figures

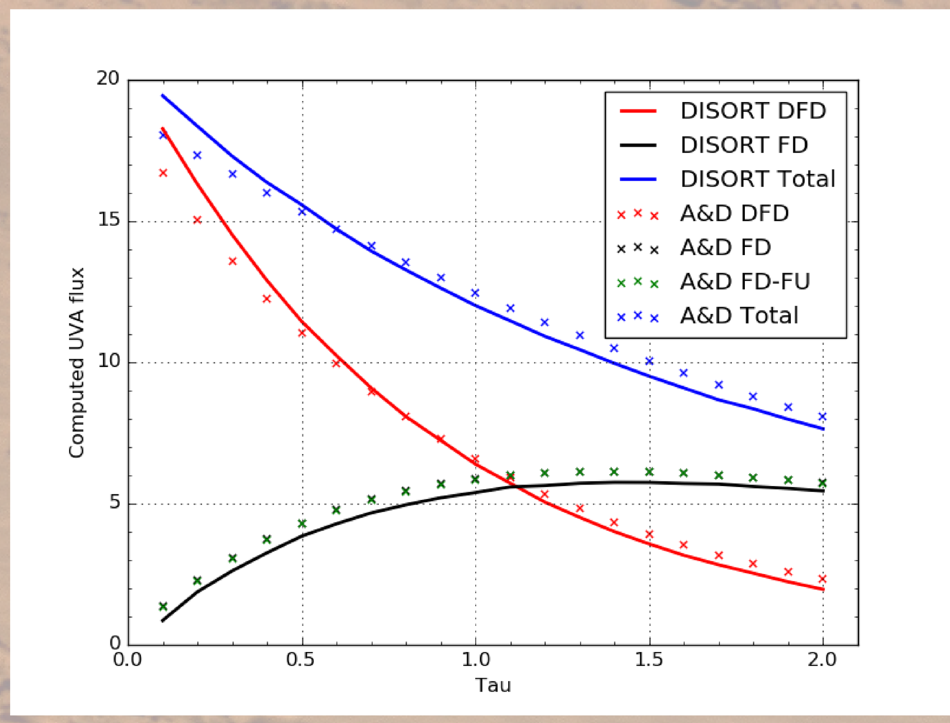

Figure 1: Model verification via comparison with [6], parameters taken from [6].

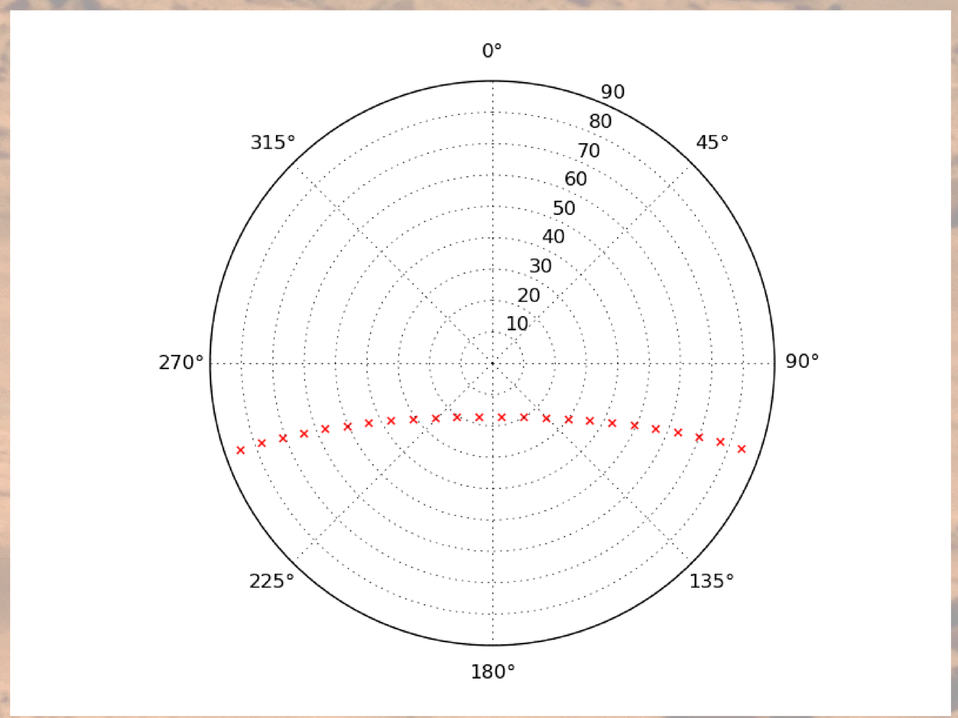

Figure 2: Sample sunpath plot for the Opportunity landing site at Ls 230 when the Sun's zenith angle is $< 90°$.

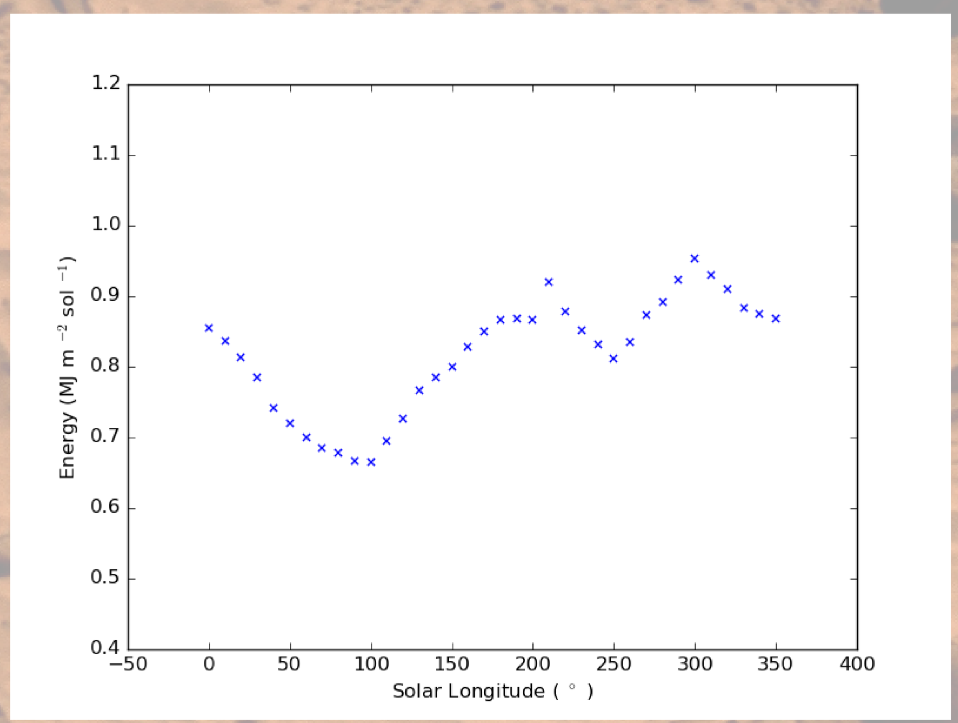

Figure 3: Total energy received by "billiard ball Mars" over a single sol as a function of Ls at the Opportunity landing site.

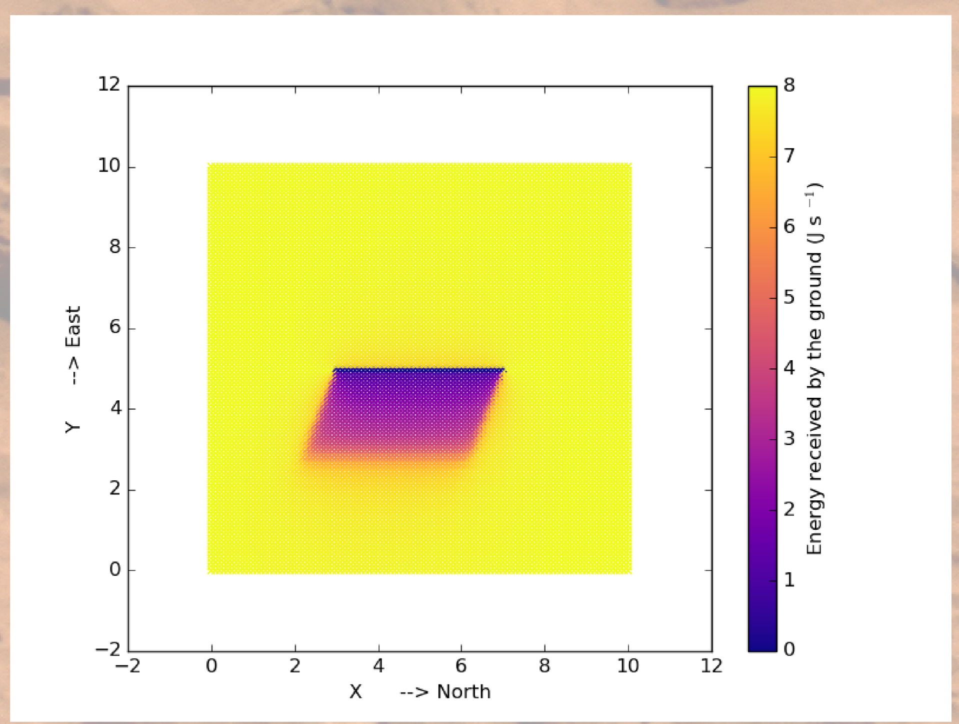

Figure 4: Instantaneous direct and diffuse shadow cast by an infinitely thin 4x1 m plate lying parallel to the x axis. Solar θ_{zen} and θ_{az} are 66° and 70° respectively.

Figures

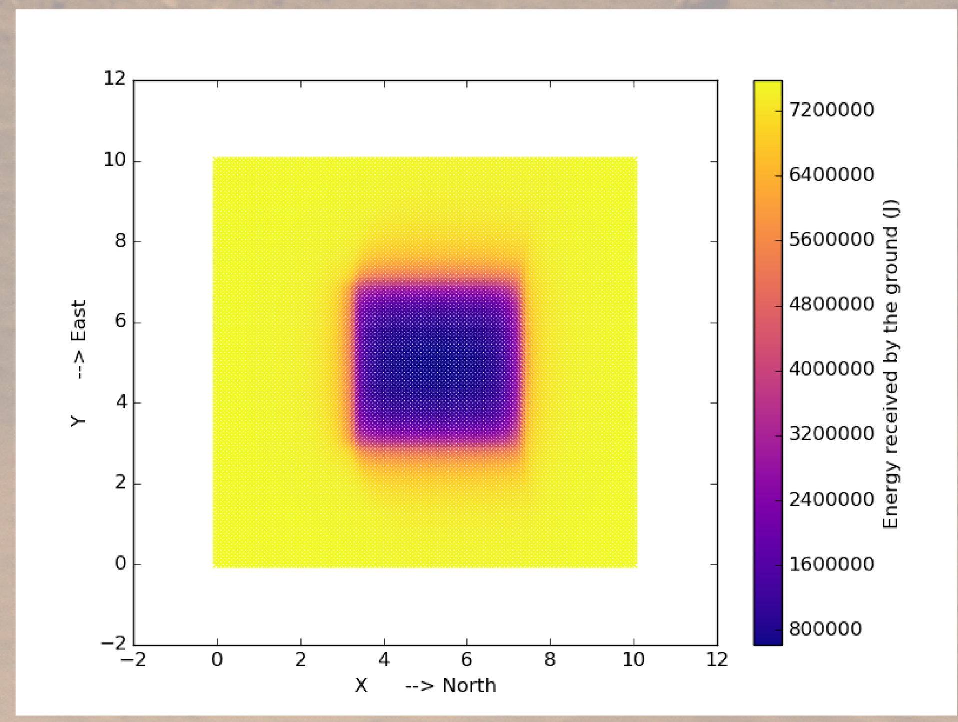

Figure 5: Energy received by the ground over a single sol at Ls 230 around a 4x4 m flat plate 1m off the ground.

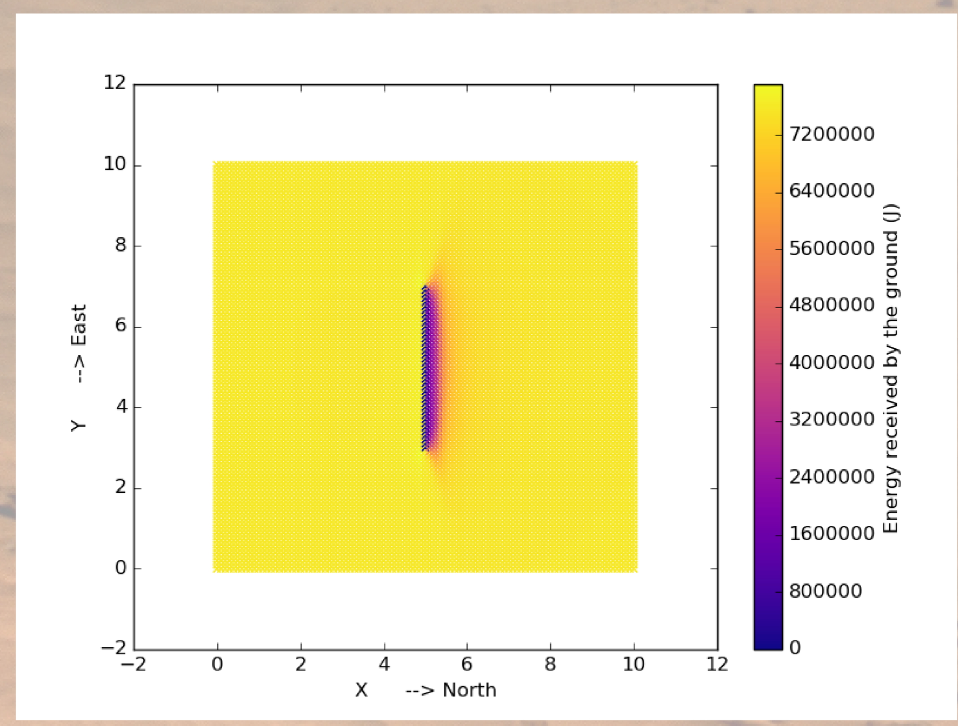

Figure 6: Total energy received on the ground over a single sol at Ls 230 in UVA band when a 4x1 flat plate, parallel to the y axis, has an albedo of 0.5.

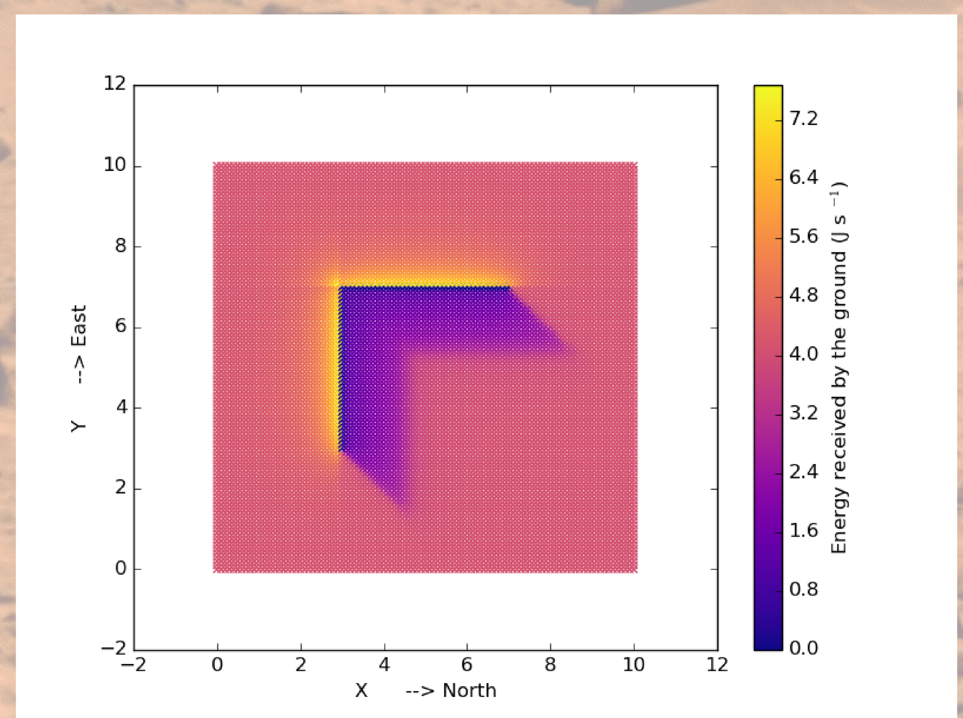

Figure 7: Two plate instantaneous reflection and shadowing. Solar θ_{zen} and θ_{az} are 66° and 135° respectively.

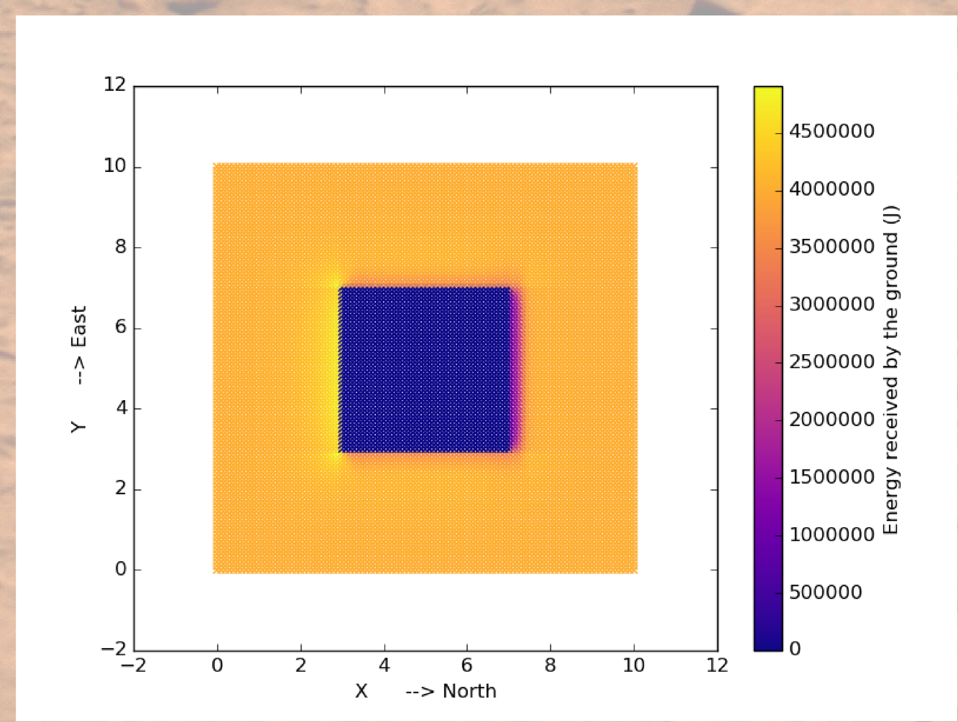

Figure 8: 4x4x1m box with albedo=0.5 on the surface over one sol at Ls 230.

References

[1] Cockell et al., 2000, Icarus 146, 343-359; [2] Moores et al., 2007, Icarus 192, 417-433; [3] Griffiths et al., 2012, Icarus, 218, 975-988; [4] Hansen, J.E., and Travis, L.D., 1974, SSR, 16, 527-610; [5] Cox, A. N., 2001, Allen's Astrophysical Quantities (4th ed.); [6] Smith M. et al., 2016 Icarus 280, p. 234-248; [7] Tomasko, M. G., et al., 1999, 104, 8987-9007; [8] Lemmon et al., 2015, Icarus 251, 96-111; [9] Allison, M., and M. McEwen, 2000, Planet. Space Sci. 48, 215-235; Image credit: NASA/JPL/Cornell, Bonneville crater, Mars, imaged by MER-A.