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Retrieving Dust Properties by Radiative Transfer Modelling of Dust Devils on Earth and Mars

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Abstract

To date, characterisation of dust devils by interpreting spectral measurements taken during a transit over a spectroscopic instrument has yet to be done and would provide valuable information of the physical size, dust load and internal structure of transiting dust devils. A Monte Carlo Radiative Transfer model (MCRT) was developed to investigate the spectral variations during a dust devil transit. Our results show that amount of scattered and the total flux are dependent on different components of the dust devil. The scattered component is highly dependent on the optical depth per unit length (τ_L) making it sensitive to the internal dust distribution and physical structure. This dependence is not observed for total flux which is strongly dependent on the total amount of dust present along the path joining the light source to the detector.

1. Introduction

Dust devils are common meteorological phenomenon on both the Earth and Mars [1]. On Earth they are secondary to boundary layer winds in the dust cycle and only play a minor role except in arid regions. In contrast, on Mars they maintain the constant aeolian dust background, especially in northern summer by playing a major role in the rapid transport of fine particulates into the martian planetary boundary layer [2, 3].

Using an MCRT the simulated spectral variation during a dust devil transit over e.g. a spectroscopic instrument is investigated to determine whether the dust load, size and internal structure of the vortex can be estimated from a dust devil transit profile. The transmission of sunlight through the vortex will depend on how the dust is distributed internally and on the vortex core diameter. The effect on the transit profile due to variations in the dust particles single scattering properties is investigated to determine the possibility of retrieval of the dust particles' optical

properties. Finally a comparison between transit profiles on Earth and Mars are compared.

2. Model Description

The Radiative Transfer model is based on the Monte Carlo method [4, 5]. The model is capable of simulating dust devils of various sizes and differing internal structure. Non-uniform internal dust distributions were modelled as a concentric ring of high optical depth around a central cylinder of lower optical depth with the dust column assumed uniform with altitude. The single scattering properties of the entrained dust particles are entered directly into the model with the single scattering albedo (ω_0) providing the probability of an absorption or scattering event. The dust particles scattering phase function is described by the Henyey-Greenstein approximation [6].

3. Dust Devil Simulations

Two scenarios are presented, detection of the full sky irradiance (S1) and (S2) applying a limited field of view which measures only the scattered component. Figure 1 shows the predicted spectral response for both scenarios for a dust devil with an outer radius of 2 m and core radii of 0.5 and 1.5 m. The optical depth of the dust devil was chosen to be 1.2 with 1/3 of the total dust amount assumed present in the core. Our simulations reveal that during a dust devil transit S1 and S2 result in opposite spectral responses with a decrease and increase in flux observed respectively. The scattered component shows significant variation with changing core radii, with $R_{\text{core}} = 1.5$ m showing ~50% less and ~55% more light detected in the core and Sun-facing wall respectively. The considerable variation in detected light is a result of τ_L in the wall increasing for larger core radii, since less volume is available for the dust particles to occupy.

This increases the probability of photon-particle interactions thus increasing the measured scattered signal in the wall. The opposite is seen in the core where the increased volume results in τ_L to decrease, lowering the probability of photon-particles interactions. The same dependence on internal structure is not observed for the S1 transit profiles and indicates that the total signal profiles are primarily governed by the total amount of dust present.

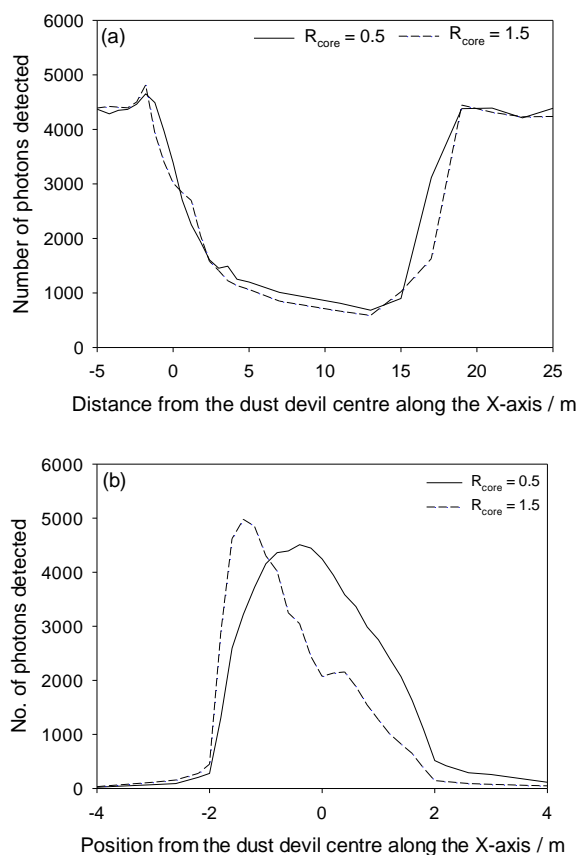


Figure 1: Dust devil transit profiles for (a) S1 and (b) S2

6. Summary and Conclusions

A MCRT was used to simulate the amount of sunlight received as a dust devil transits over a spectroscopic instrument. The aim was to investigate whether the dust devil's physical characteristics: size, dust concentration and internal structure could be constrained from its transit profile.

The S2 simulations show the scattered component is highly sensitive to the dust concentration thus the transit profile is highly dependent on the internal structure (i.e. core-wall ratio) and internal dust distribution. The S1 transits show that the total flux does not reflect the same dependence and indicate the main parameter governing the profile shape is the amount of dust present in the vortex.

Combining measurements of the scattered and total fluxes during a dust devil transit with Radiative Transfer modeling enables estimation of the dust devil size, internal structure and dust distribution.

The model was validated against actual dust devil transit measurements taken in the Eldorado Valley using a visible wavelength spectrometer. Validation of the optical property retrieval was also done using the same measurements.

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