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Testing the Hapke model by means of Montecarlo ray-tracing

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Abstract

The Hapke model is an analytical solution of the radiative transfer equation in a particulate medium. Over the years the model has gone through several modifications and updates which led to various versions. In this paper we test the output of the different formulations of the Hapke model with results from Montecarlo ray-tracing simulations, in the geometric optics limit.

1. Introduction

Remote sensing is an important tool in planetary science studies, providing informations about the composition and structure of the observed targets. In order to produce quantitative estimations of the physical parameters of the investigated objects, remote sensing data need to be compared to physical models that describe the interactions of the light with the matter and the observed photometric output. One of the most studied cases is light scattering on the surface (particulate medium) of an atmosphereless body and it has been thoroughly described in [1, 2, 3]. These models (Hapke models) have the advantage to describe the bidirectional reflectance (BDR) of a given surface in close form. However in order to do that some approximations and assumptions are required, that can in principle limit the applicability of the theory.
The aim of this paper is then to test the accuracy of the Hapke models by comparing the derived reflectances with simulations from Montecarlo ray-tracing. Effects of porosity and anisotropic multiple scattering are investigated, for various values of the single scattering albedo.

2. Hapke model

The first formulation of the Hapke model (see [3]) relies on the Isotropic Multiple Scattering Approximation (IMSA). This means that the computation of the multiple scattering contribution to the final reflectance is performed assuming that the particles are isotropic scatterers. This assumption is abandoned in the Anisotropic Multiple Scattering Approximation (AMSA) model [1] where an analytic expression of the multiple scattering contribution is derived also for anisotropic scatterers, when the single particle phase function is expressed as a Legendre polynomial series. However neither IMSA nor AMSA account for the photometric effect of porosity of the investigated medium. This problem has been addressed in [2] (H2008).

3. Montecarlo ray-tracing

We developed a Montecarlo ray-tracing algorithm in IDL language which simulates light scattering in particulate media. In this routines a packet of photon is propagated by the source into the medium, where it interacts with the particles whose physical properties are described by the single scattering albedo w (the fraction of light scattered by the particle) and the single particle phase function $p(g)$ (this quantity is proportional to the probability that light interacting with the particle is scattered in a direction individuated by the phase angle g). The medium is characterized by the filling factor ϕ (fig. 1). At this stage we assume spherical particles with a given size. For each scattering the energy of the photon is reduced by a factor $1 - w$ and the scattering direction follows a statistic that depends

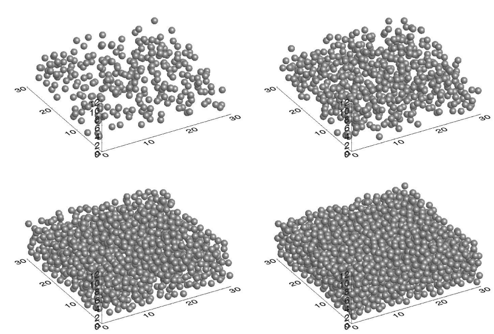

Figure 1: From the upper left panel, moving clockwise: sections of simulated particulate medium with $\phi = 0.05, 0.1, 0.2, 0.3$.

on $p(g)$. In order to save computational time we propagates photons backward, from the observer towards the source (Indirect Montecarlo ray-tracing, [4])

4. Hapke's model vs. Montecarlo ray-tracing

The main aspects we focused on are the photometric effects of medium porosity $(1-\phi)$ and anisotropic multiple scattering, testing if these are properly described in IMSA, AMSA and H2008 models. As an example it is shown the results of Montecarlo ray- tracing simulations for $\phi = 0.05, 0.1, 0.2, 0.3$ in the case of isotropic scattering with $w = 0.2, 0.5, 0.8$, compared to IMSA and H2008 models (fig. 2). It can be noted that for densely packed media H2008 produces a much more accurate description of the photometric output. Similar comparisons are carried out

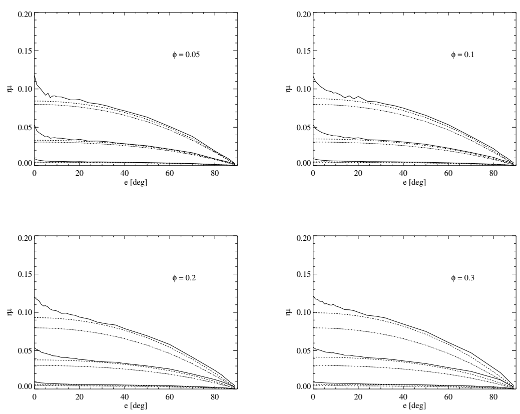

Figure 2: From the upper left panel, moving clockwise: $r\mu$ vs. emission angle e for $\phi = 0.05, 0.1, 0.2, 0.3$ with $w = 0.2, 0.5, 0.8$ (from bottom to top in each plot). Incidence angle is $i = 0°$, r is the BDR while $\mu = \cos(e)$. Solid lines refer to simulations, dashed lines to H2008 and dash-dotted lines to IMSA. Opposition effect, even if described in the Hapke models, has not been considered.

introducing anisotropic multiple scattering and will be described in the presentation.

5. Summary and Conclusions

Three different formulations of the BDR developed by Hapke (IMSA, AMSA, H2008) have been compared to reflectances derived from Montecarlo ray-tracing simulations. Preliminary results indicate that the porosity of the medium affects the overall brightness, and this is well described in H2008. IMSA model represents the $\phi \to 0$ limit of H2008 and should be applied for low filling factors. The effect of porosity is dominant when ϕ is not close to 0, making the AMSA model useful only for low density media. Further results will be discussed in the presentation.

Acknowledgements

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