EPSC Abstracts
Vol. 10, EPSC2015-91, 2015
European Planetary Science Congress 2015

Radiative transfer model for Solar System ices

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Abstract

We developed a radiative transfer model [1] that simulates the bidirectional reflectance of a contaminated slab layer of ice overlaying a granular medium, under geometrical optics conditions. Designed for planetary studies, this model has a fast computer implementation and thus is suitable for planetary high spatial/spectral resolution hyperspectral data analysis. We will present here its principles, its numerical and experimental validations and its possible applications.

1. Introduction

Ices are present in large amounts throughout the Solar System, on Earth, Mars, Europa, Triton and many other bodies. Their study is often a key to understand the planet's climate or history. Spectral unmixing has been proven a powerful technique to detect species, but cannot be trusted in quantitative analysis. Only radiative transfer models will provide quantitative analysis of the surface properties. Reflectance models for granular materials have already been developed [2,3]. However compact polycrystalline ices have been recognized to exist on several objects, CO_2 on Mars, N_2 on Triton and Pluto, owing to the very long light path-lengths measured, over several decimeters.We thus decided to develop a model designed to study contaminated ice slabs that was lacking in the literature in the goal to analyze spectro-imaging planetary data of these surfaces.

2. Model

The model [1] is inspired form an existing one [3] designed for granular media. We adapted it to compact structures. We suppose a layer of slab ice, containing various kind of impurities, overlaying an optically thick layer of granular material, as shown on figure 1. The roughness distribution of the surface is described as Gaussian using the mean slope angle **θ**, proposed by Hapke [2]. The ice matrix is described by its optical constants and its thickness. The inclusions are supposed to be close to spherical and of any other type than the matrix. It can be any type of other ice, mineral or even bubbles. We also suppose that they are homogeneously distributed in the slab.

The simulated bidirectional reflectance is the sum of a specular and a diffuse contributions. To estimate the specular contribution, we suppose that the surface is constituted of many unresolved facets. The orientations of these facets follow a probability density function determined by the roughness parameter. We integrate the various reflexions on every facet. The diffuse reflexion is estimated solving the radiative transfer equation under several hypothesis. We suppose (i) that the geometrical optics are respected. This means that the inclusions must be larger than the considered wavelength. We consider that the surface is illuminated by a collimated radiation (*e.g.* : Solar radiation). (ii) The first transit in the slab is considered collimated, but every following one is supposed isotropic due to rough granular substrate and scattering.

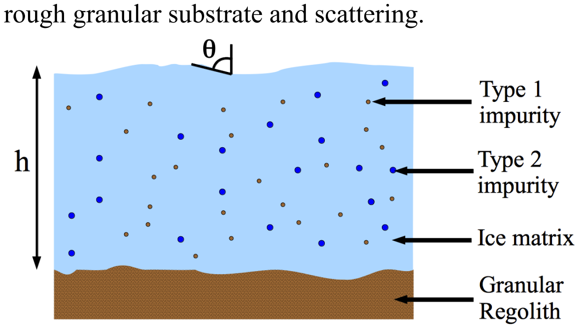

Figure 1: Scheme of the radiative transfer model.

3. Validations

We performed numerical and experimental validations on the model.

Numerical. We first checked the conservation of the energy at various points of the algorithm and showed that the model conserve the energy satisfactorily (more than 98% at the limits of the field of applicability). We will discuss the behavior of the model according to its parameters.

Experimental. We tested the model on real spectroscopic data [4]. Translucent synthetic water ice samples overlaying optically thick snow (from Arselle, in the French Alps) were measured in laboratory [5] at various geometries, inside and outside the specular spot. The model was able to reproduce correctly the data, and retrieve the parameters, as shown on figures 2 and 3. These results will be discussed thoroughly.

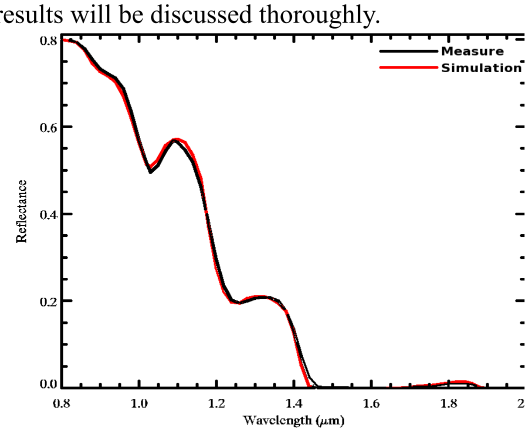

Figure 2: Measurement versus simulation for the reflectance of the first data sample. The estimated thickness of the slab (1.9 ± 0.5 mm) was consistently within the margin of uncertainties of the measurements (1.42 ± 0.3 mm).

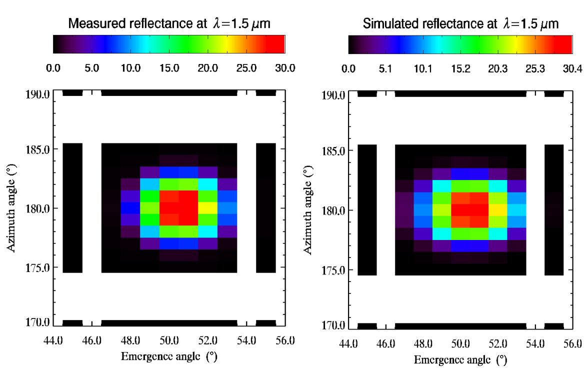

Figure 3 : Measure (left) versus simulation (right) for the specular spot at the 1.5 μm wavelength for a 50° incidence angle. The model reproduces correctly the shape as well as the level of reflectance in the specular lobe. The roughness parameter used for this simulation is very low (0.43°). That is consistent with the very flat surface described in the experiment.

5. Applications

The theoretical model does not depend on the type of material used. It is thus applicable to any matrix containing inclusions of any type. The fast implementation of the algorithm makes it suitable for massive hyperspectral data analysis. We will present a first example of application to planetary science with the case of seasonal evolution of the CO_2 ice cover on Mars. The study of other planetary bodies such as Pluto for example is also possible.

6. Conclusions and Perspectives

We developed [1] and validated [4] a radiative transfer model aiming at quantitatively studying planetary ices. This model has a fast implementation and is fully operational. It has a large field of application in the Solar System. We will start the planetary applications with the study of the Martian seasonal ice processes.

References

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