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Experimental determination of the surface photometric contribution in the spectral reflectance deconvolution processes for a simulated martian crater-like regolithic target

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Abstract

We produce bidirectional reflectance experimental measurements in the visible and near-infrared range of a macroscopic target simulating the case of a martian crater. Using Hapke's equation of radiative transfer, we compare the performance, in terms of mineralogical abundance determination, of different deconvolution processes on a multispectral image of the experimental target. In particular, we study the effects of the topography and the physical properties of natural rocky surfaces (e.g., local variations of incidence and emergence angles, grain size variations, mixtures of materials) on the data interpretation. For this purpose, we increase progressively the amount of quantitative knowledge available in terms of Hapke parameters description, textural properties and topography for the target. We estimate the accuracy of results in comparison with the known ground truth as a function of the level of knowledge we have of the target and carry out a critical assessment on the relative applicability of the different processes. This study shows that the more important parameters to take into account are (in decreasing order): (1) the textural roughness which is shown essential for the accurate determination of mineralogical abundances; (2) the disparity of Hapke parameters across the target (3) the topography (DEM) that has a limited influence on the results. These findings have obvious implications for interpreting planetary regolith reflectance properties in terms of photometry, spectroscopy and mineralogy, measured either from spaceborne (e.g., Io observations from Galileo, Mars from Mars-Express/HRSC and OMEGA) or in situ (Mars Pathfinder, MER) instruments.

Keywords: Hapke's model; Experimental measurements; Photometry; Reflectance spectroscopy; Spectral mixing analysis; Planetary regolith

1. Introduction

The planetary surfaces can be seen as a mixture of many different minerals. When interpreting remote sensing reflectance data, one of the key objectives is to quantify and map the mineralogy of planetary materials. However, it is difficult to apply a deconvolution process, which provides an accurate estimate of the mineral abundances as it depends greatly on mixture in a pixel and the correct choice of the mixing model. This arises from the fact that the reflectance spectra depend in a complex manner on (1) the properties of the individual components comprising the surface (absorption coefficients, phase function), (2) the physical state of the surface (particle size, surface roughness) and (3) the observation conditions. Several theories based on the scattering principles exist (Chandrasekhar, 1960; Van de Hulst, 1980; De Haan et al., 1987; Stamnes et al., 1988; Mishchenko et al., 1999; Shkuratov and Helfenstein, 2001). Among them, Hapke (1981, 1986, and 1993) developed an approximate analytical solution, which provides the bidirectional reflectance of a particulate medium, using the radiative transfer equation describing the multiple scattering of light from soils. It is a nonlinear function of the single

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scattering albedo and parameters linked with the geometric conditions of observations, the multiple scattering, the phase function, the opposition effect and the roughness.

Depending on the scale of the distribution of the materials within the pixel, we may consider two kinds of mixture, either areal or intimate (Poulet et al., 2002; Poulet and Erard, 2004). For areal or macroscopic mixtures, the reflectance spectrum of a pixel can be considered as a linear combination of some spectra derived from small areas representing distinct materials (called “endmembers”) chosen within the image or extracted from a spectral library: a Spectral Mixing Analysis (SMA) can be applied (Adams et al., 1986; Roberts et al., 1998; Chabrillat et al., 2000). In this approach, the spectral properties of the endmembers are combined linearly in a least-squares mixing algorithm to provide the best fit for each pixel. For intimate or “salt and pepper” mixtures, the mean single scattering albedo of a particulate mineral mixture is a linear combination of the single scattering albedo of the components, weighted by the cross sectional area of each component (Hapke, 1981; Johnson et al., 1983). An established method to handle the deconvolution process is to calculate the single scattering albedo image, using photometric modeling (such as the Hapke model) and then perform a SMA. This method is widely applied on experimental spectra (Mustard and Pieters 1987, 1989; Johnson et al., 1992; Sabol et al., 1992), or on integrated telescopic and spaceborne photometric observations for the study of photometric function of lunar terrains or regolithic soils of asteroids (Helfenstein et al., 1996; Mustard et al., 1998; Li and Mustard, 2000; Tompkins, 2002). Some studies give the comparison of Hapke’s model and other methods (Hiroi and Pieters, 1994; Nichols et al., 1999; Cheng and Domingue, 2000; Poulet et al., 2002). These works generally do not take into account the global set of Hapke’s parameters as it is not available.

Differently from earlier experimental works dealing with powder mixtures analyzed using laboratory spot spectroscopy (e.g., Mustard and Pieters, 1989; Sabol et al., 1992; Johnson et al., 1992; Hiroi and Pieters, 1994), in which the experiments were designed to minimize any influences on photometric parameters due to variations in particle size, textural roughness and regolith structure, the purpose of the present study is to investigate experimentally the case of a “real-world” extended target and to assess the effect on data interpretation when increasing progressively the amount of quantitative knowledge available in terms of surface composition, textural properties and topographic description for the controlled target. Indeed, this is an attempt at addressing the case of natural surfaces for understanding how to proceed with the deconvolution and interpretation of multispectral and hyperspectral imaging data obtained on rock/soil surfaces in planetary exploration and earth observation.

To carry out such an experiment, we have built up a controlled target, with varied mineralogies at the subpixel scale, simulating a crater modifying the martian surface (Fig. 1). Then we have produced measurements by means of a spectral wide-field imaging facility, at the Midi-Pyrenees Observatory, France, and dedicated to the measurement of the multispectral properties of macroscopic surfaces (20 × 20 cm) with a submillimeter spatial resolution within the 0.40–1.05 μm domain (Pinet et al., 2000, 2001). We compare the performance of different deconvolution processes (linear and nonlinear) applied on a multispectral image of the controlled target.

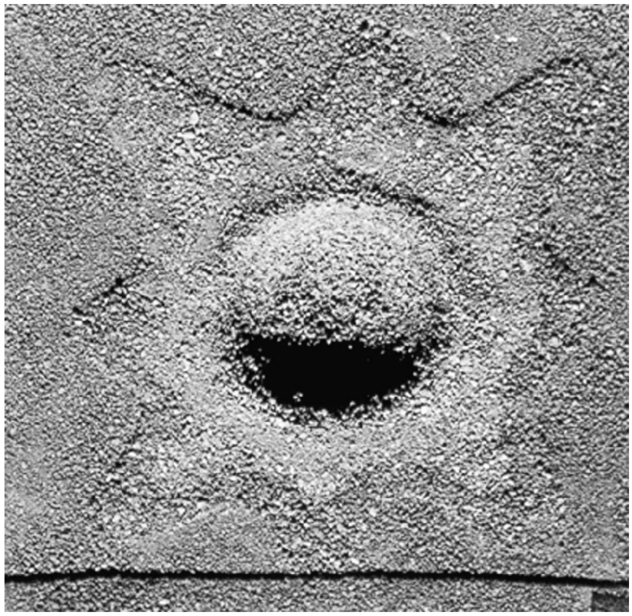

Fig. 1. Photo of the “real-world” target. It simulates a crater modifying the martian surface It sizes about 20 × 20 cm.

We first depict the target and the facility used for the measurements and then we describe the methodology (Hapke’s model, endmembers research method and spectral mixing analysis). Finally we present and analyze the results from the different deconvolution processes.

1.1. The target

We built a target that is a good simulation of a crater modifying the martian regolith (Fig. 1). We chose this kind of geologic structure because on one hand it is frequently observed on planetary surfaces (Barlow, 2000) and on the other hand it has a complex photometric behavior due to mixtures of minerals, local variations of incidence and emergence angles and grain size distributions. This synthetic target simulates the major photometric variations induced by an impact process, in terms of local topography slopes, inverted stratigraphy and surface redistribution associated with impact ejecta, not regarding the thermodynamic effects due to impact-driven pressure and temperature conditions (e.g., fusion products, glasses). In particular, the geometric aspect ratios of the crater are taken into account in order to best approximate the photometric variations expected in the real case. Since the total target size is about 20 × 20 cm, the simulated crater is 21 mm deep and 80 mm wide in diameter, providing a maximum slope angles about 35° in the