EPSC Abstracts
Vol. 10, EPSC2015-241, 2015
European Planetary Science Congress 2015

Bidirectional Reflectance of icy Samples: Application to water ice detection on the Moon and Mercury.

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Abstract

The reflectance of water ice and lunar regolith simulant (JSC-1AF) mixtures has been measured under different geometries. We have found that considerable amounts of water ice can be mixed within the soil without producing any noticeable photometric signature, as the relation between the reflectance and the amount of ice in the sample is strongly non-linear. Some reflectance models have been tested to try to reproduce this non-linearity.

1. Introduction

Some permanently shadowed craters at the poles of the Moon and Mercury are thought to host ice in their walls [1, 2, and references therein]. Laser altimeters and cameras can be used to search for potential changes of the surface reflectivity caused by the presence of ice. Laser altimeters currently in orbit around the Moon and Mercury have provided data showing some spatial variability in the reflectance of the polar areas of both bodies. In both cases, the possibility of finding the ice mixed within the regolith as in an intimate mixture is explored [3, 4]. To estimate the quantity of ice present in the craters, reflectance models are applied to the reflectivity measured by the laser altimeters [3]. Several authors have studied the reflectance of ice-free binary mixtures, showing that the models work well for predicting the mixture components abundancies [5]. Experimental studies involving water ice appear much more seldom in the literature, because the measurement of icy samples requires special equipment and procedures. We have produced intimate binary mixtures of water ice and JSC-1AF and measured their Bidirectional Reflectance Distribution Function (BRDF) with the PHIRE-2 instrument; a gonio-radiometer that allows characterizing the BRDF of ice-bearing samples in the VIS-NIR (400-1100 nm) spectral range [6]. Small (20°) and large (70°) incidence angles have been used. Null phase angle measurements are relevant for applications to laser altimetry, whereas higher phase angle measurements are relevant for the case of indirect illumination of the surface by light scattered from nearby topography. Then, we have tested the Hapke model [7] of reflectance and the “isograin” model [8] to achieve a better understanding on how these models deal with the reflectance of icy regolith analogues.

2. Methods

The particulate water ice has been created in our laboratory. Two sizes of ice particles (diameters of 5 and 70 microns) and several percentages of ice within the sample have been tested. The procedure for sample preparation was accurately defined and followed for all samples in order to guarantee a good reproducibility and mitigate the influence of the sample preparation on the reflectance of the sample. The samples show the same BDRF at 750 nm than at the laser altimeter’s wavelength (1064 nm). The measurements have been made at 750 nm in order to reduce the duration of the measurements and avoid the metamorphism of the ice.

3. Results

Phase curves presenting the reflectance as a function of the emission angle are shown in Fig. 1 for fine-grained ice (Fig. 1a) and coarse-grained ice (Fig. 1b). The phase curves measured at low incidence angle are dominated by the opposition effect, which produces a relatively strong increase of reflectance (25%) as the phase angle decreases below 10°. At high incidence angle, the reflectance increases as well at high phase angle and reaches a maximum in the forward scattering direction, for ice-rich samples. In both cases we observe that, when mixed intimately, relatively high amounts of ice within the sample do not significantly affect its reflectance. In the case of the coarse-grained ice (Fig. 1b), very high amounts of ice are required to produce a photometric signature. The reflectance measured at high phase angle however, shows a much stronger dependence on the amount of ice in the sample.

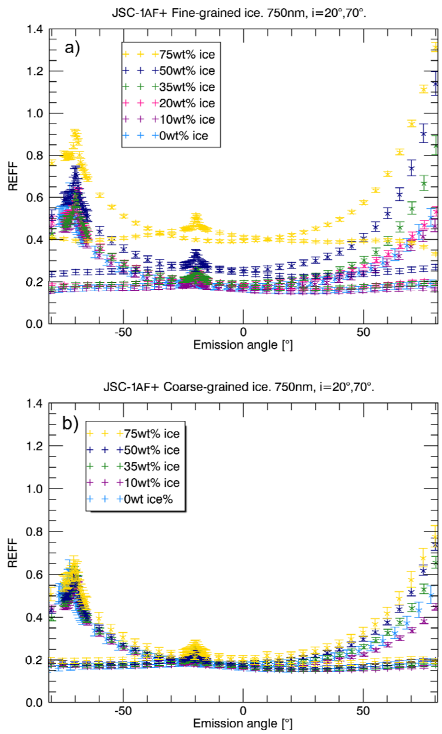

Figure 1: Reflectance phase curves for binary mixtures of JSC-1AF and water ice. a) ice diameter: 5 microns b) ice diameter: 70 microns

4. Discussion

Our results demonstrate in a few particular cases how difficult it is to detect water ice intimately mixed within a lunar-type regolith from its VIS-NIR photometric signature. For example, looking at a surface at 0°-phase and low incidence angle, one would not be able to distinguish between a dry soil and a soil containing up to 75wt% of 70 micrometer-sized water ice particles. The results for high incidence: i=70° show that high phase angles may be the best opportunities to detect water ice, due to the strong forward scattering peak in ice-rich samples. In order to expand our experimental findings from a few particular cases to more general trends, we use our data to test existing reflectance models. In particular, we have tested the Hapke and the “isograin” models, to compare their different approaches to compute the reflectance of binary mixtures from the properties of the end members.

5. Conclusions

Experimental results show that ice is more difficult to detect when it is present as bigger particles and when it is observed at low incidence and phase angles. Looking for ice at high phase angles results in better chances of detection. With regard to the reflectance models, they work well in a relative way; they are able to reproduce the shape of the phase curves described by the reflectance, as long as the mixing coefficients are correctly estimated. Calculating ice concentrations from reflectance data without any knowledge of the mixing coefficients, which strongly depend on the size/shape of the grain, results in very large errors.

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