Investigating Surface Roughness Effects on the Directional Emissivity of Surfaces Using the Oxford Space Environment Goniometer. T. Warren¹, I. Thomas, J. Arnold¹, K. Donaldson Hanna¹, and N. Bowles¹. (1) Atmospheric, Oceanic and Planetary Physics, University of Oxford, Department of Physics, Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, United Kingdom, (warren@atm.ox.ac.uk, ian.thomas@aeronomie.be, jessica.a.arnold@physics, Kerri.DonaldsonHanna@physics.ox.ac.uk, bowles@atm.ox.ac.uk).

Introduction: Measurements of the light scattering behavior of the regoliths of airless bodies in the Solar System, across wavelengths from the visible to the far infrared, are essential to understanding their surface properties through remote sensing techniques [1]. Although there have been many phase function measurements of regolith analogue materials across visible wavelengths [1-4], there have been no equivalent measurements made in the thermal infrared (TIR). The aim of this work is to begin to fill this gap. In particular, this work investigates how the roughness of a surface modifies its phase function in the TIR. In the TIR the scattering function of a surface is normally defined as the Directional Emissivity (DE, Figure 1). To measure the DE we are using the newly developed Oxford Space Environment Goniometer (OSEG) at the University of Oxford.

**Figure 1**: OSEG setup used showing the definition of scattering angles (emission angle $\theta_e$, and phase angle is not shown but is measured from an arbitrary plane coming out of the paper) for DE when the surface is heated from below.

Infrared (IR) OSEG Design: To make DE measurements, a 50mm diameter sample is placed in the centre of the OSEG. The sample is heated from below and a radiometer carriage is moved to different emission ($\theta_e$, Figure 1) and phase angles. Traditionally the phase angle is defined as the angle between the illumination plane and the emission plane. However, as the OSEG does not currently illuminate the sample the phase angle is defined from an arbitrary plane.

Radiometer. For measurements in the infrared, the radiometer uses a high performance pyro-electric detector (Infratec LIE-332F-66) with a reference chopper. Broadband wavelength selection is provided by a KBr window (0.23–20μm) on the front of the detector casing.

Initial Broadband Directional Emissivity Measurements of Nextel Black Paint 811-21: A black target was made by spray painting four layers of Nextel paint onto an aluminum base to provide a ‘smooth’ macroscopic surface. Broadband (0.23–20μm) DE measurements of Nextel black paint 811-21 were then made under ambient pressure (~1000 mbar) (Figure 2) and compared to measurements made by other IR goniometers [5-7]. Measurements made by the OSEG over its currently accessible angular range are in reasonable agreement with previous measurements of the DE (R² >0.99 compared to blue line in Figure 2) of Nextel made by other IR goniometers [5-7].

![Figure 2: Comparison between DE measurements of Nextel black paint by OSEG and other IR goniometers [5-7].](image)

Simple Fresnel Model of the DE of Nextel Black Paint 811-21: A MATLAB unconstrained least squares fitting algorithm was used to fit a Fresnel model [7] to the measured DE of the smooth target. It was found that the Fresnel model did not fit the measured DE at large emission angles where the model over predicts the drop in emissivity with emission angle (Figure 3). It was believed that the difference between the modelled and measured DE was due to sub millimeter surface roughness effects. Small differences in surface roughness could also explain the differences between the DE measurements of Nextel paint in Figure 2.

The effect of surface roughness was directly measured by creating another Nextel target with a greater roughness profile. This was achieved by roughly painting an aluminum base with a paint brush to create a millimeter scale rough target. The measured DE of the rough target was significantly different compared to the smooth target for emission angles >40° (Figure ).
Modelling the DE with Surface Roughness Effects using a MCRT Model: Clearly a model which incorporated surface roughness was required, such as a Monte Carlo Ray Tracing (MCRT) model. Before implementing such a model the surface roughness profile of the smooth Nextel target was measured and found to have an RMS height distribution of 13.5µm and a correlation length of 95µm.

An MCRT model based on the technique outlined in [8] was implemented. The roughness profile measured for the smooth Nextel black target was fed into the MCRT model. The optical constants for Nextel black paint were derived from surface conductivity measurements and found to be \( n = 1.43, \ k = 0 \). The MRCT model improves the fitting of the measured Nextel target (\( R^2 = 0.95 \), Figure 4). The main difference between the Fresnel only model and the MCRT model is at emission angles >40°. In the MCRT the number of light rays that are scattered from more than one surface becomes significant only for emission angles >40°, increasing the DE compared to the Fresnel model. This multiple scattering process drives up the emissivity at high emission angle effectively flattening out the DE of the Nextel paint.

JSC-1AF DE Measurement and Modelling: The DE of the lunar analogue JSC-1AF has been measured and shown to have an anisotropic DE (Figure 5). Just as with Nextel, the DE of JSC-1AF could not be modelled accurately with the Fresnel formula. A constrained Matlab least squares fitting algorithm was used to fit the MCRT model to the measured DE (Figure 5). The optical constants of JSC-1AF were taken to be 1.59+0.72i [9]. The two constrained parameters were the RMS height (10–30µm) and the correlation length (50–100µm).

Conclusions and Future work: The DE of a surface is defined both by the optical constants of the constituent materials and the macroscopic (submillimeter to millimeter) scale topography. To investigate the effect of macroscopic scale surface roughness on the DE further, we are developing a range of Nextel targets to compare the DE of a flat surface against those with a defined slope distribution (e.g. v-grooves).

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References: