Bi-Directional Reflectance Distribution (BRDF) Measurements and Modeling

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LONG-TERM GOALS

My work involves experimentally investigating the interrelationships and variability of optical properties in the ocean and atmosphere. My goal is to define the variability of the optical properties, particularly those dealing with light scattering, and to improve the prediction capabilities of image and radiative transfer models used in the ocean. My near term ocean optics objectives have been: 1) to improve the measurement capability of measuring the in-water and above-water spectral radiance distribution, 2) to investigate the variability of the Point Spread Function (PSF) as it relates to the imaging properties of the ocean, and 3) to improve the characterization of the Bi-directional Reflectance Distribution Function (BRDF) of benthic surfaces in the ocean, and 4) to understand the capabilities and limitations of using radiative transfer to model the BRDF of particulate surfaces.

OBJECTIVES

Our overall objective in this work is to provide the experimental and theoretical foundation to obtain both a predictive model of the BRDF of benthic surfaces in the ocean and determine the information that may be obtained about the benthic surface from measurement of the BRDF.

APPROACH

To give our modeling efforts a firm experimental foundation we have been making measurements of various prepared surfaces in the laboratory. These measurements have been made with both the in-situ BRDF instrument we built earlier (Voss et al., 2000) and a laboratory Goniometer. The BRDF instrument allows us to quickly measure the BRDF for many illumination angles, and with varied azimuthal angles. The laboratory goniometer allows to measure smaller phase angles, to look closer to the hotspot, and to measure the BRDF at finer angular resolution. In this effort we are making measurements of spherical particles, surfaces with interstitial liquids of varied indices of refraction and absorption properties, surfaces of natural sediments, and investigating the polarization properties of the BRDF.

Our theoretical approach is to compare these experimental results with various existing modeling ideas and with ray tracing models to determine the feasibility and accuracy of a predictive approach to the BRDF.

WORK COMPLETED

Experimental:

We have completed and published the results of an extensive series of measurements of surfaces made of small (on the order of 400 micron diameter) spheres (Zhang and Voss, 2005).

We have completed work on a series of measurements of surfaces (both simulated and natural sediments) in which the surface is measured dry, then wetted with either water or another liquid with a different index of refraction. We are working on a manuscript on these results.

We have just finished a series of measurents looking at the effect of absorbing interstial liquids on the overall reflectance (albedo) and BRDF of a surface.

Modeling:

We have compared the sphere measurements to existing numerical and emperical RTE models.

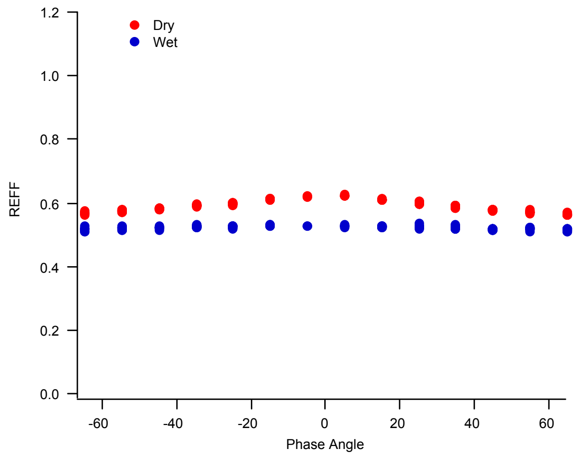
We have developed ray tracing simulations for regular arrays of uniform spherical particles for comparison with the above measurements and RTE models.

We have compared our measurements of the index of refraction effect of the interstitial liquids with two existing theoretical predictions (Twomey et al., 1986; Lekner and Dorf, 1988) and are working on these results.

RESULTS

For background, our measurements in the field (Zhang et al, 2003) showed that for natural submerged sediments the dominant feature was enhanced backscattering. Our measurements on prepared surfaces (Zhang and Voss, 2005) showed that many single scattering features of the particulates making up a surface, are still contained in the bulk BRDF measurement, but the single scattering features appear muted in the bulk measurement.

In our comparisons of dry and wetted surfaces we have found several consistent features. Figure 1 shows the REFF (BRDF normalized to the BRDF of a 100% lambertian reflector) at two different illumination angles, 0 and 65 degrees. This is a natural sample, obtained from sediments at Lee Stocking Island in the Bahamas during the ONR CoBOP program. This sample consists of 0.25-0.50 mm smooth rounded grains.



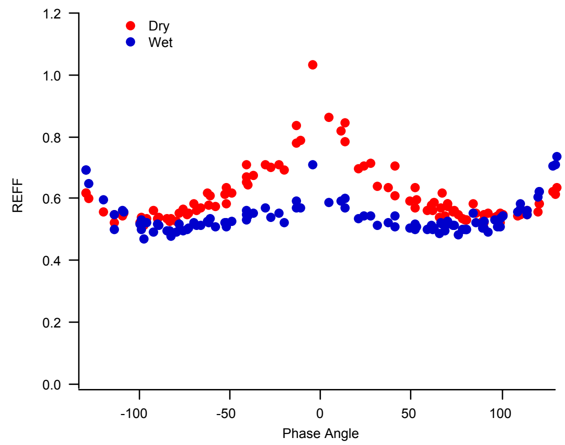


Figure 1) REFF of natural sample both dry and wetted with water. Top figure is illumination at 0 degrees, lower figure shows illumination at 65 degrees. These figures show both the decrease of the REFF when wetted, the hotspot in the sample decreases when wetted, and there is a slight increase in the forward scattering (evident at 65 degree illumination) when the sample is wetted.

The effect of wetting is to decrease the REFF overall, decrease the effect of the hotspot, and make a slight increase in the forward scattering. What we have found however, is that wetting causes multiple effects. The first seems to follow the predictions of Twomey et al (1986) where the wetted surface has increased forward scattering (as evidenced in the sample above illuminated at 65 degrees). However another effect is related to the concentraton of clear, quartz like particles in the sediment. Wetting these sediments causes an additional darkening as it allows more light to enter the surface of the particles(reduces the effective particle surface roughness) and transmit deeper into the sediment in the clear particle. Figure 2 shows the wetted albedo versus dry albedo for many of the samples we have measured.

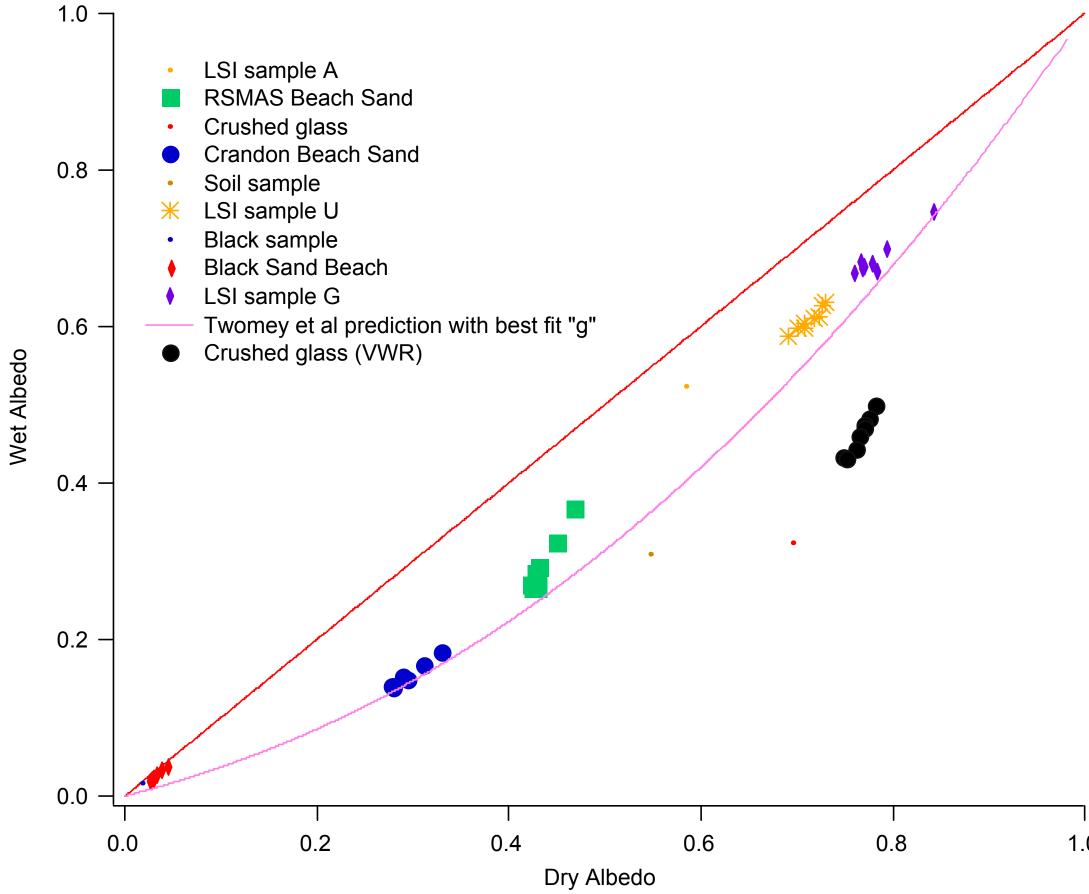


Figure 2) This is the dry albedo versus wet albedo for many different samples. Wetting the surface decreases the surface albedo. The largest decrease occurs for clear samples, such as our crushed glass sample, the least effect occurs for the opaque samples, such as LSI sample A.

The major difference affecting the variation between dry and wet albedo appears to be the transparency of the original particles. The largest change between wet and dry occurs for the crushed glass samples. The least effect occurs for the opaque particles (LSI sample A). So the change in albedo cannot be simply predicted from the dry albedo and index of refraction of the liquid. The line shown in the figure is a fit to the theory of Twomey et al., but here we have taken the best fit to the assymetry parameter "g". We have not settled on how to include the transparancy effect in the wetting effect.

IMPACT/APPLICATIONS

Predicting the BRDF of in-situ benthic surfaces is important for understanding both the natural solar illuminated light field near the bottom and the possible distribution of light from active systems. Since the BRDF is the root source of all remotely sensed data, understanding this factor is important for analyzing all types of remote sensing data.

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