Bi-Directional Reflectance Distribution (BRDF) Measurements and Modeling

Kenneth J. Voss
Department of Physics
University of Miami
Coral Gables, Fl. 33124
phone: (305) 284-2323 ext 2 fax: (305) 284-4222 email: voss@physics.miami.edu

Award Number: N000149910008
http://optics.physics.miami.edu

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 experimentally quantify the role and importance of inelastic scattering in the natural in-water radiation field, 2) to improve the measurement capability of measuring the in-water and above-water spectral radiance distribution, 3) to investigate the variability of the Point Spread Function (PSF) as it relates to the imaging properties of the ocean, and 4) to improve the characterization of the Bi-directional Reflectance Distribution Function (BRDF) of benthic surfaces in the ocean.

OBJECTIVES

Over the last several years we have made field measurements of the BRDF and have developed an empirical model of the BRDF for many of the benthic substrates measured at the CoBOP site in the Bahamas. Our objective in this work is to provide the experimental foundation for a predictive model of the BRDF based on the physical characteristics of the sediment.

APPROACH

Our work seeks to provide the experimental foundation for a physical model of the BRDF. To do this, a series of laboratory measurements are required to justify the modeling and understand the sensitivity of the BRDF to the sediment physical properties.

The series of experiments we proposed were:

1) Dependence of the reflectance on the sample thickness
2) Measurement of a surface composed of spherical particles.
3) Laboratory measurement of size sorted, geometrically characterized, sediment.
4) Effect of pore liquid index of refraction.
5) Effect of pore liquid absorption coefficient.
6) Polarized BRDF and transmission measurements.

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14. ABSTRACT
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 experimentally quantify the role and importance of inelastic scattering in the natural in-water radiation field, 2) to improve the measurement capability of measuring the in-water and above-water spectral radiance distribution, 3) to investigate the variability of the Point Spread Function (PSF) as it relates to the imaging properties of the ocean, and 4) to improve the characterization of the Bi-directional Reflectance Distribution Function (BRDF) of benthic surfaces in the ocean.

15. SUBJECT TERMS

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The experiments, listed above, will form the basis of our modeling efforts, and our modeling work and experimental work is closely coordinated with Dr. Howard Gordon's efforts. There have been quite a few reflectance models of snow, which is loosely packed compared with sediments, based on numerically solving the radiative transfer equation (For a brief review, see Leroux et al 1999). There are still many uncertainties about how RTE works for close-packed, especially touching, grains, and these models have not been validated by experiments. Our modeling efforts will be directed towards using some of the models put forward by Hapke(1993) and others. With these experiments as a foundation we will be able to evaluate these models and if needed develop a better model for the benthic substrate. Many of these models do not deal with some of the issues of in-situ in-water substrates such as the pore waters effect on the BRDF. Thus our model will have to be an extension of these other models. The final goal is a model that can take a physical description of the sediment and accurately predict the BRDF. One factor that may be in our favor is work (Shoshany 1991) indicating that the BRDF is not unique, i.e. many different types of surfaces can produce similar BRDF's. From the inversion point of view this could be distressing, but from predicting the BRDF this could be helpful as exact details of the sediment particles may not be important.

WORK COMPLETED

We have developed the laboratory instrument to make high angular resolution measurements of the BRDF and Bi-directional Transmission Distribution Function (BTDF). We have also set up the instrument so that polarization measurements can be performed.

We have performed laboratory measurements studying the sensitivity of the BRDF to the sample layer thickness with several size ranges of ooid sediments, measured the BRDF and BTDF of spheres with different layer thicknesses (single layer and multiple layers) and for several size distributions, and made measurements of the BRDF and BTDF for several size distributions of ooids, which are nearly spherical in shape. In addition many of these measurements have been done with linearly polarized incident light to start our polarization studies.

In addition we have begun our work at modeling the sphere systems to see how well existing radiative transfer models will perform. Our first efforts are aimed at using the DISORT radiative transfer model (Stamnes et al., 1988) to compare with our sphere measurements.

RESULTS

Layer Thickness

To summarize our work investigating layer thicknesses, in general only the first 2 mm (for small sediment –0.125 –0.25 mm diameter ooids) and 5 mm (for large sediment, 0.5-1.0 mm diameter) influence the BRDF. Even for these thin layers, the BRDF is mainly effected only for normal incidence; for off-axis incident light it is difficult to see any effect even for 1 mm layer samples, as shown in the figures of the reflectance factors shown below. Thus when sampling the benthic surface for quantities determining the reflectance, it is important to look at the very top layer, and not integrate parameters over depths of 1 cm or more.

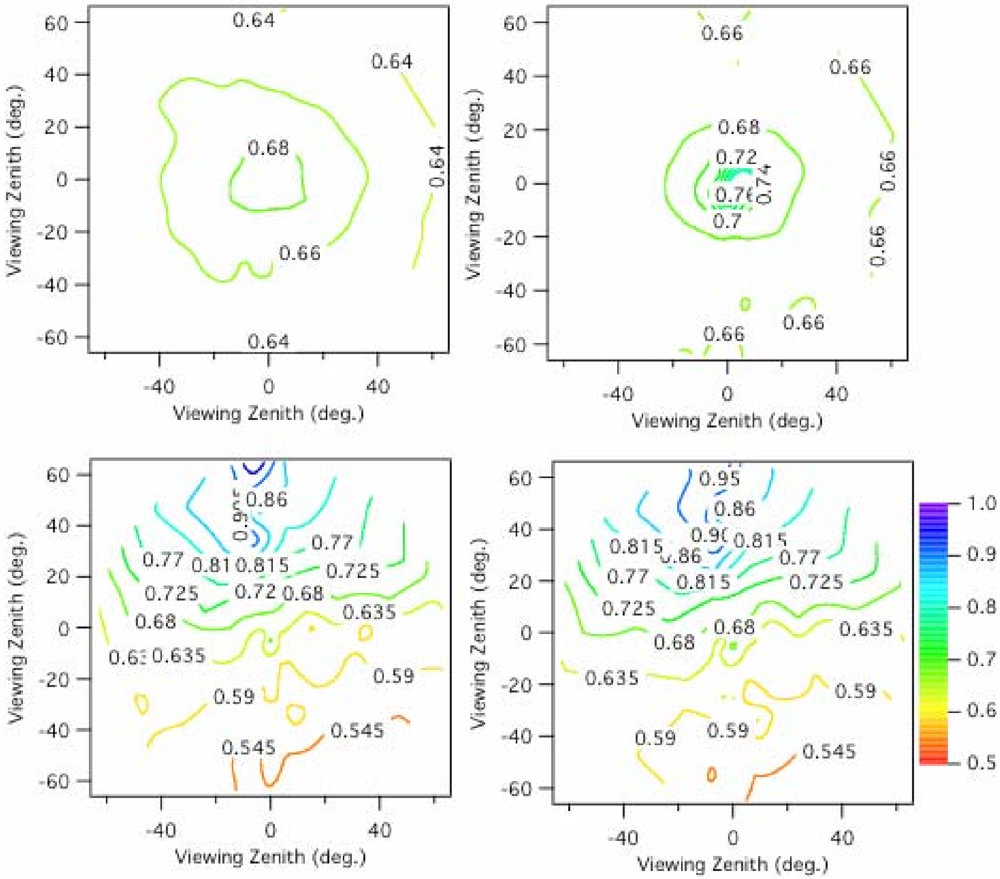

Figure 1: [Four graphs. Upper left is a 1 cm thick ooid sample above a mirror with 0 degree incident light. No effect due to the mirror is seen. Upper right is 1 mm thick ooid sample above the mirror with 0 degree incident light. In this sample the specular reflection from the mirror is evident. Lower left graph is a contour of the 1 cm thick ooid sample with 35 degree incident light, the obvious feature is the retro reflection (hot spot) towards the top of the graph. Lower right graph is contour of 1 mm thick ooid sample with 35 degree incident light. It is almost exactly the same as the 1 cm thick sample, no evidence can be seen of a specular reflection or the mirror.]

Sphere BRDF measurements

We have made measurements of several size distribution of spheres, and compared these measurements with two existing models. The first was a model by Mischenko et al. (1999), the second is the widely used DISORT model (Stamnes et al., 1988). Mishenko's model looks at semi-infinite layers, thus only predicts the BRDF, not the BTDF. The interesting feature of the measurements is the existence of many single scattering features even in the very deep layers. The dominant feature of the sphere measurements is the rainbow region from 0 to 20 degrees in phase angle. This enhancement of the backscattering is very bright and noticeable even to the naked eye. We show an image of this below.

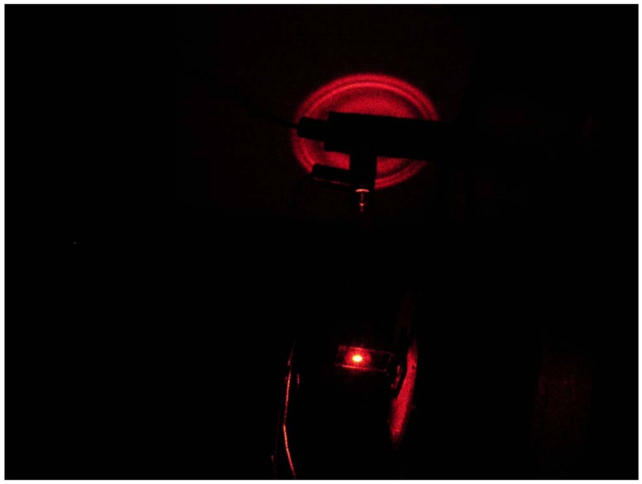

Figure 2: [This is a picture of the experiment. The picture is taken from below, looking up at the bottom of the sample (evident as a very bright white spot which is the transmitted light) and views the reflected "rainbow" light which illuminates the ceiling. The multiple rings are seen which are the fine structure inside the 20 degree rainbow angle, it is very dark outside this region, reflecting the large decrease in the BRDF outside this angle. These are for normal (0 degree) illumination.] We can also show this rainbow quantitatively by looking at the light scattering phase function from the spheres and the BRDF factor.

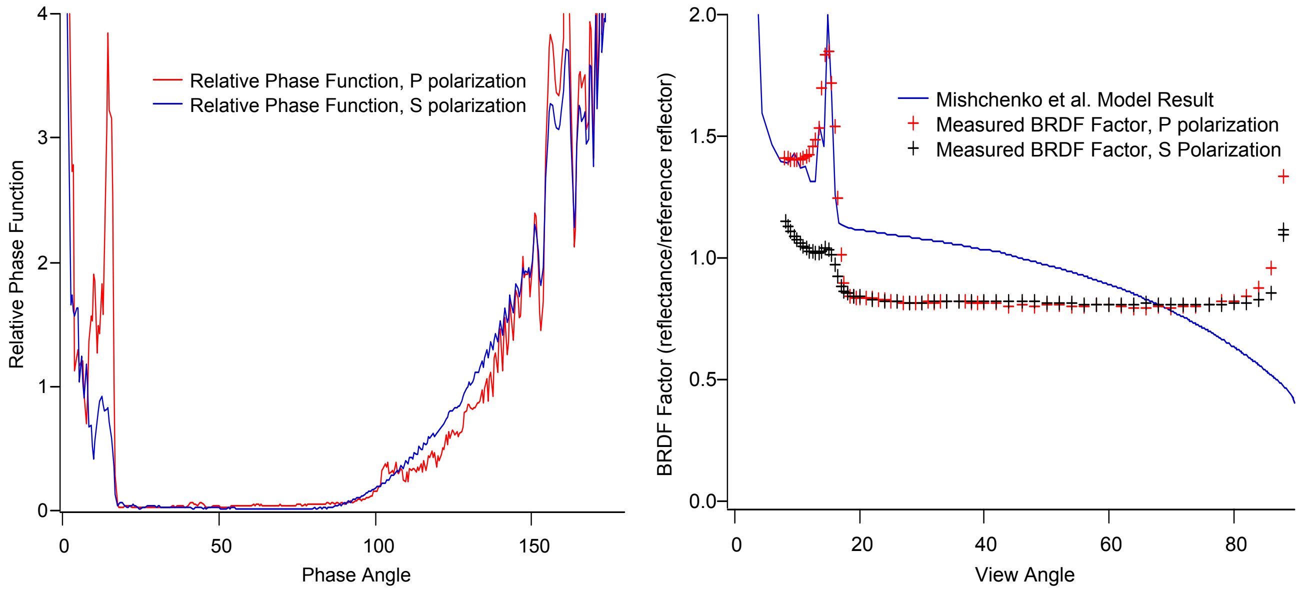

Figure 3: [Figure on left shows the relative phase function of the 200 micron sphere sample for two incident polarization angles (p and s) versus phase angle. What is evident is that there is an enhanced region near 0 degrees phase angle which has a sharp cut off of at least an order of magnitude at around 20 degrees. The region from 20 degrees to almost 90 degrees is almost zero. On the right the figure shows the BRDF factor for the 200 micron spheres. Two features are evident, first the rainbow effect is still there, but is most evident with P polarization. Second after the rainbow, between 20 and 90 degrees, the BRDF factor does not fall to zero, but stays at nearly 0.8. Thus there are single scattering effects (the rainbow) and multiple scattering effects (the region between 20 and 90 degrees) evident in the BRDF factor. Also shown in this graph on the right is the prediction of a model by Mischenko et al. (1999). There are some regions of agreement (the rainbow region seems to agree quite well with the P polarization results), but the shape in general does not follow the measurements.]

Below we show the BRDF and BTDF measurements of a 1.5 mm thick layer of the 200 micron spheres, compared with the results from the DISORT model. It is difficult to determine the correct optical depth to use when applying the model. We chose an optical thickness of 13 for this example. In general optical thickness is a strange concept with these packed surfaces, as basically all light has interacted and been scattered, thus an argument for an infinite optical thickness could be rational. As can be seen, though, the value of 13 seems to allow DISORT to work well at predicting the BRDF and BTDF, other than the region near 90 degrees.

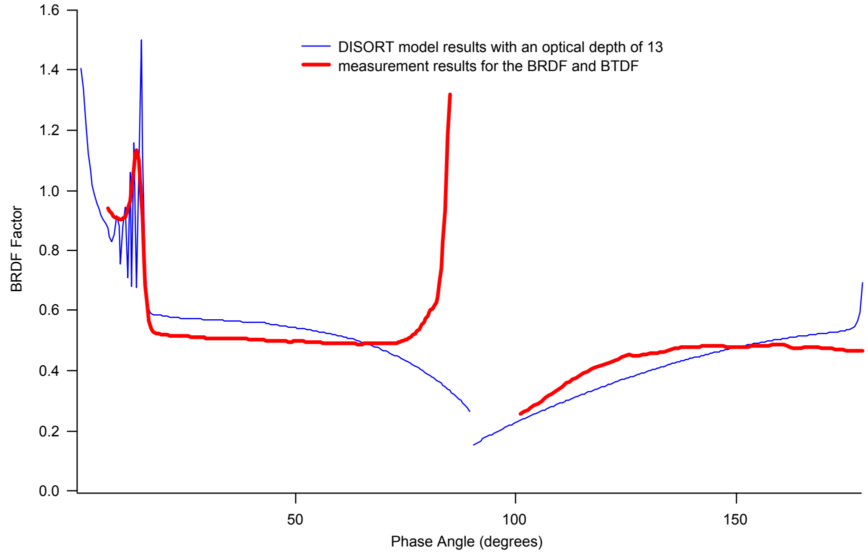

Figure 4: [Figure of the BRDF and BTDF for a 1.5 mm thick layer of small spheres. Overlaying the measurements is the DISORT model predictions for this system, but using an optical depth of 13. The agreement is actually quite good through most of the BRDF range, but departs at around 70 degrees when the measurements show the BRDF to increase, while the model predicts the BRDF will decrease. For the BTDF, there is reasonable agreement in magnitude, although the shape does not appear quite right.]

The modeling effort is showing promise, with reasonable agreement to our measurements. Thus it seems that a predictive validated model of the BRDF is achievable. We still need to investigate the effect of interstitial water and absorbing materials.

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.

RELATED PROJECTS

We are working closely with Dr. Howard Gordon, supplying the data we collect on the BRDF and BTDF to his modeling efforts.

REFERENCES

B. Hapke, 1993. Theory of reflectance and emittance spectroscopy. Cambridge University Press, New York, New York, 455 pgs.

C. Leroux, J. Lenoble, G. Brogniez, J. W. Hovenier, and J. F. De Haan, 1999, A model for the bidirectional polarized reflectance of snow, J Quant. Spectrosc. Rad. Transfer 61: 273-285.

M. I. Mishchenko, J. M. Dlugach, E. G. Yanovitskij, N. T. Zakharova, 1999, Bidirectional reflectance of flat, optically thick particulate layers: an efficient radiative transfer solution and applications to snow and soil surfaces, J Quant. Spectrosc. Rad. Transfer, 63 409-432.

M. Shoshany, 1991, The equifinality of bidirectional reflectance distribution functions of various microstructures, Internat. J. of Remote Sensing, 12: 2267-2281.

K. Stamnes, S. C. Tsay, W. Wiscombe, K. Jayaweera, 1988, Numerically stable algorithm for discrete-ordinate-method radiative transfer in multiple-scattering and emitting layered media, Applied Optics, **27**, 2502-2509.

PUBLICATIONS

K. J. Voss, C. D. Mobley, L. K. Sundman, J. Ivey, and C. Mazell, The spectral upwelling radiance distribution in optically shallow waters, Limnol. and Oceanogr, 2003, **48**: 364-373.[published, refereed]

H. Zhang, K. J. Voss, R. P. Reid, and E. Louchard, Bi-directional reflectance measurements of sediments in the vicinity of Lee Stocking Island, Bahamas, Limnol. and Oceanogr, 2003, **48**: 380 - 389.[published, refereed]

C. D. Mobley, H. Zhang, and K. J. Voss, Effects of optically shallow bottoms on upwelling radiances: bidirectional reflectance distribution function effects, Limnol. and Oceanogr, 2003, **48**: 337 – 345. [published, refereed]

Decho, A. W., T. Kawaguchi , M. A. Allison, E. Louchard, R. P. Reid., C. Stephens , K. J. Voss., R. Wheatcroft , B. B. Taylor,, "Sediment properties influencing up-welling spectral reflectance signatures: the "biofilm gel effect", Limnol. and Oceanogr, 2003, **48**: 431 - 443. [published, refereed]

K. J. Voss and R. Austin, " An instrumental history of the Scripps Visibility Laboratory", Santa Fe, N. M. November 2002. [published]

H. Zhang, K. J. Voss, and E. Louchard, "Determining the influential depth for surface reflectance of sediment by BRDF measurements", Santa Fe, N. M., November 2002. [published]

J. E. Prentice, A. D. Weidemann, W. S. Pegau, K. J. Voss, M. Lee, E. Shybanov, O. Martynov, A. Laux, A. Briggs, G. Chang, "Laboratory comparisons of optical scattering instrumentation, Ocean Optics XVI, Santa Fe, N.M., November, 2002. [published]

H. Zhang, K. J. Voss and R. P Reid, Determining the influential depth for surface reflectance of sediment by BRDF measurements, Optics Express.

H. Du and K. J. Voss, Effects of point spread function on calibration and radiometric accuracy of CCD camera, Applied Optics.