

INELASTIC LIGHT SCATTERING IN THE COASTAL ZONE AND IN BENTHIC ENVIRONMENTS

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LONG-TERM GOAL

My long term goals are to experimentally determine the interrelationships and variability of optical properties in the ocean and atmosphere. I have been concentrating on aspects of scattering, both inelastic and elastic, and measurements of the radiance distribution in the ocean and atmosphere. These measurements can be combined to test and improve radiative transfer models which are used to predict image and light transmission in the ocean.

SCIENTIFIC OBJECTIVES

Our near term objective is to characterize the inelastic scattering in clear water, coastal waters with high DOM concentrations, and the benthic environment (as part of the CoBOP program). In addition, as part of our CoBOP efforts we will be designing and constructing an instrument to make in-situ bi-directional reflectance measurements of benthic surfaces.

APPROACH

Solar stimulated inelastic scattering

We use our Fraunhofer line technique to separate the inelastically scattered or fluoresced light from the elastically scattered or direct light (Ge *et al*, 1995). Data has been collected in several environments: clear open water, DOM rich water in Florida Bay, and in marine Benthic environments with CoBOP.

Bi-directional Reflectance instrument

We are currently building an instrument to measure the in-situ bi-directional reflectance of surfaces at 3 wavelengths (450, 565, and 700 nm were chosen because of the availability of bright LED sources). The instrument is basically a hemisphere with a radius of 10 cm, which is placed on the surface to be measured. The surface is sequentially illuminated at angles ranging from 0 to 85 degrees (0, 5, 15, 25, 35, 45, 55, 65, 75 degrees). The reflected light is measured with fibers at the same zenith angles as the illumination and at 29 azimuthal angles from 0 to 360 degrees. The sample area is approximately 1 cm². Light from each illumination direction is collected with fiber optic collectors and then brought into a common "block array" which is imaged on a camera. In this way all illumination angles are collected at a single time greatly decreasing sample acquisition

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time. The instrument is small and compact enough for diver operation in-situ, however there is a power umbilical to the device.

Once the instrument has been built it will be used in field experiments in Biscayne Bay and at the CoBOP experiment sites.

WORK COMPLETED

We have participated in a cruise in Florida Bay with Dr. Rod Zika, RSMAS. In addition we have finished analyzing and writing manuscripts on inelastic measurements obtained during previous cruises in various environments (coastal, clear, and benthic).

The bi-directional reflectance instrument has been designed and is presently being constructed.

RESULTS

Our inelastic work has progressed on several fronts. The first is the inelastic scattering in clear ocean water. We have experimentally shown, in open water, that the correct Raman scattering coefficient to use in the ocean is the value of Slusher and Derr (1975), $2.6 \times 10^{-4} \text{ m}^{-1}$ (Hu and Voss, 1997). We also worked with other groups (S. Sathyendranath[BIO] and T. Vodacek[U.Md]) to investigate the issue of the wavelength dependence of the water Raman scattering coefficient. This has been somewhat of an open issue with opinion split between a wavelength dependence characterized by a power law of wavelength with an exponent of between -4 (Kattawar and Xu, 1992) and -5 (Sugihara et al., 1984). The three groups (U.M., U.Md., and BIO) made independent measurements of the wavelength dependence of the Raman scattering using absolutely calibrated spectrofluorimeters. We found that the correct wavelength dependence was dependent on the normalization (photon or energy) and which wavelength one used, excitation or emission. However the results, combining all the measurements, are shown in Table 1. The differences between these results and the theoretical value of -4 was attributed to a water absorption band at 130 nm (Bartlett et al. 1998)

Table 1) Wavelength dependence of Raman scattering

Normalization	Wavelength	Value
Photon	emission	-4.6
Photon	excitation	-5.3
Energy	emission	-4.8
Energy	excitation	-5.5

In our measurements of the high DOM environment in Florida Bay, we have found that the inelastic light in the water column is responsible for a very small part of the total light field. This is because of the large contribution of the bottom reflectance to the light field, and also because in these high DOM areas the absorption in the blue is so strong that much of the excitation light has been absorbed at shallow depths (Hu and Voss, 1998).

We used a modification of the Fraunhofer technique, using the oxygen absorption lines at 689 nm, to look at chlorophyll fluorescence. Modeling results in open water show reasonable agreement between the amount of Chlorophyll fluorescence measured and the amount predicted. We also made measurements of the chlorophyll fluorescence emitted from a brain coral head. These measurements were performed over a day to look at diurnal changes in the fluorescence level (Fig 2). What we found was that the solar stimulated fluorescence from the coral saturated early in the day, while the illumination continued to rise, thus the portion of the radiance from the head due to fluorescence decreased towards solar noon. We hope to make more measurements like this on future COBOP cruises to investigate the causes of the fluorescence saturation.

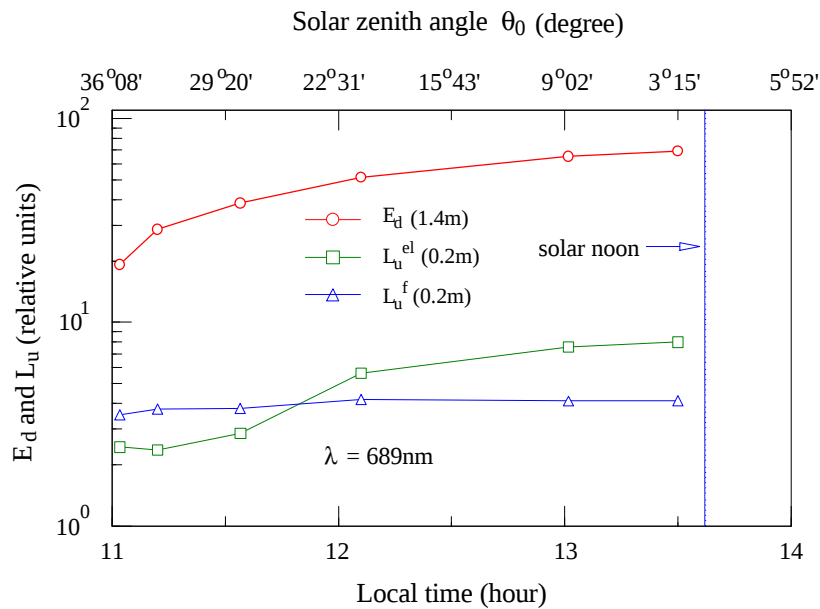


Fig 1) Partition of light from the brain coral head into inelastic (fluorescence) and elastically reflected light, along with the downwelling irradiance.

IMPACT/APPLICATION

The Raman scattering coefficients are important in predicting the inelastic light field in any realistic radiative transfer model. We have shown that the fluorescence from the DOM, even in high DOM environments does not appear to be a significant contribution to the total light field. Finally we have seen how the Fraunhofer instrument may be used to look at issues such as the solar stimulated chlorophyll fluorescence of benthic environments, which will be used during the COBOP program.

TRANSITIONS

At this point I am not aware of many transitions in this work, mostly because it is just coming out in the literature. Because of the fundamental importance of the Raman coefficient in the in-water light field, I am sure that the results will be used by many groups as time progresses. Also the measurements of the bi-directional reflectance will be used in many modeling efforts when the instrument is complete and we begin measurements in the field.

RELATED PROJECTS

1 - We are working with Dr. Rod Zika at RSMAS in ONR sponsored work, looking at the optical effects of DOM on the marine light field.

2 - With NASA support we have been making measurements of the in-water radiance distribution in clear water (using an instrument previously designed and built with ONR support).

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