Light Scattering Properties and Processes of Coastal Waters

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LONG-TERM GOAL

Characterizing the volume scattering function (VSF) of oceanic waters remains one of the most outstanding problems in optical oceanography. The goal of this program is to significantly advance our knowledge of the VSF of oceanic waters, particularly coastal waters. To achieve this goal we are developing new VSF instruments that are capable of accurately and routinely measuring *in situ* profiles of the complete VSF. Once we have developed the necessary tools for measuring the complete VSF, our long-term goal is to use these tools to quantitatively characterize and model the light scattering properties and processes of oceanic waters.

OBJECTIVES

Our scientific objective is to measure, in situ, the volume scattering function concomitant with other optical property measurements and the particle size distribution in a wide variety of oceanic waters. Since we already have at hand a number of instruments and methods for measuring the absorption, beam attenuation, and backward-scattering coefficients [Maffione and Dana, 1997; Dana et al., 1998], the VSF measurement will provide the only missing link to definitively testing instrument closure. By means of closure we will be able to quantitatively document the accuracy of our optical property measurements. A related objective is to investigate the accuracy of using Mie theory to compute the VSF based on the particle size distribution [Jackson et al., 1997] and index of refraction. In general we will apply our VSF measurements to a wide variety of modeling problems in optical oceanography. Our technological objective is to develop accurate, in-situ profiling instruments that can measure the VSF over the range of scattering angles from 0.1 to 170 degrees.

APPROACH

The existing data show that the VSF's of marine particles typically increase by four orders of magnitude as the scattering angle goes from 90 to 1 degree, and they increase by another two orders of magnitude from 1 to 0.1 degrees. This presents great difficulty in measuring the VSF, requiring exceptionally high angular resolution and dynamic range in the electro-optics of an ocean VSF meter. At larger scattering angles (approximately 30 to 170 degrees), the relative intensity of light scattered into a narrow solid angle is exceedingly small, so that highly sensitive, yet low noise photodetection is required [Maffione and Dana, 1997; Dana et al., 1998]. In addition, any in-situ VSF meter must be able to withstand the harsh ocean environment, staying radiometrically and electronically stable to maintain its calibration and accuracy. Finally, there is the important issue of accurately calibrating the instrument, which requires careful analysis of the electro-optic response of the sensor and appropriate measurements to properly characterize the light propagation through the system. Our approach to

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addressing this difficult instrument development project will make use of the unique optical and electronic technology and calibration techniques we developed to solve the problems we faced in building instruments for measuring light scattering in the ocean [Maffione and Dana, 1997; Dana et al., 1998].

Analytical modeling is the first step we take in developing a new design for an ocean optical instrument. This step consists of developing the initial optical layout and the equations that describe the transfer of radiant power through the system. The equations must also describe the propagation of radiant power through the sample volume of water. In the analytical design and modeling phase, the single-scattering approximation is used for this part of the problem. Usually these equations have to be inverted as part of the instrument calibration, and thus IOP instruments are almost always designed to minimize the detection of multiple scattering. When multiple scattering is unavoidable, it can be effectively treated using the concept of quasi-inherent optical properties, which is usually important to long-pathlength systems. To completely characterize and understand the optical response of the VSF sensor, we will employ a Monte Carlo (MC) model. The MC model will simulate photon propagation from the point where the collimated source enters the sample water volume to where the scattered light reaches the window or aperture of the detector. Any combination of the water's absorption and scattering properties can be entered into the model, so that the instrument's response to various types of oceanic waters can be explored.

The electro-optic design is a critical part in the development of an ocean-optical instrument. Not only must the optical and mechanical aspects of an instrument be carefully designed so that the instrument operates properly in the harsh oceanic environment, but so must the electronics. Often in fact, the demands placed on the electronics are much greater than those placed on the optics. In addition to the environmental problems that have to be resolved, there is the more basic problem of designing an electro-optic system that can accurately detect low levels of light with high dynamic range, often with the added complication of high ambient light that must be rejected in the detection. In general, any compact and robust ocean-optical instrument requires a highly specialized, state-of-the-art electro-optic design. While the basic principles of electro-optic detectors are simple and widely understood, numerous subtle, lesser-known engineering factors come into play in designs of the type we propose. The factors involved also change depending on the specific measurement. Scattering measurements, which involve extremely small optical signals over the general angles, require the utmost attention to the noise generated by each component in the receiver circuitry. Forward scattering measurements have inherently higher signal levels, easing noise requirements, but require extreme stability over time and temperature changes. While each measurement requires careful attention to every detail of the circuit design, they involve very different priorities and tradeoffs. We will apply techniques we have developed and refined over the course of several previous generations of scattering instruments to the present problem [Maffione and Dana, 1997].

WORK COMPLETED

The VSF instrument we are developing on this project is called HydroBeta. To date, we have completed the entire electro-optic design of HydroBeta. All of the electronics, from the 12 amplifier boards to the internal data processor, have been built and tested. The sensor responses were found to be more than adequate for measuring light scattering over the range of angles from 0.1 to 170 degrees. Moreover, our laboratory tests showed that our design achieved total ambient light rejection which will allow us to measure the VSF on undisturbed water. That is, our opto-mechanical design does not require an enclosed system or flow tubes. This unprecedented performance was achieved by adapting our successful electro-optic design used in our spectral backscattering sensors [Maffione and Dana, 1997].

The opto-mechanical design of HydroBeta is a unique and revolutionary design over all previous VSF meters. Basically, a “ring” is used for mounting 12 fiber-optic light collectors that can be positioned to measure light scattering from a source beam at nearly any angle. One of the more exciting aspects of this design is that the 12 angles at which the VSF is measured can be easily changed. HydroBeta is also designed as a profiling instrument, where it measures the VSF at 12 angles simultaneously through the water column (or in time series for moored applications).

We expect the HydroBeta will be completely built and ready for its first field trials in March, 1999. For up-to-date details and results of HydroBeta, please visit our web site at http://www.hobilabs.com.

RESULTS

This project has just completed its first year, and most of our efforts have concentrated on designing and building the HydroBeta VSF instrument. Our laboratory measurements of the optical response of the prototype opto-electronics of HydroBeta demonstrate that this instrument will have exceptional signal-to-noise response at all scattering angles and will provide total ambient light rejection.

IMPACT/APPLICATIONS

We expect that our measurements of the complete VSF will have an enormous impact on nearly all areas of optical oceanography. No measurements of the kind we plan to obtain have ever been made. Indeed, the nearest data of this type were obtained over 25 years ago. This lack of systematic and complete VSF measurements has greatly hampered our understanding of light scattering by marine particles, the testing and refinement of optical models, and the calibration of ocean-optical systems.

TRANSITIONS

This project has just completed its first year and thus there are not yet any specific transitions. However, we certainly expect that our VSF measurements and instruments will be used on many basic and applied programs involving oceanic optics.

RELATED PROJECTS

This project is closely related to the author’s ONR funded program, “Optical Closure in Coastal Waters.” The new VSF instrument will be a key component to testing optical closure. In addition, HydroBeta will be an important water-column instrument on ONR’s CoBOP program. This project is also related to an SBIR program, funded by NAWC, to develop a commercial forward-scattering meter. The technology we are developing on this basic research program is being applied to the commercial program.

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