

Light Scattering Properties and Processes of Coastal Waters

Robert A. Maffione

Hydro-Optics, Biology, and Instrumentation Laboratories

55 Penny Lane

Watsonville, CA 95076

Phone: (831) 768-0680 Fax: (831) 768-0681 Email: Maffione@hobilabs.com

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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 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

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measurements to properly characterize the light propagation through the system. Our approach to 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].

The VSF instrument we are developing on this project is called HydroBeta. The opto-mechanical design of HydroBeta is unique from 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).

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).

In parallel with the instrument VSF instrument development effort, I am conducting on-going field work on the optical properties of coastal waters with a particular emphasis on light scattering properties. Water-column optical properties are measured with a sophisticated package we developed called HydroProfiler. The HydroProfiler consists of an array of IOP instruments and spectral radiometers that together measure a nearly complete set of water-column optical properties. The HydroProfiler is equipped with manually adjustable buoyancy for controlling descent rates and to allow profiling that is mechanically decoupled from the ship. When possible, we also collect water samples for chlorophyll, total suspended solids, and particle size distribution analysis. To supplement the synoptic measurements obtained from cruises in Monterey Bay, I am collecting time-series optical measurements from moorings with our *a*-Beta, *c*-Beta, and HydroScat-2 instruments. In addition to this field work, I am conducting extensive scattering measurements in the laboratory of various types of inorganic particles and of cultured phytoplankton.

WORK COMPLETED

The design of HydroBeta was completed and all mechanical, optical, and electronic components have been built and assembled. Laboratory testing of the performance of HydroBeta are currently under way. An accurate and robust calibration scheme has been developed that is a variation of our highly successful method for calibrating the HydroScat backscattering sensors. The design of the calibration fixture for HydroBeta has been completed and is currently being machined. We expect to have HydroBeta fully calibrated and ready for sea trials by January, 2000.

Extensive field work has been conducted on obtaining data of optical properties in a wide range of coastal environments. Thus far I have conducted 12 cruises in Monterey Bay and have obtained a significant database of spatial and seasonal variability of optical properties in this region. Cruises have

also been conducted in the mid-eastern shore through Chesapeake Bay, Tasman Bay in New Zealand, and Lake Tahoe. Time-series optical measurements were obtained from moorings in Monterey Bay with our a -beta, c -beta, and HydroScat-2 instruments. Measurements of light scattering and optical properties of detritus, mineral particles, and cultured phytoplankton have been conducted in the laboratory.

RESULTS

A new, thorough analysis of the calibration of the HydroScat backscattering sensor confirmed the accuracy of this instrument in measuring b_b [Maffione, submitted]. Modeling and laboratory studies showed that b_b can be consistently measured with 95% accuracy or better. Field measurements of the spectra of b_b were often found not to be consistent with the spectra of $b = c - a$, based on measurements of c and a . Results combining other optical measurements seem to indicate that the b spectra are in error due to a measurements being too high around absorption peaks caused by a combination of path-length amplification and incorrect scattering correction.

Extensive observations of optical properties and processes in Monterey Bay are being conducted from ships and moorings. A HydroScat-2 was deployed on MBARI's M3 mooring during the spring transition and onset of the upwelling season. Figure 1 shows the time series of b_b at 676 nm and the ratio b_b to chlorophyll fluorescence as also measured by the HS-2. While both the b_b and $b_b/\text{chl-flr}$ ratio show strong diurnal variability, the $b_b/\text{chl-flr}$ ratio shows a repeating diel cycle consistent with daily photoadaptation by phytoplankton cells. Additional HOBI Labs instruments, including hyperspectral radiometers (HydroRad) are being deployed on other moorings around Monterey Bay to study the optical properties and processes of this coastal region.

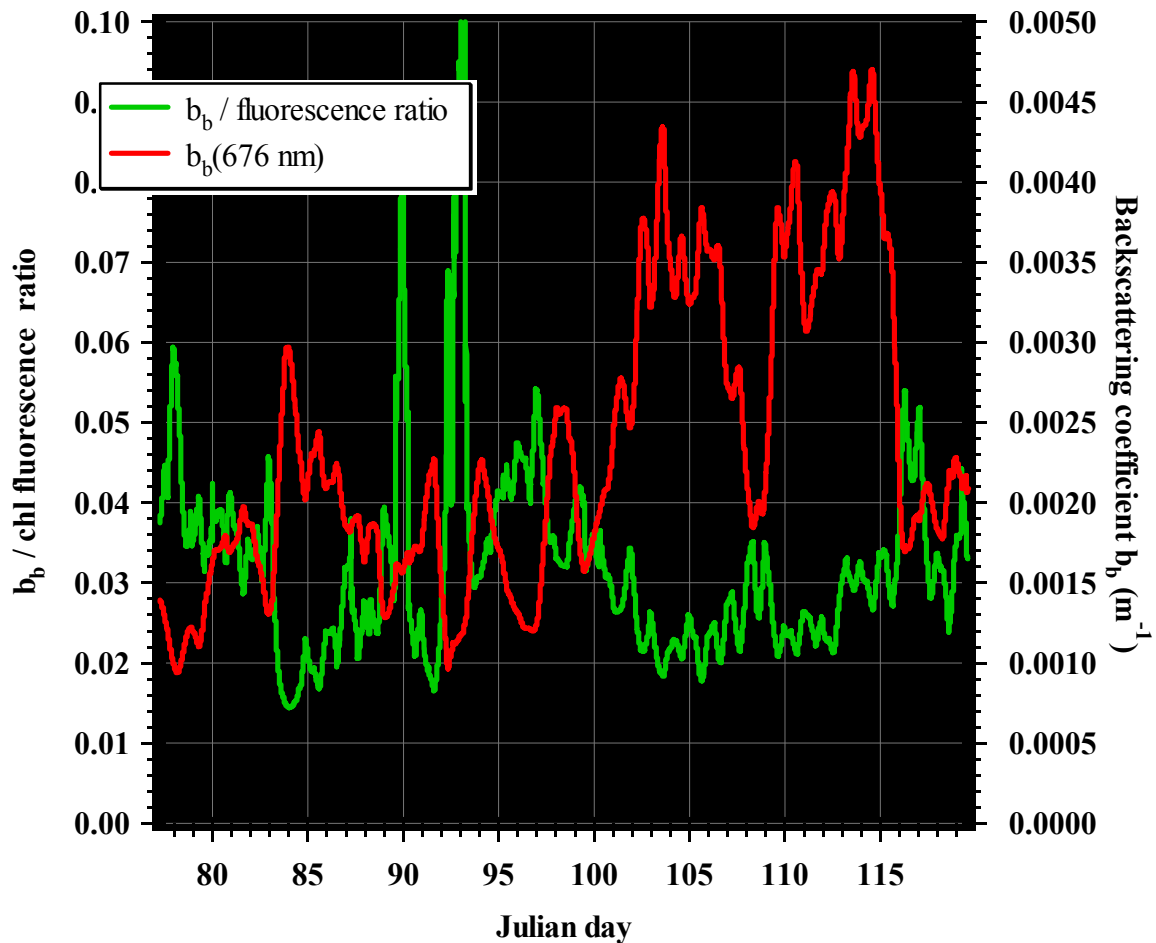


Figure 1. Surface time series of backscattering and b_b / chlorophyll fluorescence ratio measured with the HydroScat-2 on a mooring in Monterey Bay. While both the bb and $bb/chl-flr$ ratio show strong diurnal variability, the $bb/chl-flr$ ratio shows a repeating diel cycle consistent with daily photoadaptation by phytoplankton cells.

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. Our extensive collection of optical property measurements in various coastal environments will be a critical aid in developing bio-geo-optical models of coastal waters.

TRANSITIONS

The α -beta, c -beta, and HS-2 IOP instruments are being used on a wide range of programs such as CoBOP, HyCODE, NOPP, NASA funded projects, and by NRL investigators studying optical properties of coastal waters.

RELATED PROJECTS

D. Stramski (Scripps) is using the HydroScat-6 to study the relationship between backscattering and POC. He is also using the a -beta as a rapid and robust means of determining CDOM.

K. Carder (USF) is using five HS-2's on moorings in the west Florida shelf to study variability in b_b and the circulation of suspended particulate matter.

I am using the a -beta and c -beta on an applied Navy program to estimate underwater visibility for optical mine-hunting systems. These instruments are also being used on numerous other Navy programs for similar applications.

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.

REFERENCES

Dana, D.R., R.A. Maffione, and P.E. Coenen, 1998. A new instrument for measuring the backward scattering and absorption coefficients simultaneously, Ocean Optics XIV, S.G. Ackleson, Editor, Proc. SPIE.

Maffione, R.A., (submitted). Analysis of the calibration and accuracy of the HydroScat in-situ backscattering instrument, *Appl. Opt.*

Maffione, R.A., and D.R. Dana, 1997. Instruments and methods for measuring the backward-scattering coefficient of ocean waters, *Appl. Opt.*, 36, 6057-6067.

PUBLICATIONS

Maffione, R.A., (submitted). Analysis of the calibration and accuracy of the HydroScat in-situ backscattering instrument, *Appl. Opt.*

Maffione, R.A., L. McKenzie, and R. Murphy, (submitted). Distribution of optical properties in Tasman Bay, New Zealand, *N.Z. J. of Marine and Freshwater Res.*