

# Measurement of Time Varying Volume Scatter

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## LONG-TERM GOALS

The major long-term scientific goal of this program is to understand the small-scale optical properties of the ocean. This includes the spatial and temporal inhomogeneities that occur naturally over scales from km to mm. The importance of this area of inquiry is underscored by both environmental and practical concerns. In an environmental context, the radiative transfer of light in the ocean is dependent on not only the average but also the small scale (cm – m) optical properties. The role that these inhomogeneities play in light transmission is unexplored due a lack of in-situ data. In a practical sense, improved characterization of the environment is critical in understanding and predicting the outcome of Navy systems that are in and also planned for use.

## OBJECTIVES

The main focus of our work during this funding period has been to continue the development of our sensor for recording the Volume Scattering Function (VSF)  $\beta(\theta, r, t)$  and to continue the analysis of data from our Wecoma cruise in Sept '06. Measurement of the VSF function provides both empirical and environmental information about the state of the ocean. Briefly, a prototype VSF meter that uses CCD technology to “project” the scattering function onto a CCD chip has been fabricated and tested in our lab. The goal of obtaining fast, accurate images of the VSF that would permit either in-situ observation of scattering patterns or lab based observation has been the main focus of our work during this funding period. The Wecoma cruise data consist of 4 days of phytoplankton fluorescence images in conjunction with both CTD, Nutrient, SCAMP, and ADCP data. Using this data set we have started to formulate a picture of how phytoplankton are distributed in both space and also time and have met some interesting surprises.

## APPROACH

**Task 1:** *Development of a prototype to record volume scattering function.*

Under past funding from this and another proposal we have built a prototype VSF meter that is being tested in our lab. The device consists of a parabolic dish with a cuvette mounted in the center. The scatter patterns are then projected up into the imaging area of CCD chip where they are observed. The various challenges in implementing this scheme have been to model the scattering from the samples and the distorted images that result from the scatter, the lack of dynamic range from our 16 bit CCD, and the existence of multiple scatter inside our instrument. Here we present data from modeling the scatter from various size scatterers and the images taken with the device.

# Report Documentation Page

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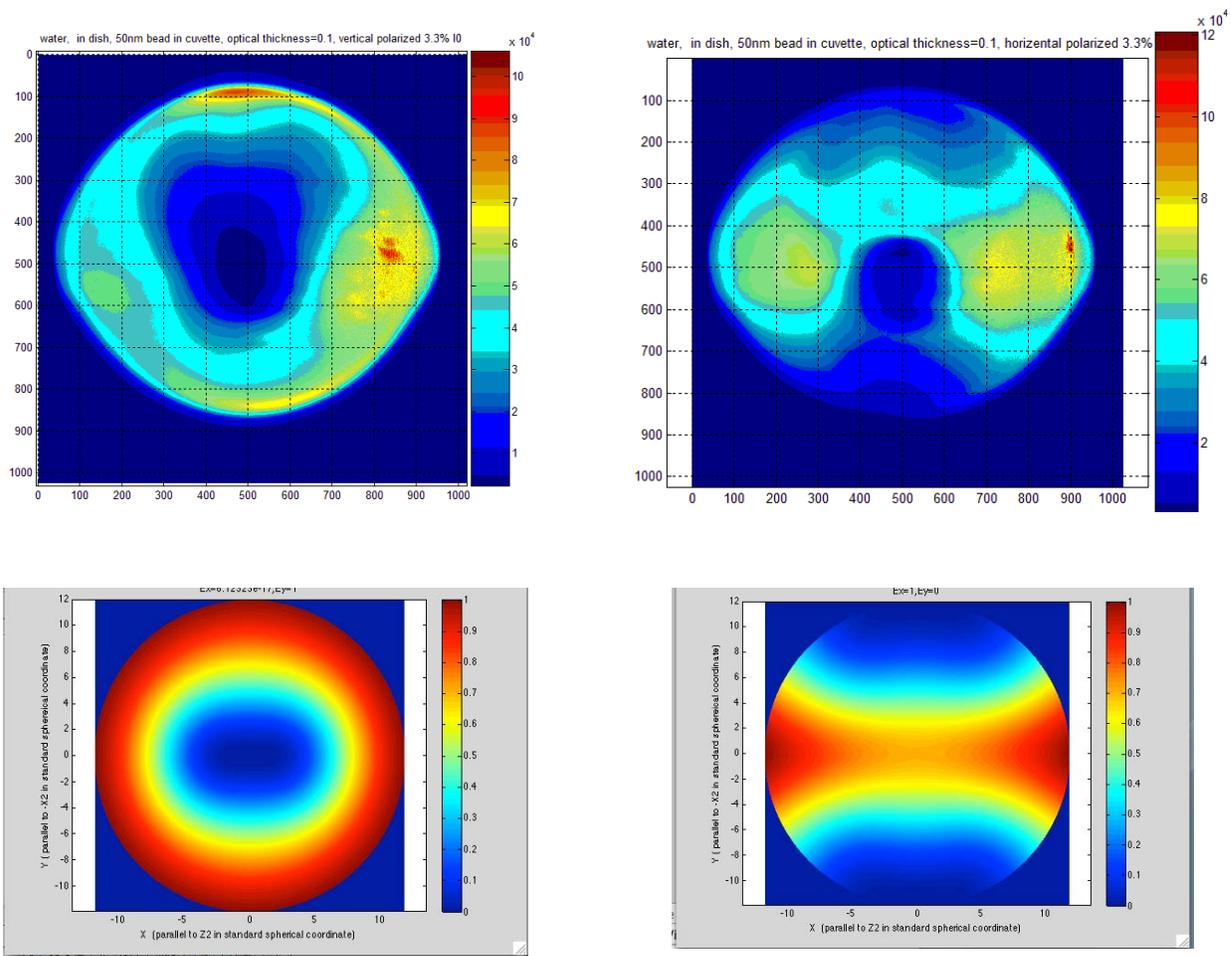
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## Task 2: Continued Analysis from the Wecoma Data

Based on 4 nights and 12 deployments of our FIDO- $\Phi$  package on the R/V WECOMA during Aug 31<sup>st</sup> – Sept 7<sup>th</sup>, 2006 we now have a high resolution data set that documents both fluorescence and scatter from small suspended particles. The data set is unique in that we used our imaging fluorometer to record the spatial distributions of particles as well as bulk fluorescence. Images from this imaging fluorometer have been shown in previous reports. Here we focus on the results.

## RESULTS

**Task 1: Fabrication and testing of a new type of VSF based on CCD technology:** During the past year we have continued to work on the design and development of a new type of scattering meter that uses CCD technology for imaging the scattered field instead of an array of PMT receivers or APDs. The instrument was built last year with ONR funding.

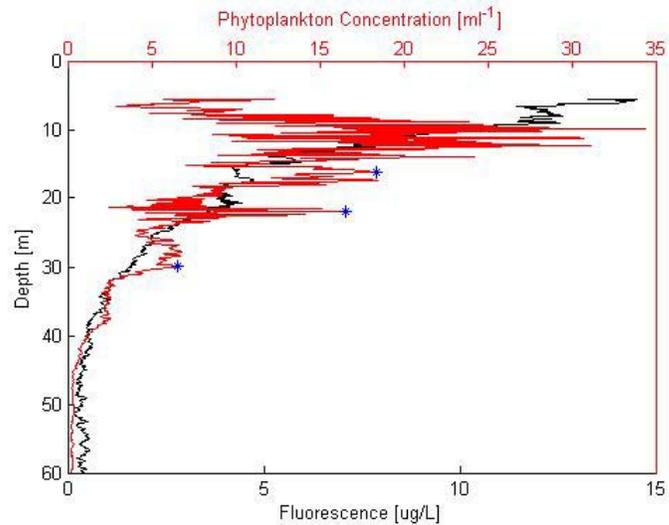


**Figure 1: The predicted and observed scatter patterns from the VSF prototype. The figure shows the observed patterns for 50 nm beads for vertically polarized (left) and horizontally polarized (right) light as observed (upper) and predicted (lower) via Mie theory.**

Here we report the comparison of the data collected with the device with a model of scatter from small particles. We used Mie theory in conjunction with the physical optics of the device to compute predicted observed scattering patterns. This was done for a range of size particles using both horizontal and vertical polarization. Figure 1 shows the predicted (via Matlab) scatter patterns and the observed scatter patterns for 50 nm particles (much smaller than the wavelength of the incident light at 600 nm). As can be seen, the familiar dipole pattern from the horizontally polarized light shows up nicely in our device and the basic pattern agrees well with the mode. For the vertically polarized light, the collection hemisphere shows a nearly isotropic pattern. Some differences are seen in the collected data that we are currently trying to understand and eventually eliminate.

**Task 2: In situ measurements carried out with the FIDO vehicle:** In the fall of 2006 we completed our 7 day cruise in order to measure the in-situ scattering of light and the temporal correlation from successive light patterns. The cruise was conducted between Aug 31<sup>st</sup> – Sept 7<sup>th</sup>, 2006 on the R/V WECOMA (Oregon State University). The cruise protocol consisted of using 4 of the nights for characterization of particles and particle size distributions and 3 of the nights for measurement of small-angle volume scattering functions (the system can only work at night because ambient light dominates the light scattered from volume suspensions). The cruise was extremely successful in that data was collected on each evening. Over the course of the 7 days, we performed a set of approximately 30 profiles. The FIDO vehicle was equipped with two CTDs, fluorometer, SCAMP temperature micro profiler and an ADCP current meter. Data collected during this cruise was shown in last years report. We have continued to work on processing this data set present here a significant result from the project.

Together with Dr. Peter Franks (SIO) and Jennifer Prarie, a graduate student that is being jointly supervised the data from this cruise has been subject to a variety of analysis methods. One aspect that has concerned us has been to compute the spatial decorrelation lengths from this data. In addition, using the capability of the imaging fluourometer, we have been formulating the relationships between bulk fluorescence and particle counts in terms of # of particles/ml. An interesting feature of the data is the existence of very high numerical densities of phytoplankton that is not reflected in the bulk chlorophyll. Dr. Franks has coined these intense layers of phytoplankton “cryptic layers” because they are invisible when examined from the bulk point of view. Figure 2 shows the fluorescence profile in conjunction with the particle counts. The blue stars show phytoplankton layers that are quite intense but their density is not reflected in the bulk fluorescence profile.



**Figure 2:** *A fluorescence profile taken with the FIDO –  $\Phi$  imaging fluorometer. The horizontal axis shows phytoplankton concentration in no./ml and fluorescence in  $\mu\text{g/L}$ . The depth is on the vertical axis.*

## RELATED PROJECTS

Several on-going projects in Jaffe's lab are related to this project. As stated above, the FIDO vehicle, funded by NSF with subsequent funding by ONR was used to measure the VSF and its fluctuations. This vehicle, under development for almost a decade now has provided a reliable and non invasive way to sample the upper 50 m of the ocean via, most recently, a three dimensional Particle Imaging Velocimetry system that was constructed under NSF funding. The extension of studies to examine the VSF is a natural area of exploration that can take place quite economically due to these companion projects. In addition, Jaffe has been funded by a private foundation (The Seaver Foundation) to characterize the use of diffraction tomography in order to infer the dynamics of small (cm size) volumes. The goals of that project are complementary (however not identical) to those of this one. In addition, the work in collaboration with Dr. Franks and Ms. Jennifer Prarie has been funded by NSF.