

INFLUENCES OF MICROBIAL AND MINERAL PARTICLES ON OCEANIC OPTICS

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LONG-TERM GOAL

The overall goal of this work is to understand in detail how various types of microbial and mineral particles and dissolved substances determine the inherent and apparent optical properties (IOPs and AOPs) of oceanic waters. In particular, we wish to quantify how variability in the detailed composition of oceanic water determines the variability in the IOPs (such as absorption and scattering coefficients) and AOPs (such as spectral reflectance and diffuse attenuation functions). This work is fundamental to the development of bio-geo-optical models for Case II waters, for which the presently available bio-optical models are known to fail.

OBJECTIVES

We seek to answer three questions: (1) In what ways does variability in the microbial and mineral composition of ocean waters determine variability in the IOPs and AOPs of such waters? (2) Is it possible to quantitatively classify the *optical* properties of water using the Case I/Case II scheme? (The Case I/II classification is based on water composition; the optical distinction between Case I and Case II is unclear.) (3) What information about the nature of suspended particles can we hope to extract from remotely sensed signals?

APPROACH

We are using a database of the single-particle optical properties (absorption and scattering cross sections, and scattering phase functions) of different types of microbes (ranging in size from viruses to nanoplankton) as input to the Hydrolight radiative transfer numerical model to study the effects of different types of particles on oceanic light fields. This approach gives us complete control in determining the constituents of a simulated water body and in examining the

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optical influences of different types of particles. The database development is carried out by Stramski, and the modeling is performed by Mobley; both investigators participate equally in the analysis of the results.

The single-particle optical properties are obtained from a combination of laboratory experiments and Mie scattering calculations (Stramski and Mobley, 1997; see also Stramski's annual report). The single-particle properties are combined with particle concentrations and standard models for dissolved substances to determine the bulk IOPs of a water body. These bulk IOPs are then used as input to the Hydrolight radiative transfer model. Hydrolight computes the full spectral radiance distribution throughout the euphotic zone (including water-leaving radiances and all quantities derived from the radiance, such as irradiances and diffuse attenuation functions). Changes in various light-field quantities (e.g., water-leaving radiances or diffuse attenuation functions) are monitored as the input to the model is systematically varied.

WORK COMPLETED

During the past year, the database of microbial optical properties has been expanded from five microbes, as used in our initial simulations (Mobley and Stramski, 1997a), to 24. The present database includes marine viruses, heterotrophic marine bacteria, 3 strains of prochlorophytes, 5 strains of *Synechococcus*, 11 species of small nanoplankton (4 to 8 μm in diameter), and a few other species up to $\sim 30 \mu\text{m}$ in size. Using these data, we have completed several hundred Hydrolight simulations using various combinations and concentrations of particle and dissolved components. Component concentrations used in these simulations have ranged from low values characteristic of open ocean waters to high values characteristic of productive coastal waters. We have studied the effects of water composition on both in-water optical properties (such as the scalar irradiance and diffuse attenuation) and on the remote-sensing reflectance.

RESULTS

This year's work yielded three major results (Mobley and Stramski, 1997b). First, we found that it is not necessary to include each microbial component in order to realistically simulate the optical properties of a water body. For example, it is sufficient to use an "average" or "generic" prochlorophyte and an average *Synechococcus* in simulations. This is not surprising because, for example, different prochlorophyte strains have similar optical cross sections and particle sizes. However, it is not possible to define an "average small nanoplankton." This is because the various species of small nanoplankton can have significantly different optical properties and size distributions. However, we do find that the detailed species composition of the small nanoplankton is not crucial, so long as the various-sized particles obey a Junge size distribution overall, with the same total concentration of these particles.

Second, we have found that the simple bio-optical models commonly used for the IOPs of dissolved substances and detritus can have subtle but large effects on the remote-sensing reflectance R_{rs} . These models have various parameters whose values are commonly assumed to have "typical" values. However, these parameters can vary widely in magnitude. We found that when these parameters are varied over their possible ranges as reported in the literature, the effects of the dissolved-

substance and detritus models on predicted remote-sensing reflectances can be as great as that of a factor-of-two change in the concentration of small nanoplankton. The surprisingly large variability in R_{rs} owing to the variability of these model parameters highlights the importance of properly modeling all components of a water body, not just the microbial components.

Third, we have found that in spite of the large variability in remote-sensing reflectances that results from the details of the water composition and from environmental conditions, it may be possible to extract some information about particle sizes or types from R_{rs} . Figure 1 shows how a simulated bloom of heterotrophic bacteria stands out from blooms of all other species when the ratio $R_{rs}(415)/R_{rs}(485)$ is considered (415 and 485 are the wavelengths in nanometers). Figure 2 shows how a simulated prochlorophyte bloom stands out when $R_{rs}(485)/R_{rs}(515)$ is used as a discriminator. Whether such ratioing algorithms are sufficiently robust for practical use, or whether more sophisticated algorithms can be developed, requires further investigation.

IMPACT/APPLICATIONS

We already have gained considerable intuition about the effects of various types of microbes on both IOPs and AOPs. This work is an important step towards achieving scale closure – the reconciliation of single-particle (small scale) optical properties with the large-scale optical character of the ocean. Achieving a detailed understanding of the roles played by various types of particles and other components on oceanic radiative transfer is a prerequisite to advancing bio-optical models beyond their present one-parameter (the chlorophyll concentration) description of very complicated and variable situations. This work also leads to a quantitative understanding of what information about oceanic particulates we can and cannot expect to extract from remotely sensed signals, which are the basis for "ocean color" assessments of the ocean's upper layer.

TRANSITIONS

As listed in Stramski's annual report, parts of the database have already been made available to several academic researchers, and such requests are likely to increase now that the database is greatly expanded. The Hydrolight model itself has been transitioned to several Navy investigators (e.g., C. Davis, NRL Code 7212; S. Gallegos, NRL Code 7240; V. Haltrin, NRL Code 7331; R. Holyer, NRL Code 7340; G. Gilbert, NCCOSC Code 740) who are using the code for studies ranging from algorithm development for hyperspectral remote sensing sensors, to the development of neural networks for oceanographic data analysis, to the simulation of background light fields for studies of passive NAASW and mine detection sensors. The Hydrolight code has been made available to dozens of U.S. and foreign academic researchers, many of whom are using it for the development and evaluation of algorithms for SeaWiFS or hyperspectral ocean color sensors.

RELATED PROJECTS

This work directly incorporates the database development results described separately by Stramski. In addition, the modeling methodology developed in the course of this work is finding wide application in other research projects. Collaborations and/or applications of Hydrolight

which have resulted in publications submitted this year include

1. Studies of Raman scattering on underwater light fields (ONR funding; reference Berwald, et al.)
2. Studies of the effects of bubbles on remote-sensing reflectances (ONR; Flatau, et al.)
3. Development of algorithms for recovering IOPs from AOPs (ONR and NASA; Stramska, et al.)
4. Development of algorithms for recovering internal light sources from irradiance measurements (INPE Brazil; Stephany, et al.)
5. Studies of the effects of coccolithophores on oceanic light fields (ONR; Tyrrell, et al.)

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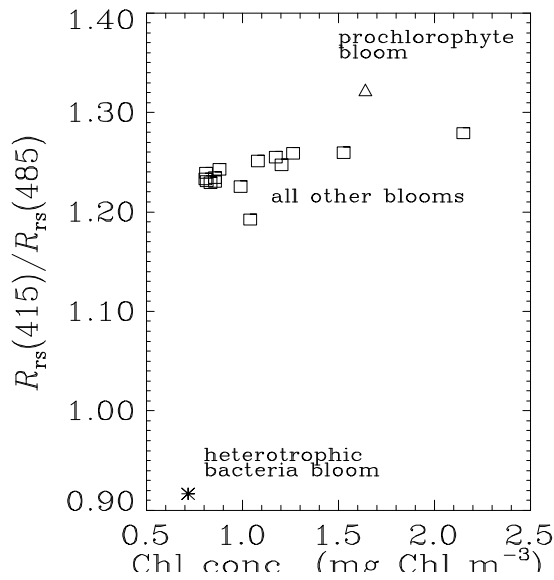


Figure 1. Use of the ratio $R_{rs}(415)/R_{rs}(485)$ to identify a bloom of heterotrophic bacteria. Note that the point representing the heterotrophic bacteria bloom is well separated from the cluster of points for blooms of all other species.

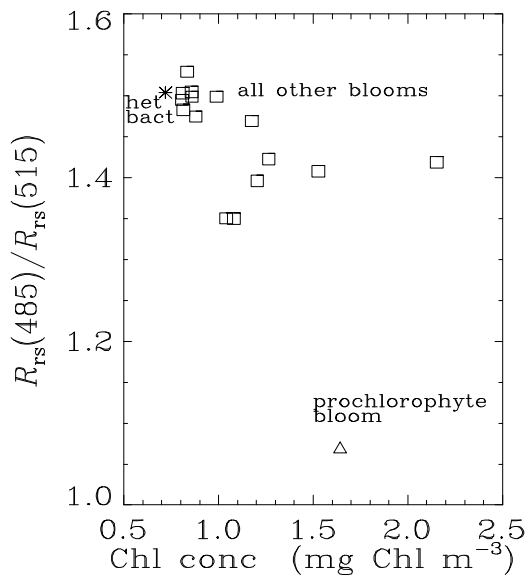


Figure 2. Use of the ratio $R_{rs}(485)/R_{rs}(515)$ to identify a bloom of prochlorophytes. Note that the point representing the prochlorophyte bloom is well separated from the cluster of points for blooms of all other species.