Characterization and Modeling of Inherent Optical Properties in the Gulf of Maine

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LONG TERM GOALS

Our long term goal is to contribute to a fundamental understanding of the sources of biological, physical, and optical variability in coastal ocean systems. Particular focus is on applications useful for studying important ecological processes and the links between phytoplankton properties and physical processes in coastal regions.

OBJECTIVES

The overall objective of this project is to improve understanding of the Gulf of Maine and Georges Bank system through characterization and modeling of optical properties in the context of physical and biological processes. We wish to describe the processes controlling space/time variability in the various constituents (CDOM, phytoplankton, sediment, detrital particles) that determine the optical properties of this region. Specific objectives fall into two categories:

Observational/Database Objectives

– Complete processing and quality control for optical and hydrographic data collected during 5 cruises to the GOM during 1997-1999,

– Compile a readily accessible database of spectral optical properties for the GOM from these cruises, as well as other recent research programs,

– Use the database to develop parameterizations of optical variability that will be used in the numerical simulations;

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14. ABSTRACT
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15. SUBJECT TERMS

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Modeling Objectives

– Implement a hierarchy of optical models (from CDOM as a single passive tracer to a full ecosystem model with optical linkages) into the three-dimensional circulation model; conduct "process-oriented" simulations to examine how the relative contributions of the various optical constituents vary spatially and temporally,

– Construct data-driven hindcast simulations based on field data from 1997-1999; use the coupled models to distinguish spatial from temporal variability in the observations.

APPROACH

Optical properties have potential to provide information about biological and chemical constituents present in coastal ecosystems; however, signals can be difficult to interpret because of the complexity and multidimensional (time, space, wavelength) nature of the relevant processes. Three-dimensional modeling offers an attractive framework for synthesis and understanding of the factors contributing to optical variability. We are taking advantage of an extensive optical dataset collected in previous work by one of us and a realistic three-dimensional circulation model coupled to an ecosystem model by the other. Our new work will include development of methods to parameterize optical variability (based on observations) within a hierarchy of models from a single passive tracer to full coupling with the ecosystem model. "Process-oriented" simulations and hindcast simulations with data assimilation will be used to examine how the relative contributions of different optical constituents vary and to distinguish spatial from temporal variability.

The Sosik laboratory is responsible for the construction of the optical database and development of the parameterizations required for the optical model. Brittan Rabinovitch (Research Assistant) and J. Ru Morrion (Postdoctoral Investigator) are assisting the principal investigator with this work. Personnel in McGillicuddy's group are designing the numerical experiments, implementing the optical models in the context of the current coupled physical-ecosystem model framework, and constructing the simulations. Valery Kosnyrev and Olga Kosnyreva (both Research Associates) are assisting the principal investigator in these activities. Sosik and McGillicuddy work together on interpretation of the simulation results.

WORK COMPLETED

During the past year we developed preliminary modeling approaches for seasonally resolved particle absorption properties. This process involved initial work on quality control and interpretation of optical data contained in our database, which includes both our own and other investigator's observations and is described in detail in last year's report (Sosik and McGillicuddy 2001). We were interested in using these results to predict spatial and temporal distributions in absorption coefficients given variations in phytoplankton biomass.

Our initial investigation into the large-scale seasonal variations in phytoplankton biomass in this region was based on an adjoint data assimilation technique. This approach was used by McGillicuddy et al. (1998) to study physical and biological controls on *Pseudocalanus* spp. distributions in this same region. The forward problem is posed as an advection-diffusion-reaction equation for organism concentration C:

$$\frac{\partial C}{\partial t} + \mathbf{v} \cdot \nabla C - \frac{1}{H} \nabla \cdot \left(HK \nabla C \right) = R(x, y)$$

where **v** is the velocity, *K* the diffusivity and *H* the bottom depth. The reaction term $R(x,y)$ represents a highly idealized parameterization of population dynamics which varies in space only. Positive *R* implies net growth, while negative *R* implies net mortality. Specifying the climatological velocity and diffusivity fields, the adjoint of the advection-diffusion-reaction equation is used to invert for the population dynamics implied by changes in organism abundance and the circulation during the intervening period. This approach has proven to be successful with the climatological phytoplankton distributions mapped from the O'Reilly and Zetlin (1996) monograph. Preliminary results are described in Wang (1999).

We used the output from the data-assimilative coupled physical—biological model combined with the measured seasonal variations in absorption properties to make predictions of absorption fields for both phytoplankton and detritus in the Gulf of Maine.

In addition, apparent and inherent optical property data and pigment data, collected in 1997, 1998 and 1999 in the Gulf of Maine were submitted to NASA's SeaWiFS Bio-Optical Archive and Storage System (SeaBass) database in and also to the National Ocean Data Center (NODC) in August 2001.

RESULTS

From our work with the optical property database, we found distinct seasonal patterns in the chlorophyll specific absorption and in the fraction of particle absorption attributable to detrital material (Figure 1). Further investigation into these patterns should provide insights into the processes leading to optical variability in Gulf of Maine waters.

The data-assimilative coupled physical—biological model analysis has revealed geographically specific patterns in phytoplankton source/sink terms. These spatial patterns vary seasonally according to the phytoplankton distributions, the climatological currents, and their orientation with respect to each other. In cases when the flow is either weak or aligned with gradients in organism abundance, changes in concentration over time are dominated by local population dynamics. In situations where the currents are normal to these gradients, complex three-way balances arise between the local tendency, advective transport, and the population dynamics source term. Diffusion does not appear to play a major role in these simulations.

We predicted absorption fields for both phytoplankton and detritus (Figure 2) that reflect both the seasonal variations in phytoplankton biomass (chlorophyll concentration) and the seasonal changes in absorption characteristics.

IMPACT/APPLICATIONS

Coastal ecosystems are highly complex and multidimensional. Understanding how they function and determining the important spatially and temporally varying processes that regulate them requires interdisciplinary and multi-faceted approaches. The combination of detailed spatially resolved observations and 3-dimensional modeling (with data assimilation) has great potential to contribute to answering these questions. Optical properties contain a lot of information about biological and chemical aspects of a coastal system. They cannot be accurately interpreted, however, without considering time-varying physical processes, which are directly responsible for moving material around and indirectly important through their role in regulating biological and chemical processes. Integration of models of optical properties into our physically realistic ecosystem simulations will contribute to better understanding of the processes contributing to optical variability in coastal waters.

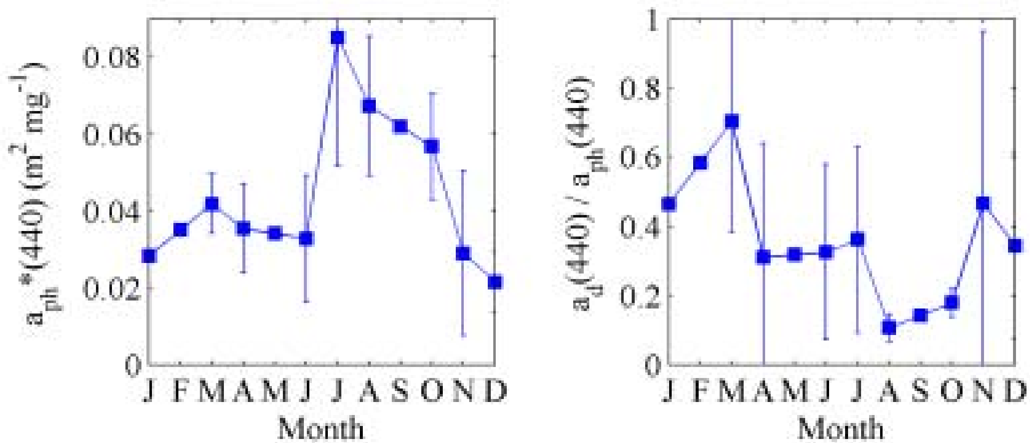

Figure 1. Gulf of Maine seasonal patterns in chlorophyll specific absorption for phytoplankton (left panel) and in the ratio between detrital and phytoplankton absorption (right panel), both for 440 nm. The patterns show low values (0.03-0.04 m^2 mg^{-1}) of specific absorption in winter and spring months and much higher (> 0.06 m^2 mg^{-1}) values in summer, and low (< 20%) detrital absorption in summer. The error bars indicate standard deviations of observed values and months with no error bar represent interpolated values (i.e., no observations exists in the database).

RELATED PROJECTS

This project builds on previous work in the Sosik laboratory supported by an ONR YIP award ("Patterns and Scales of Variability in the Optical Properties of Georges Bank Waters, with Special Reference to Phytoplankton Biomass and Production"). This previous work led to collection of a large database of optical properties of the Gulf of Maine, via conventional shipboard sampling and towed vehicle surveys. See http://www.whoi.edu/science/B/sosiklab/gbgom.htm for more details.

This project is also closely related to on-going work in the McGillicuddy laboratory supported by the ONR YIP ("Physical Forcing of Phytoplankton Abundance in the Gulf of Maine – Georges Bank Region"). Our new work is building directly on these on-going modeling efforts.

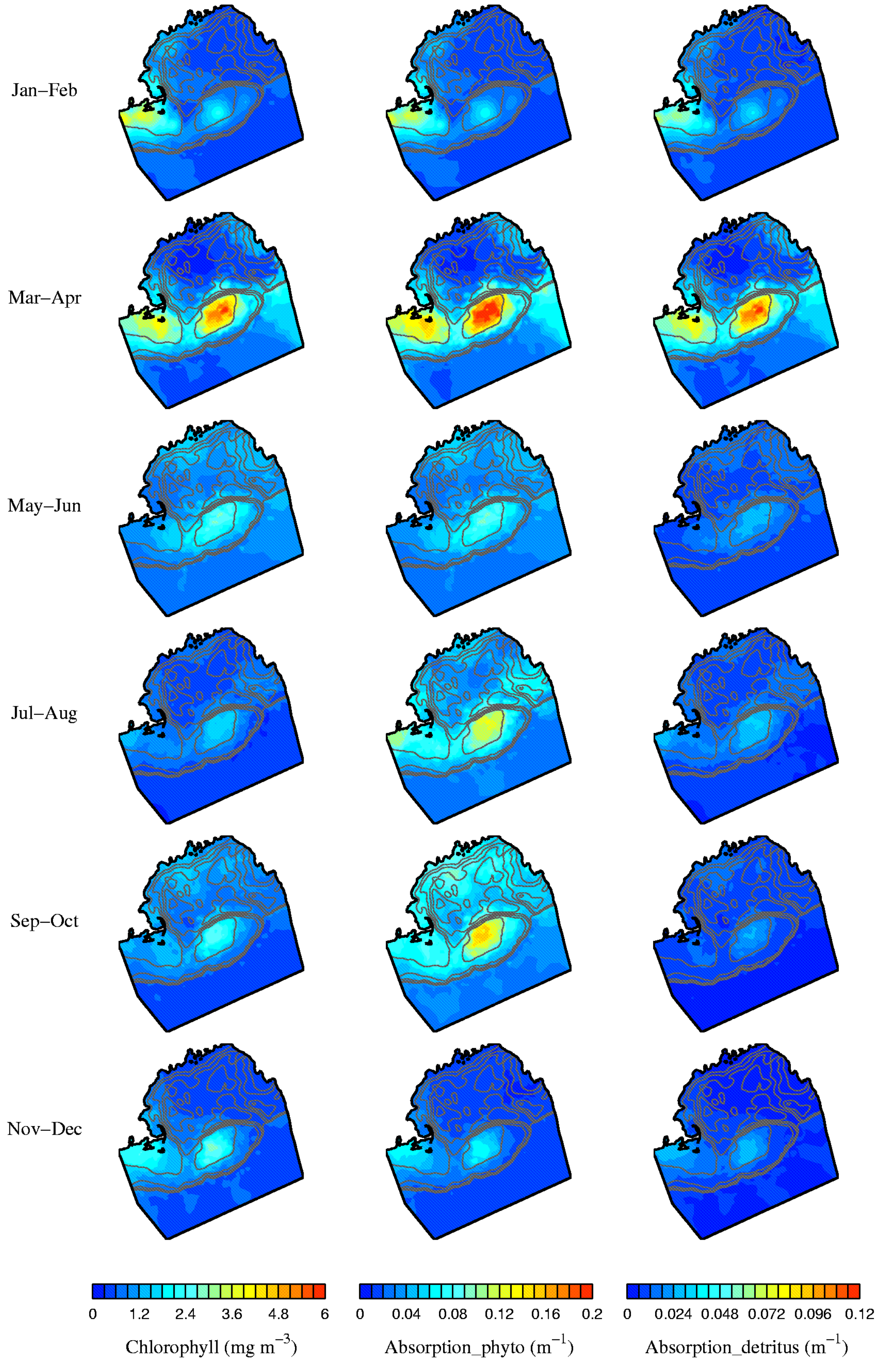

Figure 2. Seasonally resolved maps of chlorophyll concentration (right panels), phytoplankton absorption (middle panels), and detrital absorption (left panels) for the Gulf of Maine. Absorption coefficients are for 440 nm.

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