Incorporating Optics into a Coupled Physical-Biological Forecasting System in the Monterey Bay

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LONG-TERM GOALS

Modeling and predicting ocean optical properties for coastal waters requires linking optical properties with the physical, chemical, and biological processes in the upper ocean. Our long-term goal is to incorporate optical processes into coupled physical-biological models for coastal waters, develop and improve integrated ocean forecasting systems, including prediction of ocean optical properties.

OBJECTIVES

1) To improve performance of the coupled physical-biological model, which is based on the Regional Ocean Model System (ROMS), for the Monterey Bay;

2) To incorporate optical variables into a one-dimensional (1D) physical-biological as well as the improved coupled 3D physical-biological model for the Monterey Bay;

3) To use these variable to drive a radiative transfer model (HydroLight/EcoLight) that will simulate and predict the subsurface light field as well as the ocean's color;

4) To conduct ROMS-biological-optical model simulations for the Monterey Bay with focus on two intensive field experiments, ANOS II (August 2003) and Monterey Bay 2006 (August 2006), and use the bio-optical measurements to constrain and improve the models.

APPROACH

Our approach is to incorporate spectrally-resolved inherent and apparent optical properties into a one-dimensional (1D) multi-nutrient, phytoplankton, zooplankton and detritus ecosystem model. By comparing the bio-optical model output with *in situ* and satellite ocean color measurements, we highlight the fact that optical properties play an important role in identifying and reducing uncertainties in ecosystem models, which provide constraints for determining variables and related parameters. Our long term goal is to incorporate the improved 1D bio-optical modeling into the Regional Ocean Model System (ROMS) for the Monterey Bay, and make prediction of coastal ocean's optical properties on time scales of 1 to 5 days, i.e., the time scales of accurate atmospheric forecasts.

The modeling system constructed in this study consists of four individual models, physical-ecosystem model, photo-acclimation model, optical model, and radiative transfer model, Figure 1. The physical-ecosystem model used in this study is based on the Carbon, Silicon, Nitrogen Ecosystem (CoSINE) model (Chai et al., 2002), which was originally developed to simulate biogeochemistry in the equatorial Pacific upwelling region. To reproduce observed variation in phytoplankton chlorophyll to carbon ratio with growth conditions (light, nutrients and temperature), Geider et al. (1987, 1998) developed a photo-acclimation model with single nutrient of nitrogen. Moore et al. (2002) modified the photo-acclimation model so that the model could be embedded in multi-nutrient ecosystem model, which was used in this study. We developed an optical model that explicitly represents spectrally-resolved IOPs (absorption, scattering and attenuation), apparent optical properties (AOPs, such as diffuse attenuation), and radiometric quantities such as PAR. The optical model requires the inputs from the physical-ecosystem model, such as phytoplankton associated chlorophyll and non-algal particles (NAP). The radiative transfer model (Ecolight; Sequoia Scientific, Inc.) provides downwelling irradiance at sea surface and underwater average cosines of downwelling light (from 400 to 700 nm), and the hourly values are used as external forcings for the optical model. The physical-ecosystem model, photo-acclimation model, optical model and radiative transfer model are connected as one bio-optical modeling system (Figure 1). We applied this system to the equatorial Pacific upwelling region (5°S-5°N, 90°-180°W, the "Wyrtki Box"), where the physical-ecosystem model originally developed (Chai et al., 2002) and some optical properties have been measured for this region (Gardner et al., 2003; Behrenfeld et al., 2006).

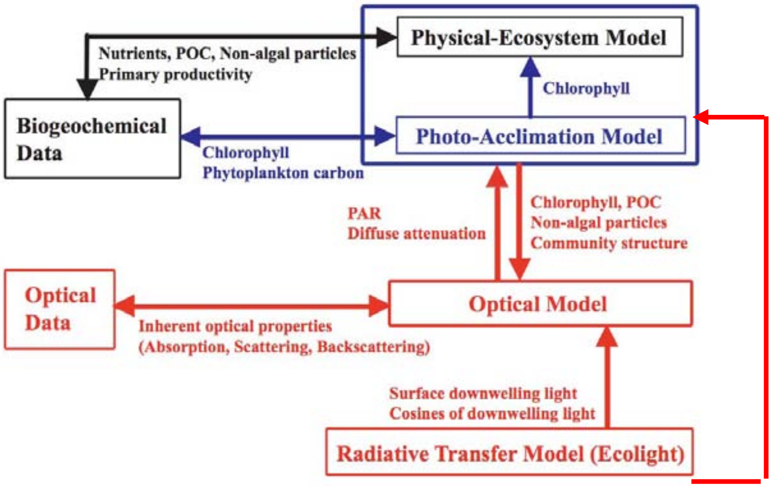


Figure 1: Overall approach for developing physical-biological-optical model. Blue and red components are new additions to an existing physical-biological model (CoSINE).

WORK COMPLETED

This report summarizes modeling activities between 1st October 2005 and 30th September 2006.

We have implemented and tested a variable nitrogen (N):carbon (C):chlorophyll (Chl) ratios in the phytoplankton groups in the existing 1D ecosystem model - CoSINE (Chai et al., 2002). Previous CoSINE version had a fixed N:C:Chl ratios produced identical vertical profiles with maxima in the surface among the three elements (N, C, Chl), and therefore, could not reproduce chlorophyll maximum which usually appears in the subsurface layer.

The second task is to construct the optical module which links the inherent optical properties (IOP), i.e., absorption coefficient (a), scattering coefficient (b), and backscattering ratio of particles (b_{bp}/b_p), with the modeled physical, biological, and chemical properties, such as temperature, phytoplankton, dissolved and particulate matter. Such connection has been established based upon both empirical and analytical relationships. We developed these relationships in very general format, so that we could apply them to various locations.

The third task is to use the IOP developed in the second task as inputs to run the radiative transfer model (EcoLight). The spectrally-resolved light field generated from the EcoLight is then used to drive the photosynthesis in the 1D ecosystem model. By doing so, we have completed the linkages from the ecosystem model to optical module and light field, Figure 1.

The fourth task is to run ROMS-CoSINE model for the Monterey Bay with focus on AOSN II (August 2003) and Monterey Bay 2006 experiments (August and September 2006). The current ROMS-CoSINE hasn't included optical module and EcoLight components yet.

RESULTS

Most of our results have been summarized in a manuscript by Fujii, Boss, and Chai, which will be presented at the 2006 Ocean Optics Conference in Montreal. We plan to submit the manuscript to Limnology and Oceanography by the end of this year. In this report, we present some results from the optical model as well as ROMS-CoSINE model simulation for the Monterey Bay 2006 experiments.

First, the modeled absorption by phytoplankton at 440nm ($a_{\varphi}(440)$) has its maximum of 0.033 (m^{-1}), Figure 2, which agrees well with observation (0.023 (m^{-1}); Dupouy et al., 2003). The modeled maximum appears at around 70m depth, which is deeper than chlorophyll maximum. This is because chlorophyll absorption is mostly contributed by picoplankton. Contribution of picoplankton to chlorophyll absorption is 93-99%, which matches observed result of 97% in this region (consistent with the observations (Dupouy et al., 2003). Modeled absorption by NAP at 440nm ($a_{NAP}(440)$) has its maximum of 0.006 (m^{-1}) at around 40m depth, Figure 2, which corresponds to maximum of NAP concentration. The absorption by NAP is lower than that of picoplankton ($a_{\varphi 1}(440)$) but is higher than that of diatoms ($a_{\varphi 2}(440)$), indicating low but evident contribution of NAP to the total particulate absorption. The modeled contribution to total particle absorption by NAP is 12-25% and increases with depth, consistent with measurements of 10-17% (Dupouy et al., 1997 and 2003; Parslow et al., 1998; Bricaud et al., 2002). Colored dissolved organic matter (CDOM) also plays an important role in absorption (e.g. Pegau, 1997; Bricaud et al., 2002; Simeon et al., 2003). We fixed absorption coefficient by CDOM at 440nm ($a_{CDOM}(440)$) vertically to 0.016 (m^{-1}), Figure 2, which stands within an observed range (0.012-0.025 (m^{-1}); Simeon et al., 2003). Modeled contribution of CDOM to total absorption (a(440)) is 26-44% and increases with depth, roughly consistent with measurements (50%

at surface and 100% below chlorophyll maximum; Simeon et al., 2003). However, we need to explicitly incorporate CDOM as a state variable and its effects on absorption in future ecosystem models to study its dynamics and its role both as a carbon reservoir and its optical impact (e.g. Arrigo and Brown, 1996).

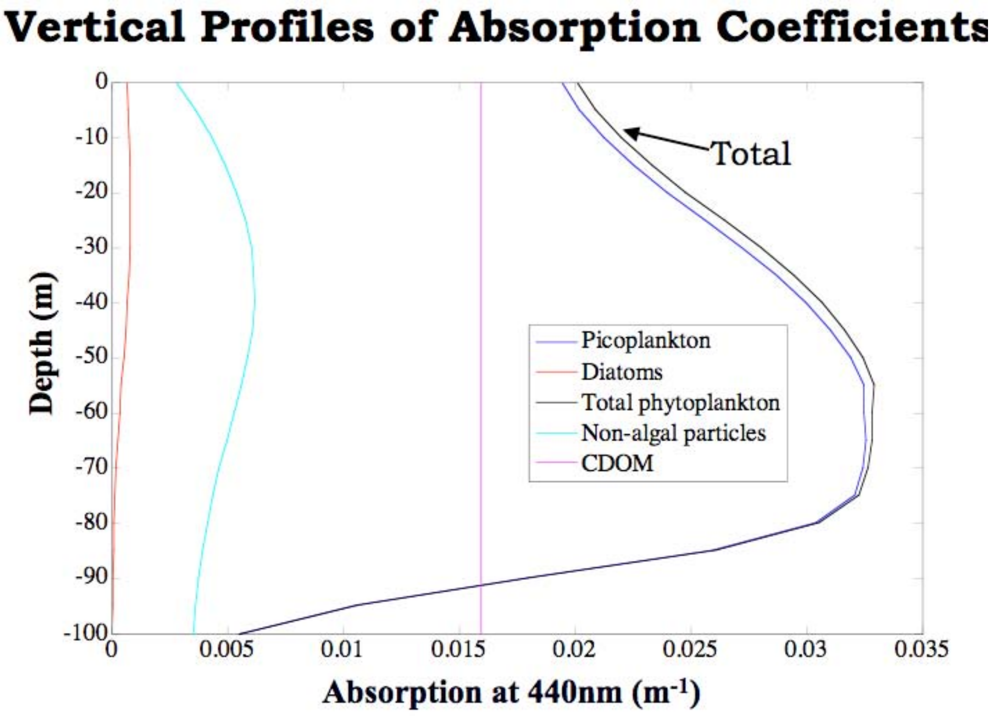


Figure 2: Modeled vertical profile of absorption coefficient at 440nm by picoplankton P1 ($a_{\varphi 1}(440)$), diatoms P2 ($a_{\varphi 2}(440)$), total phytoplankton (P1+P2) ($a_{\varphi}(440)$), non-algal particles NAP ($a_{NAP}(440)$), and colored dissolved organic matter CDOM ($a_{CDOM}(440)$) (m^{-1}).

One of uses for incorporating optical processes into the physical-biological models is to constrain some of model parameters that couldn't be measured easily. In the previous model without optical properties, values of biogeochemical parameters are tuned so as to minimize model-data misfits of nutrient concentrations, phytoplankton community structure and primary production in the euphotic layer. Modeled zooplankton biomass and NAP concentration are secondary variables because available data for evaluating these model results are very few. By incorporating optical properties, we found the modeled NAP concentration needs to be higher than the previous model result by a factor of 1.7 on average in order to reproduce contribution of NAP to absorption by total particles, Figure 3. The higher NAP concentration is reproduced in the model by modifying values of several parameters related to zooplankton dynamics, which provides NAP in terms of fecal pellets and partly grazes on NAP. This illustrates the capability of optical properties to provide additional information for constraining model parameters and thus improving model performance, which currently cannot be done with biological properties alone.

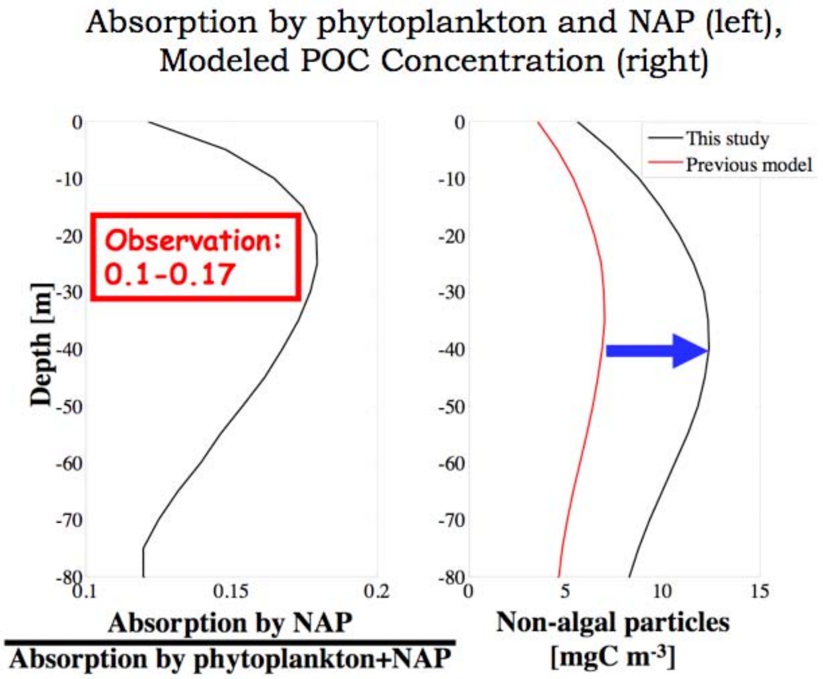
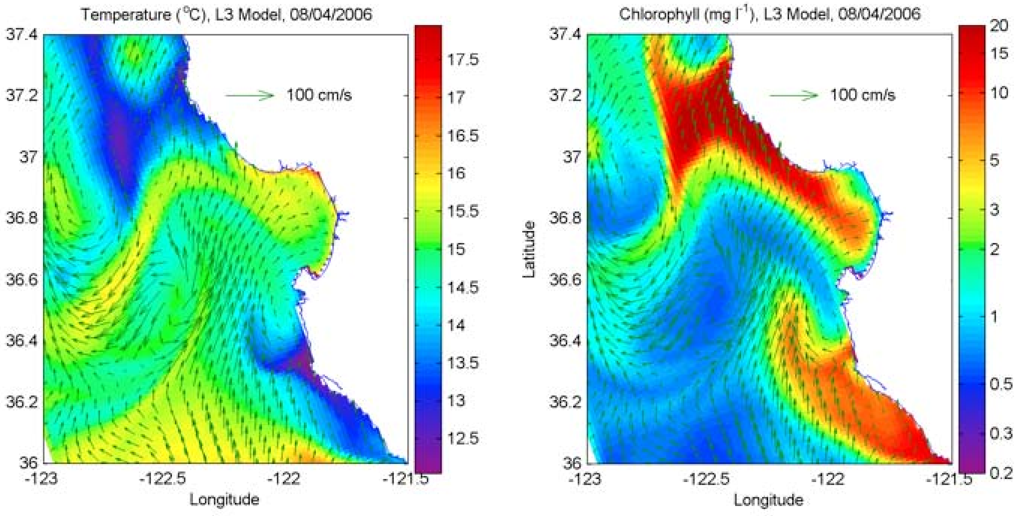


Figure 3: Modeled vertical profile of absorption coefficient by picoplankton and non-algal particles NAP (left panel). The observations suggest that the absorption by NAP is about 10 to 17% of the total absorption by phytoplankton and NAP. In order to meet this criterion, we have to adjust POC production in the ecosystem model.

Beside developing the optical module and using the IOP to run the EcoLight, we have continued on conducting three-dimensional circulation and ecosystem model simulations, ROMS-CoSINE, for the Monterey Bay. This ROMS-CoSINE modeling system has not included the optical module and the Ecolight yet. The 3-level nested coupled physical-ecosystem model has been simulated for the period of the Monterey Bay 2006 Experiments (August to September 2006) during which the high-resolution (3-km) surface daily wind is available to force the ROMS. The coupled physical-biological model captures an upwelling generated bloom of phytoplankton in the Monterey Bay, as well as the influence of the California coast current. The modeled SST and surface chlorophyll seem to follow surface current very closely. Even the preliminary results are encouraging, and we are still gaining experience on how to analyze the ROMS-biological model output and processes at such high temporal and spatial resolution. We plan to conduct more detailed model-data comparision for the Monterey Bay 2006 experiments as the data become available.



Modeled SST
4 August 2006

Modeled Surface Chlorophyll
4 August 2006

Figures 4: The modeled sea surface temperature (SST, left) super-imposed with the modeled surface current on August 4, 2006. The modeled surface chlorophyll is on the right.

IMPACT/APPLICATIONS

Incorporating ocean optical processes into coupled physical-biological models will enable us to simulate and forecast optical properties in coastal waters. With demonstration of some initial successes of developing physical-biological-optical modeling and data assimilation capability for Monterey Bay, we should be able to start the development of an end-to-end ocean forecasting system. Such modeling system would be a powerful tool to design the adaptive sampling strategy and would be an essential component of future field experiments both in and outside Monterey Bay.

TRANSITIONS

We have worked with Drs. John Kindle, Igor Shulman, and Bred Penta at the Naval Research Laboratory (NRL). The ecosystem model code has been transferred to the Dynamics of Coupled Processes group led by John Kindle at the NRL. The ecosystem model has been implemented into both Navy Coastal Ocean Model (NCOM) and Princeton Ocean Model (POM) for the west cost of U.S. and Monterey Bay region. Fei Chai traveled to the NRL in late August of 2005 to work on some issues regarding to the ecosystem component in the NCOM. We have regular communications between the NRL and the University of Maine on this collaboration. The improved ecosystem model and the optical module will be transited to the NRL Dynamics of Coupled Processes group.

RELATED PROJECTS

This project has strong collaboration with other ONR supported projects. Beside working closely with the modeling group at the NRL, we are collaborating with Dr. C. Mobley of Sequoia Scientific Inc. for linking the optical module within the ROMS. We are also collaborating with scientists at the Monterey

Bay Aquarium Research Institute (MBARI) for using the observationdal data for the region. Yi Chao is one of the investigators invovled in the Monterey Bay 2006 Experiments.

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PATENTS

None.

HONORS/AWARDS/PRIZES

None.