Development of Algorithms and Strategies for Monitoring Chlorophyll and Primary Productivity in Coastal Ocean, Estuarine and Inland Water Ecosystems

Semi-Annual Technical Report
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Summary

This is the semi-annual technical report for the period July through December 1999 for the Execution Phase of my MODIS Instrument Team investigator project. The objectives of this work are:

- Establish a protocol for developing regional or site-specific bio-optical algorithms for coastal "case 2" waters.
- Demonstrate the protocol by developing algorithms for two coastal seas: the Gulf of Maine/Mid-Atlantic region, and the Yellow Sea/East China Sea region.
- Prescribe a protocol for "stitching together" local or site-specific algorithms.
- Develop a strategy for monitoring coastal oceans, estuaries, and inland waters.

In this report, I will describe progress toward the first three objectives. This report reflects the efforts of a research team consisting of myself, an assistant research scientist (Timothy Moore), and two students (Hui Feng and Ken Jacobs). For the first half of the period covered by this report, I was working at NASA Headquarters as the Program Manager for the Ocean Biology and Biogeochemistry Program. During my tour at NASA HQ, I had limited involvement in this project, although I maintained contact with and continued to supervise the work of the team at UNH. Since returning to UNH in October 1999, I have been more directly involved.

Case 2 Algorithm Protocol Development

There are two areas of algorithm development that are addressed in this project. One is the bio-optical algorithm which retrieves chlorophyll and other optically-active constituent concentrations. The second area is the primary productivity algorithm.

<u>Bio-optical algorithms</u> The strategy for this work has been to promote the use of a standard semi-analytic remote-sensing reflectance model that relates remote-sensing reflectance to inherent optical properties (absorption and backscattering coefficients), and then to prescribe methods for parameterizing the IOPs as functions of the constituent concen-trations of interest (chlorophyll, colored dissolved organic matter, and suspended sediment).

Hui Feng has written a paper, intended for publication, which examines this strategy. He used a data set from Tokyo Bay (Kishino et al., 1985) which consisted of 45 stations. He parameterized a forward reflectance model using the whole data set, and then parameterized the same model for three subsets of the data. The subsets were determined by applying a clustering routine to the reflectance data to separate *optically-distinct classes* in the data. The rationale is that optically distinct water masses contain particles and dissolved substances with different optical properties, and thus a single parameterized model is not able to accommodate the variability that exists. A single parameterized model can accommodate variability in concentrations of the same substances, but not variability due to different substances.

This approach was found to significantly improve the performance of the forward model (i.e., substantially reduced the error between predicted and measured reflectance). However, when Hui Feng compared inversion results (i.e., the ability to retrieve chlorophyll, CDOM, and suspended sediments), this approach was not significantly different from that of the single parameterized model. We believe that much of the problem lies in the fact that we are working with a relatively small data set. Furthermore, the Tokyo Bay data did not include backscattering measurements, and so we had to estimate backscattering by assuming the forward model was exact. Progress in this area has been discouraging because of the difficulty of obtaining good in-situ bio-optical data for algorithm development and testing. *One important conclusion, however, is that accuracy in a forward reflectance model does not assure accuracy in an inversion algorithm.*

Ken Jacobs has completed his Master's thesis entitled "The Optical Properties of the Great Bay Estuary: Parameterization of an Ocean Color Model." In his thesis work, Ken collected in-situ data using a Tethered Spectral Radiometer Buoy (TSRB) outfitted with the MODIS wavelengths. He measured absorption (total, particle, phytoplankton, and CDOM) coefficients, as well as chlorophyll and TSM concentrations, and other hydrological properties. He attempted to parameterize the Roesler-Perry model for the Great Bay Estuary, a tidal estuary with a wide range of sediment and chlorophyll concentrations. Ken's conclusion was that the model had some promise, but we again need a complete set of IOP measurements. He had no backscattering measurements, and thus derived the backscattering assuming the AOP-IOP relationship (forward model) was correct. This resulted in a backscattering coefficient spectrum with a peak around 550 nm. Others have actually measured similar backscattering spectra (Roland Doerffer, pers. comm), but such a shape is not consistent with Mie theory. Our hypothesis is that the f/Q factor that most models take to be non-spectral is actually spectrally variable, and this would account for the unconventional spectral shape of the derived backscattering coefficient.

<u>Primary productivity algorithms</u> A manuscript describing the Primary Productivity Algorithm Round Robin was written in 1997, and distributed to some 24 co-authors. By the time I had received their comments, I was at NASA HQ and had no spare time to finish this manuscript. For a while, a colleague took over the manuscript revision task, but she was unable to complete it. Now, it is being returned to me. My goal is to have it completed and submitted for publication during the current semi-annual period.

Protocol Demonstration in Gulf of Maine

We have assembled a data base of bio-optical data from 114 stations within the Gulf of Maine, Middle Atlantic Bight and Sargasso Sea. The protocol, first developed by Hui Feng using Tokyo Bay data, has now been applied to this data base, augmented with the Tokyo Bay data (thus to a total of 159 stations). A clustering of the in-situ remote-sensing reflectance data resulted in the identification of 6 optically distinct clusters or classes. Bio-optical algorithms were parameterized for these classes, and then applied to a SeaWiFS image using a fuzzy logic classification scheme (see below). This demonstration will be part of a paper on fuzzy logic which is about to be submitted to the IEEE Transactions on Geoscience and Remote Sensing for publication.

Protocol for "Stitching Together" Algorithms

This work has been led by Timothy Moore. A manuscript has been prepared and will be submitted the week of January 17, 2000, to the IEEE Transactions on Geoscience and Remote Sensing.

Following is the title, authors, and abstract of that paper:

> Moore, Timothy S., Janet W. Campbell, and Hui Feng, *"A Fuzzy Logic Classification Scheme for Selecting and Blending Satellite Ocean Color Algorithms"*
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> *Abstract:* An approach for selecting and blending bio-optical algorithms is demonstrated using an ocean color satellite image of the northwest Atlantic shelf. This approach is based on a fuzzy logic classification scheme applied to the satellite-derived water-leaving radiance data, and it is used to select and blend class-specific semi-analytical algorithms. Local in-situ bio-optical data were used to characterize spectrally-distinct water classes *a priori*, and to parameterize algorithms for each class. The class-specific semi-analytical algorithms retrieve three variables for each pixel in the satellite scene. When applied to a satellite image, the approach involves three steps. First, a membership function is computed for each pixel and each class. This membership function expresses the likelihood that the measured radiance belongs to a class with a known reflectance distribution. Thus, for each pixel, class memberships are assigned to the pre-determined classes on the basis of the derived membership functions. Second, constituent concen-trations are retrieved from each of the class-specific algorithms for which the pixel has membership. Third, the class memberships are used to weight the class-specific retrievals to obtain a final blended retrieval for each pixel. This approach allows for graded transitions between water types, and blends separately tuned algorithms for different water masses without suffering from the "patch-work quilt" effect associated with hard-classification schemes.

Progress in Related Areas

Dr. Mark Dowell will be coming to UNH to join our research team, beginning March 1, 2000. Mark received his Ph.D. in Oceanography from the University of Southampton in December, 1998. His dissertation was entitled "Optical characterization and reflectance modeling in Case II water: Quantitative tools for investigations of coastal environments." He has been working at the European Commission Joint Research Center in Ispra, Italy for about 5 years, during which time he completed his dissertation, and was involved in modeling European case 2 waters. Mark's experience and research interests are closely aligned with my own, in particular with my MODIS investigation. In his future work at UNH, he will focus on primary productivity algorithms for coastal waters.

While I was at NASA HQ, I was co-chair (along with Peter Schlittenhardt of the EC-JRC) of the International Ocean Color Coordinating Group (IOCCG)'s working group on

Case 2 algorithms. We organized a workshop which has produced an IOCCG report on the current status of Case 2 algorithms. The first author will be Shubha Sathyendranath, and there are chapters co-authored by John Kirk, Bob Bukata, John Parslow, Bob Arnone, Curt Daviss, Andreas Neumann, and Motoaki Kishino.

In collaboration with Dr. Sinjae Yoo, of KORDI, South Korea, I have advocated a pilot project to the Coastal Global Ocean Observing System (C-GOOS) Panel concerning the collection of in-water bio-optical data to parameterize coastal algorithms for ocean color remote sensing. I will continue to promote this pilot project. The idea is that marine laboratories distributed around the world could (should) begin to collect bio-optical data and contribute these data to a distributed data base. Expert remote sensing scientists could then pool the data, apply a clustering routine to identify the optically distinct water types, and develop algorithms for these waters. This would facility a wider involvement of marine scientists and coastal resource managers in the use of MODIS and other ocean color data. It would also populate the data base needed to apply the protocols that I am advocating with this work.