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

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Summary

This is the semi-annual technical report for the period July through December 2000 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.
- Prescribe a protocol for "stitching together" local or site-specific algorithms.
- Demonstrate these protocols in two coastal seas: the Gulf of Maine/Mid-Atlantic region, and the Yellow Sea/East China Sea region.
- Develop a strategy for monitoring coastal oceans, estuaries, and inland waters.

This report reflects the efforts of a research team consisting of myself, three staff scientists (Dr. Mark Dowell, Timothy Moore, and Ken Jacobs), and two Ph.D. students (Hui Feng and Seung-Hyun Son).

Papers submitted in 2000 and current status:

1. Moore, T. S., J. W. Campbell and H. Feng. "A fuzzy logic classification scheme for selecting and blending satellite ocean color algorithms" (submitted to the *IEEE Trans. in Geosciences and Remote Sensing*, Feb. 2000; revised manuscript resubmitted Aug. 2000, status unknown).

2. Campbell, J.W., et al. (22 co-authors) "Comparison of algorithms for estimating ocean primary productivity from surface chlorophyll, temperature, and irradiance." (submitted to Global Biogeochemical Cycles, June 2000; status unknown).

Presentations at international conferences (July-Dec. 2000):

3. Dowell, M.D., J.W. Campbell, and N. Hoepffner. "Primary production modeling in Case II waters: Implications of the parameterization of photosynthetically usable radiation (PUR)" Proceedings of the Venice 2000 Oceanography from Space Conference.

4. Moore, T.S., M.A. Dowell, and J.W. Campbell. "Bio-Optical Provinces in the World's Oceans Based on a Fuzzy Classification of Satellite Ocean Color Data" Proceedings of the Venice 2000 Oceanography from Space Conference.

5. Moore, T. S, M. D. Dowell, J.W. Campbell and N. Hoepffner. "Universally Tailored Optical Parameter Inversion Algorithm (UTOPIA) I: Global Classification. Extended abstract in proceedings of the Ocean Optics XV Conference, Monaco, October 2000.

6. Dowell, M. D., T. S. Moore, J.W. Campbell, and N. Hoepffner. "Universally Tailored Optical Parameter Inversion Algorithm (UTOPIA) II: Algorithm Parameterization. Extended abstract in proceedings of Ocean Optics XV Conference, Monaco, October 2000.

7. Feng, H., M.D. Dowell, T. Moore, and J. Campbell. "Objective inter-comparison of inversion techniques for semi-analytic bio-optical algorithms" Poster presented at the Ocean Optics XV Conference, Monaco, October 2000.

8. Campbell, J. W., T. Moore, M Dowell, S.-H. Son, and S. Yoo. "Ocean color satellite observations of the Yellow Sea: A comparison of historical and current data." Proceedings of the Pacific Ocean Remote Sensing Conference, Goa, India, Dec. 2000.

9. S.H. Son, S. Yoo, M. Dowell, T. Moore, and J. Campbell. "Decadal trends in the Yellow Sea as revealed by satellite ocean color data (1979-1999)" Proceedings of the Pacific Ocean Remote Sensing Conference, Goa, India, Dec. 2000.

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 concentrations of interest (chlorophyll, colored dissolved organic matter, and suspended sediment). We have acquired a data base of over 1,300 in-situ measurements of optical and bio-geochemical properties for purposes of parameterizing class-specific algorithms. This data base includes the original 911 stations used to parameterize the SeaWiFS at-launch chlorophyll algorithm, and we have added approximately 400 stations from coastal (case II) waters. Six distinct water classes were identified by applying a fuzzy c-means classification to the in-situ reflectance data (presentations #4 and #5). The classes include four Case I classes (ultra oligotrophic, oligotrophic, mesotrophic, and eutrophic) and two Case II classes (CDOM dominated and sediment dominated). The in-situ data have been used to develop prototype forward reflectance models and to characterize the underlying covarying distributions of the optically active constituents (presentation #6). From these distribution functions, we have generated a large pseudo-random data set of reflectances for each class to use for training (e.g., a neural network), and for algorithm validation. Class-specific algorithms for these classes will be based on the inversion of the forward models. Preliminary results comparing a variety of inversion schemes indicate that neural network algorithms are promising in that they yield highly accurate results (comparable to a nonlinear inversion) and are much less sensitive to errors in the radiances (presentation #7) . These results were presented at the Venice 2000 and Ocean Optics XV conferences, and we are now preparing manuscripts for publication in the refereed literature.

Primary productivity algorithms

We are working on an algorithm for computing primary production in coastal waters based on a wavelength-resolved model of photosythetically usable radiation (PUR). This requires a formulation of the diffuse attenuation coefficient (K_d) to account for the optically complex characteristics of coastal waters as well as a parameterization for the geometric correction factor “g” which converts vector irradiance into scalar irradiance (highly significant in turbid coastal waters). A preliminary sensitivity analysis has shown that the influence of the coastal water IOPs is critical at various stage of the primary production calculation. This was shown firstly in the calculation of the euphotic depth (Z_{eu}), where depths calculated based on a Case I type model were shown to be typically between 50-100% higher than those calculated by a more appropriate Case II model. Similarly, when calculating primary production through a depth-integrated model, such as that adopted for operational processing by the MODIS project, it was found that a Case I model resulted in a 30-70% over estimation of the integrated primary production as compared with a Case II model. Significantly it was also shown that the IOPs of Case II water also had a significant effect on the spectral quality of the available and usable light for photosynthesis. The results of this sensitivity analysis are being synthesized through the preparation of a manuscript to a peer-reviewed journal.

The model parameterized based on Case II IOPs provides a PUR product which can be used with a coastal a_{ph} model and the light utilization index (ψ^*) to calculate the depth integrated primary production. Different solutions are being considered to retrieve ψ^* in these regions, one of which would use fuzzy methods to classify the coastal water mass based on information pertaining to chlorophyll, SST, PAR, and daylength. To this end, we have identified 9 distinct classes or regimes using the primary productivity data base of Behrenfeld and Falkowski (http://marine.rutgers.edu/opp) augmented with primary productivity measurements at 85 coastal stations. The next step is to determine a model of ψ^* for each class. Thus when a satellite image is processed, the fuzzy memberships can be calculated based on the end-member ψ^* value for each class resulting in a map of the geographic distribution of ψ^*. To merge this and the other two existing MODIS primary production products into a single global PP map, the application of fuzzy logic techniques will be taken one step further. We plan to evaluate the performance of each of the proposed algorithms in different global predetermined classes (resulting from the classification of the large global PP data sets of Falkowski and Behrehfeld). The validation exercise for each class will, however, use an independent data set not used in any of the algorithm development processes. Thus the performance of each algorithm will be evaluated in each class and a best candidate will be selected. When satellite imagery is processed based on the above defined classes, different algorithms will be used to calculate primary production in different water types and a single primary production product will be derived as a weighted sum based class memberships.

Protocol for "Stitching Together" Algorithms

The manuscript (#1) submitted to the *IEEE Transactions on Geoscience and Remote Sensing* in February 2000, was revised and resubmitted in August based on reviewer comments. We have been told that the status is "conditional acceptance" but we do not know yet what further conditions (if any) may be required.

Demonstration in Gulf of Maine and Yellow Sea Regions

We are continuing to assemble a data base of in-situ bio-optical data for the two demonstration sites: Gulf of Maine and Yellow Sea. We also have ordered MODIS data for these areas. Although what we have received (or managed to acquire) is very incomplete, nevertheless, the volume is overwhelming (see **Challenges** discussed below).

The Yellow Sea was the subject of two coordinated presentations at the PORSEC 2000 meeting in Goa, India, in December 2000 (presentations #8 and #9). In these presentations, we compared CZCS and SeaWiFS data (chlorophyll or pigment, and water-leaving radiances at 443 and 550 nm). We derived a method for converting level-2 CZCS pigment values to a SeaWiFS (OC4) chlorophyll. This was applied to all level-2 CZCS data (which we derived starting from level 1). There were significant changes in all three properties of the Yellow Sea over the 20-year period between CZCS and SeaWiFS. Specifically, it appears that the coastal regions have become more turbid and there is an overall increase in the chlorophyll levels. We cannot be certain, however, whether the differences are due to sensor differences or whether real environmental changes have occurred. The East (Japan) Sea, east of the Korean peninsula, showed opposite trends or in some areas no change. This would suggest that at least there isn't a systematic difference between the two sensors. We now are compositing MODIS data for October 2000 to compare with the SeaWiFS data for the same month. Once we are satisfied that MODIS and SeaWiFS are compatible (or understand their differences), then the issue of whether there has been a trend in the past 20 years will be reexamined.

Development of Monitoring Strategies

The Hong Kong University of Science and Technology is developing a plan to monitor the Pearl River Estuary using in-situ measurements and ocean remote sensing. They submitted an Area of Excellence proposal to HK sources to establish a Center for Coastal and Atmospheric Research, which would include an X-band ground-receiving station for receiving MODIS data. They are still waiting to learn the results of that proposal. If successful, our group will work with them to demonstrate a monitoring strategy using MODIS data.

Support of MODIS Ocean Team Activities

We are preparing for the January 23-25 meeting. Janet Campbell and Mark Dowell will attend and bring two posters.

Challenges Associated with MODIS Data

There are three ways to acquire MODIS data: the Goddard DAAC, the EOS Gateway, and the MODIS Emergency Backup Data Ordering System (MEBDOS). We have explored all three sites/sources, and have found that the MEBDOS is by far the superior system for our purposes. The EOS Gateway is tedious and confusing – and we are concerned that people with less inside knowledge of MODIS would find the challenge of ordering data from this site hopeless.

We have had trouble finding data at all three sites. Only data for October and part of November are available at the present time.

We ordered all the available data for the Yellow Sea area. This order (which consists of only about one month of data) arrived on 2 DLT tapes. Since each tape holds about 70 GB, we were not able to ingest all the data at once, even with the recent purchase of 2 new 36-GB drives. We are now in the process of loading in some of the data, remapping and extracting just the region of interest, then compressing the files (to about 50% of original volume), and copying them off to other tapes to make room for new data. We have only ordered the level-2 radiances (OCL2), the OCL2A chlorophyll files, the SST data, and their associated geolocation files. Not all the ocean color/SST data seems to have an associated geolocation file. So it has been a struggle.

Progress in Related Areas

The IOCCG report on the current status of Case 2 algorithms was published in late 2000. The citation is:

IOCCG, Remote Sensing of Ocean Colour in Coastal, and Other Optically Complex, Waters. S. Sathyendranath, editor. Reports of the International Ocean Colour Coordinating Group, No. 3, IOCCG, Dartmouth, Canada, 2000.

We have recently submitted a preproposal to the NOAA-UNH Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) to place a CIMEL sensor on a platform in Great Bay Estuary of New Hampshire. The proposed sensor will be configured like the SeaPRISM sensor currently being operated at the Venice Tower in the northern Adriatic Sea (by G. Zibordi, JRC, Ispra, Italy). In-water measurements will be made by our Coastal Marine Bio-optics Laboratory, and the relationship between above-water radiances and in-water bio-optical properties will be established. The goal is to demonstrate the use of an in-situ radiometer for site-specific monitoring of an estuary.