Final Technical Report for the SeaWiFS Project: ANALYSIS OF PHOTOSYNTHETIC RATE AND BIO-OPTICAL COMPONENTS FROM OCEAN COLOR IMAGERY

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Abstract

Our research over the last 5 years indicates that the successful transformation of ocean color imagery into maps of bio-optical properties will require continued development and testing of algorithms. In particular improvements in the accuracy of predicting from ocean color imagery the concentration of the bio-optical components of sea as well as the rate of photosynthesis will require progress in at least three areas:

1. We must improve mathematical models of the growth and physiological acclimation of phytoplankton.
2. We must better understand the sources of variability in the absorption and backscattering properties of phytoplankton and associated microparticles.
3. We must better understand how the radiance distribution just below the sea surface varies as a function sun and sky conditions and inherent optical properties.

As members of the SeaWifs Team, we have made contributions in all three areas. The work we conducted lead to the development and testing of both the *USC Photosynthesis Algorithm* and our *Components Algorithm* , which provides estimates of 3 inherent optical properties.

The *USC Photosynthesis Algorithm* was among the top performers in the 1st Round Robin Exercise. This algorithm is distinctly different from those proposed by other workers (e.g. Platt and Sathyendranath 1988, Platt et al. 1991, Morel 1988, Morel 1991) because it includes a mechanistic description of the variability in the cellular ratio of carbon to chlorophyll. Unlike most of the other algorithms that have been proposed, the *USC Productivity Algorithm* recognizes the importance of the depth of the surface mixed layer on both the vertical distribution of chlorophyll and the physiological parameters of photosynthesis. This makes the algorithm particularly well suited to coastal waters where mixed layer depths may vary.

The *Components Algorithm* that we have been developing is designed to retrieve from surface reflectance the absorption coefficients of phytoplankton and detritus as well as the backscattering corereflectance: the absorption coefficient of phytoplankton, the absorption coefficient of colored dissolved and particulate materials, and the backscattering coefficient of suspended particles. Our

algorithm shares features in common with those proposed by Carder and his co-workers (1994) and Roesler and Perry (1995); however, it also contains several unique features. We have compared predictions of our preliminary version of the *Components Algorithm* with bio-optical measurements made in the Bermuda Atlantic Time Series (oligotrophic case 1 waters), and in the Baltic Sea (mesotrophic case 2 waters). The results were promising but inconclusive. The discrepancies between predicted values of the absorption coefficient and measured values may be caused by: contributions to reflectance by Raman scattering, variations in the shape of the absorption and backscattering coefficients of the components, variations in the shape of the upwelling radiance field, and incorrect values for the absorption coefficient of water.

Accomplishments as SeaWiFS Team Members

As members of the SeaWiFS Science Team, our laboratory helped to advance knowledge of the sources of variability of ocean color and how this variability is tied to marine photosynthesis. Much of this work is described in 21 research papers that are listed below. Below we have listed the tasks found in our 1993 proposal followed by our corresponding accomplishments during our 4 years of participation.

Photosynthetic Algorithm

1. We will assemble database for the independent and dependent variables of the USC Photosynthesis Algorithm for the North Atlantic. The independent variables include surface irradiance, surface temperature, surface chlorophyll *a* concentration, photoperiod, and surface concentrations of ammonia and nitrate. The dependent variables include the vertical distribution of chlorophyll *a* concentration, downwelling irradiance (spectral and PAR) and primary production.

We have assembled databases for the North Atlantic, the Bermuda Bio-optical Time Series, and the Baltic Sea.

2. We will grow in continuous culture marine phytoplankton over a matrix of irradiances, temperatures, photoperiods, and rates of nutrient supply. For each steady-state condition we will measure rates of growth and cellular absorption of irradiance.

We have completed the most detailed study of the bio-optical properties of phytoplankton cultures to date. The studies focused on diel variability and nutrient limitation. (Stramski and Reynolds, 1993; Stramski et al., 1995; and Reynolds et al., 1996;Reynolds, 1996.)

3. We will reformulate the phenomenological model as an algorithm to transform maps of surface chlorophyll concentration obtained from the CZCS and SeaWifs into maps of the concentration of chlorophyll, phytoplanktonic carbon, and daily photosynthetic rate.

The USC Photosynthesis algorithm has been coded with Mathematica, and has been described in a NASA publication (Behrenfeld et al., 1996). In addition many of the formulations may be found in Ondercin, Atkinson, and Kiefer, 1995. The algorithm was among the top performers in NASA's Round Robin 1 exercise, and calculations for Round Robin 2 have just been submitted. At present we do not know whether the inaccuracies in prediction were caused by errors in estimating the independent variables of the model or whether they were caused by inadequacies of the formulations.

4. From our database we will map the concentration of chlorophyll, phytoplanktonic carbon, and daily photosynthetic rate for selected months in the North Atlantic and compare predictions with appropriate field measurements.

We have produced seasonal maps of the bio-optical properties of the upper water column in the north Atlantic. These maps were presented at the Brookhaven Meeting of the SeaWiFS Productivity Team. A manuscript describing this work is near completion.

Reflectance algorithm

1. We will assemble a database on spectral reflectance measured within the euphotic zone at diverse oceanographic sites. This database will include all bio-optical measurements such as chlorophyll concentration, downwelling spectral irradiance, the volume attenuation coefficient, and particle and cell concentration that will constrain our reconstruction of the spectral reflectance.

We have assembled a bio-optical database for the Bermuda Time Series and the Baltic Sea, and have begun testing algorithms used to solve for absorption and backscattering coefficients. The analysis of the BATS data is in collaboration with Dr Dave Siegel of UCSB and the analysis of the Baltic Sea is in collaboration with Nicolas Hoeppfner of the Joint Research Center, Ispra, Italy. Both databases are of high quality and comprehensive.

2. We will apply a simple regression analysis to our database on the spectral absorption coefficient of suspended particles, $a_p(\lambda)$, retrieving at least a phytoplankton and detrital components.

We tried unsuccessfully to obtain an analytical solution to a 3 component reflectance model. This approach appears to be too sensitive to variations in spectral shape of the three components and to errors in measurement.

3. We will program and test a component model of diffuse spectral reflectance in the upper ocean. This model will be developed in a fashion similar to that described in Stramski and Kiefer (1991).

In collaboration with Curt Mobley we have published 2 papers on the effect of variations in the taxonomic composition of the planktonic community upon the inherent and apparent optical properties of sea water. The papers (Stramski and Mobley, 1997 a &b) will be soon appear in Limnology and Oceanography.

4. We will continue to culture marine microorganisms in the laboratory that may be important contributors to scattering and absorption in the sea. We will focus our attention on the optical properties of detrital particles produced by the grazing of flagellates and ciliates. We will also continue our study of the contribution by bacteria to absorption and scattering.

We have continued to measure the optical properties of marine particles produced in laboratory cultures. This work includes studies on phytoplankton (Reynolds, 1996; Reynolds et al., 1997; Stramski and Reynolds, 1993), detrital particles (Rosser and Berwald, 1994), and bacteria (Nagao and Stramski, 1994).

5. We will attempt to adapt our reflectance model to an analysis of CZCS and SeaWifs imagery.

During the last year, we have inverted a 3 component version of the reflectance model and compared predicted values of the concentration of chlorophyll a with measured values. In some BATS profiles the agreement is very good and others it is unsatisfactory. The same can be said for profiles from the Baltic Sea.

Publications Supported by our membership as NASA SeaWiFS Team

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