Semi-Annual Report
First Half 1994

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MODIS UPN: 229-01-04

A. Task Objective: Algorithm Development for Global Mapping of Phycoerythrin Pigment, Dissolved Organic Matter, and Chlorophyllous Pigment

1. MODIS North Atlantic Test Site Establishment and Characterization

As previously reported, the MODIS North Atlantic Test Site has been established as originally proposed. The Test Site includes the New York Bight/Mid-Atlantic Bight/Gulf Stream/Sargasso Sea and is conveniently located north and east of GSFC/WFF. Characterization has been initiated by ship sampling, aircraft overflights, and analysis of historical data available from within the NASA AOL project since 1980. Much of the data obtained in the northwestern portion of the test site will be used for algorithm development in Case 2 waters.

a. During this 6-month reporting period the Test Site was again both characterized and used as a source of new experimental airborne active-passive ocean color data in pursuit of this team member's algorithm for the detection and mapping of the phytoplankton chlorophyll accessory pigment, phycoerythrin. A ship flow-thru spectrometer designed to measure phycoerythrin fluorescence was again tried by Dr. Niel Blough (WHOI) during the field experiments in April 1994. The results suggest that a laser excitation source is required to produce the requisite phycoerythrin fluorescence spectra. The active (laser) airborne detection of phycoerythrin has been established since 1979 and the evidence for passive (solar) detection at 600nm was published in 1986 and 1990.

Dr. Blough also acquired filtered samples to allow further evaluation of the dissolved organic matter (DOM) within the MODIS Test Site from the Delaware Bay mouth across the shelf, slope, Gulf Stream and Sargasso Sea waters. The spectral absorption and fluorescence of these samples are being measured by Dr. Tony Vodacek, a National Research Council Resident Research Associate (RRA). These data are being used for developing algorithmic corrections for dissolved organic matter absorption.

Airborne flights were conducted in the northeast Atlantic ocean in early April 1994. These flights allowed the concurrent evaluation of a new 256 channel ocean color spectrometer designed and built at Wallops Flight Facility. It was found that the color sensor possessed the requisite sensitivity for ocean color spectra in a high-rate/low-integration-time mode needed to allow editing of data containing sun glint. The prototype sensor was successfully flown during the JGOFS Iron Enrichment Experiments off the coast of Ecuador in November 1993. A still higher p73 sensitivity

detector and higher resolution digitizer will be installed during the next quarter.

Additionally, the evaluation of a sea surface temperature sensor manufactured by Heimann/EG&G was conducted during the flights. The temperature sensor data evaluation indicated that the sensor had the requisite stability and accuracy needed to support the airborne active-passive ocean color measurements. Preliminary evaluation of these new surface temperature radiometers indicate that they are of excellent quality and yield very reproducible data. More evaluation is required to determine if the units can be used to support the validation of MODIS products and algorithms relative to sea surface temperature.

2. Selection of Case 1 Data Sets.

As previously given in the quarterly report, airborne active-passive ocean color data acquired within Case 1 oceanic regions with the NASA Airborne Oceanographic Lidar have now being screened for use in algorithm development. Several promising candidate data sets have been identified. In particular, AOL active-passive data in the northwestern Atlantic Ocean east of St. Johns , Newfoundland (obtained in 1989 as part of the Joint Global Ocean Flux Study of the North Atlantic Bloom Experiment) has displayed remarkable quality and freedom from non-chlorophyllous backscatterers. This data is being used to establish the baseline radiance model to be used for the retrieval of phycoerythrin pigment (as well as DOM and pigment). Data sets from the Monterey Bay flights (Sept 1992) and Mid-Atlantic Bight (April 1989 and 1991) are now under evaluation.

B. Other Work Accomplished

1. Production of the Algorithm Theoritical Basis Document (ATBD).

The required ATBD was delivered to the Project Office during this reporting period. The document details a new procedure for retrieving the phycoerythrin pigment by using the absorption bands. Existing MODIS bands are expected to be sufficient to effect the retrieval.

2. In-situ and Airborne Optical Characterization of MODIS North Atlantic Test Site.

A manuscript describing some of the algorithm work was published during the previous reporting period. The reader should consult this paper for details of the progress of the DOM retrieval using fluorescence methods. The manuscript is: Hoge, Frank E., Anthony Vodacek, Neil V. Blough, "Inherent Optical Properties of the Ocean: Retrieval of the Absorption Coefficient of Chromophoric Dissolved Organic Matter from Fluorescence Measurements", Limnology and Oceanography, 38(7) 1394-1402, 1993. p73

The validity of the Test Site samples and data have also been addressed during this reporting period. Specifically, the DOM absorption from prior cooperative ship experiments (see above paper) have been used to establish the levels of DOM fluorescence measured with the NASA Airborne Oceanographic Lidar in both the Atlantic and Pacific Oceans. These results were also published during this reporting period. The reference is : Hoge, Frank E., Robert N. Swift, James Y. Yungel, Anthony Vodacek, "Fluorescence of Dissolved Organic Matter: A Comparison of North Pacific and North Atlantic Oceans during April 1991", Jour. Geophysical Res. 98, No. C12, 22,779-22,787 (1993).

Some of the data used in the above publications came from the in situ characterization of the test site as initiated on February 28, 1991 with the acquisition of surface layer samples obtained during the Surface Wave Dynamics Experiment (SWADE). As previously reported, through cooperation with Dr. Charles Flagg, arrangements were made to collect 20 samples along an in-bound track line from the Gulf Stream to the mouth of the Delaware Bay. The samples were filtered (0.45 um) to remove particulate matter other than the dissolved organic matter (DOM). Spectral absorbance of the filtered samples were acquired at Wallops, Cornell Laboratory for Environmental Remote Sensing (CLEARS), and Woods Hole Oceanographic Institute (WHOI). Spectral fluorescence of the filtered samples was also measured at CLEARS (Dr. Tony Vodacek, now a NRC Resident Research Associate at Wallops) and WHOI (Dr. Niel Blough).

As reported in the above Limnology and Oceanography paper, recovery of the absorption coefficients for the light-absorbing or chromophoric components of the dissolved organic matter (aCDOM) from their fluorescence emission has been established by laboratory analyses of the surface samples gathered from the Feb. 28, 1991 cruise as well as other cruises. These absorbance and fluorescence analyses, (and work reported by others), show that absorption coefficients in the near ultraviolet can be directly retrieved from measurements of the fluorescence emission of CDOM. Thus, absorption coefficients in the visible spectrum can potentially be obtained from the fact that CDOM absorption is exponentially related to wavelength. The errors in the laboratory fluorescence measurements were minimized through the combined use of the water Raman scatter as an internal radiometric standard and a quinine sulfate solution as a reference. This methodology reduces aCDOM algorithm retrieval errors [reported by other researchers) primarily attributable to the use of commercial spectrophotometers having maximum optical path lengths of 10 cm. While the aCDOM retrieval appears feasible, the relationship between aCDOM and CDOM fluorescence emission is susceptible to changes in CDOM fluorescence yield, so the continued temporal study of marine samples from many diverse oceanic locations is needed. When applied to shipboard and aircraft laser fluorometers, this retrieval methodology and the resulting CDOM absorption coefficients will be used in ocean color models and associated satellite sensor/algorithm development directly

aimed at phycoerythrin retrieval. The DOM is important since it is a major interferant to the detection and quantification of chlorophyll and chlorophyll accessory pigments (CAP) such as phycoerythrin. Moreover, DOM is a contributor to the carbon cycle itself.

Recent laboratory and resulting analytical efforts have shown that the retrieval of dissolved organic carbon from absorption or from fluorescence emission still needs considerable work to prove feasibility.

During this reporting period a manuscript: "Oceanic Radiance Model Development and Validation: Application of Airborne Active-Passive Ocean Color Spectral Measurements" by F. Hoge, R. Swift, and J. Yungel was submitted to the Journal of Geophysical Research. This manuscript shows that voluminous, wide-area airborne active (laser) and passive (solar) ocean color spectral data can be used to develop radiance models and currently provide for their validation. The application of such models to algorithm development by direct inversion is under development. Such inversion was detailed in the recently developed ATBD.

2. In Situ Optical Characterization of the MODIS North Atlantic Test Site.

The continued characterization of the Test Site is partially described in the previously mentioned publication in Limnology and Oceanography.

A. Cooperative overflights within the MODIS Test Site were conducted during April, 1994 in conjunction with shipboard sampling activity conducted by Dr. N. Blough, an EOS Interdisciplinary Team member and in conjunction with additional shipboard sampling activity by Dr. Dan Repeta (WHOI) in conjunction with the DOE Coastal Ocean Program. The shipboard phycoerythrin fluorescence experiments of Dr. N. Blough with the flow-thru spectrometer were unsuccessful but will be tried again on a subsequent mission. The phycoerythrin data from the cruise of Dr. Dan Repeta (WHOI) are not yet available. Dr. Repeta is internationally recognized in the field of phycoerythrin pigment extractions and measurement. The airborne data is now undergoing analysis.

1. Phycoerythrin Algorithm Development Activities Plans call for us to again directly address the quantification of the phycoerythrin signal as outlined in the original MODIS proposal. The phycoerythrin retrieval was detailed in the ATBD as submitted the project office.

2. Chlorophyll Pigment and CDOM Corrections to the Phycoerythrin Algorithm.

Major perturbations or influence to the ocean color spectrum are provided by chlorophyll and CDOM. These oceanic constituents

significantly impede the retrieval of phycoerythrin pigment from the upwelled radiances. Accordingly, they must be dealt with in a systematic way in order to understand their effects and the impact on the retrieval of phycoerythrin and its ultimate quantification. In situ and airborne data gathered to date will be used to model the effects and to ascertain the extent that p73 they can be quantified and removed.

3. Other Data Acquisition for Algorithm Development

In addition to the previously reported airborne data acquired over the cruise of Dr. Blough, overflights of Dr. Tom Fisher/Dr. Larry Harding (Horn Point Environmental Laboratory/Univ. Md.) together with Dr. Frank Muller-Karger were conducted in the region extending from the Chesapeake Bay mouth to Cape Hatteras.

During late October and early November 1993 flights were conducted in cooperation with NSF's Joint Global Ocean Flux Study of Iron Enrichment in the Eastern Equatorial Pacific. Considerable Case 1 ocean color data was obtained during these JGOFS flights both during the mapping of the ship-deployed iron and during the transit to and from the experiment site at -90W and -5S. Quality algorithm-development ocean color data was also obtained on pre-determined transects within the naturally-occuring Galapagos Island plume. The transit flights from Wallops Flight Facility to Guayaquil (via Belize) likewise yielded ocean color data suitable for algorithm development. During the latter transit flights, numerous watermasses were crossed. These data are being evaluated.

C. Anticipated Activities During Next Half Year.

1. Additional flights of the NASA Airborne Oceanographic Lidar are planned within the MODIS Test Site. Specifically, Dr. Tom Fisher/Dr. Larry Harding (Horn Point Environmental Laboratory/Univ. Md.) together with Dr. Frank Muller-Karger will be overflown in the region extending from the Chesapeake Bay mouth to Cape Hatteras in November 1994.

2. Plans are being made to participate in the JGOFS Arabian Sea Experiment in July 1995. This is an opportunity to obtain data in an entirely different oceanic province. As was the case with the Iron Enrichment Experiment flights, these flights will serve as a valuable data source for algorithm development. This activity should contribute to the goal for universality of the algorithms being developed.

D. Other Concerns

In past reports, the lack of a 600nm band on MODIS-N was given as the biggest problem facing the retrieval of the phycoerythrin pigment on the first sensor launch. Recent studies of available models, however, suggests that the retrieval of the phycoerythrin pigment at the absorption peaks of 495nm (phycourobilin, PUB) and

545nm (phycoerythrobilin, PEB) can be achieved using the 490nm and 555nm MODIS bands. Such retrievals will require a highly accurate model to account for the significant amounts of chlorophyll and DOM absorption occuring simultaneously with the p73 phycoerythrin absorptions. The details of the phycoerythrin retrieval have been recently detailed in the ATBD.