SEMI-ANNUAL REPORT

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OCEAN OBSERVATIONS WITH EOS/MODIS:

Algorithm Development and Post Launch Studies

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Preamble

As in earlier reports, we will continue to break our effort into seven distinct units:

- Atmospheric Correction Algorithm Development
- Whitecap Correction Algorithm
- In-water Radiance Distribution
- Residual Instrument Polarization
- Pre-launch Atmospheric Correction Validation
- Detached Coccolith Algorithm and Post-launch Studies

This separation has been logical thus far; however, as launch of AM-1 approaches, it must be recognized that many of these activities will shift emphasis from algorithm development to validation. For example, the second, third, and fifth bullets will become almost totally validation-focussed activities in the post-launch era, providing the core of our experimental validation effort. Work under the fist bullet will continue into the post-launch time frame, but will be driven in part by algorithm deficiencies revealed as a result of validation activities. We will continue to use this format for CY97.

Abstract

Several significant accomplishments were made during the present reporting period.

- We developed a new method for identifying the presence of absorbing aerosols and, simultaneously, performing atmospheric correction. The algorithm consists of optimizing the match between the top-of-atmosphere radiance spectrum and the result of models of both the ocean and aerosol optical properties.

- We developed an algorithm for providing an accurate computation of the diffuse transmittance of the atmosphere given an aerosol model. A module for inclusion into the MODIS atmospheric-correction algorithm was completed.

- We acquired reflectance data for oceanic whitecaps during a cruise on the *RV Ka'imimoana* in the Tropical Pacific (Manzanillo, Mexico to Honolulu, Hawaii). The reflectance spectrum of whitecaps was found to be similar to that for breaking waves in the surf zone measured by *Frouin, Schwindling and Deschamps* [1996]; however, the drop in augmented reflect ante from 670 to 860 nm was not as great, and the magnitude of the augmented reflectance was significantly less than expected [*Gordon and Wang, 1994].*

- We developed a method for the approximate correction for the effects of the MODIS polarization sensitivity. The correction, however, requires adequate characterization of the polarization sensitivity of MODIS prior to launch.

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1. Atmospheric Correction Algorithm Development.

a. Task Objectives:

During CY 1996 there are four objectives under this task:

(i) Complete development of an algorithm module for removing the effects of stratospheric aerosol and/or cirrus clouds from MODIS imagery over the oceans.

(ii) Conduct research on the effects of strongly absorbing aerosols, and their vertical structure, on the existing atmospheric correction algorithm. Use the results of this research to develop a strategy for their removal.

(iii) Develop a detailed model of the diffse transmittance of the atmosphere and the manner in which it is influenced by the angular distribution of subsurface upwelling spectral radiance. Add a module for this to the atmospheric correction algorithm.

(iv) Investigate the effects of ignoring the polarization of the atmospheric light field on the performance of the proposed atmospheric correction algorithm.

b. Work Accomplished:

(i) This task was placed on hold to free time to accelerate Major Task #4 below in response to the higher-than-expected MODIS polarization sensitivity in some ocean bands. However, a paper submitted to *Applied Optics* describing our work in this area was accepted for publication (Appendix 2 in the Jan. to June 1996 Semi-Annual Report), and talks with MODIS Science Team Member B.-C. Gao were initiated to coordinate effort for cirrus cloud removal.

(ii) As demonstrated our last Semi-Annual Report (Jan. to June 1996), strongly absorbing aerosols present a serious problem for atmospheric correction. The nature of the problem is two fold: (1) in contrast to weakly-absorbing aerosols, when the aerosol is strongly absorbing its distribution in altitude becomes very important; and (2) the technique of distinguishing aerosol type through examination of the spectral variation of the radiance in the near infrared, used by the MODIS atmospheric-correction algorithm, cannot distinguish between weakly-absorbing and strongly-absorbing aerosols. During this reporting period, we have tested a “spectral matching algorithm” that, although very slow, is capable of distinguishing between weakly- and strongly-absorbing aerosols. It is based on combining an atmospheric model with a water-leaving radiance model for the ocean, and effecting a variation of the relevant parameters until a satisfactory fit to the MODIS top-of-atmosphere radiance is achieved. We believe that the algorithm is also capable of functioning in the same manner when aerosol vertical structure is an additional parameter. (Note that vertical structure is only important when the aerosol is strongly absorbing.) A report describing this algorithm is attached as Appendix 1.

(iii) The basic correction algorithm yields the product of the diffuse transmittance t and the water-leaving reflectance p_w. However, t depends on the angular distribution of p_w. If p_w were uniform, t would be easy to compute, and this approximation has always been employed in the past. In a series of papers Morel and Gentili *[Morel and Gentili*, 1991; *Morel and Gentili, 1993]* studied theoretically the bidirectional effects as a function of the sun-viewing geometry and the pigment concentration. Their simulations suggest that, although the bidirectional effects nearly cancel in the estimation of the pigment concentrate ion using radiance ratios, p_w can depend significantly on the solar and viewing angles. (Our major task number 3, a study of the in-water radiance distribution, experimentally addresses this problem.)

In this reporting period, we completed a study to understand the influence of bidirectional effects on the diffuse transmittance t. Through the use oft he reciprocity y principle, we were able to develop a simplified method of computing t, given the upward radiance distribution with direction just beneath the sea surface. We showed that the difference between t (the correct diffuse transmittance) and t^* (the diffuse transmittance computed by assuming the subsurface upward radiance is uniform) is typically $\leq$ 4%, and is a relatively weak function of the aerosol optical thickness. Thus, considering the error likely to result from the removal of the aerosol path radiance, it appears that in the blue *t can* be replaced by t^*, except in waters with low pigment concentrations, e.g., $\leq$ 0.5 mg/m^3. A paper describing this work has been submitted to *Applied Optics,* and is at t ached here as Appendix 2.

We have written a software module to accurately compute the diffuse transmittance, and produced the required lookup tables. This module has been delivered to R. Evans for integration into the atmospheric correction software.

(iv) This task was completed as described in the last Semi-Annual Report (Jan. to June 1996).

c. Data/Analysis /Interpretation: See item **b** above.

d. Anticipated Future Actions:

(i) We must now implement our strategy for adding the cirrus cloud correction into the existing atmospheric correction algorithm. Specific issues include (1) the phase function to be used for the cirrus clouds, (2) the details of making two passes through the correction algorithm, and (3) preparation of the required tables. These issues will be addressed during CY 1997 with the goal of having a complete implementation ready by the end of CY 1997.

(ii) We will continue the study of the "spectral matching" algorithm with the goal of having an algorithm ready for implementation by the end of CY 1997. As our work has shown that a knowledge of the vertical distribution of the aerosol is critical, if it is strongly absorbing, we have procured a micro pulse lidar (MPL) system for use at sea on validation cruises, and from islands (likely Barbados or the Canary Islands) in the Saharan dust zone, to begin to compile the climatology of the vertical distribution required to adopt candidate distributions for use in this region.

(iii) This task is nearly complete; however, we still need to develop a method to include the effects of the subsurface BRDF for low-pigment waters in the blue.

(iv) Task completed

Additional tasks for CY97:

(1) We will initiate a study to determine the efficacy of the present atmospheric correction algorithm on removal of the aerosol effect from the measurement of the fluorescence line height (MOD 20).

(2) We will examine methods for efficiently including earth-curvature effects into the atmospheric correction algorithm [*Ding and Gordon*, 1994]. This will most likely be a modification of the look-up tables for the top-of-the-atmosphere contribution from Rayleigh scattering.

(3) We will examine the necessity of implementing our out-of-band correction [*Gordon*, 1995] to MODIS.

e. Problems/Corrective Actions:

(i) None.

(ii) None.

(iii) None.

(iv) None.

(v) None.

f. Publications:

H.R. Gordon, Atmospheric Correction of Ocean Color Imagery in the Earth Observing System Era, *Journal of Geophysical Research, Atmospheres* (Accepted).

H.R. Gordon, T. Zhang, F. He, and K. Ding, Effects of stratospheric aerosols and thin cirrus clouds on atmospheric correction of ocean color imagery: Simulations, *Applied Optics (In* press).

H. Yang and H.R. Gordon, Remote sensing of ocean color: Assessment of the water-leaving radiance bidirectional effects on the atmospheric diffuse transmittance, *Applied Optics* (Submitted).

2. Whitecap Correction Algorithm (with K.J. Voss).

a. Task Objectives:

As described in earlier reports, a whitecap radiometer system has been built and tested to provide a database for developing and validating the whitecap correction algorithm, as well as for providing an estimation of the whitecap contribution to the water-leaving radiance during the post-launch validation phase. The database includes spectral information as well as variables associated with the formation and occurrence of whitecaps such as wind speed and air/sea temperate.

b. Work Accomplished:

The basic design, calibration procedure, operation, and data analysis methods for the whitecap radiometer are described in a paper prepared for submission to the *Jour. Atm. Ocean. Tech.* **and** attached here as Appendix 3.

From **29** March to 18 April 1996 the whitecap radiometer system was deployed on the NOAA ship *RV Malcolm Baldrige* on a cruise from Miami to a test location in the Gulf of Mexico, approximately 70 miles off shore from Cedar Key (Florida) in the Apalachicola Bay. The location provided relatively warm waters (16°-17°C) with a number of cold fronts moving off the mainland. These fronts usually lasted a couple of days bringing strong winds (sometimes as high as 18 m/s) and lowering the air temperature to about 12°C. The occurrence of an unstable atmosphere and good winds provided an interesting spectral whitewater data set. From 1 to 13 November 1996, the whitecap radiometer was operated on a cruise from Manzanillo, Mexico to Honolulu, Hawaii. This cruise provided whitecap data under conditions of steady winds (the trades) of essentially unlimited duration and fetch. The analysis of these two data sets is provided in a paper prepared for submission to *Jour. Geophys. Res.* and attached here as Appendix 4.

c. Data/Analysis/Interpretation

There have been three significant results from our whitecap research: (1) our measurements confirm the spectral fall off of the augmented reflectance in the NIR, although the reduction at 865 compared to 670 nm was not as large as observed in the surf zone [*Frouin, Schwindling and Deschamps,* 1996]; *(2)* whitecaps show significant nonlambertian effects, particularly at large solar zenith angles; and (3) the augmented reflectance of whitecaps appears to be about one-forth that predicted by recent models [Gordon *and Wang,* 1994; *Koepke,* 1984]. The details of these results are provided in Appendix 4.

d. Anticipated Future Actions:

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As the basic objectives of this task have been realized, it is being suspended until the validation phase. Karl Moore, the post doctoral associated who was responsible for the operation of the instrument and the data analysis, has accepted a position at the Scripps Institution of Oceanography.

e. Problems/Corrective Actions: None

f. Publications:

K.D. Moore, K.J. Voss, and H.R. Gordon, Whitecaps: Spectral reflectance in the open ocean and their contribution to water-leaving radiance, Ocean Optics XIII, Halifax, Nova Scotia, October 22-25, 1996.

K.D. Moore, K.J. Voss, and H.R. Gordon, Spectral reflect ante of whitecaps: Instrumentation, calibration, and performance in coastal waters, *Jour. Atmos. Ocean. Tech.* (Submitted).

K.D. Moore, K.J. Voss, and H.R. Gordon, Spectral reflectance of whitecaps: Fractional coverage and the augmented spectral reflectance contribution to the water-leaving radiance, *Jour. Geophys. Res.* (Submitted).

3. In-water Radiance Distribution (with K.J. Voss).

a. Task Objectives:

The main objective in this task is to obtain upwelling radiance distribution data at sea for a variety of solar zenith angles to understand how the water-leaving radiance varies with viewing angle and sun angle.

b. Work accomplished:

We acquired upwelling radiance distribution data with the RADS camera system during a cruise with Dennis Clark during November. It was very windy during this cruise, but data was acquired in the configuration expected to be used during validation cruises.

c. Data/ Analysis/Interpretation: none

We are currently performing the post-cruise calibrations of this instrument, and will be reducing the cruise data when this is completed.

d. Anticipated future actions:

We will be completing the calibrations and reducing data acquired during the cruise. We are also planning on making some minor changes to the instrument to improve its operation at sea. Finally we will be acquiring more data during another cruise with Dennis Clark this spring.

e. Problems/Corrective actions: None.

f. Publications: None.

4. Residual Instrument Polarization.

a. Task Objectives:

The basic question here is: if the MODIS responds to the state of polarization state of the incident radiance, given the polarization-sensitivity characteristics of the sensor, how much will this degrade the performance of the algorithm for atmospheric correction, and how can we correct for these effects?

b. Work Accomplished:

We have developed a formalism [*Gordon*, 1988] which provides the framework for removal of instrument al polarization-sensitivity effects, and a method for approximately correcting for them. The correction method is presented in a paper submitted for publication in *App/ied Optics*, and at t ached as Appendix 5. The main difficulty that we see now in correcting for the polarization-sensitivity effects is the requirement of an adequate pre-launch characterization of the polarization sensitivity.

c. Data/Analysis/Interpretation:

See Appendix 5.

d. Anticipated Future Actions:

Although this task is now basically complete (a correction algorithm has been developed), we still need to prepare a module for including the polarization-sensitivity correction algorithm in the MODIS atmospheric correction algorithm. Also, as operation of the polarization-sensitivity correction algorithm requires an adequate pre-launch characterization of the polarization sensitivity y, we will continue to work with MCST and SBRS to insure that proper characterization is realized.

e. Problems/Corrective Actions: None

f. Publications:

H.R. Gordon, T. Du, and T. Zhang, Atmospheric correction of ocean color sensors: Analysis of the effects of residual instrument polarization sensitivity, *Applied Optics (Submitted).*

5. Pre-launch Atmospheric Correction Validation (with K.J. Voss).

a. Task Objectives:

The long-term objectives of this task are four-fold:

(i) First, we need to study aerosol optical properties over the ocean in order to verify the applicability of the aerosol models used in the atmospheric correction algorithm. Effecting this requires obtaining long-term time series in typical maritime environments. This will be achieved using a CIMEL sun/sky radiometer that can be operated in a remote environment and send data back to the laboratory via a satellite link. These are similar the radiometers used by B. Holben in the AERONET Network. Thus, the first objective is to deploy a CIMEL Automatic Sun Tracking Photometer in a suitable location for studying the optical properties of aerosols over the ocean.

(ii) Second, we must be able to measure the aerosol optical properties from a ship during the initialization/calibration/validation cruises. The CIMEL-type instrumentation cannot be used (due to the motion of the ship) for this purpose. The required instrumentation consists of an all-sky camera (which can measure the entire sky radiance, with the exception of the solar aureole region) from a moving ship, an aureole camera (specifically designed for ship use) and a hand-held sun photometer. We have a suitable sky camera and sun photometer and must construct an aureole camera. Our objective for this calendar year is (1) to assemble, characterize and calibrate the solar aureole camera system, (2) to develop data acquisition software, and (3) to test the system.

In the case of strongly-absorbing aerosols, we have shown that knowledge of the aerosol vertical structure is critical [*Gordon*, 1996]. Thus, we need to be able to measure the vertical distribution of aerosols during validation exercises. This can be accomplished with ship-borne LIDAR. We have to procure a LIDAR system and modify it for ship operation.

(iii) The third objective is to determine how accurately the radiance at the top of the atmosphere can be determined based on measurements of sky radiance and aerosol optical thickness at the sea surface. This requires a critical examination of the effect of radiative transfer on “vicarious” calibration exercises.

(iv) The forth objective is to utilize data from other sensors that have achieved orbit (OCTS, POLDER, MSX), or are expected to achieve orbit (SeaWiFS) prior to the launch of MODIS, to validate and fine-tune the correction algorithm.

b. Work Accomplished:

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(i) During the fist part of this period we were operating the CIMEL in it's location in the Dry Tortugas. In October this instrument was removed for recalibration. At the same time the AERONET network, run by B. Hobren, decided to upgrade the CIMEL instruments with more stable interference filters and small hardware changes. We will be reinstalling this instrument when it is returned from NASA.

(ii) The sky camera system and aureole system was used on three cruises during this period. The first cruise we participated in occurred during the NASA TARFOX experiment between Bermuda and New York. This cruise took place on a cruise liner, and we participated in all three weeks of the cruise effort. During this time we made measurements with the sky camera (including polarization), aureole camera system (to measure the sky radiance near the sun), and a hand held sunphotometer. In general the weather was not as good as expected (a hurricane when through the area dining the cruise) but there were several clear periods during the cruise. The second and third cruises were with Dennis Clark off of Hawaii (during September and November). In the fist of these cruises we obtained data with all three system, but in the third Dennis Clarks group provided the sun photometer data. In addition to participating on the cruises we performed calibrations of all the systems pre and post cruise. We are currently rewriting the data reduction programs for the sky radiance distribution system to allow data reduction to take place on the cruise, to speed this process. In addition this is giving an opportunity to review this process and to perform tests of this data. We have reduced the aureole data from the first two cruises, and are currently evaluating this data.

To address the problem of vertical distribution of aerosols we have acquired a Micro Pulse Lidar from SSEI. This system was delivered at the very end of the period (December 16th), so we have not had a chance to do anything with the system yet.

(iii) As described in our last Semi-Annual Report (Jan. to June 1996), we have completed a study of the accuracy with which one can compute the radiance at the top of the atmosphere from sky radiate measurements made at the sea surface. The results suggest that the bulk of the error is governed by the uncertainty in the sky radiance measurements. Furthermore, it was shown that the largest error in the radiative transfer process was that due to the use of scalar radiative transfer theory, and that improvement would require the use of vector theory, and thus, measurement of the the polarization of the sky radiance. We have started to analyze the use of polarization measurements at the surface and it appears that when polarization is included in the sky radiance inversion algorithm, the radiative transfer error can be made very small. Furthermore, we are now examining the extent to which the full linear polarization of the top-of-atmosphere radiance can be deduced from surface measurements. This may be very important for validating the pre-launch polarization-sensitivity characterization of MODIS.

(iv) We have been in contact with personnel involved with SeaWiFS, OCTS, and MSX to acquire data formats, and satellite data from these instruments to assess the validity of the atmospheric correction algorithm. We have procured an SGI R10000 Workstation (same chip set and operating system as used by MODIS SDST). This will provide the necessary image processing capability for the pre- and post-launch era.

c. Data/Analysis/Interpretation:

(i) The CIMEL instrument was at NASA for most of this period for recalibration and refitting of the interference filters. Thus there has been little data analysis.

(ii) We have been working to reduce the data from the sky camera and aureole camera acquired this period but have not finished this process. Thus there is little to report in terms of analysis or interpretation. We also do not have any data from the LIDAR yet.

d. Anticipated Future Actions:

(i) We will be reinstalling the CIMEL in the Dry Tortugas at the first opportunity after its return from NASA. We are also working on a better method of acquiring the data through NASA. This will enable us to look at the sky radiance data in a more timely manner.

(ii) We will finish the data reduction work with the sky camera system in the next quarter. We are also reworking portions of this system to allow more automation of the data collection, and fix minor problems which developed during the last cruise (specifically overheating of the system computer and corrosion on the computer backplane). The reduced aureole data will be merged with the sky radiance data to provide a complete sky radiance distribution during this next period. We will also finish reducing all of the aureole data during this next period.

Much of our effort in the next several months will be spent learning the new MPL Lidar system, and making the modifications necessary to use the system at sea. We would like to have this system ready for operation during the next cruise opportunity, if possible ready for a field trial in February.

(iii) We will continue development of a sky radiance inversion algorithm that utilizes the full vector radiative transfer equation. This should remove the largest radiative transfer error in predicting the top-of-atmosphere radiance from the bottom-of-atmosphere radiance.

(iv) We will continue to try to obtain ocean color data from other sensors to assess the correction algorithm. Now, OCTS appears to be the most likely candidate. We will instead R. Evans' implementation of our atmospheric correction algorithm on the R10000 computer to facilitate fine-tuning the algorithm.

e. Problems/corrective actions: None.

f. Publications:

H.R. Gordon and T. Zhang, How well can radiance reflected from the ocean-atmosphere system be predicted from measurements at the sea surface?, *Applied Optics 35, 6527-6543 (1996).*

D.K. Clark, H.R. Gordon, K.J. Voss, Y. Ge, W. Broenkow, and C. Trees, Validation of Atmospheric Correction over the Oceans, *Jour. Geophys. Res.* (Accepted).

K.J. Voss and Y. Liu, Polarized radiance distribution measurements of skylight: Part 1, system description and characterization, *Applied Optics* (Submitted).

6. Detached Coccolith Algorithm and Post Launch Studies (W.M. Balch).

During the second half of 1996, we participated in one cruise to the Gulf of Maine, a well known region for mesoscale coccolithophore blooms. We measured coccolithophore abundance, production and optical properties. We also completed a flow cytometer experiment in which we sorted field-derived calcite particles to measure their calcite specific scattering coefficients. A thorough Understanding of the relationship between calcite abundance and light scatter, in coccolith-rich and coccolith-poor regions, will provide the basis for a generic suspended calcite algorithm to be used with MODIS data.

a. Task Objectives:

The algorithm for retrieval of the detached coccolith concentration from the coccolithophorid, E. huxleyi is described in detail in our ATBD. The key is quantification of the backscattering coefficient of the detached coccoliths. Our earlier studies focussed on laboratory cultures to understand factors affecting the calcite-specific backscattering coefficient. As with algorithms for chlorophyll, and primary productivity, the natural variance between growth related parameters and optical properties needs to be understood before the accuracy of the algorithm can be determined. To this end, the objectives of our coccolith studies have been to define the effect of growth rate on:

(1) the rate that coccoliths detach from cells (this is also a function of turbulence and physical shear);

(2) rates of coccolith production;

(3) morphology of coccoliths; and

(4) volume scattering and backscatter of coccoliths.

For perspective on the directions of our work, we provide an overview of our previous activities. During 1995, we focussed on all of the above objectives using chemotstat cultures (in which algal growth rate is precisely controlled). During the latter half of 1995, our work focused on shipboard measurements of suspended calcite and estimates of optical backscattering as validation of the laboratory measurements. We participated on two month-long cruises to the Arabian sea, measuring coccolithophore abundance, production, and optical properties. During the first half of 1996, we focused again on objectives 2 and 4, during two Gulf of Maine cruises, one in March and one in June. During the second half of 1996, we participated on another cruise to the Gulf of Maine, and further addressed objectives 2 and 4.

b. Work Accomplished:

We have continued data analysis for the Arabian Sea cruises as well as the first two Gulf of Maine cruises of 1996. The current state of the data are as follows:

(1) We completed our third cruise of 1996 to the Gulf of Maine in November. During this cruise, we sampled for total and calcite-dependent backscattering (continuously), suspended calcite concentrations, calcification rates, chlorophyll concentrations, and coccolithophore and coccolith counts.

(2) We completed our last set of flow cytometer experiments in which we sorted field-derived calcite particles into vials of pure seawater, measured their volume scattering functions, and measured their calcite concentrations.

(3) Suspended calcite samples from all Arabian Sea cruises and two cruises to the Gulf of Maine (March and June) have been run in the graphite furnace atomic absorption spectrometer at the University of Maine. We now only have samples from our most recent cruise in November.

(4) The 400 cell and coccolith counts from the southwest Monsoon cruise (summer ’95) have been completed and the data are being hand-entered into spreadsheets at this time. We are currently working on the Arabian Sea Samples from the ’95 intermonsoon cruise.

(5) All calcification data from the Arabian Sea cruise have been processed to units of gC $m^{-3} d^{-1}$ and integrated over the water column at each station and they have been processed into complete sections.

(6) The Arabian Sea bio-optical data is now processed for temperature, salinity, pH, fluorescence and backscatter (with and without calcite) averaged over each kilometer of all trips. All calibration checks have been done for the underway data. Hydrographic plots have been made in which light scattering is plotted as a function of temperature and salinity and the optical and pigment data superimposed.

(7) We have examined the relationship between the calcite-dependent backscattering (b'_b) and the concentration of suspended calcite or concentration of detached coccoliths for our previous work in the Straits of Florida, Arabian Sea, and North

Atlantic. We have also analyzed these data relevant to our flow cytometer results. This is of major relevance to our MODIS algorithm efforts. Besides actually checking our algorithm, it allows us to define the accuracy and precision of the algorithm. This is exceedingly important for subsequent interpretation. Our results suggest that for the Gordon reflectance model, the algorithm will have a precision of+ 25,000 coccoliths/mL (or in terms of carbon equivalents, ± 5 µg C as calcite per liter).

c. Data/Analysis /Interpretation:

As expected, calcite-dependent backscattering was low in the Gulf of Maine during March, but it was still measurable. Typically, calcite scattering accounted for 5-10% of total backscattering. A very different picture was observed in June. Acid-labile scattering increased to 30-40% of total backscattering in Wilkinson Basin, a stratified basin in the middle of the Gulf of Maine. Acid-labile scattering dropped over Georges Bank as the predominant populations were diatoms, and values increased again in the Northeast Channel, similar to previous blooms that we have observed. The observations are consistent with the calcite being produced in the more stable Wilkinson Basin with subsequent advection around the NE flank of Georges Bank. We completed another Gulf of Maine cruise at the end of October, and again took the flow-through system. Much of these data are still in the process of being worked-up.

Calcification measurements from the March 1996 cruise were remarkably high, given that this was at the beginning of the Spring bloom. We were finding > 10% of the carbon being fixed into coccoliths. This also explains the relatively high fraction of calcite-dependent light scattering seen during this time. Calcification rates are still being processed for the June cruise but preliminary results suggest that they were quite high.

d. Anticipated Future Actions:

Work in CY97 will address several areas:

(1) Processing of the suspended calcite samples from the November **'96** cruise.

(2) Data will be collated from the Arabian Sea and Gulf of Maine cruises in order to calculate turnover of the calcite particles. This can only occur after step 1 is completed.

(3) We are continuing analysis of our latest flow cytometer results from the fall '96 experiment. The suspended calcite samples from that last experiment will be run.

(4) The underway data from the Gulf Maine will be merged with our calibration measurements (vicarious calibrations are periodically made at sea and these data must be processed to verify whether instrument calibrations changed).

(5) Hydrographic plots of the Gulf of Maine data will be made in which light scattering and chlorophyll are plotted in temperature salinity space.

e. Problems/Corrective Actions: None

f. Publications:

W. M. Balch, J. J. Fritz, and E. Fernandez, Decoupling of calcification and photosynthesis in the coccolithophore Emiliania huxleyi under steady-state light-limited growth. *Marine Ecology Progress Series,* 14287-97 (1996).

E. Fernandez, J. J. Fritz and W. M. Balch, Growth-dependent chemical composition of the coccolithophorid Emiliania huxleyi in light-limited chemostats, *J. Exp. Mar. Biol. Ecol. (In* press).

J. J. Fritz and W. M. Balch, A coccolith detachment rate determined from chemostat cultures of the coccolithophore Emiliania huxleyi, *J. Exp. Mar. Bio1. Ecol.* (In press).

K. J. Voss, W. M. Balch, and K. A. Kilpatrick. Scattering and attenuation properties of Emiliania huxleyi cells and their detached coccoliths, *Limnol. Oceano~.* (Submitted).

8. Other Activities.

The bulk of the PI's effort during this reporting period was focused on five activities. The first was the preparation of revisions of the Water-leaving Radiance and Coccolith concentration ATBD 's. These revisions were completed and delivered to the EOS Senior Project Scientist on August 15, 1996. The second was a detailed revision of the MOCEAN Validation Plan on behalf of the Group. This occurred after attending the MODIS Ocean Group (MOCEAN) Meeting in July. The third was participation in the MCST audit of progress toward the Level 1B algorithm in the VIS/NIR bands on September 5, 1996. The forth was participation in the MODIS ATBD review November 20, 1996. The fifth was an intensive effort to assess the effects of the larger-than-expected MODIS polarization sensitivity y on MODIS products, and to understand the anomalous polarization-sensitivity characterization tests.

9. Publications, submissions, and abstracts for CY 96.

H.R. Gordon, Atmospheric Correction of Ocean Color Imagery in the Earth Observing System Era, *Journal of Geophysical Research, Atmospheres* (Accepted).

H.R. Gordon, T. Zhang, F. He, and K. Ding, Effects of stratospheric aerosols and thin cirrus clouds on atmospheric correction of ocean color imagery: Simulations, *Applied Optics (In* press).

H.R. Gordon and T. Zhang, How well can radiance reflected from the ocean-atmosphere system be predicted from measurements at the sea surface?, *Applied Optics, 35, 6527-6543 (1996).*

T. Zhang and H.R. Gordon, Columnar aerosol properties over oceans by combining surface and aircraft measurements: sensitivity analysis, *Applied Optics* (Accepted).

D. K. Clark, H.R. Gordon, K.J. Voss, Y. Ge, W. Broenkow, and C. Trees, Validation of Atmospheric Correction over the Oceans, *Jour. Geophys. Res.* (Accepted).

H. Yang and H.R. Gordon, Remote sensing of ocean color: Assessment of the water-leaving radiance bidirectional effects on the atmospheric diffuse transmittance, *Applied* Optics (Submitted).

H.R. Gordon, T. Du, and T. Zhang, Atmospheric Correction of Ocean Color Sensors: Analysis of the Effects of Residual Instrument Polarization Sensitivity, *Applied Optics (Submitted).*

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