QUARTERLY REPORT

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OCEAN OBSERVATIONS WITH EOS/MODIS:
Algorithm Development and Post Launch Studies

by

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ABSTRACT

- The influence of stratospheric aerosols and cirrus clouds on the performance of the atmospheric correction algorithm was studied. It was concluded that under typical conditions (low stratospheric aerosol optical depth) utilization of the 1.38 micron MODIS band would provide only a minimal improvement in atmospheric correction in the presence of this contamination unless a very complex multiple scattering algorithm was implemented.

- The whitecap radiometer system was field-tested at sea and performed well. It will be utilized on two cruises this fall.

REPORT

I shall describe developments (if any) in each of the major task categories.

1. Atmospheric Correction Algorithm Development.

a. Near-term Objectives:

(i) Continue investigating the effects of stratospheric aerosol and/or cirrus clouds on the performance of the proposed atmospheric correction algorithm.

(ii) Investigate the effects of vertical structure in the aerosol concentration and type on the behavior of the proposed atmospheric correction algorithm.

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

(iv) Begin a detailed investigation of the performance of the correction algorithm in atmospheres with strongly absorbing aerosols.

b. Task Progress:

(i) The goal of this objective was two-fold: (1) estimation the severity of the degradation of atmospheric correction using the Gordon and Wang (1994) algorithm, and (2) examination of several methods of removal of the stratospheric component prior to application of the Gordon and Wang algorithm (MODIS). This latter goal is of particular interest because, if it were realized, little or no modification of the present MODIS atmospheric correction algorithm would be required to accommodate correction for the stratospheric aerosol. We investigated the effect and removal of the presence of stratospheric aerosol on the atmospheric correction of ocean color sensors in the simplest possible situation: (1) all of the tropospheric aerosol is in the marine boundary layer; (2) all of the radiance exiting the top of the atmosphere at 1380 nm is due to scattering from the stratospheric aerosol alone; (3) there is no water vapor above the stratospheric aerosol, and (4) the is no horizontal variability in the stratospheric aerosol optical thickness. In reality, some radiance at 1380 nm can originate from below the stratospheric aerosol either from molecular scattering in the free troposphere or possibly even from the marine boundary layer under conditions of very low relative humidity (unlikely over the oceans). Also, there may be water vapor above thin cirrus clouds in which case their reflectance would be underestimated at 1380 nm, and cirrus typically display considerable horizontal structure.

To effect the study, six procedures were examined for addressing the effect of the stratospheric aerosol ranging from simply ignoring its presence to requiring full knowledge of its spectral optical properties, lacking only its concentration. As might be expected, the stratospheric aerosol correction procedure requiring full knowledge of the spectral optical properties, except the concentration, which is determined by the reflectance at 1380 nm, and employing multiple and interactive scattering between stratospheric aerosol and tropospheric molecular scattering in the visible usually yielded the best overall correction when combined with the Gordon and Wang algorithm. However, often this was not significantly better than the simplest procedure, simply ignoring the stratospheric aerosol. The fact that simply ignoring the stratospheric aerosol usually provided a good correction agrees with the conclusion of Gordon and Castano (1988) that the presence of the El Chichon aerosol had little effect on CZCS atmospheric correction.

Considering the fact that, even in these idealized simulations, the three procedures that required full knowledge of the stratospheric aerosol spectral optical properties did not perform significantly better than the trivial procedures, i.e., ignoring the stratospheric aerosol or simply subtracting the reflectance at 1380 nm from the other MODIS bands, we conclude that the latter two procedures should be applied to the atmospheric correction of SeaWiFS and MODIS, respectively.

(ii) No new progress this quarter.

(iii) No new progress this quarter.

(iv) No new progress this quarter.

c. Anticipated Activities During the Next Quarter:

(i) Complete paper on the analysis of the influence of stratospheric aerosol and submit for publication.

(ii) Devise a set of realistic vertical profiles for aerosols over the oceans. Use the multi-layer Monte Carlo code to compute the reflectance measured by MODIS in both the scalar (polarization ignored) and the vector (polarization included) modes. Use these as pseudo data in the atmospheric correction algorithm and evaluate the algorithm's performance.

(iii) Simulations described in (ii) above will be used to study polarization effects as well.

(iv) Begin simulations to understand how absorbing aerosols are treated by the atmospheric correction algorithm. We will also modify the correction algorithm so that a different set of candidate aerosol models can be employed when it is suspected that absorbing aerosols are present, and investigate the behavior of the subsequent algorithm in the presence of absorbing aerosols. The key to using such a procedure in practice will be to devise a way of knowing when absorbing aerosols are present, e.g., excessive aerosol reflectance in the NIR.

2. Whitecap Correction Algorithm.

a. Near-term Objectives:

As described in our previous reports, we constructed and tested a whitecap radiometer for development and validation of the whitecap correction algorithm. Based on its performance during the first deployment, objectives for the remainder of 1995 were:

(i) adding a video system to the whitecap radiometer to allow us to understand the radiometer signal and to remove artifacts more accurately;

(ii) rebuilding the 5 channel deck cell (which measures the downwelling irradiance) to increase stability and reliability (also, increase the number of channels from 5 to 6 to match the upwelling radiance channels of the whitecap radiometer);

(iii) integrating a meteorology package into the whitecap radiometer system;

(iv) reducing the data obtained during the October-November Hawaii MOCE-3 cruise; and

(v) testing the integrated system at sea and beginning acquisition of a whitecap- wind speed data set.

b. Task Progress:

We have currently finished integrating the meteorology package and video camera into the whitecap radiometer system. The 5 channel deck cell (really 6 now) has been rebuilt and is working well. We have also integrated instrumentation for collecting simultaneous data on the air and sea surface temperature into the system.

We tested the instrument at sea on two one-day cruises as a trial and to collect data with the entire system. The integrated system worked well and we are now looking at the data to devise data reduction strategies.

We had expected to participate in a short cruise in Hawaii during this quarter, however this cruise was delayed until later in the fall.

c. Anticipated activities during the next quarter:

We will deploy the instrumentation during a 14-day cruise off of Southern California and during a 5-day cruise off of Hawaii with Dennis Clark. This will hopefully give us a good opportunity to acquire data with higher wind speeds and copious whitecaps.

3. In-water Radiance Distribution Schedule.

a. Near-term Objectives:

Our near-term objective on this task is to acquire data at sea at the next opportunity.

b. Task Progress: None.

c. Anticipated Activities During the Next Quarter:

We are currently scheduled to use this system during a cruise out of Hawaii during this quarter.

4. Residual Instrument Polarization.

a. Near-term Objectives: None.

b. Task Progress: None.

c. Anticipated Activities During the Next Quarter:

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? Now that we have the capability of computing the polarization state of the top-of-atmosphere radiance, we shall begin to study this question. We will examine the visible sensors on MSX, which will probably be the first in-space instrument that can provide MODIS-like data. This instrument has greater polarization sensitivity than is anticipated for MODIS, so it should provide an excellent test of our methodology.

5. Direct Sun Glint Correction.

a. Near-term Objectives: None.

b. Task Progress: None.

c. Anticipated Activities During the Next Quarter: None.

6. Prelaunch Atmospheric Correction Validation Schedule.

The long-term objectives of this task are two-fold. First, we need to study the aerosol phase function and its spectral variation in order to verify the applicability of the aerosol models used in the atmospheric correction algorithm. Effecting this requires obtaining long-term time series of the aerosol optical properties in typical maritime environments. This will be achieved using a CIMEL sun/sky radiometer that can operate in a remote environment and send data back to the laboratory via a satellite link. These are similar to the radiometers used by B. Holben and Y. Kaufman. Second, we must be able to measure the aerosol optical properties from a ship during 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 have constructed an aureole camera.

a. Near term objectives:

Our near term objectives have been to deploy the CIMEL instrument locally so that we would be able to check its operation during a check out period. We anticipated field testing the solar aureole system during a cruise this summer; however, this cruise was delayed so we anticipate doing this during the next quarter.

b. Task Progress:

We have been operating the CIMEL instrument on the roof of a building at RSMAS on Virginia Key since July. The instrument has worked well with little attention required during this period. We have also received the permit to install the CIMEL in the Dry Tortugas. This location (a small island in the Gulf of Mexico off Key West, with little ground reflectance problems, particularly in the near infra-red) should provide a typical maritime atmosphere and is conveniently close to Miami. We believe that it could also serve as an ideal site for MODIS vicarious calibration exercises. We are planning to install the CIMEL instrument in the Dry Tortugas during late October. Due to the ferocity of the Hurricane season this year, we believed it would be better to hold off deployment until the season is nearly over, to avoid risking the instrument.

c. Anticipated activities during the next quarter:

We will be acquiring data with the aureole camera system, in conjunction with the sky radiance distribution camera system during the fall on a cruise with Dennis Clark. We will continue to collect data with the CIMEL locally. By the end of this quarter we plan to have the CIMEL instrument in place and operating on the Dry Tortugas.

7. Detached Coccolith Algorithm and Post Launch Studies.

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 showed that calcite-specific backscattering coefficient was less variable than coccolith-specific backscattering coefficient, and this would be more scientifically meaningful for future science that will be performed with this algorithm. The variance of the calcite-specific backscattering has been analyzed for only a few species, thus, we have been examining this in other laboratory cultures and field samples.

a. Near-term Objectives:

With this in mind, the near-term objectives of our coccolith studies this last quarter have been to measure the calcite-specific scattering coefficient using a combination of flow cytometry (for sorting calcite particles) and atomic absorption (for measuring associated calcite concentration). We now have access to a graphite furnace atomic absorption spectrometer, with three orders of

magnitude more sensitivity (50 pg Ca/ml) than the flame atomic absorption spectrometer at RSMAS. The strategy was to re-examine the calcifying algae in the Bigelow Culture Collection and measure volume scatter and calcite concentration on the same flow cytometer sorts. For example,
we sorted 100,000 coccoliths of Emiliania huxleyi with the flow cytometer(~25ng C or 83ng Ca), which, in a 5 mL final volume, gave a concentration of 16,600 pg Ca/ml (a signal to noise ratio >300 for the calcite determination).

b. Task Progress:

Species of calcifying algae (both coccolithophores and Thoracosphaera heimii, the calcifying dinoflagellate) were purchased from the Bigelow Laboratory Culture Collection, and grown in K media. Cultures were kept in the temperature-controlled rooms at Bigelow on a 14h:10h light:dark cycle. Cultures were harvested in logarithmic growth phase for sorting with an EPICS V flow cytometer with multi-parameter data acquisition. The calcite particles were sorted using the
birefringence properties of calcite. Polarizing filters were placed, at right angles, over a "quad" detector on the EPICS flow cytometer which has duplicate forward-angle scatter detectors (Olson et al., 1989). Olson previously showed that the ratio of horizontally to vertically polarized forward light scatter was about 3 for calcite particles and one for all others (we have found a ratio closer to 12 for coccoliths using the Bigelow Laboratory flow cytometer). This provided a highly effective method for discriminating and sorting calcite particles. Our experience from previous work was that we could perform the necessary set-up, cell counts and cell sorting for one species each day of the experiment. This required setting up our culturing activities at least 2.5 weeks prior to the beginning of the experiment. We also found that some of the species clumped easily, and needed to be transferred several times before they could be sorted effectively. Other clones never lost their clumping tendencies and sorting was an impossibility. In the end, we were able to examine 6 clones over the 1 week of flow cytometer time.

In past experiments, we have spent considerable time verifying the flow cytometer counts versus regular cell counts and generally found good agreement. Nevertheless, this is something that must be frequently verified, as accurate cell counts are absolutely critical to the final results. This experiment was no exception. It is mentioned here as this was one of the more time consuming controls that went into this work. One aspect that allowed this work to proceed more rapidly than in previous experiments, however, was that there was no need to sort plated cells since the goal was to define the backscattering coefficient per mg of calcite carbon.

c. Anticipated Activities During the Next Quarter

We have considerable sea time obligations in the next quarter (which also will involve sampling for the MODIS Detached Coccolith Algorithm). This will be in the Arabian Sea. Following this cruise, there will be considerable data work-up from the previous growth experiments, flow cytometer experiments (the graphite furnace samples still need to be run) and ship work (more graphite furnace samples plus under-way light scatter data). We anticipate that these activities will extend well into 1996.

8. Post Launch Vicarious Calibration/Initialization.

a. Near-term Objectives: None.

b. Task Progress: None.

c. Anticipated Activities During the Next Quarter:

We are initiating a critical examination of the effect of radiative transfer on "vicarious" calibration exercises. In particular, we are trying to determine the accuracy with which the radiance at the top of the atmosphere can be estimated based on measurements of sky radiance and aerosol optical thickness at the sea surface. We are carrying out a complete sensitivity analysis of the transfer process including the effects of earth curvature, polarization, sea surface roughness, and calibration error in the surface-based radiometer.

OTHER DEVELOPMENTS

A study of the effect of a bright target (such as a cloud), in the field of view of the MODIS, on the behavior of the atmospheric correction and bio-optical algorithms was carried out. Near-field scatter data provided by MCST was combined with simulations of the top-of-atmosphere clear-sky radiance over the ocean to effect the study for the protoflight instrument. The results were forwarded to Wayne Esaias for transmittal to the Team Leader.

REFERENCES

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