SEMI-ANNUAL REPORT

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OCEAN OBSERVATIONS WITH EOS/MODIS:

Algorithm Development and Post Launch Studies

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Following the format established in earlier reports, I shall describe developments (if any) in each of the major task categories separately.

1. Atmospheric Correction Algorithm Development.

a. Task Objectives:

During CY 1993, there were three objectives under this task:

(i) Complete and test the performance of the algorithm that was proposed for SeaWiFS and that we believe could form the basis of an atmospheric correction algorithm for MODIS.

(ii) Implement the preliminary code so that it can be tested and evaluated through the processing of SeaWiFS imagery.

(iii) Develop a method to correct imagery for the effects of the curvature of the earth. This will be required for imagery obtained at high latitudes.

b. Work Accomplished:

(i) Development and initial testing of the proposed SeaWiFS algorithm using simulated pseudo data has been completed and was described in the last Semi-Annual Report. A paper detailing the algorithm in now in press in Applied *Optics*.

(ii) Implementation of the prototype atmospheric correction algorithm on our image processing system and testing with CZCS imagery has been effected through collaboration with R. Evans and J. Brown. Operating with SeaWiFS data, the algorithm will use measured radiances near 765 and 865 run (where the ocean is essentially a black body) to correct the radiances in the visible for atmospheric effects. CZCS has only half of the spectral bands of SeaWiFS with no bands in the near infrared (NIR). Thus, there are no bands for which the ocean can be approximated as a black body. To test the implementation with CZCS data, we examined “clear” water imagery, e.g., the Sargasso Sea, for which the water-leaving radiance is known at three of the bands (520, 550, and 670 nm) and used the algorithm to derive the water-leaving radiance at 443 nm. The resulting water-leaving radiances were typically within one sensor digital count of the radiances derived with the

standard CZCS atmospheric correction algorithm. This suggests that the initial implementation software contains few coding errors; however, tests of the adequacy of the algorithm must await SeaWiFS data.

The CZCS test provided estimates for the minimum computational resources required to run the algorithm. The timing's that were determined for a single processor are provided in the table below. They refer to a CZCS image with about 50% clouds. Cloud pixels are not processed but they are counted in the total. The speed of the present algorithm is well above that required to

Speed (in pixels/s) of the implementation of the proposed SeaWiFS atmospheric correction algorithm

Computer	Frequency (MHz)	Rate (Pixels/s)
SGI 4D/480	40	181
SGI Indigo 2	150	509
DEC 3000/400	133	569
DEC 3000/500	176	679
DEC 7000/610	183	860

keep up with the SeaWiFS data flow; however, it must be increased — either through increases in CPU speed or algorithm modifications — to keep up with the volume of MODIS data. Possible modifications are being considered; however, their effectiveness must await the available of SeaWiFS data.

(iii) Our study of the effects of the curvature of the earth on the proposed SeaWiFS/MODIS atmospheric correction algorithm is now nearly complete. A paper on the study has been submitted for publication in *Applied Optics* and is attached as Appendix 1. Briefly, the study revealed that the effects of the curvature are only important at high latitudes, i.e., at large solar zenith angles, and that they can effectively be removed from the imagery by simply computing the contribution to the top-of-atmosphere radiance by Rayleigh scattering using a radiative transfer code for a spherical shell atmosphere rather than a plane parallel atmosphere, and then operating the rest of the correction algorithm as in the plane parallel atmosphere case.

c. Data/ Analysis/Interpretation:

(i) None.

(ii) None.

(iii) See Appendix 1.

d. Anticipated Future Actions:

(i) It is necessary to gain an understanding of why the algorithm fails in certain conditions and to try to develop ways to correct it, e.g., in atmospheres with strongly absorbing aerosols, and how the algorithm will perform when all polarization effects are included. Additional aerosol models must be investigated to understand the limitations of the algorithm. The influence of stratospheric aerosol (volcanic origin) must be assessed. To this end we have added a third layer to our basic radiative transfer code to simulate the effects of stratospheric aerosols on the performance of the algorithm and will also investigate polarization effects during the next calendar year. Finally, we need to perform an end-to-end algorithm test using simulated data the includes realistic vertical structure for the aerosol, polarization, and earth curvature. Our goal is to be able to at least have developed the end-to-end assessment code during 1994.

(ii) We will continue to work with GSFC on implementation of the algorithm for SeaWiFS processing. The state of the implementation at the end of January 1994 will constitute the first version of the MODIS code to be delivered to the MODIS SDST.

(iii) We will add polarization to the radiative transfer model for the spherical shell atmosphere and test our scheme (Appendix 1) for computing the Rayleigh scattering component of the top-of-atmosphere radiance.

e. Problems/Corrective Actions: None.

f. Publications:

(i) A paper “Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: A preliminary algorithm” by Howard R. Gordon and Menghua Wang is now in press in *Applied Optics.*

(ii) None,

(iii) A paper ‘Atmospheric correction of ocean color sensors: Effects of earth curvature” by

Kuiyuan Ding and Howard R. Gordon describing the results of this work has been submitted to *Applied Optics*.

2. Whitecap Correction Algorithm.

a. Task Objectives:

(i) During CY 1993 we planned to arrange to borrow the required CCD camera from NOAA and obtain some whitecap data at sea from a ship or aircraft. This would allow us to complete our evaluation of the feasibility of using the subject camera to carry out the whitecap study. It is important to note that present MODIS funding does not allow purchase of such a camera until CY 1995, so experimental data can only be obtained when the camera can be borrowed from NOAA coincident with available ship or aircraft time.

(ii) We also planned to survey the literature on whitecaps and develop a model so their effects on the SeaWiFS/MODIS atmospheric correction algorithm could be simulated.

b. Work Accomplished:

(i) During the period from June 7 to June 28 a large air-sea interaction experiment (sponsored by Office of Naval Research and Naval Research Lab [NRL]) took place off the coast of Maryland. This experiment was supported by two oceanographic ships, a blimp, and several aircraft. One of these aircraft, flown by NRL, carried the NOAA Xybion camera system. We believed this to be a very good opportunity to obtain data with which to evaluate the suitability of the Xybion system for studying the whitecap problem. During one week of the operations we monitored the data, during the time available before and after the flights, to check the operation of the camera. At that time the data appeared encouraging. Our plan was to examine this data to determine the effectiveness of the camera for our proposed whitecap study. We were able to borrow the camera and recorder during two weeks in November to perform calibrations on the system. At this time we also tested the VCR, on which all the data taken during the field exercise was recorded.

(ii) Based on available information relating whitecap reflectance to wind speed, whitecap albedo, etc., we have simulated the influence of whitecaps on radiance leaving the top of the atmosphere over the oceans to understand the performance of the SeaWiFS/MODIS atmospheric correction algorithm when whitecaps are present. Specifically, we started with the top-of-the-atmosphere

radiance simulated with whitecaps present and, based on the assumed presence of surface winds as ancillary data, estimated the contribution from the whitecaps and removed it from the simulated top-of-the-atmosphere radiance. However, because of the poor relationship between whitecap coverage and wind speed, the estimated contribution could have considerable error. By inserting radiances with incorrect whitecap correction into our implementation of the algorithm, the error in the recovered water-leaving radiance as a function of the error in the whitecap estimation was determined. The results suggest that present models of oceanic whitecaps, although very incomplete may be good enough to allow retrieval of the water-leaving radiance from SeaWiFS imagery, in an atmosphere dominated by aerosols with backscattering that is nearly independent of wavelength, e.g., maritime aerosols, with an accuracy within stated goals for wind speeds <~ 10 — 12 m/s. For an atmosphere dominated by any aerosol that scatters with a strong spectral signature, the simulations suggest that as long as the whitecap reflectance is not overestimated, the water-leaving radiance accuracy goal can be met for solar zenith angles <~ 60°; however, the error is roughly twice a large as for the maritime-like aerosol. Uncertainty in the whitecap contribution may set the ultimate limit on the accuracy with which the water-leaving radiance can be retrieved from ocean color imagery, as well as the accuracy with which aerosol properties can be retrieved from satellite radiances. This is discussed in greater detail in a paper we have submitted to *Applied Optics* and have included here as Appendix 2.

c. Data/Analysis /Interpretation:

(i) The calibration of the camera system went fairly well, however problems developed when working with the recorder. Basically, the recorder supplied with the camera system had an AGC circuit which made it impossible to obtain calibrated images from the tapes. This effect was particularly bad when whitecaps or other high reflectance objects are in the image. Because of this, no quantitative data from the field exercise was suitable for use in the whitecap program. The instrument is presently being fielded by NOAA and NRL with a new tape deck which does not have an AGC circuit. NRL will be performing tests on the ability to record data on tape and recover this data in a quantitative manner.

(ii) See Appendix 2.

d. Anticipated Future Actions:

(i) It is apparent that the without the complete Xybion camera system permanently resident at our laboratory, there is little chance that we will be able to acquire meaningful data with which to test the whitecap model. Thus, we will suspend activity in this area until funding permits actual purchase of the instrumentation.

(ii) We believe that it is important to test the whitecap model we are using with actual data, i.e., see if the model provides whitecap reflectance in the proper range for a given wind speed. However, we also believe that funding will never be sufficient to carry out a comprehensive whitecap study, so we will limit our activities to trying to collect sufficient data to verify that the model we are using is reasonable.

e. Problem/Corrective Actions: See item "2d" above.

f. Publications:

(i) None.

(ii) A paper 'Influence of Oceanic Whitecaps on Atmospheric Correction of SeaWiFS" by Howard R. Gordon and Menghua Wang has been submitted for publication to *Applied Optics.* It is included here as Appendix 2.

3. In-water Radiance Distribution Schedule.

a. Task Objectives:

During CY 1993 the objectives are to complete modification of the instrumentation and to start to obtain high-quality radiance data for studying the variation of the water-leaving radiance with sun and viewing angles.

b. Work Accomplished:

Instrument modification is nearly complete.

c. Data/ Analysis/Interpretation: None

d. Anticipated Future Actions:

Will deploy the instrument on the next MODIS cruise that we participate in.

e. Problems/Corrective Actions: None

f. Publications: None.

4. Residual Instrument Polarization.

a. Task Objectives: None

5. Direct Sun Glint Correction.

a. Task Objectives: None

6. Prelaunch Atmospheric Correction Validation Schedule.

a. Task Objectives:

The objectives of this task are two fold. First, we need to demonstrate that our atmospheric correction scheme will work to the required accuracy. To effect this we will apply the algorithm to compute the sky radiance in the blue from measurements in the near infrared. We should be able to do this to about the same accuracy as looking downward from space. Second, we need to study the aerosol phase function and its spectral variation in order to verify the applicability of the aerosol models. To effect these requires instrumentation for *measuring* the sky radiance and the optical thickness of the atmosphere. Such instrumentation is available in our laboratory and has been modified to operate with the relevant MODIS spectral bands. Our near-term objective is to learn how to invert sky radiance to obtain aerosol optical properties, to carry out such inversions, and to study the variation of the phase function with wavelength.

b. Work Accomplished:

Measurements of the sky radiance distribution were performed on a cruise in Monterey Bay during August . Also obtained during this cruise were measurements of the atmospheric optical depth. Similar measurements are now being made in Miami.

c. Data/ Analysis/Interpretation:

Much of the sky radiance data retrieved from the Monterey measurements does not appear to be useful. We attribute this to two problems: (1) the close proximity of land perturbed the radiance distribution in an unknown manner (our inversion routine requires the surface have a low albedo, e.g., the ocean); and (2) the atmosphere appeared to be horizontally inhomogeneous because the light field did not possess the proper symmetry with respect to the sun. The lack of proper symmetry could also be caused by the proximity of the land (a problem that the Miami-based measurements will also have).

d. Anticipated Future Actions:

Since at-sea measurements are required to complete this task, we will make every effort to acquire a data set at sea during the next calendar year. However, it will be necessary to build (or acquire) a second camera system. In our present whole-sky camera system, the image of the sun must be blocked, and for shipboard operation the shade must be oversized due to the motion of the ship. This means that the solar aureole cannot be obtained which makes the inversion much more difficult. Because of this, we are designing a separate aureole camera which we believe can be operated from the deck of a ship. When the design concept is complete, we will reprogram some funding planned for the whitecap study to build the camera.

e. Problems/Corrective Actions: None

f. Publications:

"Retrieval of the Columnar Aerosol Phase Function and Single Scattering Albedo from Sky Radiance over the Ocean: Simulations," M. Wang and H.R. Gordon, *Applied Optics,* 3245984609 (1993). This paper describes our scheme for inverting sky radiance measurements to obtain aerosol properties.

7. Detached Coccolith Algorithm and Post launch Studies.

a. Task Objectives:

There were no objectives for the first two years of the contract, and no funding has been directed toward this task. However, the PI has prepared an Algorithm Theoretical Basis Document (ATBD) for the detached coccolith algorithm based on present knowledge. Funding for this task will begin

in January 1994, and a key focus will be to try to generalize the algorithm to obtain calcite (rather than coccolith) concentration.

8. **Post Launch Vicarious Calibration/Initialization.**

a. Task Objectives: None

9. **Single Scattered Aerosol Radiance and PAR Algorithms.**

a. Task Objectives: None

Other Developments:

The PI submitted two ATBD's.

Publications

The following is a list of submitted, accepted, or published papers generated with full or partial support under this contract.

M. Wang and H.R. Gordon, Retrieval of the Columnar Aerosol Phase Function and Single Scattering Albedo from Sky Radiance *over* the Ocean: Simulations, *Applied Optics* 3245984609 (1993).

H.R. Gordon and M. Wang, Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: A preliminary algorithm, *Applied Optics* (Accepted).

M. Wang and H.R. Gordon, A Simple, Moderately Accurate, Atmospheric Correction Algorithm for SeaWiFS, *Remote Sensing of Environment* (Submitted).

H.R, Gordon and M. Wang, Influence of Oceanic Whitecaps on Atmospheric Correction of SeaWiFS, *Applied Optics* (Submitted).

K. Ding and H.R. Gordon, Atmospheric correction of ocean color sensors: Effects of earth curvature, *Applied Optics* (Submitted).