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

by

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Following the format of my monthly 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 1992, there are three objectives under this task:
i) Complete and thoroughly test our present radiative transfer codes and begin production runs and analysis with the goal of improving the performance of the algorithm that was originally proposed for SeaWiFS (Wang 1991) and that we believed could form the basis of an atmospheric correction algorithm for MODIS.

ii) Develop and test a radiative transfer code that accounts for the curvature of the earth. This will be used to study modifications to the atmospheric correction algorithm that may be required at high latitudes.

iii) Study the variation of aerosol scattering with wavelength and scattering angle using the aerosol models (size distributions and indices of refraction) that are utilized in the LOWTRAN code.

b. Work Accomplished:

i) Over the past several years have written several radiative transfer (RT) codes in support of our algorithm development effort. These include (1) scalar RT codes for a two-layer atmosphere bounded by a flat or wind-roughened Fresnel-reflecting ocean utilizing the successive order of scattering solution (van de Hulst 1980) and the matrix operator method (Plass, Kattawar, and Catchings 1973), and (2) vector codes for the same problem using the successive order of scattering solution. To be useful for algorithm development, it is necessary that these codes yield radiances that are accurate to 1-3 parts in 1000. This accuracy exceeds the capabilities of most codes, thus assuring that the codes can in fact yield such accuracies is difficult. We can compare the output of our code with the solution of standard problems, e.g., Rayleigh scattering in a homogeneous atmosphere (Coulson, et al., 1960) which should have such accuracy; however, there are very few such problems that are useful for our codes. Our approach has been to apply different numerical solutions to a particular problem and require that they agree to the required accuracy. This is a slow and tedious process, requiring the development of two codes with the required accuracy rather than one. This process has now been completed for our scalar codes. In conjunction with (ii) and (iii) above, we have carried out a detailed comparison between our scalar code for a flat ocean (with a rough surface) and a Monte Carlo code for the same problem, using the LOWTRAN aerosol models to provide the scattering phase functions for the aerosols. The two codes provide radiances that agree to within approximately 2--3 parts out of 1000 under the least favorable conditions. Because of this we have started to use the successive order of scattering code to produce the initial set of look up tables to be utilized by the SeaWiFS atmospheric correction algorithm --- the MODIS prototype.

We have also modified our full vector code to compute accurate downwelling radiances to be used to test our method for inverting sky radiance to derive aerosol properties (see major task category 6 below).

ii) The development of an accurate (approximately 1--2 parts per 1000) Monte Carlo code for RT in a spherical shell atmosphere bounding a rough, Fresnel-reflecting, ocean has been carried out in stages. First, we developed a basic code to handle Rayleigh scattering in an atmosphere above a totally absorbing surface. The results of this code agreed well with those of Adams and Kattawar (1978) and with our standard code when the radius of the earth is allowed to become very large, i.e., the spherical shell atmosphere goes over to a plane parallel atmosphere when the radius of the shell goes to infinity. [The agreement with Adams and Kattawar is at the 1--2 parts per 1000 level.] Next, we added a smooth Fresnel-reflecting sea surface to the bottom of the spherical shell atmosphere and, again, tested the results by taking the limit as the radius of the shell becomes very large. Finally, we have added a wind-roughened Fresnel-reflecting surface. Testing the wind ruffled case by taking the limit as the radius of the earth goes to infinity and comparing with the successive order code because the treatment of the sea surface using the Cox and Munk (1954) surface slope density function is approximate in both codes, i.e., the Monte Carlo code takes multiple reflection from the sea surface into account while the standard analytical codes do not. Thus, we were able to test in only against the Monte Carlo code for a plane parallel atmosphere over a rough ocean. We believe the error is at most approximately 3 parts per 1000. We have started using this code to investigate the error induced in the CZCS algorithm by the assumption of a plane parallel atmosphere.

iii) A central feature of all atmospheric correction algorithms for oceanic imagery is that the properties of the atmosphere (in particular the aerosol) are assessed in the NIR portion of the spectrum where the ocean is almost totally absorbing. This assessment must then be utilized to provide a correction in the visible (in the case of MODIS down to 412 nm). To help in understanding how one should extrapolate measurements of the aerosol in the NIR into the visible we examined the properties of several standard aerosol models in this regard. Our plan was to use the LOWTRAN 7 aerosol models (Shettle and Fenn 1979) to quantify the relationship between the spectral variation of the aerosol optical thickness and the spectral variation of the single-scattered aerosol reflectances. To this end we developed as set of Mie scattering codes to compute the aerosol phase functions an extinction coefficients for the LOWTRAN models. These have been used to generate the optical properties for several LOWTRAN models, which have then been used in our RT codes to simulate the radiance at the top of the atmosphere.

c. Data/Analysis/Interpretation:

i) On the basis of the results of the simulations using the realistic LOWTRAN aerosol models described under (iii) above, we found it necessary to develop an entirely new approach to the proposed atmospheric correction algorithm. The problem was that the spectral variation in the single-scattered aerosol radiance did not follow a simple law that would enable extrapolation into the visible from the NIR. Furthermore, the multiple scattering effects were found to be strongly dependent on the aerosol model. The new algorithm is presented in the Appendix to this report. It is our major accomplishment during this reporting period.

ii) None.

iii) See item (i) above.

d. Anticipated Future Actions:

i) Our proposed algorithm for atmospheric correction will utilize a set of look up tables (generated from various aerosol models) for its implementation. We are now generating a preliminary set of tables (coarse resolution) that will be used with SeaWiFS.

We also need to examine more aerosol models to determine the minimum required for an adequate atmospheric correction.

ii) We will examine the influence of earth curvature on the newly proposed SeaWiFS algorithm.

iii) No further action planned above that in (i) above.

e. Problems/Corrective Actions:

i) Even the preliminary set of simulations for constructing the coarse look up tables for SeaWiFS is very computationally intensive. For example, our scalar RT code, which includes scattering by molecules and aerosols, vertical stratification of the atmosphere approximated by two layers (molecules and aerosols in the lower layer, molecules only in the upper layer), and a stochastically rough Fresnel-reflecting air-sea interface, requires about 1.5 hours to run a single simulation on a DECstation 5000/200. These preliminary SeaWIFS look up tables consist of all combinations of nine aerosol models (phase functions), eight aerosol optical thicknesses, fifteen sun angles, eight wavelengths and a single wind speed (0), which would require a total of 9x8x15x8x1x1.5 hours or about 1.5 years. Please note that these computations are short of the those required for the full lookup tables. We estimate that the full lookup tables will require forty sun angles, twenty phase functions, and at least four wind speeds, or approximately 24 times the preliminary computation above. Thus the SeaWiFS algorithm when fully implemented will have required about 35 years of DECstation 5000/200 CPU time just to generate the lookup tables. In the case of MODIS, the computations will probably have to be done in the vector mode (includes polarization) and vector code is 4 times slower than the scalar code (four elements of the Stokes vector are required), so lookup tables with the same resolution will require about 140 years on our existing DECstation.

Presently, we are addressing this computational burden with the help of Robert Evans and unused CPU cycles on a large number of DECstations which are dedicated to other projects; however, we have totally ``out grown'' our computational facilities. This is discussed in considerable detail in our ``Team Member Computer Facilities Plan'' submitted during this reporting period.

ii) The code for this analysis is very computational intensive (Monte carlo) and we face a critical shortage of CPU cycles.

iii) None.

e. Publications:

i) A paper will be submitted in the next 6 months.

ii) None.

iii) None.

2. Whitecap Correction Algorithm.

a. Task Objectives:

During CY 1992 we planned to arrange to borrow the required CCD camera from NOAA and complete its calibration. We also planned to try to obtain some whitecap data by deploying the instrument either from a ship or a bridge/dock. This will 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 time.

b. Work Accomplished:

We initially anticipated borrowing the camera from NOAA for a cruise in Monterey Bay in August. However, in discussions with NOAA it was discovered that the instrument was already loaned to NASA/Wallops (F. Hoge) for use in overflights of a JGOFS leg in the central Pacific Ocean. The same group was also planning to work in conjunction with the cruise doing overflights, thus we made arrangements to obtain the camera data after their operations. This would have allowed us to have a much expanded data set to work with. Unfortunately the camera failed during the initial operations and no data was acquired.

c. Data/Analysis/Interpretation: None

d. Anticipated Future Actions:

The camera system has been fixed by NOAA. We are presently arranging for the camera system to be used during an unrelated cruise in March. NOAA has agreed to send us the system in February for use during February and March. We anticipate being able to test this camera during this cruise and obtain shipboard measurements of whitecaps.

e. Problems/Corrective Actions: None

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 time.

f. Publications: None.

3. In-water Radiance Distribution Schedule.

a. Task Objectives:

During CY 1992 the objectives are to modify 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:

The new instrument was tested at Lake Pend Oreille, Idaho. Initial data from this cruise have been analyzed.

c. Data/Analysis/Interpretation:

Initial test data have been analyzed mainly to look at instrument response and performance.

d. Anticipated Future Actions:

Information from the test will be used to improve the system operation. The camera system will then be used in field work in the coming summer or early fall of this year.

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 computing the sky radiance, which we should be able to do at about the same accuracy. Second, the complex nature of the spectral variation of the scattering phase function that is being revealed in the computations described under Task 1, item (iii), above will have to be verified and if true, the methods developed under this task will be used to try to better understand this spectral variation. 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 is being 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.

c. Data/Analysis/Interpretation: None.

The atmospheric optical depth data from this cruise have been reduced. We are presently reducing the sky radiance distribution data.

d. Anticipated Future Actions:

We will complete the data reduction on the sky radiance distribution data, early this year and start working this data into the phase function retrieval models.

e. Problems/Corrective Actions: None

f. Publications:

A manuscript ``Retrieval of the Columnar Aerosol Phase Function and Single Scattering Albedo from Sky Radiance over the Ocean: Simulations,'' by M. Wang and H.R. Gordon, has been accepted by Applied Optics. It describes a possible scheme for inverting sky radiance measurements to obtain aerosol properties. The reported work received partial support from the project

7. Detached Coccolith Algorithm and Post Launch Studies.

a. Task Objectives: None

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 new atmospheric correction algorithm for SeaWiFS (on which MODIS will build) was presented in a one-hour oral report to the full MODIS Ocean Group during the MODIS Science Team October meeting.

The PI reviewed the MODIS Software and Data Management Plan.

The PI completed his Team Member Computer Facilities Plan.

Finally, the second MODIS Semi-Annual report was prepared and submitted.

References

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