QUARTERLY REPORT

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

by

Howard R. Gordon
University of Miami
Department of Physics
Coral Gables, FL 33124

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ABSTRACT

Much of this reporting period has been focussed on the continued development of our whitecap radiometer system, and our ship-borne solar aureole camera. The first draft of a validation plan for normalized water-leaving radiance was prepared and submitted for incorporation into the MODIS Ocean Group validation plan.

REPORT

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

1. Atmospheric Correction Algorithm Development.

a. Near-term Objectives:

(i) Investigate 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) We are continuing our effort to understand how to utilize the 1380 nm MODIS spectral band to atmospherically correct imagery for the effects of stratospheric aerosol and/or thin cirrus clouds. As described in our last semiannual report, we found that relatively simple algorithms utilizing the reflectance in this band appeared to perform well in cases in which the stratospheric aerosol could be represented by the volcanic and/or background stratospheric aerosol models. However, the results of further computations with a cirrus cloud model (hexagonal ice crystals) for the stratospheric aerosol appeared to negate this conclusion. We expected a better atmospheric correction for the cirrus cloud model because of the weak dependence of optical depth with wavelength; however, it was much poorer. We are presently attempting to understand the source of the problem.

(ii) No new progress; see (iii) below.

(iii) We have added polarization to our 50-layer Monte Carlo radiative transfer code, which includes a surface roughened by the wind. For cases that can also be handled with our successive order of scattering code (with two layers), a careful comparison between the results of the two codes indicated that the computed radiances agreed to better than 0.06% for a Rayleigh scattering atmosphere. This suggests that each code is capable of computing the radiance to at least this accuracy, which is better than the maximum error of 0.10% required for atmospheric correction algorithm development and testing. We are now modifying the code to accept aerosols and expect this will be completed in the next quarter.

(iv) We have acquired modeled optical properties of "yellow dust" (from the Gobi desert) and will begin simulations to understand how such absorbing aerosols are treated by the atmospheric correction algorithm.

c. Anticipated Activities During the Next Quarter:

(i) Continue examination schemes for employing the 1380 nm band for correcting for stratospheric aerosols. In particular, try to understand the poor performance of simple correction techniques in the presence of cirrus clouds.

(ii) Upon completion of the Monte Carlo code including polarization described in (iii), produce a complete set of pseudo data to test the effects of both vertical structure and polarization on the correction algorithm.

(iii) Finish adding aerosols to the Monte Carlo code which now includes polarization as well as a rough surface.

(iv) Begin simulations to understand how such absorbing aerosols are treated by the atmospheric correction algorithm.

2. Whitecap Correction Algorithm.

a. Near-term Objectives:

As described in our last Semi-Annual Report, 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 near-term are;

(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, and

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

b. Task Progress:

We have selected the video system, obtained NASA permission to procure it, and ordered the camera from the vendor. The camera system will consist of a Sony color security camera (SSC-C350), with a HI-8 video recorder (Sony EVC100), and an in-line time/date generator. This will allow us to obtain camera images with a time date stamp which will enable matching the whitecap radiometer data and the video images.

We have all of the parts required for rebuilding the deck cell and now have the meteorology package in house.

We have carried out some preliminary data reduction of the whitecap data acquired during the first deployment. The basic result thus far is the requirement for simultaneous video imagery to enable the removal of artifacts. We are continuing analysis of the small quantity of data obtained during the few instances we were able to borrow a video camera from Dennis Clark, in order to develop a procedure for data analysis.

c. Anticipated activities during the next quarter:

We will complete the rebuilding of the 5 channel deck cell, and the integration of the meteorology package. We also anticipate having the video camera integrated into the system by the end of this next quarter. We are planning to participate in a cruise with Dennis Clark this summer (June-July) off Hawaii, and will deploy the complete system during this cruise.

3. In-water Radiance Distribution Schedule.

a. Near-term Objectives: None.

b. Task Progress: None.

c. Anticipated Activities During the Next Quarter:

We will be acquiring data at the earliest opportunity, probably during cruises scheduled in June-July 1995 and fall 1995.

4. Residual Instrument Polarization.

a. Near-term Objectives: None.

b. Task Progress: None.

c. Anticipated Activities During the Next Quarter: None.

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 be operated 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 must construct an aureole camera.

a. Near term objectives:

To assemble, characterize and calibrate a solar aureole camera system. To develop data acquisition software and test the system. To acquire a CIMEL Automatic Sun Tracking Photometer, calibrate it and deploy it in a suitable location.

b. Task Progress:

We have the solar aureole camera system assembled, along with a trial version of the data acquisition software. We have taken test images, and are working to optimize the system performance. We have just received the CIMEL instrument from the manufacturer (April 13, 1995), and will be sending it to Brent Holben (NASA/GFSC) to do a comparison calibration with his instruments which have been calibrated at Mauna Loa, HI.

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 summer on a cruise with Dennis Clark. We will test the CIMEL locally. By the end of this quarter we plan to have the CIMEL instrument in place in a suitable location. At this point we are investigating the possibility of installing the instrument 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 maritime atmosphere and is conveniently close to Miami. We believe that it could also serve as an ideal site for MODIS vicarious calibration exercises.

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 need to examine this in other laboratory cultures and field samples. There is also a relationship between the rate of growth of the calcifying algae and the rate of production and detachment of the coccoliths which needs to be further quantified.

a. Near-term Objectives:

With this in mind, the objectives of our coccolith studies are, under conditions of controlled growth of coccolithophores (using chemostats), to define the effect of growth rate on:

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

2) rates of coccolith production;

3) morphology of coccoliths; and

4) volume scattering and backscattering of coccoliths.

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.

b. Task Progress:

In the last 3 months, we have run the first chemostat growth rate experiments. These involve maintaining chemostats at steady state growth rates for a minimum of 5d, before each sampling. Each of 6 growth rates will be sampled three times. This, combined with the minimal 5d waiting period means that the full experiment will require several months total. For each sample, the volume scattering functions are measured, scanning electron and light micrographs are taken for coccolith concentration, size, and thickness calculations, and atomic absorption measurements are performed to determine the carbon content of the coccoliths. The volume scattering functions are then used to calculate the backscattering coefficients which will then be used for a MODIS calcite algorithm. It is anticipated that the first chemostat experiments will be completed by May 1, 1995.

The field coccolithophore work has been written into 2 manuscripts and submitted to Limnology and Oceanography for publication. The first paper has been returned for revision and should be returned to Limnology and Oceanography shortly. I have not received reviews on the second paper yet. A third manuscript on calcite distributions in the Equatorial Pacific has also been submitted to Deep Sea Research, and is currently in revision.

c. Anticipated Activities During the Next Quarter:

Continue trials with our new chemostat reactors.

8. Post Launch Vicarious Calibration/Initialization.

a. Near-term Objectives: None.

b. Task Progress: None.

c. Anticipated Activities During the Next Quarter: None.

9. Single Scattered Aerosol Radiance and PAR Algorithms.

a. Near-term Objectives: None.

b. Task Progress: None.

c. Anticipated Activities During the Next Quarter: None.

OTHER DEVELOPMENTS

The PI participated the MOCEAN Team meeting and the Multisensor Calibration and Validation Workshop in Miami in February 1995. Also, the PI prepared a first draft of a validation plan for normalized water-leaving radiance and forwarded it to Frank Hoge and Wayne Esaias for incorporation into the MODIS Ocean Products Validation Plan. This draft is included here as an appendix. A shortened version was prepared for the report of the Multisensor Calibration and Validation Workshop to be submitted to NASA Headquarters.

APPENDIX

Validation of Normalized Water-leaving Radiance (Atmospheric Correction)

Preface

In the preparation of this validation plan, it has been assumed that there will be a series of MODIS Ocean Team (MOCEAN) validation cruises. Unless otherwise indicated, the activities described in this plan are envisaged to take place on these cruises. Specific details, such as station locations and the schedule of events at each station, will be provided in the individual cruise plans. The instrumentation to obtain the required data and the methods of data analysis are identified here.

I. Scope of validation.

For validation of atmospheric correction, we mean quantification of the expected uncertainty associated with the retrieval of the water-leaving radiance from measurement of the total radiance exiting the ocean-atmosphere system combined with measurement or estimation of auxiliary data required in the retrieval process, e.g., surface wind speed, surface atmospheric pressure, total column Ozone concentration. For a proper validation, this quantification should be carried out over the full range of water-leaving radiance values (determined largely by the phytoplankton pigment concentration in Case 1 waters) and the full range of atmospheric types expected to be encountered in the retrievals.

II. Introduction.

There are several components required in the process of atmospheric correction. [See Gordon and Wang (1994) and the Normalized Water-leaving Radiance Algorithm Theoretical Basis Document (Version 2) by H.R. Gordon for a complete description of the proposed SeaWiFS/MODIS atmospheric correction algorithm.] The most important is the removal of the aerosol component from the sensor-measured radiance. Unlike the earlier CZCS algorithm, in the SeaWiFS/MODIS era, accuracy requirements force one to address the issue of multiple scattering in a quantitative manner. Assessing multiple scattering is accomplished by examination of the aerosol component of the radiance in the near infrared, where the water-leaving radiance is negligible except in very turbid coastal waters, to select an aerosol model for extrapolating the result into the visible. The models that are currently employed in the prototype MODIS algorithm (the SeaWiFS algorithm) are those provided by Shettle and Fenn (1979). These aerosol models were developed to predict atmospheric transmission and, although widely used, have not been validated for the radiative transfer computations required in remote sensing. Such a validation is the subject of research at the present time and will be on-going during the initial phases in the validation of SeaWiFS imagery. As this validation is incomplete at present, we shall assume it is a subject to be addressed in this plan.

Other components of the full atmospheric correction algorithm requiring validation are the whitecap and residual sun glitter removal algorithms, which are based on estimates of the wind speed from numerical weather models, and the stratospheric aerosol/thin cirrus cloud component removal algorithm, which is based on utilizing the MODIS 1380 nm band.

III. Validation Concerns and Recommended Approaches.

At the very basic level, sensors utilizing algorithms based on the use of aerosol models must be validated initially under the most favorable of conditions, i.e., a relatively clear atmosphere as would be found over the open ocean free of land and anthropogenic sources. In such a region, the aerosol is likely to be locally generated and reside in the marine boundary layer. Also, the within-pixel variability of the water-leaving radiance will be small if the validation site is properly chosen. In the absence of intense stratospheric aerosol, as might be present following a volcanic eruption, and in the absence of thin cirrus clouds, only whitecaps and residual sun glitter are required to be removed in order that conditions satisfy those assumed in the development of the correction algorithm, i.e., a relatively clear two-layer atmosphere with aerosols in the lower layer. Such a location is also ideal for vicarious calibration, and for initialization --- the initial post-launch adjustment of the sensor calibration based on a complete radiative transfer model of the air column. Under such conditions, the error in the water-leaving radiance due to the aerosol removal should be small, and specifying this component of the error field under these conditions relatively simple. Also, errors due to whitecaps and sun glitter may make a significant contribution to the overall error and such a location would be ideal for specifying the error fields due to these processes.

Recommendation (1): Perform a validation experiment in a region that is expected to be dominated by a locally-generated aerosol and over waters with a low pigment concentration, e.g., the waters off Hawaii. Along with the basic aerosol correction, such a region will also be essential for validating the whitecap and sun glitter removal algorithms. If permanent, such a site would also be invaluable for continuous vicarious calibration of MODIS.

There are two situations in which the atmospheric correction algorithm as presently formulated may not retrieve the water-leaving radiances within acceptable error limits: situations in which the aerosol is strongly absorbing, but the absorption is relatively independent of wavelength (urban aerosols transported over the oceans); and situations in which the aerosol is absorbing with a wavelength-dependent absorption (desert dust transported over the oceans). The reason for the difficulty is that near infrared spectral measurements of the spectral radiance resulting from the aerosol is not as good an indication of the aerosol influence in the visible as in the case of nonabsorbing or weakly-absorbing aerosols. This is particularly true in the case of desert dust for which the aerosol absorption properties can change considerably from the near infrared to the visible. We are examining the possibility of using the short-wave infrared bands on MODIS to help in identifying the presence of these aerosols so that appropriate aerosol models can be invoked to effect the correction; however, at present this idea is only under study. Clearly, it will be important to perform validation in regions and times where significant amounts of absorbing aerosol are expected to be present over the water; first, to validate methods of dealing with the correction, and second, to estimate the upper limit to the aerosol concentration in which a valid correction can be effected. In the case of urban pollution an ideal location is the Middle Atlantic Bight during summer (excellent logistics as well). For desert dust there are two important regions: (1) the North Pacific (Gobi desert influence) and the Tropical North Atlantic (Saharan desert influence).

Recommendation (2): Perform validation studies in regions expected to be influenced by strongly absorbing aerosols. Examples are the Middle Atlantic Bight (urban pollution) and the Northwest Pacific and Tropical North Atlantic (desert dust).

It is also desirable to validate the water-leaving radiances at high latitudes in which the curvature of the earth can be important because of the possibility of very large solar zenith angles. Ding and Gordon (1994) have predicted that for sun angles greater than 70-75 deg, significant errors in atmospheric correction are possible if the atmosphere is assumed to be plane parallel. They provided a correction method, which unfortunately cannot be validated using CZCS because of its insufficient radiometric sensitivity. Such a validation study will be attempted for SeaWiFS.

Recommendation (3): Perform a validation exercise at high latitude to assess the quality of the earth-curvature correction component of the basic algorithm.

In order to utilize MODIS in the more turbid Case 2 waters near coasts, it is critical to understand the limitations that significantly higher (than typical oceanic) concentrations of suspended particulate matter place on atmospheric correction. Thus, validation of normalized water-leaving radiance should be carried out in a coastal region of spatially varying turbidity. Such a validation could be effected in the Middle Atlantic Bight (suggested above for urban aerosol validation) by making measurements at a set of stations successively closer to the coast. In this manner, it may be possible to combine the validation cruises for studying the limitations imposed by urban aerosols and by waters of high turbidity.

Recommendation (4): Perform a validation exercise in waters of high turbidity to assess the limitations on the correction algorithm imposed by increasing quantities of suspended particulate matter.

It is important to examine in detail the influence of stray light from bright targets (ghosting, internally reflected and scattered light, etc.) in the MODIS focal plane fields-of-view, on atmospheric correction. For example, how close can one perform adequate atmospheric correction to a cloud bank or coastline? This can be effected by examining the atmospheric correction in broken cloud fields and near islands in clear water. The Hawaii MOBY mooring site appears to be ideal for such studies. These would provide error bounds on normalized water-leaving radiances under such conditions. This single site should be adequate for assessing this component of the error field.

Recommendation (5): Perform validation to relate the effects of internally scattered light within the MODIS instrument to the accuracy of the normalized water-leaving radiances

Finally, validation of the removal algorithm for stratospheric aerosols and/or thin cirrus clouds is also required; however, it will not be necessary to conduct a focussed validation experiment for this purpose. One need only track the quality of the atmospheric correction in the experiments recommended above with regard to the scene reflectance at 1380 nm (used to indicate the presence and amount of stratospheric aerosol and/or thin cirrus) to assess the efficacy of this component of the algorithm.

IV. Validation Data Acquisition Plans and Recommendations.

The fundamental data required for the validation of the normalized water-leaving radiance is obviously the normalized water-leaving radiance itself. This quantity can be measured using ships, buoys, or drifters. A full spectral measurement is best so that the validation data can be combined with the sensor's spectral response to provide the expected sensor output. In regions where significant horizontal gradients can be present (e.g., the Middle Atlantic Bight) it will also be necessary to assess the within-pixel variability. This assessment can be effected by surveying the vicinity of the station before and after the satellite overpass with the ship and/or by aircraft-borne sensors. Measurements of the normalized water-leaving radiance are usually made with nadir-viewing radiometers; however, it is known (Morel and Gentilli, 1993) that the water-leaving radiance can depend on both the viewing geometry and the solar zenith angle, i.e., the water-leaving radiance viewed at an angle of 45 deg with the surface is not the same as that viewed at nadir. This must be considered for validation of any given sensor over its entire range of scan angles. To effect the water-leaving radiance validation, we plan to utilize the measurements of subsurface upwelling (nadir only) radiance to be made by D. Clark using a spectrometer with approximately 5 nm resolution. We will also measure the complete subsurface upwelling radiance distribution at several visible wavelengths utilizing a radiance camera system developed by Voss (1989). Combining these data will provide the appropriately corrected water-leaving radiance for the actual MODIS viewing geometry at the time of the validation exercise.

Planned water-leaving radiance (WLR)-related measurements (MOCEAN validation cruises):

A. Spectral WLR (ships)
B. Assess within-pixel variability (ships, aircraft)
C. Water-leaving BRDF at a few wavelengths (ships)

In addition to ship-based measurements, the water-leaving radiance can be measured from buoys and drifters as well. These can provide an important source of additional validation data, albeit at a reduced level of accuracy (nadir-viewing only) and without the auxiliary measurements required for algorithm "fine tuning" (see below). These data would also be valuable for understanding the radiometric stability of the instrument. Such measurements are strongly recommended for extending the geographical area of coverage available for validation. This is important for providing validation over the full range of expected water-leaving radiances.

Recommended water-leaving radiance-related measurements:

Spectral WLR from buoys and drifters

It is to be expected that in some cases the satellite-derived normalized water-leaving radiances will not agree with the surface measurements within the required error limits. In such cases it is important to understand what part of the atmospheric correction algorithm is at fault in order to facilitate algorithm "fine tuning." Since the major (highly variable) component to be removed during atmospheric correction is the aerosol, it is important to make detailed measurements of the columnar aerosol optical properties as part of the over-all validation effort. Quantities to be measured include the spectral aerosol optical thickness and the spectral sky radiance, both close to (the aureole) and far from the sun. From such measurements, it is possible to obtain the columnar aerosol size distribution, aerosol phase function and aerosol single scattering albedo, an index of the aerosol absorption (King et al. 1978, King and Herman 1979, Nakajima et al. 1983, Wang and Gordon 1993, Kaufman et al. 1994). This data will be used to determine the applicability of the aerosol model selected by the algorithm for use in the atmospheric correction, and to provide a determination of the presence or absence of strongly absorbing aerosols. As mentioned in Section III, the correction algorithm is based on the assumption that all of the aerosol is locate in the marine boundary layer. (Note that this may be changed based on experience derived from SeaWiFS imagery; however, the correction algorithm will, of necessity, be based on some "standard" vertical profile of aerosol concentration.) Thus, an additional possibility for degradation in the accuracy of the retrieved water-leaving radiances is the presence of significant quantities of aerosol in the free troposphere or the stratosphere. For instruments like MODIS, which have spectral bands capable of detecting stratospheric aerosol and thin cirrus clouds, the contamination due to the presence of these components will be partially removed. Although surface measurements described above may be capable of detecting the presence of stratospheric aerosols (Kaufman et al., 1994), the most direct technique of detecting deviations from the assumed vertical structure of the aerosol is LIDAR, and such measurements, either ship-borne or air-borne, should be included in validation exercises. Such at-sea LIDAR measurements would also be extremely valuable in pre-launch algorithm development work to develop a climatology of aerosol vertical profiles over the oceans.

We plan to acquire the necessary aerosol validation data as follows. On MODIS Ocean Team validation cruises we will employ multichannel sun photometers to measure the aerosol optical thickness as a function of wavelength. A sky radiometer (Voss 1989) will be used to measure the sky radiance distribution (radiance as a function of position in the sky) at several wavelengths over the visible and NIR regions of the spectrum. This will provide the sky radiance required to operate the Wang and Gordon (1993) phase function and single scattering albedo retrieval algorithm. A newly-developed solar aureole camera for operation on board ship will be used to measure the solar aureole at several wavelengths. This will improve the accuracy of the retrievals using the Wang and Gordon (1993) algorithm and also allow derivation of the size distribution using the methods described by Kaufman et al. (1994). Further, we have proposed to develop a compact atmospheric LIDAR system that can be operated easily aboard ship (Shevey, Gordon and Voss: Proposal to the NASA Innovative Research Program). We believe that such a ship-based LIDAR will be more cost effective and logistically effective than aircraft-based LIDAR because, unlike the aircraft-based systems, which require considerable advanced planning (and cooperating weather) to support ship operations, ship-based LIDAR will be available on a daily basis to provide support to the ship-based validation campaigns. If this proposal is funded the LIDAR system will be used during the validation experiments.

In addition to the ship-based validation studies, we plan to carry out experiments in which an automated sun/sky radiometer (built by CIMEL Electronique) will be placed on remote islands near regions in which the optical properties of the water are relatively stable. The main purpose of this is to provide atmospheric data for the vicarious calibration (Koepke 1982, Fraser and Kaufman 1986, Slater et al. 1987, Gordon 1987, Evans and Gordon 1994) of MODIS, particularly the red and NIR bands; however, in the proper ocean setting --- stable optical properties with low phytoplankton pigment concentration so the normalized water-leaving radiance can be predicted in the green through near infrared regions of the spectrum (Gordon and Clark 1981) --- MODIS data acquired over such a location could provide additional validation for the green through NIR MODIS bands. Aerosol optical thickness data from such locations will also provide a validation of the MODIS-derived aerosol optical thickness, a by product of the MODIS atmospheric correction algorithm.

Planned aerosol-related measurements:

A. Aerosol optical thickness (ships, islands)
B. Sky radiance for aerosol properties (ships, islands)

1. CIMEL-type instruments (islands)
2. All-sky camera (ships)
3. Aureole camera (ships)

Recommended aerosol-related measurements:

Aerosol vertical profile (LIDAR from islands, ships, aircraft)

Other major contributors to the radiance measured by a satellite radiometer include the whitecaps and sun glitter. The algorithm estimates their contribution based on the wind speed and direction. The estimate of the sun glitter contribution is based on the Cox and Munk (1954) surface slope distribution. It is generally accepted as being correct for slopes relevant to the direct sun glitter. Its applicability to large slopes is unknown and would be difficult to determine; however, their contribution should be small (Gordon and Wang 1992a, 1992b). Thus, we shall simply assume that the Cox and Munk distribution is correct. Whitecaps present a more important problem. We are collecting data with a newly-developed whitecap radiometer to validate the whitecap retrieval algorithm that was based on historical data. In particular, we need to establish the relationship between the whitecap-enhanced surface reflectance and the wind speed. Also, we need to know the spectral nature of the enhanced reflectance, as recent whitecap measurements suggest that the assumption of a nonspectral reflectance may not be valid (Frouin, Schwindling, and Deschamps 1995). Thus, it is important to measure the contribution of whitecaps along with the wind speed and direction during validation exercises. We plan to utilize the newly-developed whitecap radiometer to measure the spectral enhancement of the water-leaving reflectance due to the presence of the whitecaps. Wind speed and direction will be measured as well by observing the winds on deck and using a GPS unit and to provide the absolute speed and direction of motion of the ship.

Planned surface structure measurements:

A. Whitecap spectral reflectance enhancement (ship-borne radiometer)
B. Wind speed and direction (ships)

Aircraft measurements of the whitecap-enhanced reflectance of the sea surface would also be highly desirable. In such an application, one would image the sea surface (in several spectral bands) with sufficient spatial resolution to be able to identify whitecap-free areas. The reflectance of an entire scene (the average over all pixels) minus the reflectance of the whitecap-free pixels, would provide the reflectance enhancement. Such measurements were originally proposed for development of a whitecap removal algorithm, but were abandoned due to financial constraints.

Recommended surface structure measurements:

Whitecap spectral reflectance enhancement

Finally, there are several additional parameters that are used in the atmospheric correction algorithm and are estimated based on numerical weather models or measurements from MODIS or other satellite sensors, e.g., surface pressure and total Ozone concentration. These should be measured during all validation exercises.

V. Identification of key regions for validation.

Based on the discussion above regarding atmospheric correction concerns (Section II), four general locations for validation are recommended.

A. Middle Atlantic Bight (Urban aerosol, Turbid water)
B. Sea of Japan and Equatorial Atlantic (Dust)
C. Very high-latitude site (Earth curvature, Resolute Bay, Canada?)
D. Hawaii (Strong winds, e.g., trades, for whitecaps and glitter, clear air for aerosol models, Bright target effects)

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