Use of Multiangle Satellite Observations To Retrieve Aerosol Properties and Ocean Color

John Martonchik[1], David Diner[1], and Ralph Kahn[1]

[1]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA

Abstract: A new technique is described for retrieving aerosol over ocean water and the associated ocean color using multiangle satellite observations. Unlike current satellite aerosol retrieval algorithms which only utilize observations at red wavelengths and longer, with the assumption that these wavelengths have a negligible ocean (water-leaving radiance), this new algorithm uses all available spectral bands and simultaneously retrieves both aerosol properties and the spectral ocean color. We show some results of case studies using MISR data, performed over different water conditions (coastal water, blooms, and open water).

1. Introduction

The retrieval of aerosol optical depth over ocean waters is performed routinely by many different single-view satellite instruments. Because most of the ocean surface is sufficiently black in the red and near-IR, its radiance contribution to the measurements can be conveniently ignored, which greatly simplifies the retrieval process [1]. Once the aerosol properties are determined using these wavelengths, the scene then can be atmospherically corrected to determine the amount of water-leaving radiance in all the visible spectral bands of the instrument (i.e., ocean color). It is this particular ocean surface information which can be analyzed to determine aspects of the biological and chemical content of the water. However, there are many ocean regions where this black water criterion is not met, particularly in coastal waters with continental runoff and areas with heavy phytoplankton bloom. In these situations aerosol retrievals become much more difficult and the determination of ocean color become more uncertain.

Preliminary studies indicate that simultaneous multiangle satellite observations of the ocean with an instrument like MISR can help to provide more robust aerosol and ocean color retrievals. Here, the directional properties of the ocean color radiances (and not the lack of ocean color radiance in the red and near-IR) can potentially supply the necessary surface constraint needed to perform a reasonably accurate aerosol and ocean color retrieval. As such, the applicability of this retrieval algorithm could extend over a much wider range of water conditions than is currently attempted routinely. An additional benefit of this approach is that it allows all spectral bands of the multiangle instrument to be used by the algorithm, thus providing a more robust determination of aerosol properties.

2. Method

The basic idea of the algorithm is the assumption that the directional behavior of the water-leaving radiance is isotropic, i.e., the radiance appears to be reflected from a lambertian surface with an albedo dependent on the ocean color. Thus, the observed radiance can be expressed by

$$L^{toa} = L^{atm} + L^{glint} + L^{w} \times T \qquad (1)$$

where L^{toa} is the measured radiance at the top-of-atmosphere, L^{atm} is the atmospheric path radiance, L^{glint} is the glint radiance produced at the top surface of the water, T is the upward direct and diffuse atmospheric transmittance, and L^{w} is the isotropic water-leaving radiance. L^{toa}, L^{atm}, L^{glint} and T are a function of both view angle and wavelength; L^{w} is a function only of wavelength. The retrieval is performed by selecting a given aerosol model, which then defines L^{atm}, L^{glint}, and T, and solving for L^{w} at each wavelength with Eq. (1), using a least squares analysis on the view angle dependent terms. These wavelength dependent best fit values for L^{w} are then used in the equation to obtain a quality of fit metric for the aerosol model. The aerosol model with the smallest quality of fit metric is deemed the best solution to the retrieval process.

The assumption that L^{w} is reasonably isotropic is best investigated and validated through the use of multiangle satellite observations of various water types since *in situ* multiangle measurements of L^{w} are very limited. This is the approach we use in this study.

3. Results

Fig.1 shows a image of the Ganges river delta in the Bay of Bengal obtained by MISR. Two locations are noted in the delta area, one labeled as clear and the other labeled as silt. The clear area is dark water and an aerosol retrieval can be performed here under the typical assumption of a dark or black water surface, However, the silt area which is much closer to the coast should not allow an aerosol retrieval to be performed there under the dark water assumption since the water is providing non-negligible amounts of water-leaving radiance. Doing so would incur large errors in the retrieved aerosol properties. To test whether L^{w} in the silt area is isotropic (or nearly so), we first performed an aerosol retrieval in the clear patch. The aerosol model obtained from that retrieval then was used in the retrieval process for the silt area. Since the two patches are separated by less than 50 km, it was assumed that the aerosol conditions are the same in both areas.

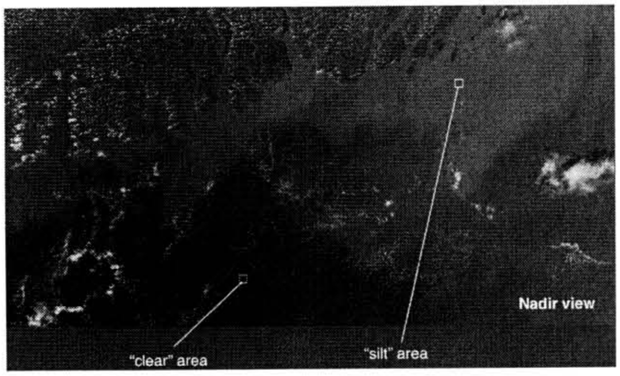

Fig. 1. MISR image of silt near the mouths of the Ganges in the Bay of Bengal, 26 Sept 2001.

The results of the clear area retrieval are shown in Fig. 2 where the MISR and best fit model radiances (in units of equivalent reflectance) are displayed as a function of MISR view angles and spectral bands. The model reflectance listed for each spectral band in the figure is the effective lambertian surface albedo describing the amount of isotropic water-leaving radiance used in the modeling. The values are those typical for dark water at these wavelengths [2]. The break in the curves is due to a camera view not used in the analysis because of glint contamination.

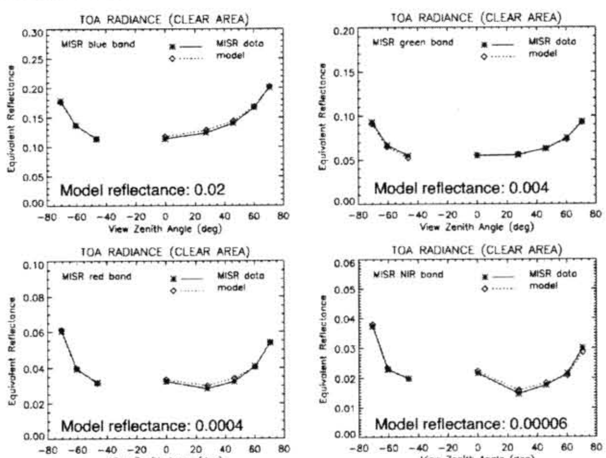

Fig. 2. Comparison of MISR and the best fit aerosol model for the clear area.

The green band (558 nm) optical depth of the best fit aerosol model was determined to be 0.18 and effective particle radii for the accumulation and coarse modes were 0.26 μm and ~1 μm, respectively.

This aerosol model was used in the analysis of the silt area, but now the effective lambertian surface albedo was adjusted for each spectral band. Fig. 3 shows the best fit comparison between the model and the MISR observations. Here, the model effective lambertian surface reflectance in the four spectral bands is considerably higher than the corresponding values in the clear area, resulting in a water color that is distinctly muddy in appearance. The important point to note here is that the introduction of an isotropic water-leaving radiance in the modeling procedure provides a very good fit to the observations, indicating that the isotropy assumption is reasonable, at least for this particular case.

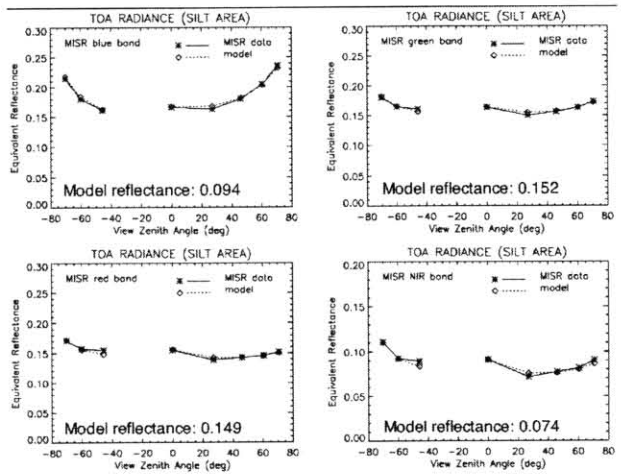

Fig. 3. Comparison of MISR and the best fit model for the silt area.

A second case study is a phytoplankton bloom off the coast of Brittany shown in Fig. 4.

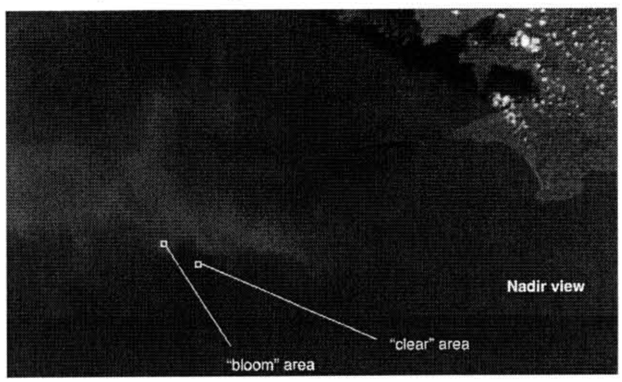

Fig. 4. MISR image of a phytoplankton bloom near the western coast of France, 04 June 2001.

Again, a clear area and a nearby bloom area were selected for analysis. This clear area was analyzed in a similar manner as the one in the previous case study with the results shown in Fig. 5. The green band optical depth was determined to be 0.11, with effective particle radii for the accumulation and coarse modes equal to 0.12 μm and ~1 μm, respectively.

This aerosol model was then used in the analysis of the bloom area, with the values of the effective lambertian surface albedo again adjusted for each spectral band to obtain a best fit to the MISR observations. The results are shown in Fig. 6 with the effective lambertian surface albedo indicated for each spectral band. Here, we see that the largest albedo value is in the blue band, steadily decreasing with increasing wavelength, which results in a distinct turquoise color of the water.

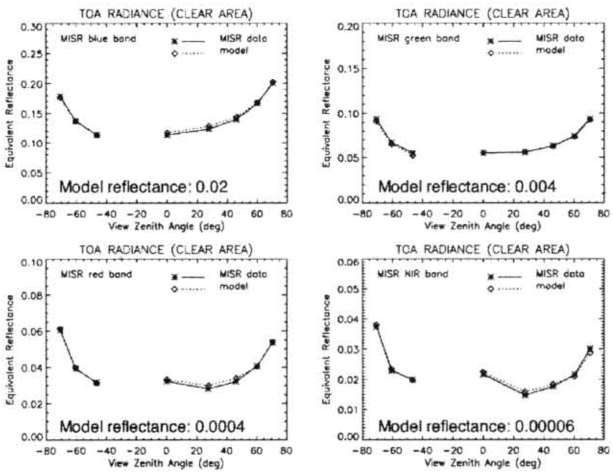

Fig. 5. Comparison of MISR and the best fit aerosol model for the clear area.

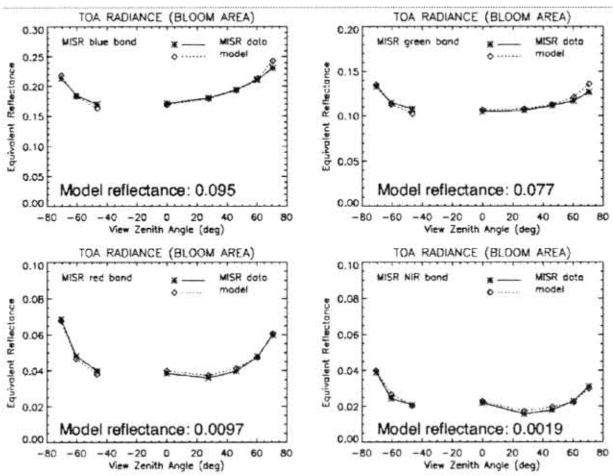

Fig. 6. Comparison of MISR and the best fit model for the bloom area.

Again, a good fit is obtained with the assumption that the water-leaving radiance is isotropic.

Even if the assumption of an isotropic water-leaving radiance is perfectly valid, the question remains as to whether a coupled aerosol and surface retrieval algorithm with this assumption as the sole constraint is stable in an operational mode. The two cases considered in this study had the additional constraint that for each case two patches of water were analyzed separately, one in which the water properties were assumed known (dark water patch) and the atmospheric properties were retrieved and the other in which the atmospheric properties were assumed known and the water properties then retrieved. Is the isotropy assumption sufficiently strong to correctly interpret the appropriate amount of water-leaving radiance and atmospheric path radiance when both are retrieved simultaneously? That is, if the water-leaving radiance is truly small then the algorithm should retrieve a small value and not allow the some of the atmospheric path radiance to be misinterpreted as water-leaving radiance. Likewise, if the water-leaving radiance has a sizable value, then the algorithm should not allow some or all of this radiance to be misinterpreted as atmospheric path radiance (or equivalently, as increased aerosol amount).

To test the stability of a coupled atmosphere-surface retrieval algorithm, the current MISR aerosol retrieval algorithm for use over water [3] was modified to include the isotropic water-leaving radiance constraint. The current version processes only the red and near-IR band data under the assumption of negligible water-leaving radiance in these bands whereas the modified version processes data from all four MISR bands. The modified algorithm was then used to analyze the MISR bloom data (Path 203, Orbit 7778). The results are displayed in Fig. 7, where the central image shows the retrieved green band aerosol optical depth (~0.1 over the image) at MISR's standard spatial resolution of 17.6 km (the optical depths from the MISR aerosol retrieval algorithm used over land [3] is also displayed). At the same spatial resolution is the retrieved effective lambertian albedo of the water-leaving radiance shown in the image on the right. It can be seen that the modified algorithm does a good job of separating the water-leaving radiance from the atmospheric path radiance.

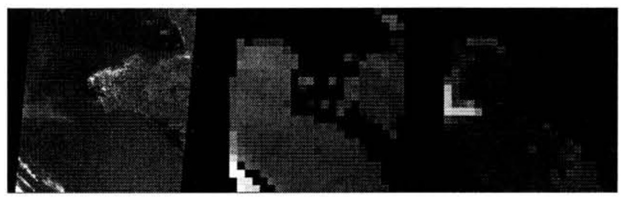

Fig. 7. The MISR image on the left shows the bloom off the coast of France, the center image shows the aerosol green band optical depth from the coupled atmosphere-surface retrieval algorithm;, and the image on the right shows the retrieved ocean color .

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Address:

John Martonchik, M.S. 167-237, Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena CA 91109 (John.Martonchik@jpl.nasa.gov)