ASSESSMENT OF THE MODIS ALGORITHM FOR RETRIEVAL OF AEROSOL PARAMETERS OVER THE OCEAN

Kexin Zhang[a], Wei Li[a], Knut Stamnes[a], Hans Eide[a], Robert Spurr[b], and Si-Chee Tsay[c]

[a]*Light and Life Laboratory, Stevens Institute of Technology, Hoboken, New Jersey 07030, USA.*
[b]*RT SOLUTIONS Inc., Cambridge, MA 02138, USA*
[c]*Earth Sciences Directorate, NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA*

SUMMARY

The MODIS aerosol algorithm over the ocean derives spectral aerosol optical depth and aerosol size parameters from satellite measured radiances at the top of atmosphere (TOA) by **adding of Apparent Optical Properties** (AOPs): TOA reflectance is approximated as a linear combination of reflectances resulting from a small particle mode and a large particle mode; correct only in the single scattering limit.

For **physically correct results**: use **linear combinations of the Inherent Optical Properties** (IOPs) of small and large particle modes. Using these IOPs as inputs to an accurate multiple scattering radiative transfer model, and we find that:

- Reflectance errors incurred with the AOP method are as high as 30%.
- The retrieved optical depth has a relative error of up to 8%, and the retrieved bimodal fraction an absolute error of about 8%.
- **Accurate radiative transfer simulations yields accurate values for both the retrieved optical depth and the bimodal fraction.**

MODIS Aerosol Retrieval Algorithm (AOP approach)

The TOA reflectances are combined from two log-normal aerosol models by the weighted average of the reflectance of each individual mode for the same optical depth:

$$\rho_\lambda^{AOP}(\tau_{550}^{tot}) \approx \eta\rho_\lambda^{s}(\tau_{550}^{tot}) + (1-\eta)\rho_\lambda^{l}(\tau_{550}^{tot}) \qquad (1)$$

$$\eta \equiv \eta_{550} = \frac{\tau_{550}^{s}}{\tau_{550}^{tot}} = \frac{\tau_{550}^{s}}{(\tau_{550}^{s}+\tau_{550}^{l})}$$

where s stands for the small-particle mode; l for the large-particle mode. By comparing the computed and measured reflectance for each of the combinations of one small and one large-particle mode, we find the relative error (ϵ_λ^{AOP}) for each channel:

$$\epsilon_\lambda^{AOP} = [\rho_\lambda^m - \rho_\lambda^{AOP}]/[\rho_\lambda^m + 0.01]. \qquad (2)$$

We sum over all 6 MODIS channels employed in the retrieval (0.55, 0.66, 0.86, 1.24, 1.6, 2.13 μm) to get the total relative error. The final solution for τ_{550}^{tot} and η_{550} is that which gives the minimum total relative error for ϵ_λ^{AOP}.

Weaknesses of the AOP approach:
1. It is based on the single scattering assumption.
2. In Eq. (1), the same value $\eta = \eta_{550}$ is employed to combine reflectance at all wavelengths. – not correct – η-values are different at wavelengths other than 550 nm.

Improved Aerosol Retrieval Algorithm (IOP Approach)

The physically correct way to combine two aerosol modes is to add the IOPs. The TOA reflectance should be calculated by a radiative transfer model with this combined IOPs. The IOPs of an aerosol mixture for a layer of thickness h are given by:

$$\tau_m = c_m\, h = [f\ N\ \sigma_s^e + (1-f)\ N\ \sigma_l^e]\ h \qquad (3)$$

$$f = \frac{N_s}{N_s + N_l}; \qquad N = N_s + N_l,$$

Here τ_m and c_m are the layer optical depth and extinction coefficient of the mixture of particles. σ_s^e and σ_l^e are the extinction cross section due to small and large particles, respectively, while N_s and N_l are the corresponding concentrations of small and large particles.

Advantages of the IOP Approach:
1. It is based on a physically correct and accurate TOA reflectance computation.
2. The weighting parameter f has a clear physical meaning which is the number density fraction of the small particle mode. The f-value does not depend on the wavelength. So we can use it for all MODIS channels employed in the retrieval.

Difference between AOP and IOP Approach

We assume η_{550} and f have same values at 550 nm. f-value does not depend on wavelength. The relationship between η_λ and f at all wavelength will be (see Fig. 1 left panel):

$$\eta_\lambda = \tau_\lambda^s/\tau_\lambda^{tot} = \frac{f\ c_s(\lambda)}{f\ c_s(\lambda) + (1-f)\ c_l(\lambda)} \qquad (4)$$

Actually, the retrieved η is η_{550}. It is clear that the η-value varies considerably with wavelength.

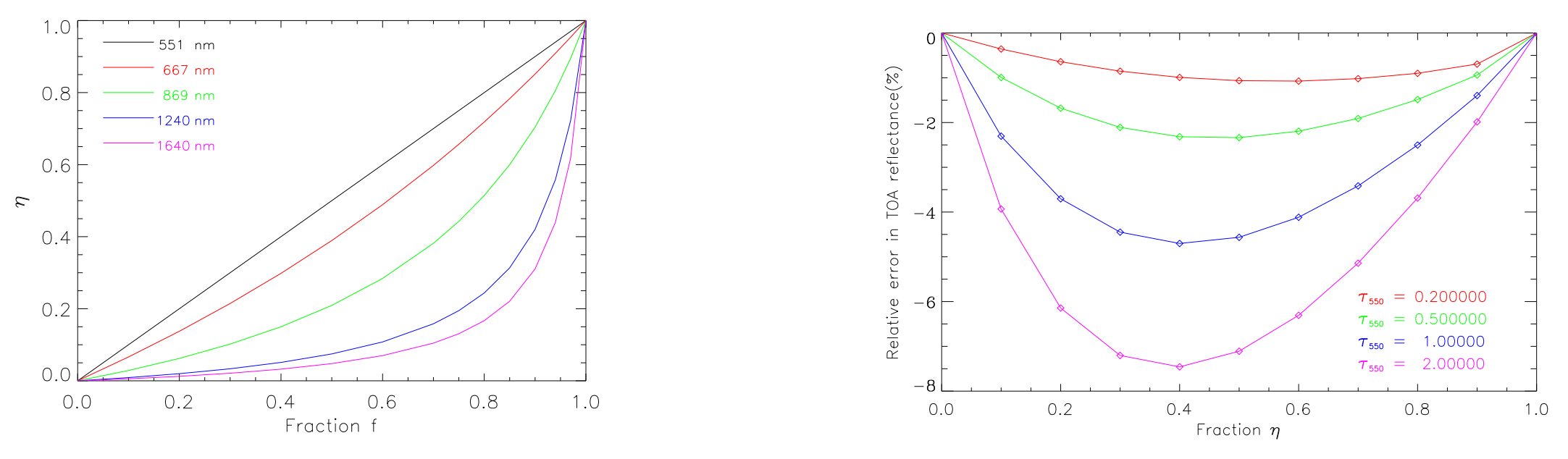

FIGURE 1: Left panel: the relationship between η and f-values at each MODIS wavelength. Right panel: TOA reflectance difference ρ_{diff} versus η for a bimodal distribution of aerosols at 550 nm. The curves from top to bottom correspond to 5 optical depth values from 0.0 to 2.

In order to evaluate MODIS aerosol retrieval algorithm, we use the accurate and self-consistent radiative transfer model DISORT to calculate the TOA reflectance for both the AOP and the IOP approach. The difference in results is defined as follows:

$$\rho_{diff} = \Big[\frac{\rho^{AOP}(\tau_a) - \rho^{IOP}(\tau_a)}{\rho^{IOP}_{TOA}(\tau_a)}\Big] \times 100) \qquad (5)$$

Fig. 1 (right) shows that the errors are considerable for large optical depths, caused by the breakdown of the single scattering assumption upon which the AOP approach is predicated. The biggest error is up to 8% when η close to 0.4. For more general situation with different geometries, we found that the largest error could be up to 30%.

Retrieval Procedure

We use same retrieval procedure for both the AOP and the IOP approach, but the different look-up tables for the TOA reflectance. The retrieval steps are:

1. Use the measured reflectance at 550 nm to estimate τ_{550} for all 101 pre-set η-values and 20 small-large mode combinations.
2. Use these estimated τ_{550}-values to find the best match between measured and computed (LUTs) reflectances at the other five MODIS bands: $\epsilon = \sum_{i=1}^{n}[(\rho_i^m - \rho_i^{LUT})/\rho_i^{LUT}]^2$, where n=5 for the remaining 5 MODIS bands. The minimum ϵ corresponds to the retrieved aerosol optical depth τ_{550}, η and mode combination.

Simulation Test Results

Following MODIS aerosol retrieval procedure, we use simulated data to test the aerosol retrieval accuracy. 9 aerosol modes (4 fine modes and 5 coarse modes) have been used here. We have a total 404 test cases (4 different aerosol optical depths and 101 mode fractions η). Below are the retreival errors. Our improved algorithm gives much better acuracy than the MODIS algorithm.

For our improved algorithm 98.8% of the aerosol optical depth retrievals have relative error less than ± 0.5% compared to only 36.6% for the MODIS algorithm (Fig. 2, left). The absolute error of η retrieval for our improved algorithm is negligible, but up to 8% for MODIS algorithm (Fig. 2, right). For aerosol model, the correct selection is the small particle model 2 and the large particle model 5. So the correct selection of aerosol model retrieval is 97.77 - 99.01% for our improved algorithm and 74.01 - 77.97% for MODIS algorithm (see Fig. 3).

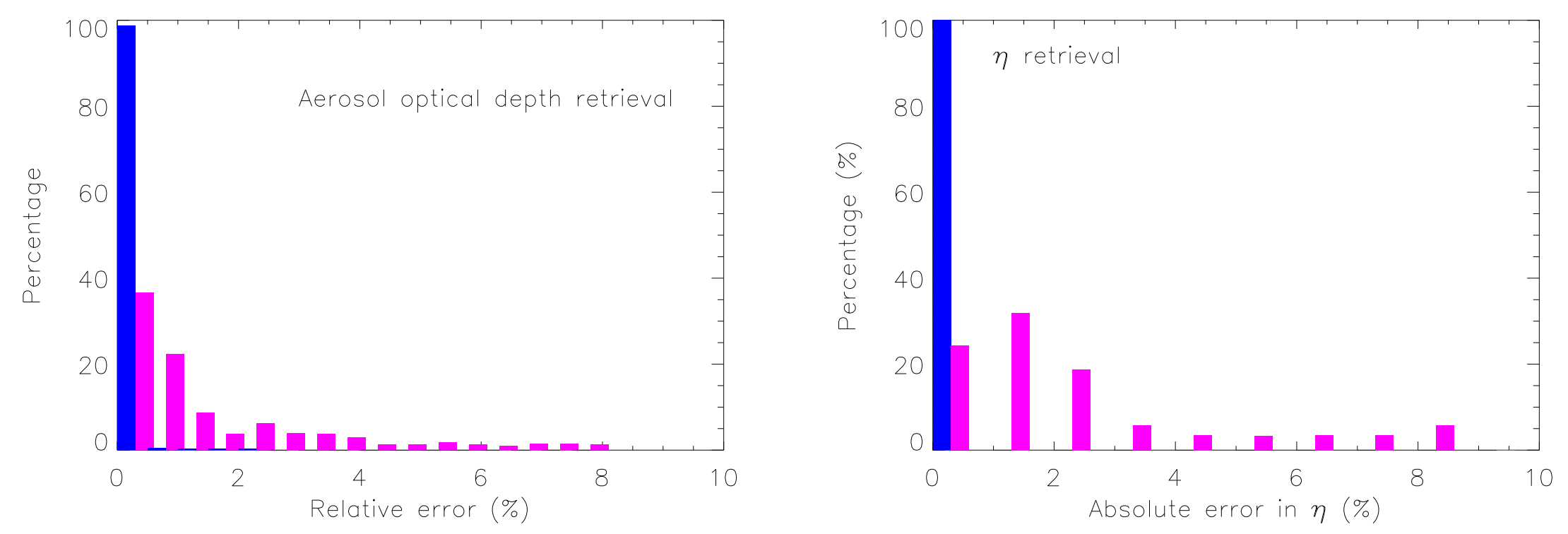

FIGURE 2: Left: Relative error for the aerosol optical depth retrieval. Right: Absolute error for η retrieval. The magenta bar is for MODIS algorithm and blue bar for our improved algorithm.

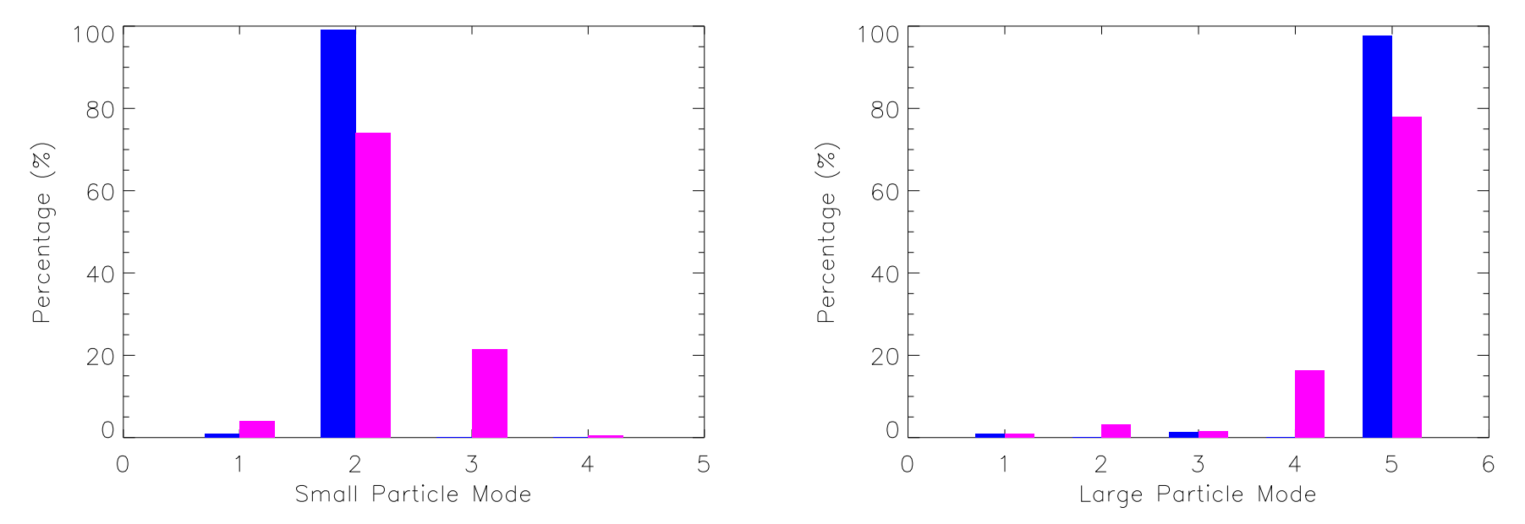

FIGURE 3: Aerosol mode retrieval for small particle mode (left) and large particle mode (right). The magenta bar is for MODIS algorithm and blue bar for our improved algorithm.

REFERENCE:

K. Zhang, W. Li, K. Stamnes, H. Eide, R. Spurr, S. C. Tsay, Assessment of the MODIS Algorithm for Retrieval of Aerosol Parameters over the Ocean, Applied Optics (accepted), 2006.