TIME SERIES ALGORITHM FOR AEROSOL RETRIEVALS FROM MODIS

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1. INTRODUCTION

The Earth Observing System [1] initiated high quality global Earth observations and operational aerosol retrievals over land. With the wide swath (2300 km) of MODIS instrument, the MODIS *Dark Target* algorithm [2-3] currently complemented with the *Deep Blue* method [4] provides daily global view of planetary atmospheric aerosol. With MODIS aerosol program being very successful, there are still several unresolved issues in the retrieval algorithms. The current processing is pixel-based and relies on a single-orbit data. Such an approach produces a single measurement for every pixel characterized by two main unknowns, aerosol optical thickness (AOT) and surface reflectance. For this reason, MODIS *Dark Target* algorithm makes spectral assumptions about surface reflectance, whereas the *Deep Blue* method uses ancillary global database of surface reflectance. Both algorithms assume Lambertian surface in the radiative transfer model.

2. MULTI-ANGLE IMPLEMENTATION OF ATMOSPHERIC CORRECTION (MAIAC)

Recently, a new algorithm was developed for MODIS [5]. The Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm simultaneously retrieves AOT and surface bi-directional reflection factor (BRF) using the time series of MODIS measurements and image-based rather than pixel-based processing. MAIAC starts with accumulating 3 to 16 days of MODIS level 1B (L1B) data which are gridded to 1 km resolution. The multi-day data provide different view angles, which are required for the surface BRF retrieval. MAIAC uses two assumptions: 1) the surface reflectance changes little during accumulation period, and 2) AOT changes little at short distances (~25 km), because aerosols have a mesoscale range of global variability of ~50-60 km [6]. Under these generic assumptions, the system of equations becomes over-defined and formally can be resolved. Indeed, we define the elementary processing area as a block with the size of N~25 pixels (25 km). With K days in the processing queue, the number of measurements exceeds the number of unknowns

$$KN^2 > K+3N^2 \text{ if } K>3, \quad (1)$$

where K is the number of AOT values for different days, and 3 is the number of free parameters of the Ross-Thick Li-Sparse (RTLS) [7] BRF model for a pixel. To simplify the inversion problem, the algorithm uses BRF, initially retrieved in B7, along with an assumption that the shape of BRF is similar between the 2.1 μm (B7) and the Blue (B3) spectral band:

$$\rho_{ij}^{B3}(\mu_0,\mu;\varphi) = b_{ij}^{B3}\rho_{ij}^{B7}(\mu_0,\mu;\varphi). \qquad (2)$$

This physically well-based approach reduces the total number of unknown parameters to $K+N^2$. Theoretically, MAIAC is based on a high accuracy semi-analytical formula for the top-of-atmosphere (TOA) radiance as a function of surface BRF derived with the Green's function method [8-9]. The principle of spectral similarity (2) of the BRF shape was extensively tested and implemented in ATSR-2 [10] and MISR [11] operational aerosol retrievals. During minimization, MAIAC tests its assumptions. For example, the objective function is high if surface changed rapidly or if aerosol variability was high on one of the days. Such days are filtered and excluded from the processing. The algorithm combines the block-level and the pixel-level processing, and produces the aerosol and surface reflectance (BRF, albedo) parameters at 1 km resolution.

Figure 1 shows an example of AERONET [12] validation for several sites, including GSFC (Greenbelt, Maryland, USA), Moscow (Russia) and Beijing (China). Figure 2 shows retrievals over Zambia, Africa during biomass-burning season. The MODIS TOA image shows dozens of small-to-large fires which are resolved at fine 1 km resolution of MAIAC. Individual fire plumes disappear at the coarse 10 km resolution of operational MODIS aerosol product MOD04 shown on the inset. Finally, Figure 3 compares MAIAC and MOD04 AOT during the dust storm event over India in May, 2008. The south-east dust transport is visible in both MAIAC and "Deep Blue" algorithms, whereas it is mostly filtered in MOD04 product.

In summary, MAIAC is a new algorithm for aerosol-surface retrievals over land which combines a time series analysis with image-based processing. The high 1 km resolution of MAIAC AOT provides new information on intensity and distribution of aerosol sources, which is needed in air quality applications. The initial comparison shows an overall agreement of MAIAC with Deep Blue algorithm in cases with dust transport. These results will be complemented by detailed comparison with ground data collected over India in 2008-2009 during TIGERZ aerosol characterization campaign.

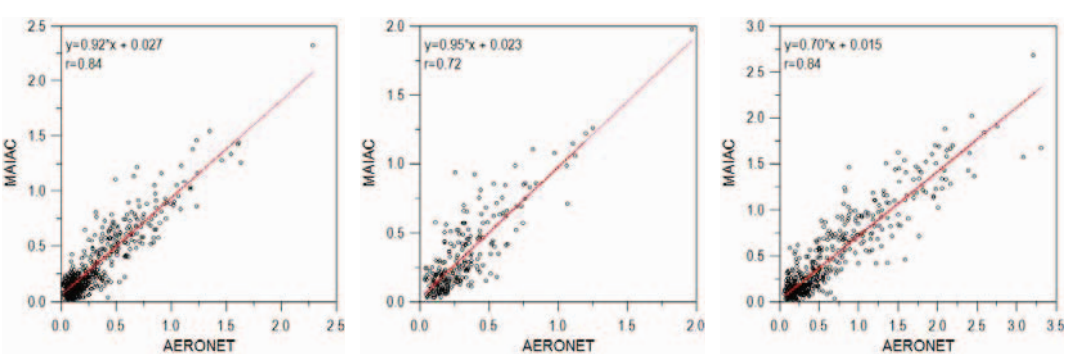

Figure 1. Comparison of MAIAC AOT with AERONET data for the Goddard Space Flight Center (GSFC, USA), Moscow and Beijing using MODIS TERRA data for 2000-2007.

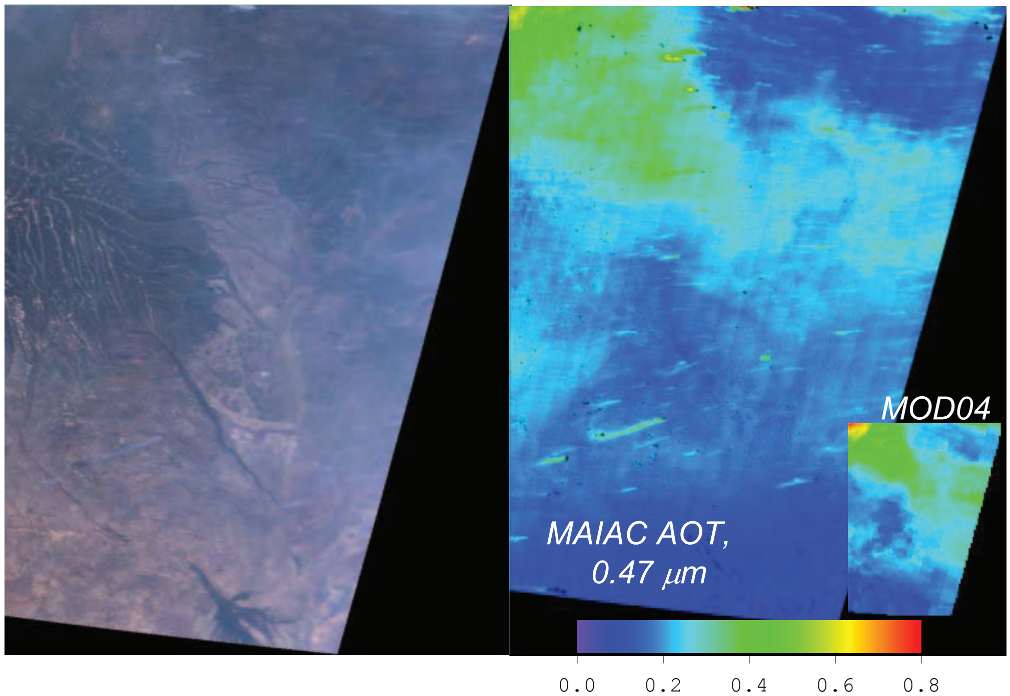

Figure 2. Fires during dry biomass-burning season in Zambia, Africa, for day 205 of 2005 (area 1200×1200 km^2). The 1km gridded MODIS TERRA TOA RGB image is shown on the left and MAIAC-retrieved AOT at 0.47 µm is on the right. The result of the MODIS dark target algorithm (MOD04) is shown in the inset.

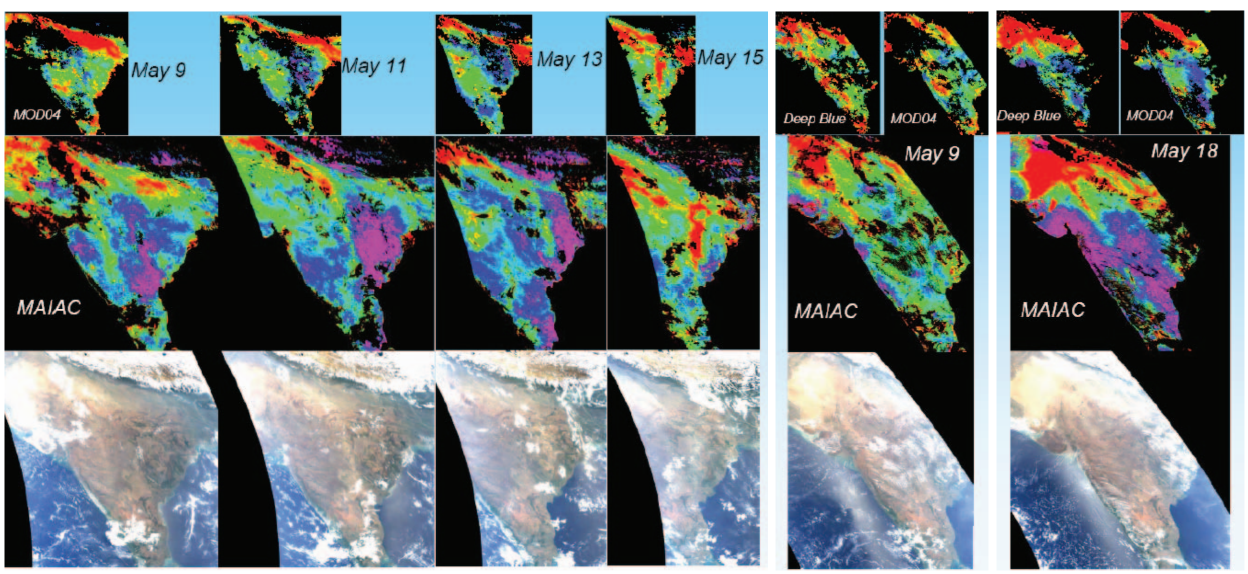

Figure 3. Comparison of MOD04, Deep Blue and MAIAC AOT from MODIS TERRA over India in May, 2008. The left 4 images show results from MODIS TERRA, and the last two images show results from MODIS AQUA where the "Deep Blue" aerosol product is available.

3. REFERENCES

[1] NASA (1999). M. King, & R. Greenstone (Eds.), *EOS reference handbook: a guide to Earth Science Enterprise and the Earth Observation System* (p. 355). Greenbelt, MD: EOS Project Science Office, NASA/Goddard Space Flight Center.

[2] Kaufman, Y. J., D. Tanre et al., "Operational remote sensing of tropospheric aerosol over land from EOS moderate resolution imaging spectroradiometer," *J. Geophys. Res.*, 102, pp. 17051-17067, 1997.

[3] Levy, R. C., L. Remer, S. Mattoo, E. Vermote, and Y. J. Kaufman, "Second-generation algorithm for retrieving aerosol properties over land from MODIS spectral reflectance," *J. Geophys. Res.*, 112, D13211, doi: 10.1029/2006JD007811, 2007.

[4] Hsu, N.C, Tsay S. C., King, M. D., et al., "Aerosol properties over bright-reflecting source regions," *IEEE Trans. Geosci. Remote Sensing*, 42, pp. 557-569, 2004.

[5] Lyapustin, A., Y. Wang, "The Time Series Technique for Aerosol Retrievals Over Land from MODIS," pp. 69-99, in *Satellite aerosol remote sensing over lan*d, Eds. A. Kokhanovky and G. De Leeuw. Springer Praxis Books, 2009.

[6] Anderson, T. L., R. J. Charlson, D. M. Winker, J. A. Ogren, K. Holmen, "Mesoscale Variations of Tropospheric Aerosols," *J. Atm. Sci.*, 60, pp. 119-136, 2003.

[7] Lucht, W., Schaaf C. B., Strahler A. H., "An algorithm for the retrieval of albedo from space using semiempirical BRDF models," *IEEE Trans. Geosci. Remote Sens.*, 38, pp. 977-998, 2000.

[8] Lyapustin, A., and Yu. Knyazikhin, "Green's function method in the radiative transfer problem. I: Homogeneous non-Lambertian surface," *Appl. Optics*, 40, pp. 3495-3501, 2001.

[9] Lyapustin, A., and Wang, Y., "Parameterized Code Sharm-3D for Radiative Transfer Over Inhomogeneous Surfaces," *Appl. Optics*, 44, pp. 7602-7610, 2005.

[10] Veefkind, J. P., G. de Leeuw, P. Durkee, "Retrieval of aerosol optical depth over land using two-angle view satellite radiometry during TARFOX," *Geophys. Res. Lett.*, 25, pp. 3135-3138, 1998.

[11] Diner, D. J., J. V. Martonchik, R. A. Kahn, B. Pinty, N. Gobron, D. L. Nelson, B. N. Holben, "Using angular and spectral shape similarity constraints to improve MISR aerosol and surface retrievals over land," *Rem. Sens. Environ.*, 94, pp. 155-171, 2005.

[12] Holben, B. N., T. F. Eck, I. Slutsker, D. Tanré, J. P. Buis, A. Setzer, E. Vermote, J. A. Reagan, Y. J. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak, A. Smirnov, "AERONET-A Federated Instrument Network and Data Archive for Aerosol Characterization," *Rem. Sens. Environ.*, 66, pp. 1-16, 1998.