Collection 005 Change Summary
for MODIS Aerosol (04_L2) Algorithms

Lorraine Remer, Yoram Kaufman, Didier Tanré
Shana Mattoo, Rong-Rong Li, J.Vanderlei Martins, Robert Levy, D. Allen Chu, Richard Kleidman, Charles Ichoku, Ilan Koren

Summary:

1. Land: Subpixel snow mask implemented
2. Land: Cloud mask adjusted and QA flag set to 0 in some situations.
3. Land: Geographic distribution of aerosol models adjusted to agree with observed ranges of heavy aerosol.
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1. Land: Subpixel snow mask implemented.

Aerosol retrieval from satellites requires assumptions about the surface reflectance in order to separate the radiance signal originating in the atmosphere from that originating from the Earth's surface. Over ocean it is relatively easy. Over land it is much more difficult. The MODIS aerosol retrieval over land is limited to pixels where our assumptions about the land surface reflectance will hold. These tend to be dark, vegetated pixels. The over land algorithm does not work over bright deserts or over snow. Since launch, the aerosol algorithm has relied on a snow mask based on other MODIS products and auxilliary data that is passed to us through the MOD35 product. This snow mask effectively identifies fully snow covered pixels, such that can be seen in Figure 1 as the black regions in the most northerly latitudes of the northern hemisphere in April 2004. However, just south of the properly masked snow fields lies a band of bright colors representing aerosol optical thicknesses greater than 0.60. These high aerosol values are not real, but an artifact caused by snow-contaminated pixels slipping through the standard snow mask.

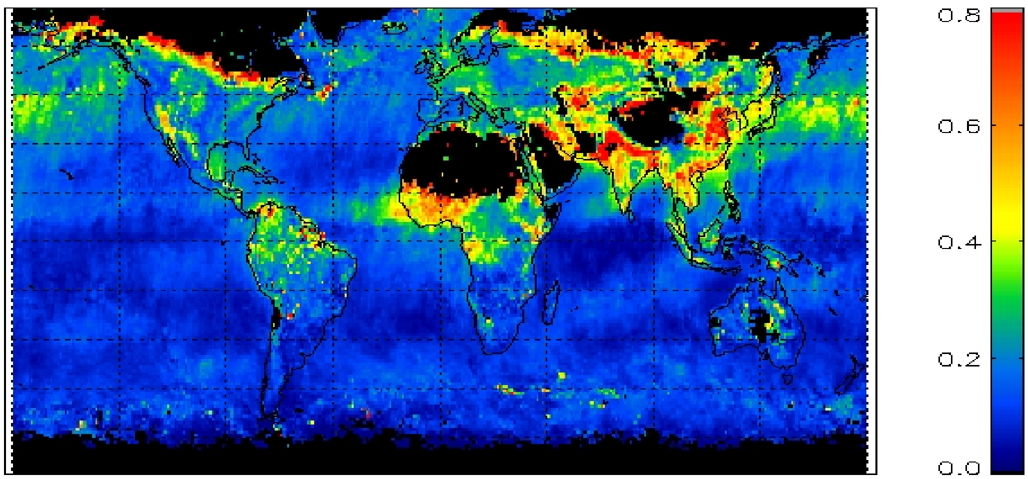

Fig. 1. A sample Level 3 monthly-mean global aerosol optical depth image retrieved from the Terra MODIS data for April 2004.

We have developed a new method that is sensitive to pixels only partially filled with snow. The method is based on the fact that snow is darker at 1.24 µm than at 0.86 µm, but almost all other surface types exhibit the reverse spectral dependence. We apply the normalized difference ratio,

$$R = [\rho^*_{0.86} - \rho^*_{1.24}] \,/\, [\rho^*_{0.86} + \rho^*_{1.24}], \qquad (1)$$

and couple the ratio to a threshold of the 11 µm channel brightness temperature to identify snow-contaminated pixels. This ratio was previously suggested for remote sensing of liquid water content of vegetation canopies (Gao, 1996). The result effectively eliminates snow contamination in the aerosol land product without accidentally masking out perfectly good pixels in other regions. An example is shown below in Figure 2. The method is described in full, and other examples given in Li et al. (2005).

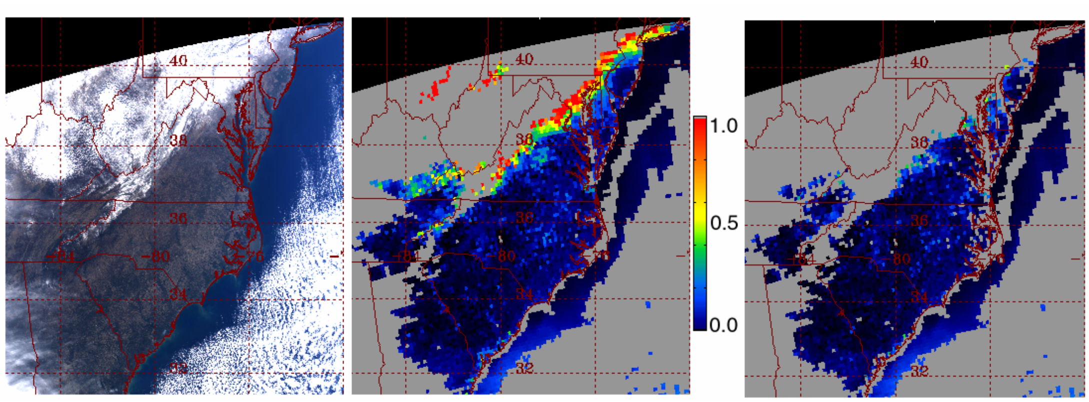

Fig. 2. (a) – An Aqua MODIS image over North America on February 8, 2004; (b) the derived aerosol optical depth image using the operational MODIS aerosol algorithm; and (c) the aerosol optical depth image with improved snow masking.

2. Land: Cloud mask adjusted and QA flag set to 0 in some situations.

Masking clouds without masking aerosol events remains one of the most challenging issues faced by the aerosol retrieval algorithms. At Terra launch, the aerosol retrievals relied on the standard cloud mask products available in MOD35. Almost immediately we realized that these products were not going to be adequate. A new cloud mask based on a spatial variability test, supplemented by cirrus tests using the 1.38 μm channel and a few remaining MOD35 products, was implemented in the over *ocean* aerosol algorithm (Martins et al., 2002). The mask proved to be very successful, especially after adjustments to the cirrus identification part of the algorithm (Gao et al. 2002). All of Collection 004 data over ocean, both from Terra and Aqua, were produced using this cloud mask.

A separate but similar cloud mask for masking clouds over land was developed later and not implemented until November 2002. The spatial variability cloud mask over land improved the aerosol retrievals, especially when it came to confusing heavy aerosol with cloud. However, isolated, residual cloud contamination in the product remained. For Collection 005, we have made a few adjustments to the technique, but maintained the general philosophy and structure of using spatial variability tests coupled with threshold tests only in the 1.38 μm channel. This seems to remove isolated artifacts in the retrieval. For example, in Figure 3, the red spots associated with clouds over India in a relatively clean area are removed with the new cloud logic.

For the record, the new logic of the cirrus part of the cloud mask for over land aerosol retrievals is as follows:

If var(1.38)* refl_1.38 >= 0.025 then CLOUD
  If refl_1.38 > or = 0.025 then CLOUD
  If refl_1.38 < 0.025 then NOT CLOUD
  If 0.01 < refl_1.38 < 0.025 then NOT CLOUD but Quality is set to 0

where var(1.38) is the standard deviation of the 1.38 μm reflectance of the 3x3 array of pixels centered on the pixel of interest, and refl_1.38 is the reflectance of the pixel at 1.38 μm. A refl_1.38 < 0.0025 threshold will allow cirrus contamination into the land aerosol retrieval. However, those retrievals will have Quality parameter set to zero. Checking the Quality of every land retrieval is essential to understanding the final products.

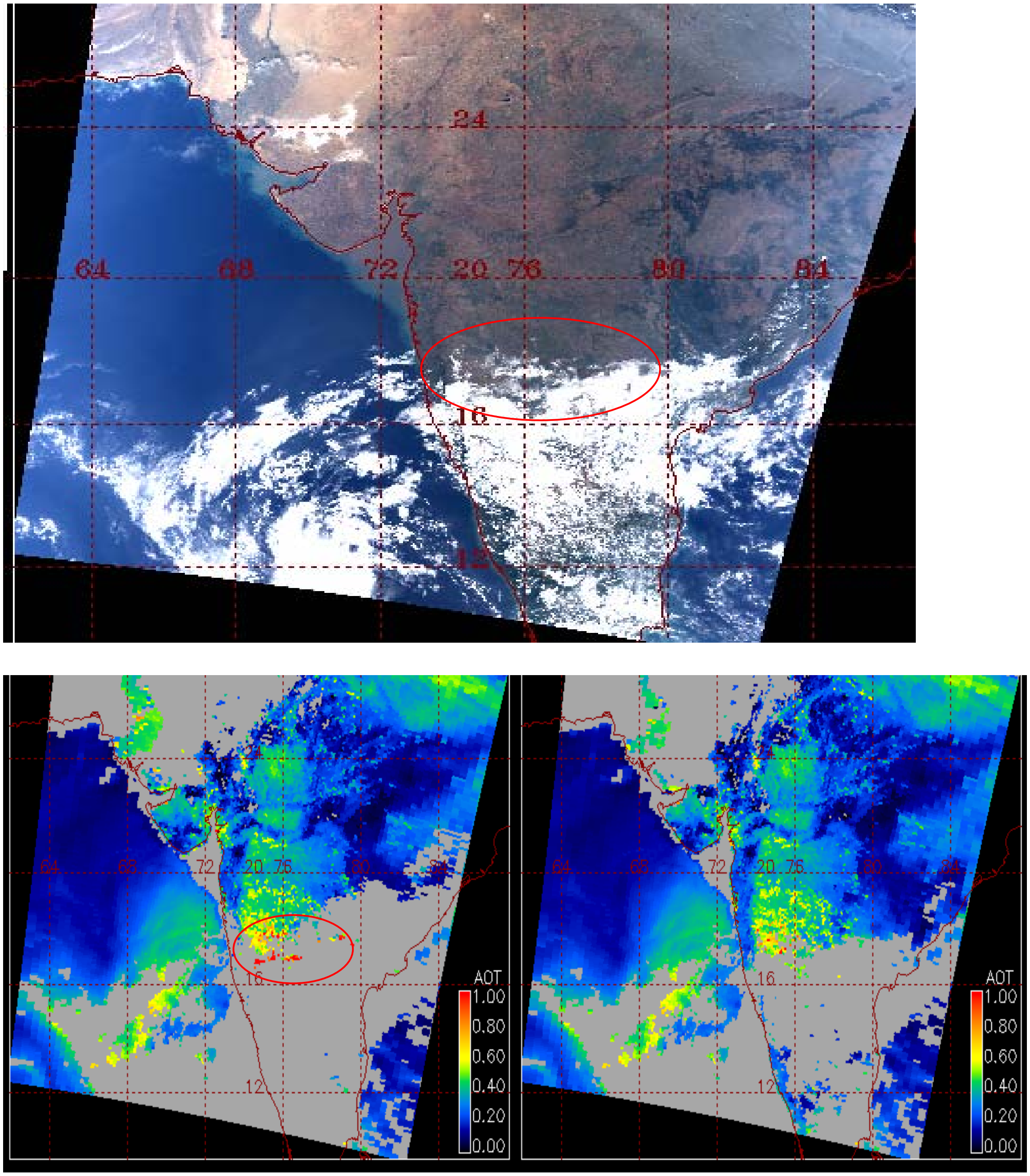

Figure 3. Images from MOD04 from year 2000, day 337, time 0555 located over India. The top image is a true color rgb with the red oval highlighting the edge of a cloudy area. The same area is identified by the oval in the lower left image, which shows aerosol optical thickness retrieval available in Collection 004. The bright red spots are an artifact of cloud contamination. These are eliminated in the lower right image, which was produced with Collection 005 software and improved cloud masking logic over land. The increased number of retrievals in the Collection 005 image result from permitting negative values in the 1.38 µm channel, as described in Section 6 below.

3. Land: Geographic distribution of aerosol models adjusted to agree with observed ranges of heavy aerosol.

The aerosol algorithm over land requires a set of assumed aerosol properties in order to retrieve the aerosol optical thickness. The algorithm has some flexibility to combine the properties of background dust with the optical characteristics of a specific combustion produced aerosol model. The combustion (or fine mode) model is specified by season and geographical location. This philosophy has not changed since launch. However, a new highly absorbing aerosol with single scattering albedo of 0.85 was introduced in November 2002.

The November 2002 implementation of the new aerosol model improved retrievals in Southern Africa, as expected. It did not improve retrievals in Asia. The reason was traced to an incorrect interpretation of the true geographic distribution of this type of aerosol. In the Collection 005 algorithm we keep the same aerosol models, unchanged, but we have adjusted the geographical distribution to resemble Figure 4.

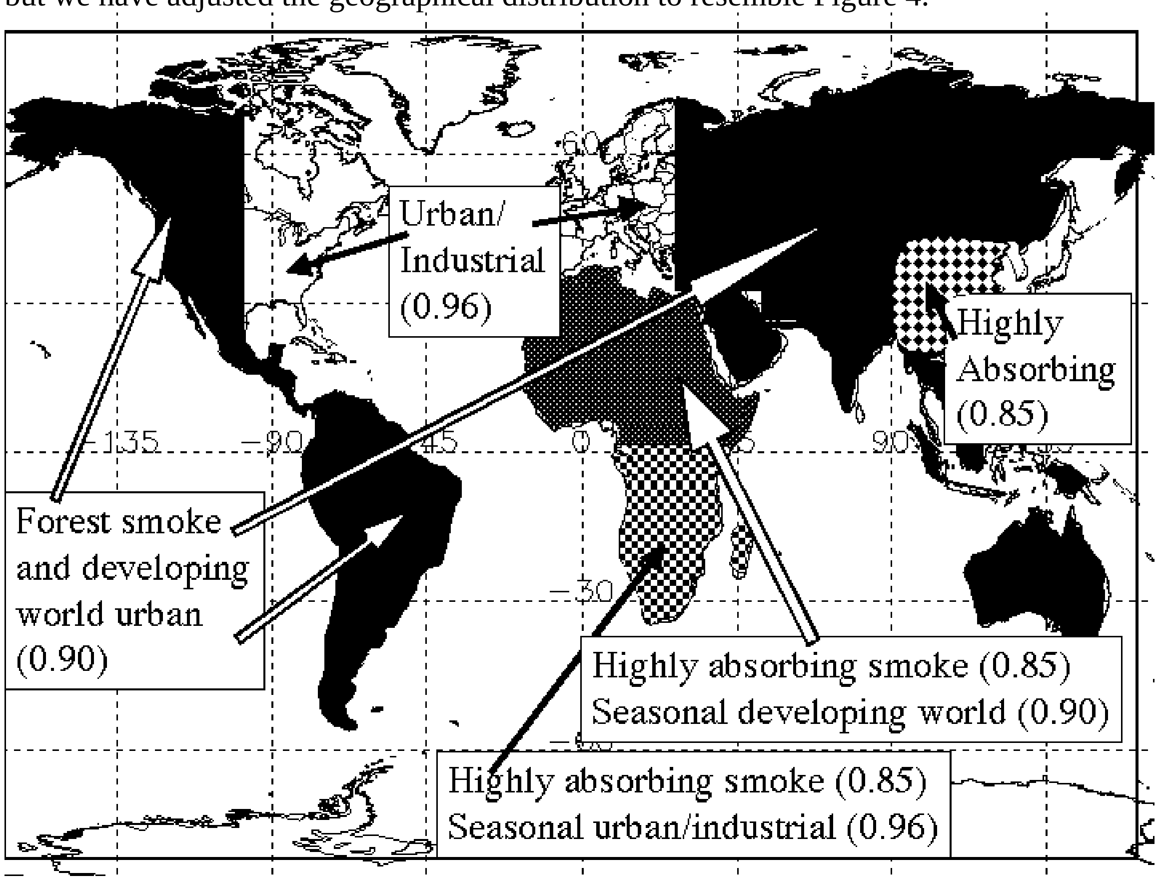

Figure 4. Geographic and seasonal distribution of fine mode aerosol optical properties in Collection 005.

4. Ocean: CCN units corrected.

The units of the cloud condensation nuclei (CCN) are supposed to be number/cm^2. The over land algorithm reported the correct units, but the ocean algorithm reported values off by 10^6. The Collection 005 product will be reported in the correct units, number/cm^2, over both land and ocean.

5. Land and Ocean: Cloud fraction redefined.

Since launch, both the over land and over ocean aerosol retrievals have reported a parameter called "cloud fraction" (Cloud_Fraction_Land and Cloud_Fraction_Ocean). These parameters were used as a diagnostic and included ALL pixels not included in the retrieval. Over ocean, not only clouds, but glint and sediments would be included in the "cloud fraction". Over land, "cloud fraction" included clouds, inland water, and bright surfaces that did not fall within acceptable range of the retrieval. In Collection 005 we are changing the definitions of these parameters to include only clouds identified by the MOD04/MYD04 internal cloud masks based on spatial variability. Those pixels identified only as thin cirrus will NOT be included in this new "cloud fraction". Those pixels not used because of sediment, glint, internal water or bright surfaces also will NOT be included in this new "cloud fraction".

These new "cloud fraction" parameters continue to be diagnostic and experimental in nature, and may still not correspond to a true cloud fraction.

6. Land and Ocean: Negative reflectances in 1.38 µm channel permitted.

The aerosol retrieval algorithms continually check incoming data before using the L1B radiances to derive aerosol. Pixels identified as containing bad data in specific channels are discarded and fill values placed in the final product. One important channel contains the 1.38 µm reflectance, which is used to identify cirrus in the pixel. This channel is especially sensitive to cirrus clouds because in the absence of particles high in the atmosphere the channel returns reflectances near zero due to the strong water vapor absorption at this wavelength. As it turns out, near zero reflectance could either be slightly positive or slightly negative. The aerosol algorithm required incoming reflectances in this channel to be non-negative. If negative values were found, no aerosol retrieval was attempted. The result was that in cirrus free conditions when the 1.38 µm was slightly negative the aerosol algorithm would often fail make an aerosol retrieval. Many retrieval opportunities were lost. We have adjusted the checking of incoming data to permit slightly negative values. The result is the recovery of many additional retrievals, especially over land. Figure 7 illustrates the increased number of retrievals.

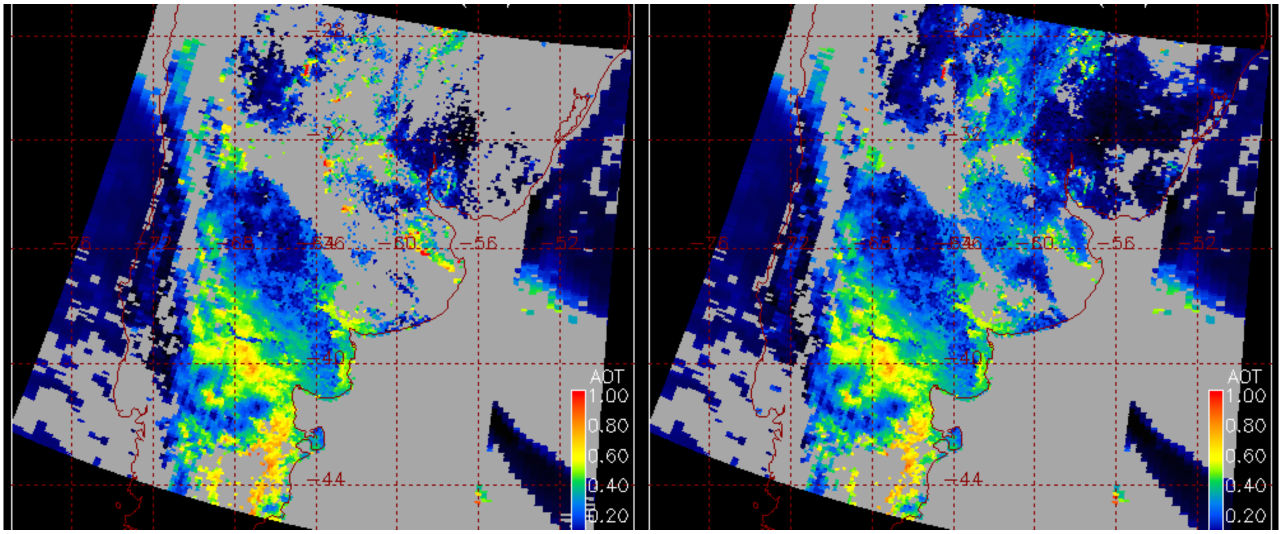

Fig.7 Image of aerosol optical thickness from MOD04 from year 2000, day 337, time 1425 located over South America. On the left is the retrieval from the 004 collection, while on the right, from the 005 collection. Note the increased range of the aerosol retrieval in Brazil. The extended range of retrieval is due simply to permitting slightly negative values of 1.38 μm reflectance to be processed. Note that the image on the right also benefits from the adjusted cloud mask logic over land described in Section 2, and therefore several patches of high aerosol optical thickness associated with cloud contamination are eliminated.

7. Land and Ocean: New SDS introduced to hold diagnostic information on the cloud mask.

Separating aerosols from clouds continues to be one of the most challenging aspects of remote sensing of aerosol. We have introduced new SDSs Aerosol_Cldmask_Byproducts_Land and Aerosol_Cldmask_Byproducts_Ocean to hold additional diagnostic information on different aspects of the internal cloud mask. For the time being these new SDSs will contain fill values. We expect to submit a software patch in the near future to fill the SDSs with useful diagnostic information that can inform us of the spatial variability statistics, detection of thin cirrus, etc. for every aerosol retrieval.

8. Land and Ocean: Removal of SDSs and general clean up of code.

The definitions of the family of SDSs called "Fluxes", which are the hemispherical irradiances, have been changed several times since launch, never satisfactorily. At this point it is unclear how to make use of them, and so, we have decided to eliminate the following SDSs:

Reflected_Flux_Land_And_Ocean
Estimated_Uncertainty_Land
Reflected_Flux_Land
Transmitted_Flux_Land

Reflected_Flux_Best_Ocean
Reflected_Flux_Average_Ocean
Transmitted_Flux_Best_Ocean
Transmitted_Flux_Average_Ocean

In addition, the Collection 005 software has undergone a general housecleaning, without making significant changes to the products.

9. References

MODIS Aerosol Algorithm and Validation Reference List

Additional publications also listed at http://modis-atmos.gsfc.nasa.gov/reference.html

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