

Comparison of MISR and AERONET aerosol optical depths over desert sites

J. V. Martonchik, D. J. Diner, R. Kahn, and B. Gaitley

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

B. N. Holben

Goddard Space Flight Center, Greenbelt, Maryland, USA

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[1] Comparisons of the Multi-angle Imaging SpectroRadiometer (MISR) aerosol optical depths (AOD) with those of the AErosol RObotic NETwork (AERONET) were made at four desert sites, covering a two-year time period from December 2000 to November 2002. The two data sets show good correlation with no obvious systematic biases or trends, demonstrating MISR's ability to retrieve reliable visible and near infrared AOD over surfaces with relatively high reflectance. For MISR AOD obtained at 17.6 km spatial resolution, the estimated uncertainty is about 0.08. When the spatial resolution was degraded to 52.8 km, the estimated AOD uncertainty decreased to about 0.05. Year-long time-series comparisons of MISR and AERONET AOD at the four desert sites showed that MISR can quantitatively capture the temporal nature of strong dust activity in desert regions.

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1. Introduction

[2] A major component of aerosol loading in Earth's mid-latitude regions is dust. Besides being an effective reflector of solar radiation back into space, it also plays an important radiative role in the infrared [Zhang and Christopher, 2003], impacting climate forcing [Kaufman *et al.*, 2002]. Dust can be readily observed and analyzed when over ocean but much less so when it is over land [Kaufman *et al.*, 2000; Torres *et al.*, 2002].

[3] The Multi-angle Imaging SpectroRadiometer (MISR) on the NASA Terra platform has been producing aerosol optical depths (AOD) globally since February 2000. Observing continuously at nine distinct zenith angles, ranging from 70° aftward to 70° forward, and in four narrow spectral bands centered at 446, 558, 672, and 866 nm, MISR's unique blend of directional and spectral data allow aerosol retrieval algorithms to be used which do not depend on explicit radiometric surface properties. As such, MISR can retrieve aerosol properties over a variety of terrain, including highly reflective surfaces like deserts. In a previ-

ous paper [Diner *et al.*, 2001] AOD obtained by MISR over southern Africa were validated by comparing them to simultaneous ground-based results from the AErosol RObotic NETwork (AERONET) [Holben *et al.*, 1998] at a number of sites. The surface properties of these sites were spatially variegated, being a mosaic of highly vegetated to sparsely vegetated areas. In this paper MISR-retrieved AOD are compared to those from AERONET, with the site selection restricted to desert areas where the surface reflectance in the visible is relatively high and generally increases with wavelength. Typical values are about 0.25 in the green (MISR 558 nm) and reach about 0.4 in the near IR (MISR 866 nm). This is one of the more difficult surface types over which to perform retrievals but one where aerosol property information is needed, owing to the importance of such sites as strong dust sources.

2. MISR Aerosol Retrieval Approach

[4] All 36 channels (9 cameras \times 4 spectral bands) are used when performing aerosol retrievals over land. This approach relies on describing the change in surface contrast with view (camera) angle over a region 17.6 km \times 17.6 km in size, composed of 16 \times 16 (256) subregions, each 1.1 km \times 1.1 km. This subregion size is the nominal spatial resolution of MISR when observing in Global Mode and 17.6 km is the spatial resolution of MISR's retrieved aerosol product. The view angle variation of contrast within each 17.6 km cloud-free region is mathematically captured by means of a principal component analysis, which produces empirical orthogonal functions (EOFs) used to describe the surface reflectance contribution to the radiance at the top-of-atmosphere [Martonchik *et al.*, 1998, 2002]. The combination of this empirical surface component with a modeled atmospheric path radiance component (encompassing various aerosol types and conditions), provides hybrid multi-angle radiances which are fitted to the 36 regional MISR radiances, obtained by averaging the 256 subregional radiances for each channel. Therefore, aerosol retrievals are performed only on a regional and not a subregional basis. Those atmospheric models which provide the best fitting results determine the best estimate of the aerosol properties for the region.

3. Aerosol Optical Depth Comparisons

[5] One objective of this comparison study was to sample desert locations over a wide longitude range across the

Table 1. Number of AOD Comparison Cases

Site	1 × 1 Region	3 × 3 Region
Ad Dakhla	20	8
Sede Boqer	18	17
Solar Village	27	23
Dalanzadgad	30	12

African and Asian continents. The four desert AERONET sites selected on the basis of sufficient temporal coverage include Ad Dakhla, Mauritania in western Africa; Sede Boqer in southern Israel; Solar Village in central Saudi Arabia; and Dalanzadgad in southern Mongolia. The data cover from December 2000 through November 2002, which allows the monitoring of aerosol events at these sites over the course of two years. At some of the sites, however, there are gaps in the AERONET coverage due to the unavailability of a sunphotometer. An additional physical limitation on coverage is due to cloud cover and MISR's 7–9 day revisit period, which results in only 3–4 possible visits per month at each site. The criterion for an acceptable AOD comparison at a site requires that AERONET data be available within a 1 hour window centered on the MISR overpass time. If, for any reason, a MISR retrieval was not available for the 17.6 km region containing the AERONET site, a lower spatial resolution (52.8 km × 52.8 km, i.e., 3 × 3 regions) MISR AOD product was created by averaging the available AOD of the eight regions surrounding the site. A comparison of this 3 × 3 region AOD product with AERONET was done to test for possible improved retrieval performance and spatial resolution effects. Table 1 lists the number of available AOD comparison cases at each site for the two year period for both the single region (1 × 1) and 3 × 3 region MISR products. Although the number of cases are generally less than 30 for a given site, they are representative of the number of coincidences to be expected at a typical AERONET site over a two year period [Kahn *et al.*, 2004]. The number of sites selected for analysis is also small, but they include virtually all available bright desert sites that also have AERONET time coverage extending at least one year.

[6] Figure 1 shows a comparison of MISR single region AOD in the four MISR spectral bands with those from AERONET (interpolated to the MISR wavelengths), displaying results from the four sites for the two year period. For each plot point a vertical bar is shown, indicating the formal uncertainty in the MISR-retrieved AOD derived from the averaged results of multiple aerosol model solutions. As an aid to describing the quality of the agreement, two (dotted) reference lines are shown on each plot; one is the 1:1 line and the other is the unconstrained linear fit. Visual inspection of the 16 plots shows some site-specific bias in the MISR AOD but no obvious bias or trend which is common to all sites. The site with the best agreement and smallest residuals is Ad Dakhla (red symbols), which has one of the larger AOD ranges (up to 0.5 in the green band) of the four comparison data sets. The good agreement was undoubtedly influenced by the fact that the site sits on a small finger of land jutting out into the Atlantic ocean, providing better than normal surface contrast for the retrieval algorithm. Solar Village (blue symbols) has a similar AOD range but the retrievals are much more noisy (large single point uncertainties) than that of Ad Dakhla. Here, the surface contrast was the weakest of the four sites, providing less of a

signal for analysis and resulting in more aerosol models to be selected as possible solutions. The Sede Boqer and Dalanzadgad sites (green and brown symbols, respectively) show an AOD range that is generally smaller than that of Ad Dakhla and Solar Village. Their plots show too few if any comparisons at AOD larger than 0.2 to make any useful judgments as to systematic trends or biases. The linear fit line for Sede Boqer data seems particular skewed with respect to the 1:1 line but only three or four poor comparison points out of 18 account for most of this. It is to be expected that AOD data sets covering a relatively small range will have less reliable trending. Figure 1 shows no significant differences in AOD trending with respect to spectral band for each of the four sites. Given the relatively small spectral range of MISR, this implies that any accumulation mode sizes deduced from the aerosol models selected by the retrieval process are probably not unreasonable estimates of the actual sizes.

[7] Table 2 lists the estimated 1 × 1 MISR AOD uncertainties per spectral band and site, when referenced to AERONET. These uncertainties are referenced to the 1:1 line thereby incorporating any bias that may be present. On average over the four desert sites, the MISR AOD uncertainty is about 0.08 (1 sigma), with little dependence on spectral band. Performing the same analysis, but using the MISR 3 × 3 region AOD, resulted in uncertainty estimates which are generally smaller (see Table 2) but with more site dependence. This decrease in uncertainty would be expected due to the additional number of AOD retrieval results used (i.e., decrease in statistical noise) and if the aerosol amount is largely constant over the 3 × 3 region area.

[8] In Figure 2 the MISR and AERONET AOD at 558 nm (green band) are compared over time for each of the four sites. Here the coverage is only one year, from December 2001 to November 2002. As previously demonstrated in Figure 1 and now shown in these temporal displays, the correlation between simultaneous AERONET and MISR AOD is quite good. This provides some assurance that for the periods in Figure 2 where AERONET data are non-existent (April–July at Sede Boqer and June–July at Solar Village and Dalanzadgad) the MISR AOD paint a realistic picture of aerosol activity. For the latitude band containing the Ad Dakhla site (lat 23°43′) and the Solar Village site (lat 24°54′) there is considerable dust activity during much of the year, extending from May through September for Ad Dakhla and from March through August for Solar Village. Much of the dust from these outbursts eventually finds its way across the Atlantic ocean. In contrast, the two more northern sites, Sede Boqer (lat 30°31′) and Dalanzadgad (lat 43°34′), appear relatively inactive over the same time period.

4. Discussion and Conclusions

[9] In the UV aerosol retrievals over deserts are facilitated by the intrinsically low surface reflectance at these wavelengths [Torres *et al.*, 2002]. In the visible and near IR, however, the desert terrain can be highly reflective and accurate retrievals of AOD are extremely difficult to do using single view multispectral satellite instruments because of their general inability to separate the atmospheric and surface contributions to the measured radiances. Multiangle instruments like MISR can make use of the directional properties of the surface to assist in the separation proce-

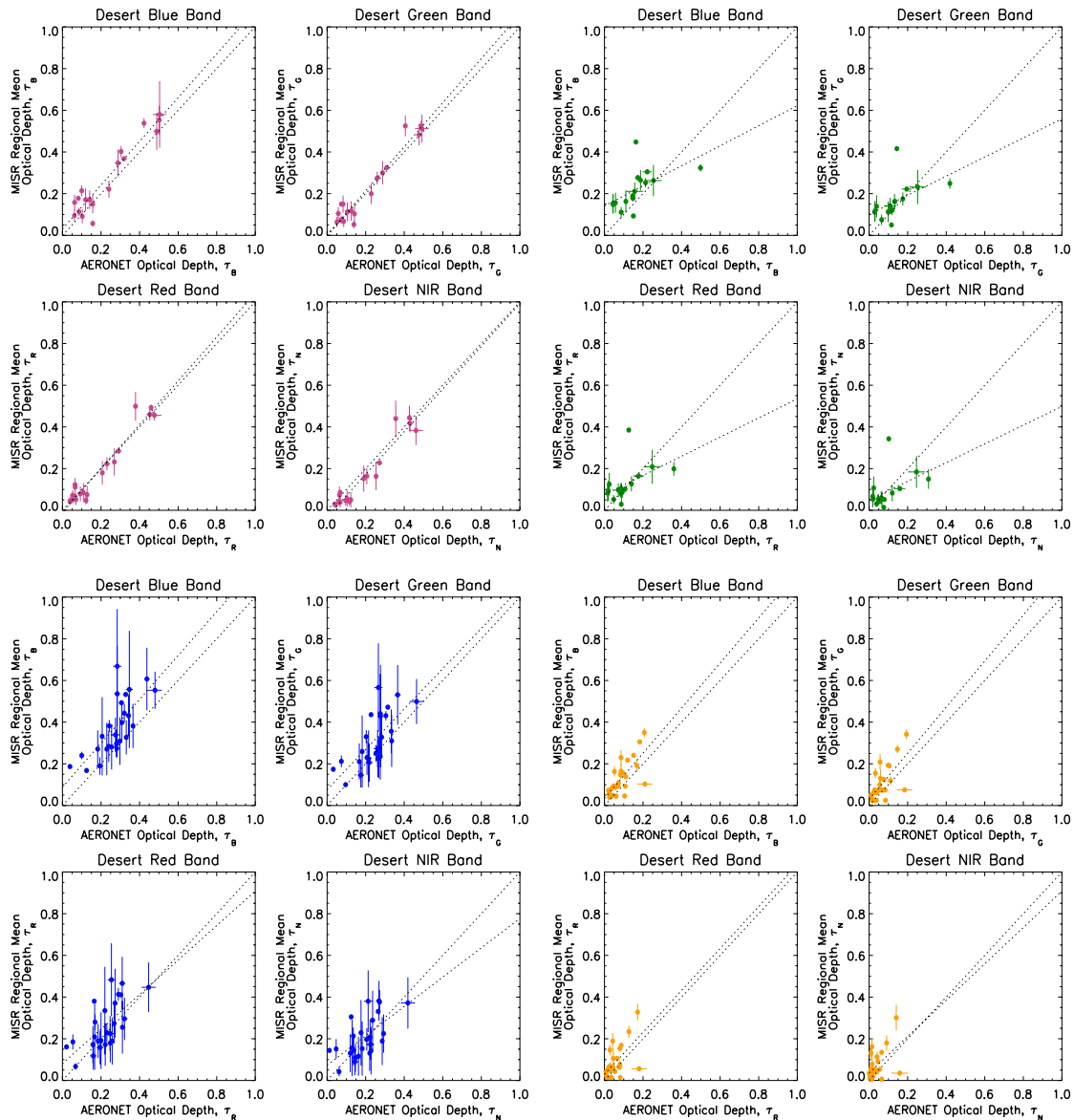


Figure 1. A comparison of MISR single region (1×1) AOD with those of AERONET in MISR's four spectral bands (Blue = 446 nm, Green = 558 nm, Red = 672 nm, NIR = 866 nm) for the sites Ad Dakhla (red symbols), Sede Boqer (green), Solar Village (blue), and Dalanzadgad (brown). All comparisons cover the two year period from December 2000 to November 2002. The dotted lines in each plot are the 1:1 line and the unconstrained best linear fit.

ture. A comparison of coincident MISR and AERONET AOD at four desert sites across Africa and Asia has shown that MISR provides reliable AOD over these relatively bright surfaces. Although the MISR observation repeat time is only 3 or 4 visits per month for those latitudes where Earth's large desert areas occur, much of the major dust activity can be captured at this temporal resolution as Figure 2 demonstrates. The current estimated uncertainty in the determination of desert dust optical depth by MISR is about 0.08 when the spatial resolution is 17.6 km. If this resolution is degraded to 52.8 km, then the uncertainty approaches 0.05. The current set of MISR aerosol models used by the operational algorithm has known deficiencies, particularly with regard to dust particle properties and variety in the bimodal particle mixtures. It is expected that much of the site-specific AOD bias perceived in Figure 1

will be reduced when these aerosol models are improved. Activity in this area is currently ongoing by the MISR team and includes modification of the particle properties used by the dust models [Kalashnikova *et al.*, 2004] and provision of a wider variety of bimodal mixture types. Based on extensive radiometric calibration studies of MISR [Bruegge *et al.*, 2003] and continuous monitoring of the MISR

Table 2. MISR Spectral AOD Uncertainties^a

Site	B1	G1	R1	N1	B3	G3	R3	N3
Ad Dakh	0.071	0.048	0.045	0.052	0.084	0.097	0.111	0.137
Sede B	0.095	0.082	0.077	0.074	0.037	0.020	0.024	0.031
Solar V	0.140	0.114	0.099	0.080	0.078	0.072	0.069	0.055
Dalanz	0.073	0.072	0.071	0.069	0.037	0.019	0.015	0.019

^aB1 = 1×1 blue; G1 = 1×1 green; R1 = 1×1 red; N1 = 1×1 NIR
B3 = 3×3 blue; G3 = 3×3 green; R3 = 3×3 red; N3 = 3×3 NIR.

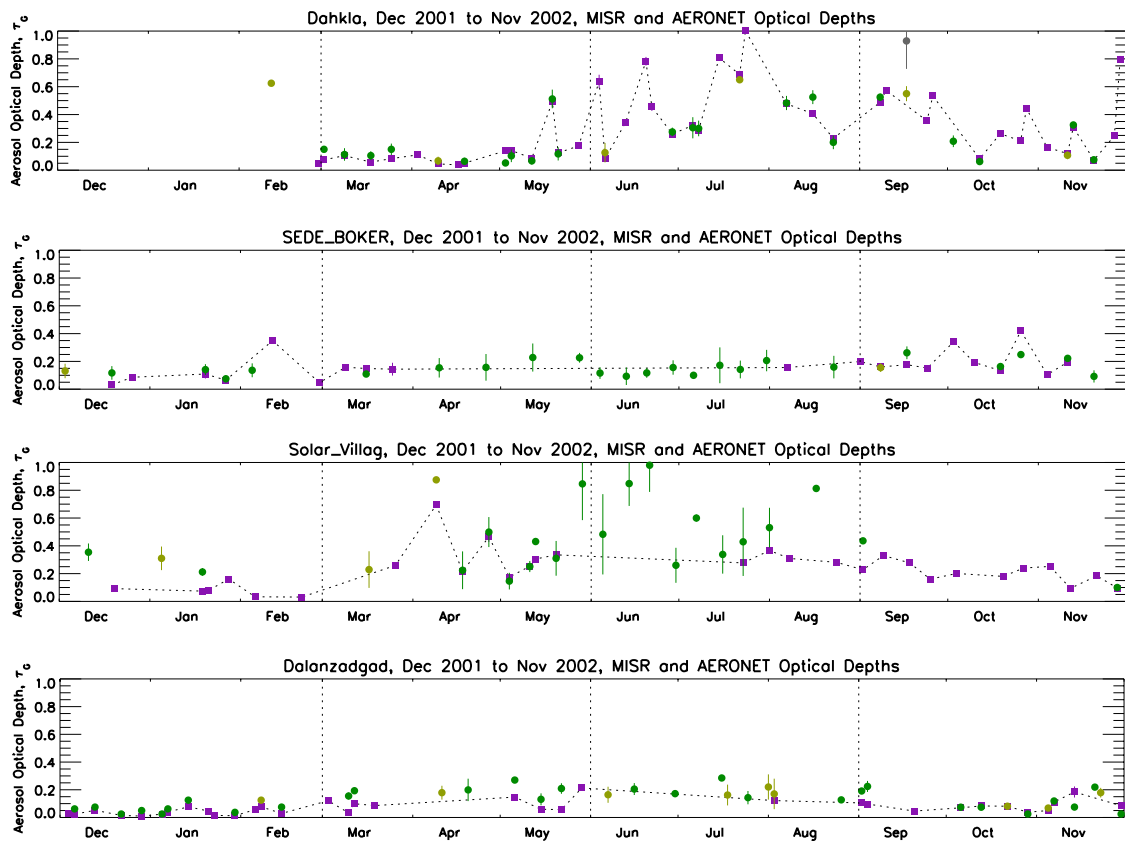


Figure 2. A time series comparison of AOD for MISR (1×1 = solid dark green circles, 3×3 = solid light green circles) and AERONET (solid purple squares and dotted line) at 558 nm (MISR green band) and covering a one year period from December 2001 to November 2002. The sites are Ad Dakhla, Sede Boqer, Solar Village, and Dalanzadgad. Note that both MISR single region (1×1) and averaged region (3×3) results are shown.

operational aerosol retrieval product, the expectation is that aerosol optical depth can be consistently retrieved with an uncertainty of 0.05 at 17.6 km resolution over the Earth's land surface, including bright desert regions. Once these aerosol model improvements are implemented, more detailed validation studies can be conducted to address additional aerosol properties including particle size, sphericity, and absorption.

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D. J. Diner, B. Gaitley, R. Kahn, and J. V. Martonchik, Jet Propulsion Laboratory, California Institute of Technology, Mail stop 169-237, 4800 Oak Grove Drive, Pasadena, CA 91109, USA. (john.v.martonchik@jpl.nasa.gov)
B. N. Holben, Goddard Space Flight Center, Code 923, Greenbelt, MD 20771, USA.