Dust Aerosol Retrieval Results from MISR

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ABSTRACT

Satellite measurements provide important tools for understanding the effect of mineral dust aerosols on past and present climate and climate predictions. Multi-angle instruments such as Multi-angle Imaging Spectro-Radiometer (MISR) provide independent constraints on aerosol properties based on their sensitivity to the shape of aerosol scattering phase functions. The current MISR operational retrieval algorithm (version 16 and higher) was modified by incorporating new non-spherical dust models that account for naturally occurring dust shapes and compositions. We present selected examples of MISR version 16 retrievals over AERONET sunphotometer land and ocean sites during the passage of dust fronts. Our analysis shows that during such events MISR retrieves Angstrom exponents characteristic of large particles, having little spectral variation in extinction over the MISR wavelength range (442, 550, 672 and 866 nm channels), as expected. The retrieved fraction of non-spherical particles is also very high. This quantity is not retrieved by satellite instruments having only nadir-viewing cameras. Our comparison of current (version 16) MISR-retrieved aerosol optical thickness (AOT) with AERONET instantaneous AOT shows better coverage and stronger correlations than when making identical comparisons with previous AOT retrievals (version 15). The MISR algorithm successful mixtures include a non-spherical dust component with high frequency in retrievals over dark water and slightly lower frequency over land. Selection frequencies of non-spherical dust models also decrease in dusty regions affected by pollution.

Keywords: MISR retrievals, atmospheric dust, optical properties of nonspherical particles

1. INTRODUCTION

Some of the world's largest dust plumes emanate from Saharan and Northern Eurasian deserts and are expected to increasingly affect the world's environment and climate. High spatial and temporal variability of dust morphological and mineralogical properties currently limit our knowledge of dust physical and optical properties and the processes responsible for dust production, transport and evolution. Dust-aerosol amounts vary greatly with season and locale. Micro-physical properties depend on source region and evolve during transport due to size- and composition-selective removal, as well as interactions with other atmospheric species. Compared to other atmospheric aerosols, our understanding of dust radiative forcing is highly uncertain in its magnitude and even in its sign, making cooling and heating effects equally possible.[1]

Together with field experiments, satellite observations of dust outbreaks, placed into the context of large-scale dust transport modeling, can help understand the impact of mineral dust aerosols on past and present climate and climate predictions in dusty regions. Multi-angle instruments such as the Multi-angle Imaging SpectroRadiometer (MISR) can provide independent constraints on aerosol properties based on their sensitivity to the shape of aerosol scattering phase functions.[2,3] However, good-quality optical properties of selected aerosol types are required for MISR retrieval algorithm lookup tables.[4] Mineral dust non-sphericity, complex composition, and large spatial and temporal variability are important characteristics that can have a profound effect on reflected intensity and must be explicitly accounted for in satellite-aerosol retrievals in general, and in MISR retrievals in particular.[5,6]

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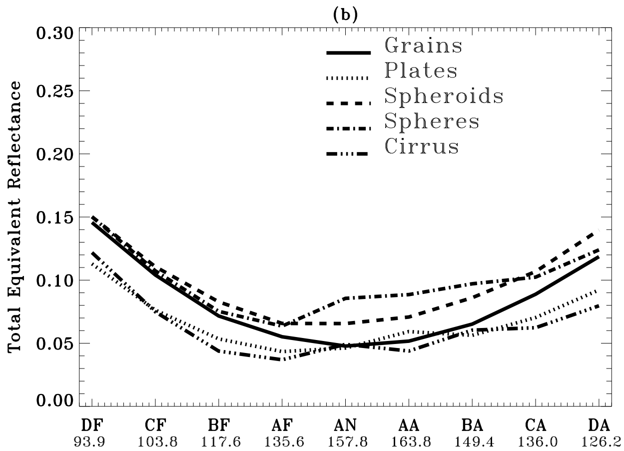

Figure 1. TOA reflectances calculated for pure shape models for optical depth of 0.5 at red ($0.672\mu m$) channel. The nine MISR cameras are indicated at abscissa with associated scattering angles. Adopted from Kalashnikova et al., 2004.[11]

A few important changes have been made to some of the operational aspects of the MISR aerosol retrieval algorithm (version 16 and higher), which are described by Diner et al., 2004.[7] One of these modifications included updating non-spherical dust models to include more realistic, wavelength-dependent refractive indices in the MISR look-up tables. These models were developed based on morphological and mineralogical properties of natural dust particles collected in the atmosphere.[8, 9] Here we show several comparisons of the new MISR aerosol AOT retrieval to AERONET sunphotometer results over both ocean and land sites during the passage of dust fronts.

2. MISR SENSITIVITY TO DUST NON-SPHERICITY

The MISR instrument views Earth in nine different directions in order to detect angular variations of the sunlight reflected by aerosols, clouds and the surface.[3] The nine MISR push-broom cameras are displaced with respect to the nadir camera (An), with nominal viewing angles of $26.1, 45.6, 60.0$ and 70.1^0 in forward (Af, Bf, Cf, Df) and backward (Aa, Ba, Ca, Da) along-track directions. Each camera images the underlying scene in four spectral bands centered at 446.4, 557.5, 671.7 and 866.4 nm with bandwidths of 41.9, 28.6, 21.9 and 39.7 nm, respectively. The time interval between observations of a point on the surface by the Df and Da cameras is 7 minutes, global coverage is obtained in nine days, and the MISR spatial sampling is 275m to 1.1km. MISR retrievals take advantage of a high absolute radiometric accuracy of 3% at the maximum signal.[10]

Recent MISR theoretical sensitivity studies of dust shape and composition under good viewing conditions assuming that only dust aerosols are present in the atmosphere, demonstrate that MISR is sensitive to dust shape with uncertainty less than 20% in fraction of mid-visible optical depth. In addition these studies show MISR's ability to distinguish weakly-absorbing from strongly-absorbing dust particles.[11] Figure 1 shows Top of Atmosphere (TOA) reflectances modeled for several shapes at the MISR mid-latitude viewing geometry. This figure demonstrates large differences in the intensity signal from grain-like, plate-like, spherical and spheroidal dust components as well as from cirrus particles for all MISR cameras. MISR aerosol retrievals performed with the MISR *research* retrieval code[12] over thick dust plumes[9] and during dust events over dark water[11] preferably selected the grain dust component and rejected the plate, spheroidal and spherical components. The MISR research retrieval also preferred weakly absorbing dust particles having 1 and 2% hematite over strongly-absorbing dust particles having 10% hematite. Based on these sensitivity studies, we choose to include a grain-shaped medium-sized dust component (median diameter of $1\mu m$ and standard deviation of $\sigma = 1.5$) having 1% hematite in the MISR operational aerosol retrieval (version 16 and higher). We also included a large-sized dust component with spheroidal shape (median diameter of $2\mu m$ and $\sigma = 2.0$) having 1% hematite into the operational algorithm. This component, while rarely selected in the research retrievals over dark water, may be required for MISR land retrievals during dust storms. Properties of these two models are summarized in Table 1.

Table 1. Physical and optical properties of new dust particle models incorporated in MISR operational aerosol retrieval algorithm. Summary from Kalashnikova, et al., 2004[9]

Name	Shape	n_r	n_i*10^3 $0.672\mu m$	n_i*10^3 $0.866\mu m$	ω_0 $0.672\mu m$	ω_0 $0.866\mu m$
medium-sized dust	Grains	1.51	0.652	0.472	0.994	0.996
large-sized dust	Spheroids	1.51	0.652	0.472	0.970	0.983

The currently modified MISR aerosol retrieval algorithm (version 16) uses a set of 74 prescribed aerosol mixtures,[7] 24 of which include dust components. Among these dusty mixtures, 12 mixtures contain a medium-sized dust component mixed with small and large-sized non-absorbing spherical particles, 8 mixtures contain bi-modal dust distributions (medium and large-sized dust components) mixed with small-sized non-absorbing spherical particles, and 4 are solely dust, containing the only bimodal dust distribution.

3. MISR DUST RETRIEVAL EXAMPLES AND DISCUSSIONS

Here we selected a number of retrieval cases, illustrating various dusty conditions over land and water, close to dust sources and after long-range dust transport.

3.1. Dust plumes over dark water. Cape Verde Islands and Bermuda

The best MISR retrievals with the new dust models were archived over dark-water dusty sites located relatively close to the dust source.

The MISR version 16 aerosol algorithm retrieves expected optical properties and characteristics (including non-sphericity) of a dust plume over dark water. Figure 2 shows an example of a MISR retrieval on June 11, 2003 over the Cape Verde Islands. Here a heavy dust front passed just north of the Islands and is clearly visible on a true color RGB image from the MISR DF camera. The retrieval shows a large optical depth, a small Angstrom exponent, a large (close to 1) single scattering albedo, and a large concentration of non-spherical particles over the dust plume. For comparison, observe on the RGB image a much less dusty area south of Cape Verde; here MISR detects a smaller AOT, a larger Angstrom parameter, and a larger concentration of spherical particles. See[13] for additional examples.

Compared to version 15, MISR new dust models significantly improve retrieval coverage. Version 16 now provides aerosol optical properties over optically thick dust areas where version 15 retrievals previously failed. For example, Figures 3-4 show a comparison of version 15 and 16 AODs over dust plumes retrieved at Capo Verde on June 11, 2003 and June 6, 2004. These Figures demonstrate increased MISR coverage and MISR's ability to retrieve aerosol properties over optically-thick dust.

In addition, MISR version 16 AOTs tend to be lower over dust than previously-retrieved values (version 15). This is encouraging because previous MISR validation studies[14] have shown that version 15 retrieval algorithm tended to overestimate the AOT over ocean sites especially in the presence of dust. Figure 5 shows a comparison of version 15 and version 16 MISR AODs retrieved for dusty pixels near Cape Verde Islands. AODs retrieved with new models are smaller and have less variation between MISR bands (i.e., smaller Angstrom exponent).

A detailed comparison of MISR-retrieved AOTs with both versions 15 and 16 and AERONET AOTs demonstrate that AOT retrievals with the new models were in better agreement with instantaneous AERONET values in cases where dust plumes were passing directly over the Cape Verde Islands. Figure 6 shows MISR-AERONET comparisons during dust front passages on June 11, 2003, February 6, 2004, February 8, 2004, and June 6, 2004. February 8 was the only day, from all considered dark-water cases, when the MODIS camera was not in sun-glint, so it is our only case where simultaneous MISR, MODIS and AERONET retrievals are available. The MODIS land retrieval actually failed, therefore we could only use the MODIS ocean best AOTs adjacent to the AERONET site. The MISR version 15 retrieval appears similar to the MODIS ocean retrieval, but both

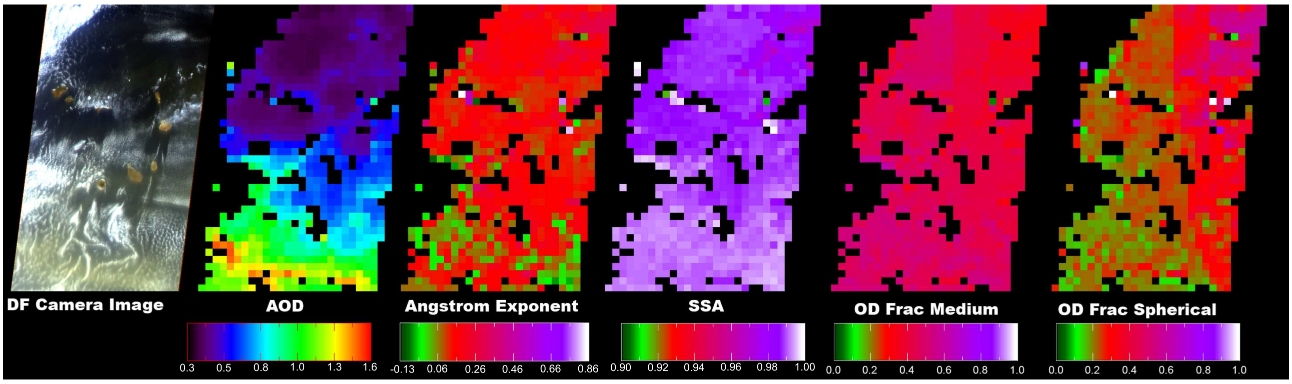

Figure 2. MISR retrievals of aerosol optical properties (from left to right): MISR image, aerosol optical depth, Angstrom Exponent, single scattering albedo, optical depth fraction of medium particles, optical depth fraction of spherical particles; path 210, 0rbit 18511, June 11, 2003.

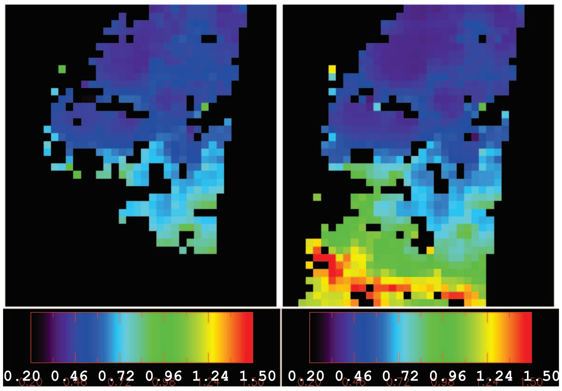

Figure 3. Comparison of MISR retrieved AOTs using the old (version 15, left) and the new (version 16, right) MISR dust models for dust over the Cape Verde Islands, June 11, 2003.

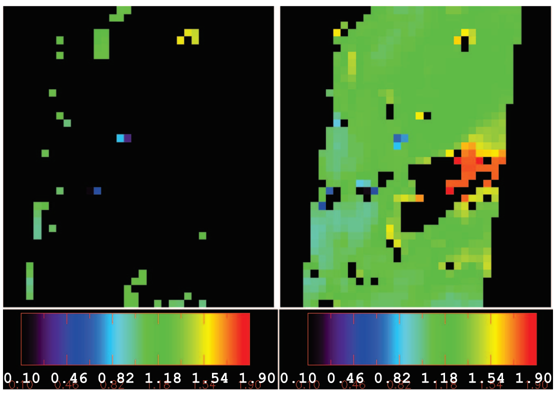

Figure 4. Comparison of MISR retrieved AOTs using the old (version 15, left) and the new (version 16, right) MISR dust models for dust over the Cape Verde Islands, June 6, 2004.

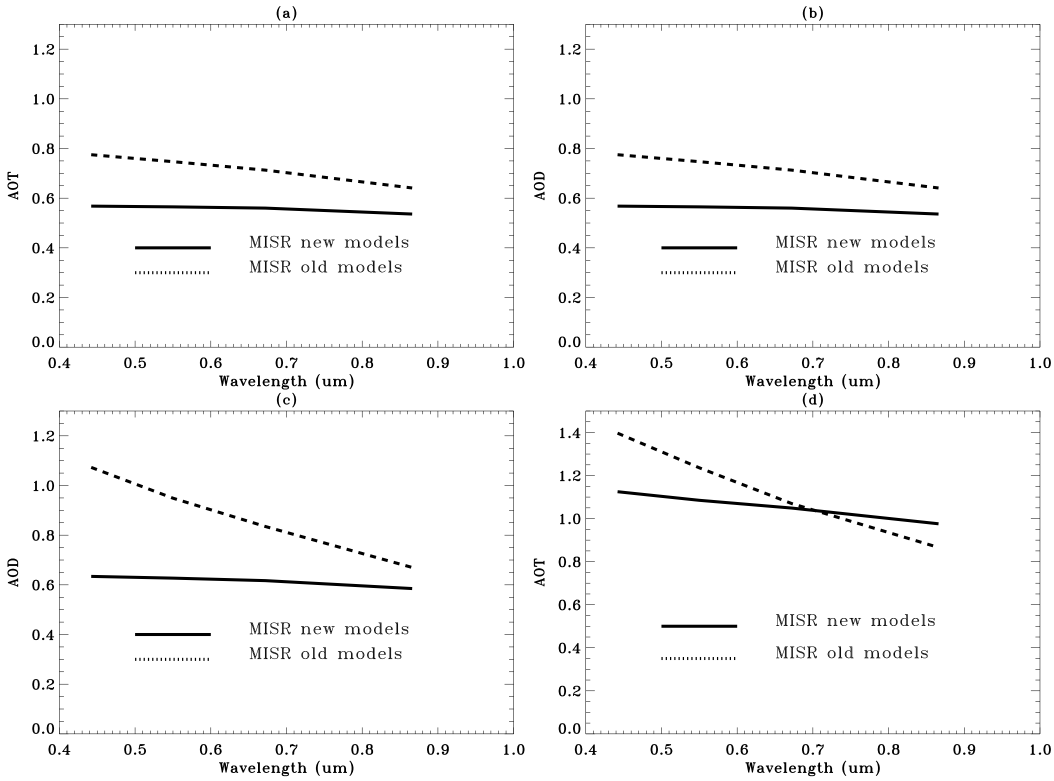

Figure 5. Comparing MISR Version 15 and 16 retrieved AOT. Cape Verde, (a) June 11, 2003. (b) February 6, 2004, (c) February 8, 2004 (d) June 6, 2004

AOTs are higher in the visible and lower in the near-IR when compared to the AERONET AOTs. MISR AOTs retrieved with the new dust models have much better agreement with AERONET than those of MODIS or MISR version 15.

Our performance tests confirmed that MISR version 16 retrievals are able to capture non-spherical dust particles not only close to the dust source but also over remote ocean sites affected by long-range Saharan dust transport. Figure 7 shows two examples of MISR retrievals at the AERONET Bermuda site and compares MISR version 15, MISR version 16 and AERONER AOTs. This figure also shows version 16 SSA and retrieved percentage of nonspherical particles. In these two cases, the new dust models improved MISR's retrieved AOT and Angstrom exponent when compared with coincident AERONET data. The retrieved fraction of nonspherical particles was relatively high for this remote ocean site.

In all the cases presented in this section, MISR retrievals selected the new dust models as successful models for dust plumes and spherical models for non-dusty areas. We have obtained similar results in many additional test cases. In all cases we have tested over dark-water, MISR was able to detect non-sphericity over dust plumes. We will next discuss MISR's ability to retrieve dust properties over land.

3.2. Retrievals over land

Version 16 retrievals over dusty land sites showed some improvements, however the fraction of retrieved non-spherical particles was smaller when compared to ocean sites.

During dust events over land when contributions from other absorbing aerosol particles were relatively small, new dust models significantly improved MISR-retrieved AOD and Angstrom exponent. For example, Figure8 shows MISR's AOT version 15 and 16 retrievals compared to AERONET over the land Banizombou AERONET site during passage of dust. As shown, the retrieved AOTs and Angstrom exponent have significantly improved in version 16, and the fraction of non-spherical particles was relatively high as expected for dust.

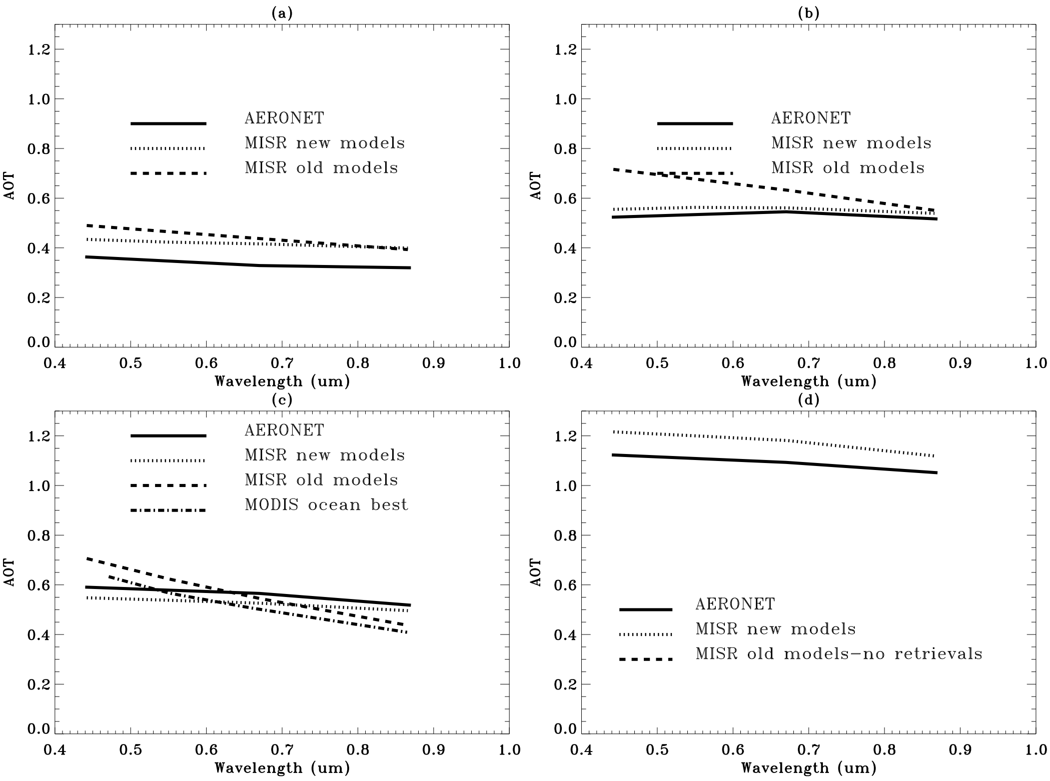

Figure 6. MISR-AERONET AOT comparison, Cape Verde, (a) June 11, 2003; (b) February 6, 2004; (c) February 8, 2004; (d) June 6, 2004

While MISR-retrieved AOTs were in good agreement (±0.07) with coincident AERONET data over land sites tested, MISR still has problems obtaining good-quality data over regions where dust is mixed with smoke and pollution, as probably due to the absence of dust and absorbing particle mixtures in the current set of 74 MISR mixtures. At dusty sites (Yulin, Solar Village, SEDE BOKER and Nes Ziona) that were affected by both dust and pollution at the time of MISR overpasses, both versions 15 and 16 underestimated AOT when compared to coincident AERONET measurements. Analysis of MISR-retrieved AOTs for some sub-Saharan AERONET sites (Banizombou, Ouagadougou and Dakar) for days with both dust and biomass burning, showed a MISR AOT overestimation. Results of version 16 appear similar to those of version 15 as analyzed by Kahn et al., 2004[14] for dusty sites affected by pollution and biomass burning. Although both versions retrieved similar AOTs, version 16 did detect a non-negligible fraction of non-spherical particles.

4. CONCLUSIONS

The examples described in Section 2 indicate we have achieved a significant degree of success in using MISR data to retrieve optical properties of non-spherical dust particles. What led to this success was MISR's sensitivity to aerosol scattering phase functions and the routine use of data from all nine viewing angles. Performance tests of our new dust models in MISR operational retrievals over dark-water regions affected by dust show improved coverage and better agreement with coincident AERONET AOTs when compared with MISR version 15. However, some algorithm improvements, such as adding reliable aerosol models for absorbing dust particles and adding representative dust-pollution and dust-smoke mixtures, could improve MISR retrievals even further.

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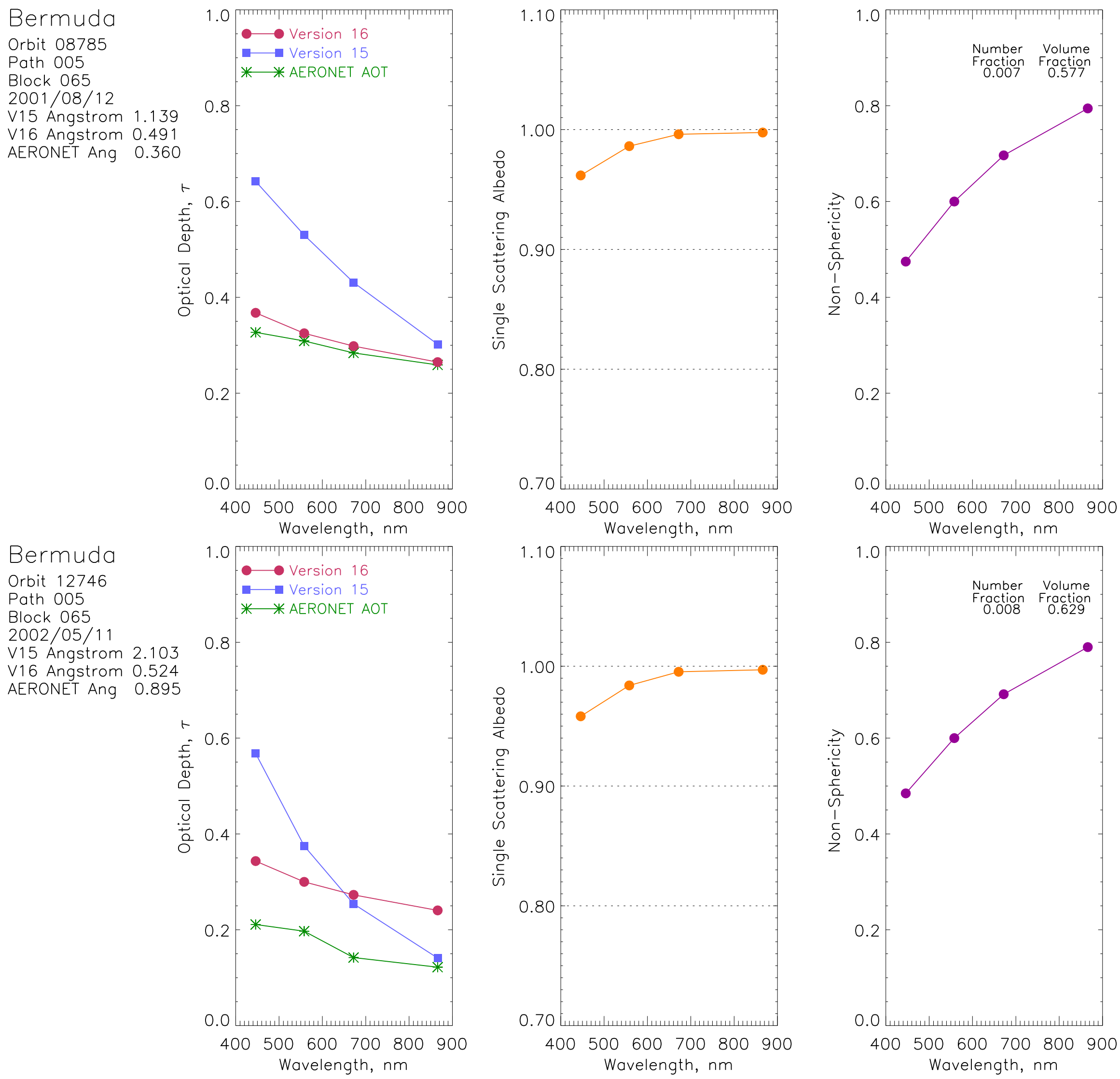

Figure 7. The left most figures compare retrieved vs. measured AOT of MISR version 15, version 16 and AERONET over the Bermuda ocean site on two dusty days. The center and right figures shows version 16 retrievals of SSA and non-sphericity.

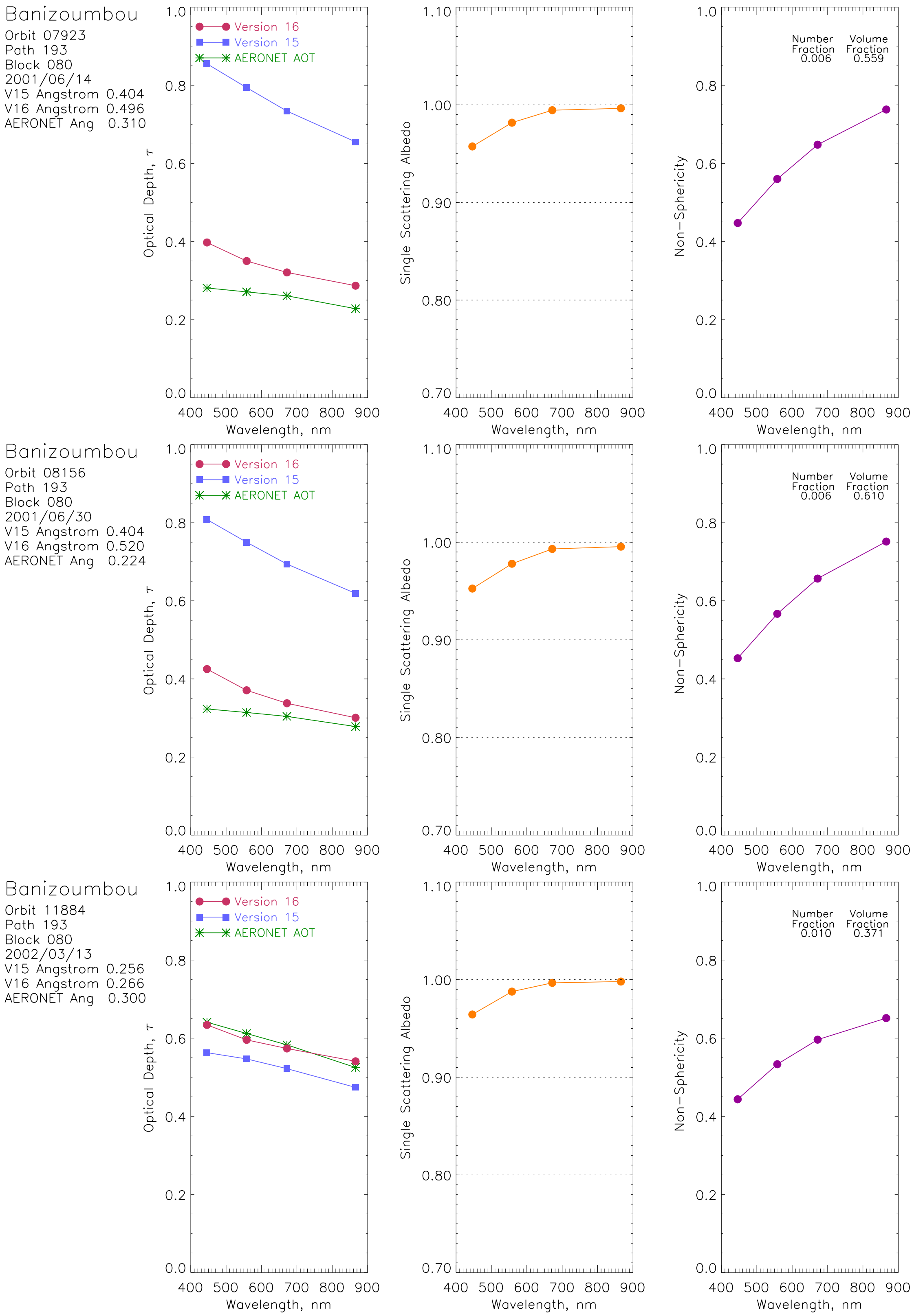

Figure 8. The left most figures compare retrieved vs. measured AOT of MISR version 15, version 16 and AERONET over Banizombou land site on three dusty days. The center and right figures shows version 16 retrievals of SSA and non-sphericity.

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