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Response to "Toward unified satellite climatology of aerosol properties. 3. MODIS versus MISR versus AERONET"

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A B S T R A C T

A recent paper by Mishchenko et al. compares near-coincident MISR, MODIS, and AERONET aerosol optical depth (AOD), and gives a much less favorable impression of the utility of the satellite products than that presented by the instrument teams and other groups. We trace the reasons for the differing pictures to whether known and previously documented limitations of the products are taken into account in the assessments. Specifically, the analysis approaches differ primarily in (1) the treatment of outliers, (2) the application of absolute vs. relative criteria for testing agreement, and (3) the ways in which seasonally varying spatial distributions of coincident retrievals are taken into account. Mishchenko et al. also do not distinguish between observational sampling differences and retrieval algorithm error. We assess the implications of the different analysis approaches, and cite examples demonstrating how the MISR and MODIS aerosol products have been applied successfully to a range of scientific investigations.

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1. Introduction

To begin this response, we offer some context by briefly reviewing the roles the Multi-angle Imaging SpectroRadiometer (MISR) and MODerate resolution Imaging Spectroradiometer (MODIS) play in satellite aerosol remote sensing, and the validation efforts that are central to the instrument programs. MISR and MODIS, both of which fly aboard the NASA Earth Observing System's Terra spacecraft, represent significant advances over the previous generation of space-based aerosol instruments. Relatively high spatial resolution imaging, calibration accuracy, and radiometric stability, along with an increased number of spectral bands for MODIS and the combination of spectral bands and multiple view angles for MISR, have led to more robust aerosol optical depth (AOD) retrievals over both water and land, with less-restrictive algorithmic assumptions [1–5]. In addition, the MODIS algorithm derives coarse vs. fine-mode ratio over water, whereas MISR can distinguish about a dozen aerosol air mass types under favorable retrieval conditions, based on particle size, shape, and single-scattering albedo constraints. And unlike most remote sensing algorithms that assume aerosol properties based on seasonally and/or geographically fixed prescriptions, MISR AOD retrievals are performed self-consistently, using aerosol types retrieved without prescribed spatial or temporal constraints.

Critical to the application of these satellite products is validation, which entails establishing uncertainties,

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assessing strengths and limitations, and reporting overall data quality. The MISR and MODIS instrument teams, as well as many other research groups, have performed such evaluations using a variety of methods, ranging from theoretical sensitivity studies to comparisons with other satellite, surface-based, and aircraft data sets, covering a wide range of environmental conditions [e.g., 2,6–27]. The statistical evaluations have been complemented by representative case-study analyses, often aimed at identifying the underlying causes of discrepancies [e.g., 2,6,8–10,12,14–16,18–22,25–27]. Explanations for the most prominent differences between the MISR Standard aerosol products and validation data are given in a number of these papers, including focused investigations using the MISR Research aerosol retrieval algorithm for dust [13], spherical absorbing and non-absorbing particles [7], thin cirrus [17], and algorithmic issues [11]. Detailed analysis of MODIS issues is presented in [2,4,14,19,21,22,29–31]. This body of work, developed over the past ten years, has yielded better characterization of existing products, the identification of specific issues such as calibration biases and limitations in particle mixture options, along with a series of algorithm upgrades, based upon what is learned from the growing collection of coincident ground-truth data, aerosol field observations, and the continuing validation effort.

In their recent paper, Mishchenko et al. [32] evaluate the MISR and MODIS AOD retrievals in light of near-coincident AERONET observations, and present a picture of the aerosol products that is far less favorable than that provided by the studies listed above. For several months of data, we can reproduce the numerical results of the primary metric adopted by [32] to compare MISR and MODIS. However, this metric is more appropriate for assessing random error about a single, expected value, than global satellite AOD data, where the true value varies in space and time, and sampling is non-uniform. As implemented, their approach also exaggerates small differences in values near the lower limit of measurement sensitivity. They interpret all discrepancies as caused by retrieval error despite significant contributions from sampling differences, and they do not take account of other issues with the MISR and MODIS products already identified, characterized, and in many cases explained in the validation papers cited above. As such, their presentation lacks the deeper understanding of the data, discussed in previous publications, that indicates how the MISR and MODIS aerosol products have been, can be, and should be used, given known limitations.

The current response highlights the differences in the assessment of data quality between [32] and our published work, yielding insight as to how these studies arrive at such different conclusions about the utility of the satellite products. We focus here on the interpretation of results presented in [32]; broader questions about MISR and MODIS data product quality are treated in the validation papers cited above, and are summarized in the Data Quality statements distributed with the MISR and MODIS products.

Our analysis shows that the largest contribution to the disparate results comes from differences in the treatment of *outliers*; other factors are involved as well, such as the seasonally varying *spatial distribution of coincident MISR-MODIS AOD retrievals*, and differences in the application of *absolute vs. relative criteria* for testing agreement. We review the implications of these below, clarify several other technical points for the benefit of those interested in using the data sets, and conclude by referencing studies that demonstrate how the MISR and MODIS aerosol products have already been applied to a range of cutting-edge aerosol questions.

2. The limits of collocation

Although operating from the same Terra satellite, MODIS and MISR offer different views of aerosols, clouds, and surface radiation. Due to differences in their observational approaches, these instruments are sensitive to different properties of the scene, even when viewing nearly coincident target regions. Aside from global coverage differences [e.g., 12], MISR and MODIS do not observe, or perform aerosol retrievals on, top-of-atmosphere radiances from exactly the same locations within their 17.6 and 10 km retrieval regions, respectively. Where variability occurs on spatial scales of ~10 km or less [e.g., 19], this leads to *sampling* differences even for "collocated" observations [11].

MISR and MODIS data are often complementary, hence differences do not always represent algorithm issues; sometimes they offer a deeper understanding of realistic natural scenes. For example, case studies that take detailed account of instrument sampling have indicated where MISR and MODIS—retrieved AOD differences are due to aerosol spatial variability [9,11]. Further, several analyses show that the fraction of MISR-AERONET outliers attributable to spatial and/or temporal variability amounts to ~70% or more of all significant outliers [10,28]. Sampling differences must be taken into account for some applications, including assessments of algorithm performance.

3. Influence of outliers

The treatment of outliers in [32] has a major effect on the overall magnitude of the errors they report. In ([32], Figure 1c), a normalized standard deviation metric (RSTD) is used to assess the MISR and MODIS time series, separately for ocean and land. The RSTD, in this case a measure of MISR-MODIS relative discrepancy, is calculated from the root-sum-square of the MISR-MODIS AOD difference. *This metric is especially sensitive to the largest outliers*, which can be caused by retrieval error or by sampling differences, as mentioned above. In addition, although sampling differences tend to produce outliers of both signs, AOD retrieval errors are often systematic rather than random [10,11], and most are localized geographically within regions where certain algorithmic assumptions are violated ([12], Figure 6; [28], Section 3.4). As a statistical tool, the RSTD is most appropriate for assessing *random error about a single, expected value*; interpretation of RSTD values under other circumstances is not straightforward, especially for highly diverse, global AOD retrieval distributions.

Despite generally good agreement between MISR and MODIS in the AOD time series (32, Figure 1a), high percentage-differences appear in the RSTD plots ([32], Figure 1c), averaging around 40% over ocean and near 90% over land.