Validation of MODIS Aerosol Retrieval Over Ocean

Popular Summary

Submitted to Geophysical Research Letters

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EOS-Terra is the pride of NASA's Earth Observing System. One of the many products derived from Terra's sensors is the global aerosol product retrieved using the MODerate resolution Imaging Spectroradiometer (MODIS) radiances. Aerosols, which are suspended particulates such as dust, smoke and air pollution, can affect the earth's climate, weather, rainfall patterns, human health and aircraft safety. Although aerosols are important, exact knowledge of their distribution and characteristics continues to elude us. We expect the MODIS aerosol product to correct this deficiency, and pre-launch experiments indicated that MODIS would retrieve aerosol information with sufficient accuracy to make a substantial improvement to our understanding of aerosol climatology and characteristics. Will our pre-launch expectations be met?

This paper reports on the accuracy of the MODIS algorithm in determining aerosol characteristics over the ocean. It describes the methods used to measure the accuracy of MODIS and reports on the results of data collected over a two-month period in 2000. For this two-month period, the study found MODIS remarkably accurate.

The method used for validation involved comparing data from the MODIS to data from the ground based AERONET network. Comparisons were made in two areas, aerosol optical thickness and measures of particle size, including the first operational attempt to retrieve effective radius from space. The accuracy of MODIS in determining aerosol optical thickness was well within expected uncertainty at 660 nm and 870 nm, while the retrievals of aerosol effective radius agree with AERONET retrievals to within ± 0.1 μm for the size range of 0.2 –0.8 μm. The study puts confidence in the ability of MODIS to characterize ocean aerosol; however, more extensive studies in terms of global area and time period are still necessary.

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Submitted to *Geophys. Res. Lett.*
March 2000

Abstract

The MODerate resolution Imaging Spectroradiometer (MODIS) algorithm for determining aerosol characteristics over ocean is performing with remarkable accuracy. A two-month data set of MODIS retrievals co-located with observations from the AErosol RObotic NETwork (AERONET) ground-based sunphotometer network provides the necessary validation. Spectral radiation measured by MODIS (in the range 550-2100 nm) is used to retrieve the aerosol optical thickness, effective particle radius and ratio between the submicron and micron size particles. MODIS-retrieved aerosol optical thickness at 660 nm and 870 nm fall within the expected uncertainty, with the ensemble average at 660 nm differing by only 2% from the AERONET observations and having virtually no offset. MODIS retrievals of aerosol effective radius agree with AERONET retrievals to within ±0.10 μm, while MODIS-derived ratios between large and small mode aerosol show definite correlation with ratios derived from AERONET data.

1.0 Introduction

The MODerate resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra spacecraft began collecting data in February 2000. One of the important products delivered by MODIS is the Level 2 daily, global aerosol characterization parameters (Tanré et al., 1997; Kaufman et al., 1997). The aerosol characteristics are derived over the land and oceans separately, using independent algorithms. This paper addresses the validation of the algorithm used for aerosol retrievals over oceans. A companion paper (Chu et al., this issue) addresses the retrievals over land.

Over oceans, the MODIS aerosol algorithm inverts the measured 500m resolution radiance from six MODIS bands (550-2100 nm) to retrieve the aerosol information. Specifically, in cloud-free, glint-free ocean scenes (Martins et al., this issue), MODIS retrieves aerosol properties at a 10 km resolution. Primary products include: aerosol optical thickness in seven wavelengths, the effective radius of the aerosol, and the fraction of the total optical thickness contributed by the fine (sub-micron size) mode aerosol (Tanré et al. 1997). Figure 1 shows the global distribution of the monthly mean primary products for September 2000. In addition, various aerosol-related quantities are derived from these primary products.

2.0 Validation Strategy

Roughly six months after MODIS began collecting radiance data, the sensor's calibration had stabilized to the point where accurate validation of the aerosol products could begin. Our primary validation strategy is to co-locate MODIS retrievals with automatic Sun/sky radiometers of the AErosol RObotic NETwork (AERONET) (Holben et al. 1998) coastal and island stations (http://aeronet.gsfc.nasa.gov). We calculate the statistics of the aerosol products in a spatial subset consisting of an array of 5 by 5 aerosol "pixels", centered on the AERONET location (Ichoku et al., this issue). Since the aerosol "pixel" size is 10 km, the subsetted area is approximately 50 km square. The selection and spatial subsetting of the MODIS product is objective and automatic (Ichoku et al., this issue). Not all of the 25 aerosol pixels contain ocean aerosol retrievals at every co-located overpass. Some pixels are over land, and some contain clouds or are otherwise rejected by the MODIS algorithm during processing. We require at least 5 of the 25 aerosol pixels to contain ocean aerosol retrievals before including in the validation data set.

The AERONET data provide the ground truth for the MODIS validation. The globally distributed ground-based AERONET radiometers measure aerosol optical thickness in seven channels (340 to 1020 nm) although certain stations record only a subset of these channels (Holben et al., 1998). The instruments make measurements every 15 minutes. We calculate statistics from the observations taken within $\pm$ 30 minutes of the MODIS overpass time (Ichoku et al., this issue). Therefore the maximum number of AERONET observations in the hour surrounding overpass is 5. Fewer observations in the hour indicate data has been removed by the AERONET Run-Time Cloud Checking procedure. We require that there be at least 2 of the 5 observations in order for the AERONET data to be included in the validation data set. We also use the size parameter quantities derived from the AERONET sky retrievals based on the Dubovik inversion scheme (Dubovik and King, 2000; Dubovik et al., 2000). The sky retrievals occur less frequently than the optical thickness measurements. We require the size parameters to have been retrieved ± 2 hours of MODIS overpass.

Data used in this study were collected globally for 2 months starting August 21, 2000. Eleven stations were included in the validation data set. These represent the Mediterranean (4 stations), the coastal western North Atlantic (2 stations), the Caribbean (2 stations) and a few island sites in the central North and South Atlantic (2 stations) and Indian oceans (1 station). The Pacific is not represented. All MODIS data used in this study are derived with Version 2.6.1 of the algorithm (http://modis-atmos.gsfc.nasa.gov). All AERONET data is Level 1.5, which indicates preliminary cloud clearing, but no final calibration or Quality Assurance (Smirnov et al., 2000).

3.0 Aerosol Optical Thickness Validation

Figure 2 shows the scatter plots of co-located MODIS and AERONET aerosol optical thickness (τ). Although MODIS and AERONET both report aerosol optical thickness for seven wavelengths, only the 660nm (670 nm for AERONET) and 870 nm channels are sufficiently similar for direct comparison. Plotted are the mean values of the 5x5 MODIS subset and the ± 30 minute temporal average of the AERONET time series. The ensemble agreement, as represented by the linear fit (R= 0.94 at 660 nm), is exceptionally good and well within the expected uncertainty ($\Delta\tau = \pm 0.03 \pm 0.05\tau$) as denoted by the dashed lines in the figure (Tanré et al., 1997; Tanré et al., 1999; King et al., 1999). Even by removing the one very high optical thickness point the correlation remains high (R=0.90) and the linear regression changes only slightly to $\tau_{MOD} = 0.005 + 1.01\,\tau_{AER}$. The 870 nm validation shows MODIS to be slightly offset from AERONET, but still within the expected uncertainty.

4.0 Size Parameter Validation

MODIS derives two primary size parameters: the effective radius of the total aerosol size distribution and the fraction of optical thickness contributed by the fine mode aerosol. AERONET employs the Dubovik and King (2000) inversion scheme on the sky radiance data to derive the aerosol size distribution and from the size distribution calculates the effective radius and the aerosol volume in each mode. The Dubovik and King (2000) effective radius is identical to the MODIS effective radius and directly comparable. The MODIS ratio of optical thickness should correlate to the AERONET ratio of volumes, but it is not the same quantity, and the two parameters are not expected to agree quantitatively.

Figure 3 shows the validation of the effective radius and the comparison of the ratio of modes. Only data with $\tau660 > 0.15$ are plotted. We examine size parameters only for moderate or large aerosol loading because at low optical thickness there is greater susceptibility to small calibration and retrieval errors for both instruments. These errors make little difference in optical thickness retrieval but create large errors when size parameters are calculated. There are two outlying points, and these are associated with dust situations and nonspherical effects. However, for most of the range of sizes in this data set, MODIS retrievals fall within ± 0.10 μm of the AERONET retrievals, as indicated by the dashed lines. The bottom panel of Figure 3 shows the comparison of the ratio of modes. MODIS and AERONET ratios show definite correlation, even though the values of the two parameters differ. This comparison with ground-based data gives us confidence that MODIS can differentiate between large mode and small mode aerosol, and begin to quantify the size of the aerosol particles.

5.0 Discussion and Conclusions

The MODIS ocean aerosol retrieval is meeting and exceeding our expectations. The direct comparison of aerosol optical thickness is excellent. The spectral dependence and size parameter comparisons are showing an unprecedented accuracy in the ability to characterize aerosol size from space. Also significant is that most of the error in fitting the MODIS observed spectral radiances in the algorithm look-up tables enters from errors in assumptions of the surface properties, not errors in the assumptions of the aerosol characteristics. We see this in Figure 4 where the fitting error is inversely correlated to the optical thickness. The largest errors occur at small optical thickness where the surface contributions such as foam and ocean color have the greatest influence. At higher optical thickness the aerosol signal dominates and the fitting error improves. Even the suspected Saharan dust points follow the trend in Figure 4. This gives us much confidence in the inherent inversion method and in our look-up tables.

Despite the obvious excellent agreement with ground-truth in this validation set, caution needs to be taken. The data set spans a mere two months. It is skewed towards coastal sites, and has a heavy emphasis on the Mediterranean. We will expect more cloud contamination than is apparent in the scatter plots when the MODIS retrievals are not selected to correspond to cloud-screened AERONET data. Furthermore, there are indications that nonsphericity may affect some retrieved products and needs to be further examined. Still, this first validation exercise shows clearly that the operational MODIS algorithm can characterize ocean aerosol with a remarkable and unprecedented accuracy.

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Figure Captions

Figure 1. Monthly mean distribution of aerosol effective radius in μm (top), aerosol optical thickness at 550 nm (middle) and aerosol small mode weighting (bottom). The center panel shows

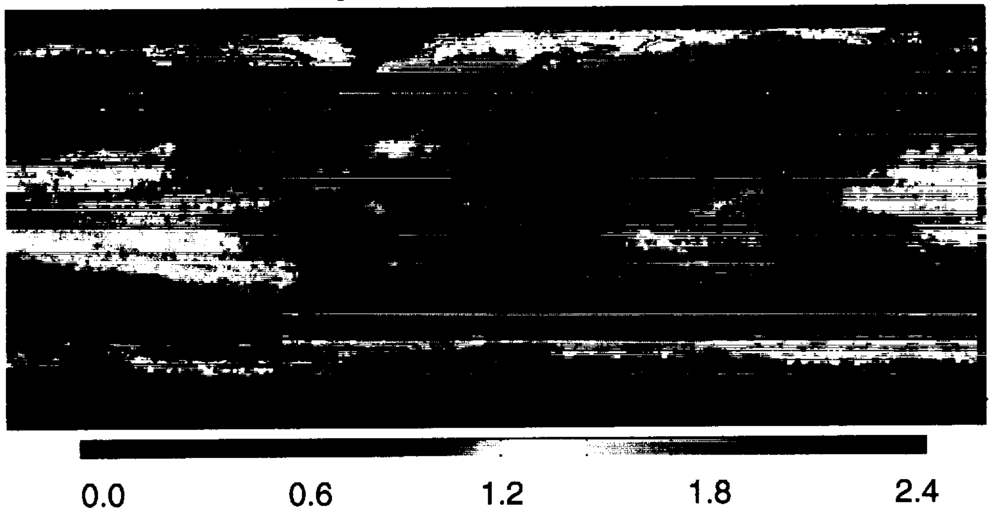
the over land aerosol retrieval merged with the over ocean retrieval. Validation of the over land retrieval is addressed in a separate paper (Chu et al., this issue).

Figure 2. MODIS retrieved aerosol optical thickness (τ) at wavelengths 660 and 870 nm plotted as function of identical AERONET derived quantities. The linear regression and correlation coefficients are shown. The dashed lines denote the expected uncertainty in the retrieval (Tanré et al., 1997; Tanré et al., 1999; King et al., 1999). The different colors represent the different geographical locations: western Mediterranean (purple), eastern Mediterranean (orange), coastal Atlantic (green), Caribbean (light blue), Atlantic islands (dark blue) and the Indian Ocean island (red). Altogether there are 64 co-located measurements that span 2 months and represent 11 stations.

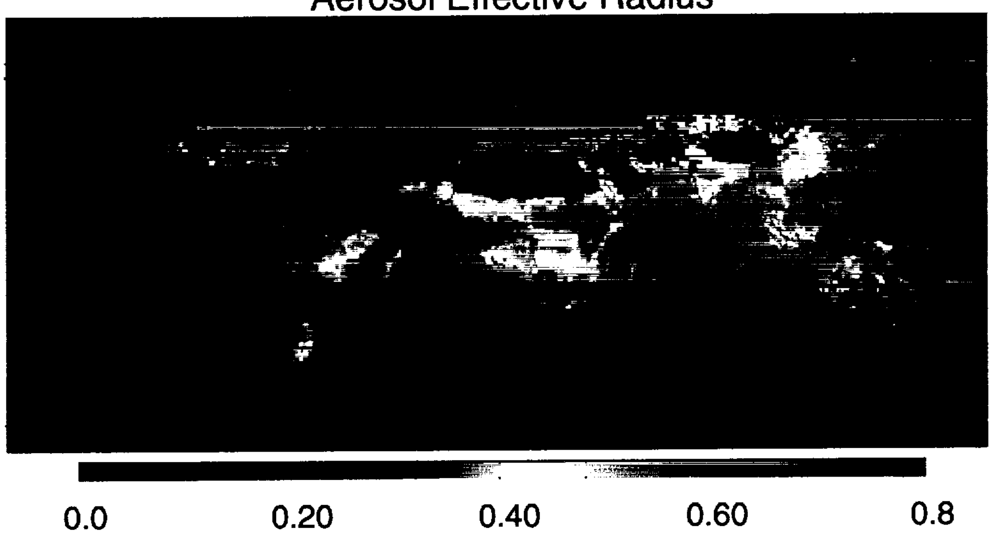
Figure 3. MODIS retrieved aerosol particle effective radius (top) and fine mode fraction of optical thickness (bottom) plotted against AERONET-derived effective radius and fine mode fraction of volume. Only points with AERONET $\tau_{660} > 0.15$ are plotted.

Figure 4.MODIS retrieved aerosol optical thickness in two wavelengths (660 nm – open circles and 2100nm – solid circles as function of residual error from fitting the observed MODIS radiances using the calculated look-up table. The dashed line (660 nm) and solid line (2100 nm) represent the linear regression through the points.

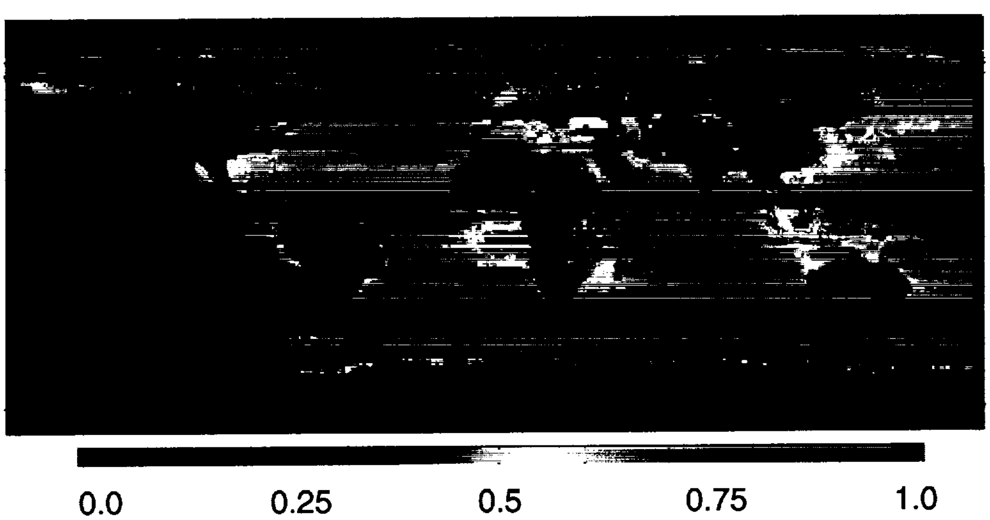
September, 2000



Aerosol Effective Radius



Aerosol Optical Depth



Small Mode Weighting

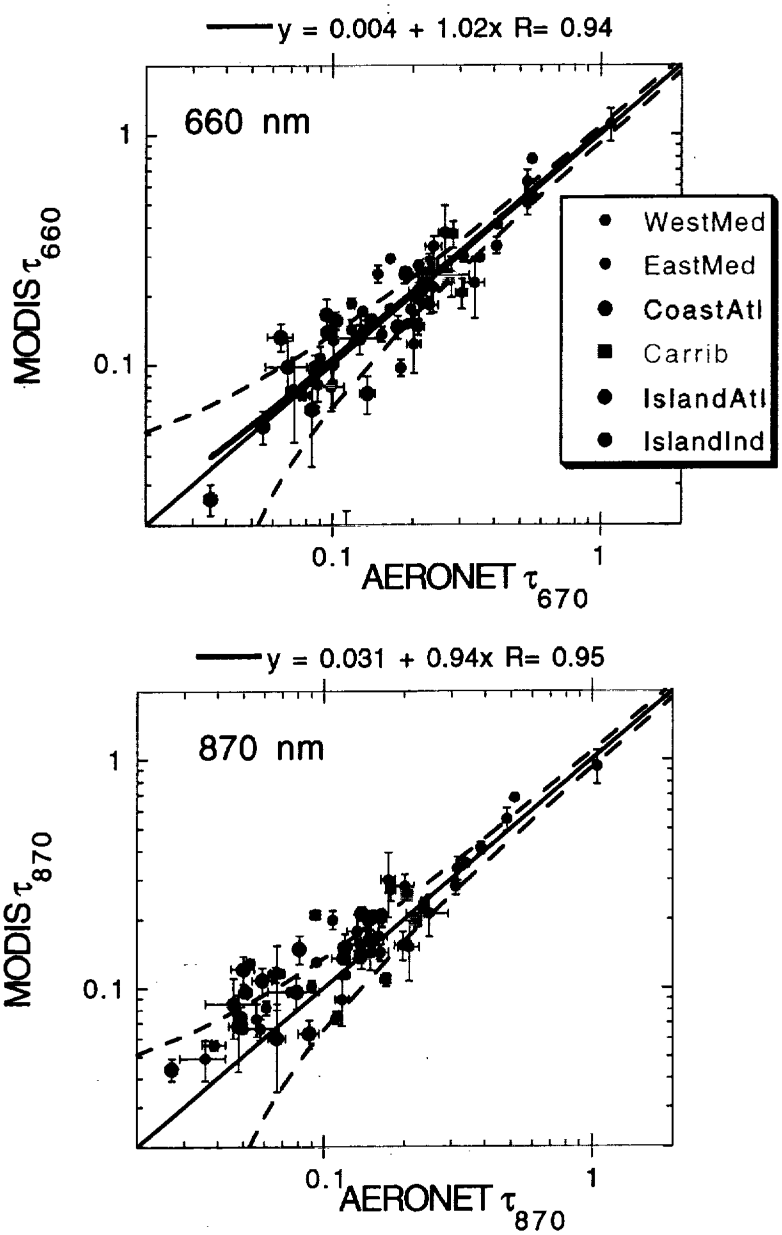


Figure 2. MODIS retrieved aerosol optical thickness (τ) at wavelengths 660 and 870 nm plotted as function of the same AERONET derived quantities. The linear regression and correlation coefficients are given. The dashed lines denote the expected uncertainty in the retrieval (Tanré et al., 1997; Tanré et al., 1999; King et al., 1999). The points are color-coded as to geographical region. Altogether there are 64 co-located measurements that span 2 months and represent 11 stations.

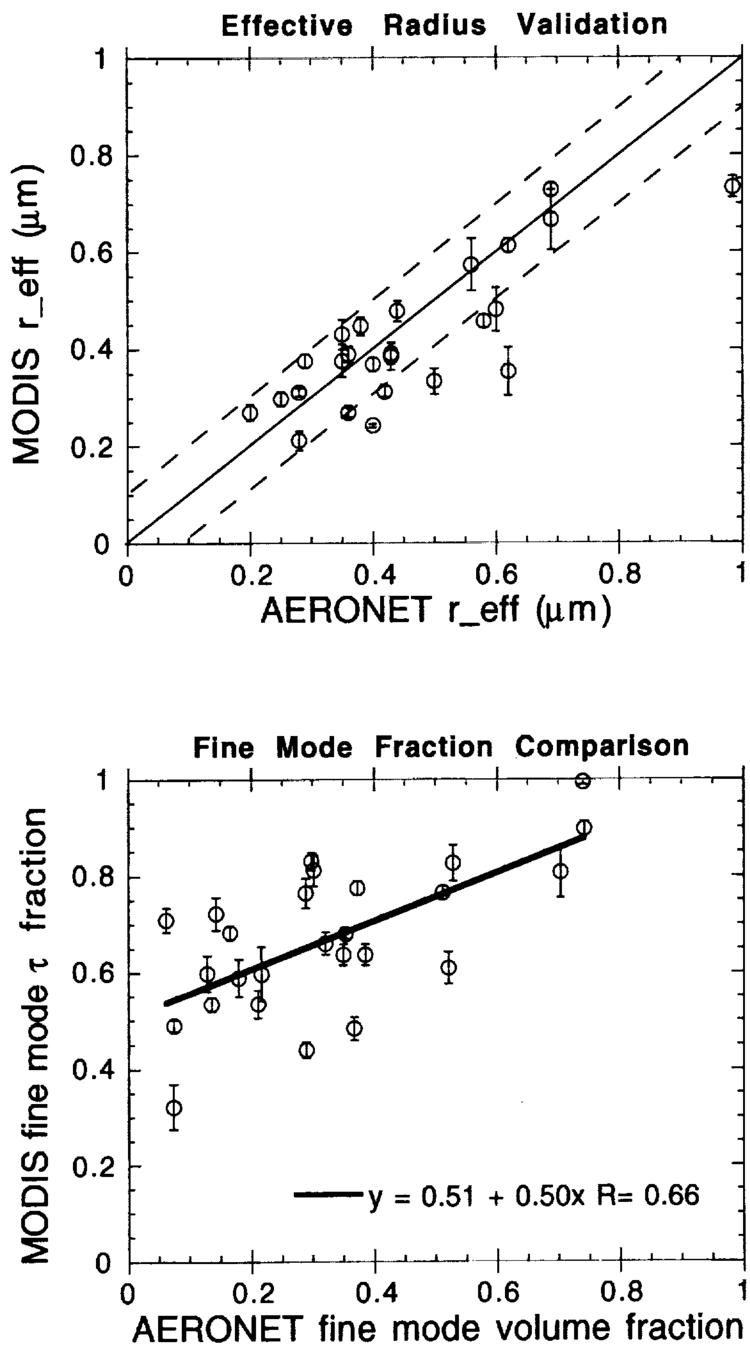


Figure 4. MODIS retrieved aerosol particle effective radius (top) and fine mode fraction of optical thickness (bottom) plotted against AERONET-derived effective radius and fine mode fraction of volume. Only points with AERONET $\tau 660 > 0.15$ are plotted.

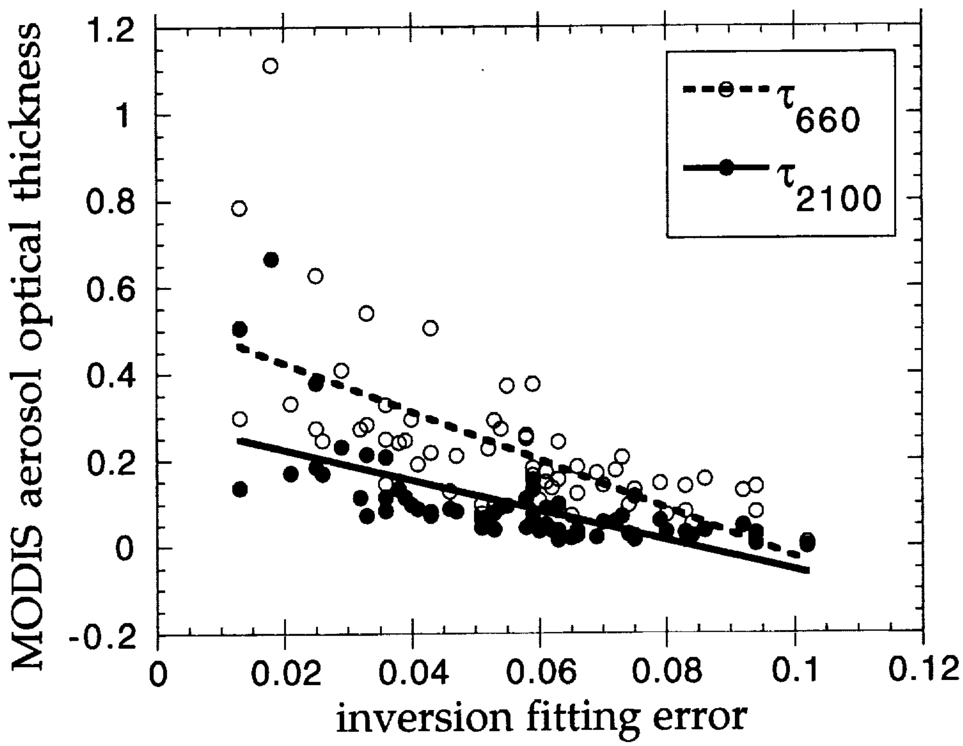


Figure 5. MODIS retrieved aerosol optical thickness in two wavelengths (660 nm – open circles and 2100nm – solid circles) as function of residual error from fitting the observed MODIS radiances using the calculated look-up table. The dashed line (660 nm) and solid line (2100nm) represent the linear regression through the points.