Ground-based Observation of Dust Optical Properties in the Chinese Dust Source Region and Intercomparison with MISR Aerosol Retrievals

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Abstract

Long-term continuous observation of dust aerosol optical thickness (AOT) near the dust source regions is of great importance for various applications, including the computation of seasonal and diurnal dust radiative forcing and the validation of satellite retrievals. Using 22 months of Sunphotometer (SP) AOT data collected near the Taklamakan and Gobi dust source regions (Dunhuang, 40.09°N, 94.41°E) in 1999 and 2000, this paper examines the diurnal and seasonal change of dust AOT and dust Angström exponent. The comparison between SP AOT with Multi-angle Imaging Spectroradiometer (MISR) AOT product is also performed. Results showed that most dust events are during the spring through early summer months with a season-invariant diurnal change of more than 10% for AOT and 30% for Angström exponent. Larger AOT and smaller Angström exponent values usually appeared late in the afternoon. Comparison showed that MISR AOT overestimates SP AOT by 0.05, but such overestimation decreases as SP AOT increases. Overall, MISR AOT has a good agreement with the SP AOT with linear correlation coefficients (R) of 0.94, and fall within the predicted uncertainties (0.05 or 20% of SP AOT, whichever is larger). Due to the diurnal change of AOT, the difference between daily-averaged SP AOT and the instantaneous MISR AOT is about 0.09. This study implies that large diurnal variations of aerosol properties at or near dust source regions may be significant enough for consideration in regional radiative forcing, air quality and numerical modeling studies.

1 Introduction

The effect of aerosols on climate is one of the largest uncertainties in current global climate models [*Hansen et al.*, 1997]. The understanding of radiative forcing of dust aerosols is still very low [*IPCC*, 2001], especially over the dust source region where ground observations are limited and multi-spectral satellite retrievals are often difficult due to the bright surface background [*Kaufman et al.*, 2002]. On the other hand, recently-launched multi-angle satellite sensor such as MISR has capability to retrieve the AOT over the desert regions [*Martonchik et al.*, 2002] and provides valuable information to study dust radiative forcing over the desert regions [*Zhang and Christopher*, 2003].

Due to its reliability, ground-based Sunphotometer (SP) measurements have been used extensively in the past for the validation of satellite AOT retrievals [e.g., *Remer et al.*, 2002], and refinement of satellite aerosol retrieval algorithms [e.g., *Wang et al.*, 2003]. One important factor that should be carefully considered in dust radiative forcing computations is the diurnal variability of dust AOT [e.g., *Kaufman et al.*, 2000; *Christopher et al.*, 2003]. To date, few long-term systematic observations of dust AOT in the Chinese dust source region have been presented, making the validation of MISR dust AOT and the computation of dust forcing in this region a challenge.

Using twenty two months (from 1999 to 2000) of Sunphotometer AOT (SP AOT) data collected near the Chinese dust source region, the intent of this paper is two folds, i.e., analyze the diurnal and seasonal variations of Chinese dust properties (AOT and Angström exponent), and compare SP AOTs with MISR AOTs. Section 2 briefly describes the Sunphotometer data and MISR aerosol product used in this study. The analysis and results are presented in section 3. Section 4 summaries the paper.

2 Data Description

Twenty two months (from 1999 and 2000) of AOT data (also denotes as τ) inferred from a Sunphotometer (Model Pom-01, Prede Inc.) located at Dunhuang airport

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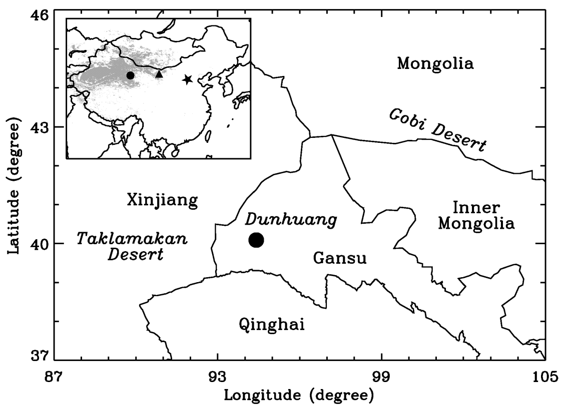

Figure 1: Map of the observation site Dunhuang (denoted as filled circle) and its vicinity. The inset shows the map of eastern Asia. The shaded area in the inset is the location of Taklamakan desert and Gobi desert (based on the on the ecosystem database from USGS). The five-point star denotes the location of Beijing, and triangle denotes the AERONET site at Dalanzadgad, Inner Mongolia.

(40.09°N, 94.41°E) was used to study the dust aerosol optical properties and temporal characteristics. The observation site is located at the eastern edge of Takalamakan desert, northern edge of Gobi desert, and western edge of Hexi corridor (also an important dust source region in China, see figure 1). The Sunphotometer measures the direct solar radiation centered at 315, 400, 500, 675, 870, 940, 1020 nm. The AOT is then calculated from the measured radiation based on the Beer-Lambert-Bouguer law. Included in the calculation is a correction for Rayleigh scattering, ozone optical depth, and an air mass that accounts for Earth-Sun distance. The measurement uncertainty of AOT is approximately 0.01 $\sim$ 0.02 [see *Wang et al.*, 2004].

The MISR level 2 aerosol product on Terra has a spatial resolution of 17.6 X 17.6 km^2, and due to the narrow swath width of the sensor, global coverage can be obtained only every 7 to 9 days. The product contains AOT at 0.558 μm with an expected accuracy of 0.05 or 20%, whichever is larger [*Kahn et al.*, 2001]. It should be emphasized that MISR retrieval algorithms and the associated products continue to evolve with time[*Kahn et al.*, 2004], the MISR AOT product used in this study is version F06_0013. The excellent agreement between MISR AOT (hereafter τ_{MISR}) and SP AOT (hereafter τ_{SP}) has been reported for smoke aerosols over South Africa [*Diner et al.*, 2001] and urban aerosols over the different continents [*Kahn et al.*, 2004], but only a few comparisons have been made near dust source regions [*Martonchik et al.*, 2004], and no comparisons have been made in the dust source region near the Taklakaman desert in East Asia. Since the Sunphotometer does not have a channel at 0.558μm, to compare the τ_{MISR} with τ_{SP}, we calculated the τ_{SP} at 0.558μm based on logarithmic interpolation between τ_{SP} at 0.5 μm and 0.675 μm.

3 Analysis and Results

3.1 Diurnal and Seasonal Change of Dust Optical Properties

To be consistent with other previous studies [e.g. *Smirnov et al.*, 2002], the dust optical properties in this study is characterized by two parameters: (τ_{SP}) at 500nm, and the Angström exponent (hereafter α) derived from a multi-spectral log linear fit to the equation $ln\tau \sim -\alpha ln\lambda$.

The monthly mean AOT and the histogram of seasonal AOT are presented in figure 2 and figure 3 respectively. In both years, the monthly mean τ_{SP} is larger during spring and summer (mean τ_{SP} around 0.3), with smaller values (around 0.2) during the fall (August - October) and winter (November - January) seasons. The monthly mean α is generally less than 0.35 with slight seasonal variations, and over 20% of daily mean α are less than 0.1 in all seasons (inset in figure 3). This feature implies that the aerosols in this region are dominated by coarse mode particles that are different when compared with urban conditions [*Holben et al.*, 2001].

To calculate the hourly statistics for different seasons, all individual AOT and Angström exponent values in a day are expressed as a percentage difference from the daily mean[*Smirnov et al.*, 2002]. The computed percentages are then averaged in hourly intervals for four sea-

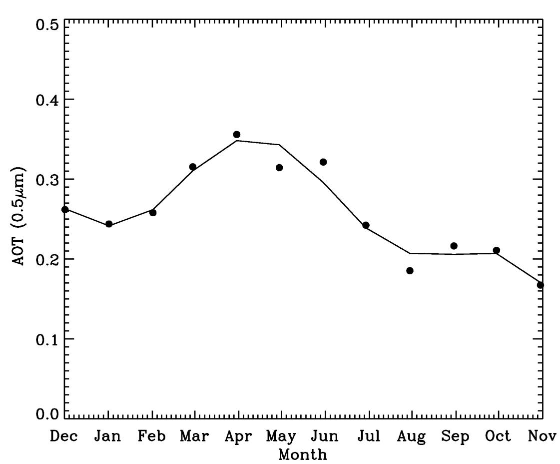

Figure 2: Monthly mean AOT (solid dots) in Dunhuang. The solid curve is the fit of AOT as a function of month (m): $AOT = 0.52 - 0.11m - 1.07\,cos(2\pi(0.21m/12 - 0.29)) + 0.05\,sin(2\pi(1.09 - 1.84m/12))$. Note m starts from December, i.e., m= 1 for December, m=2 for January and m = 12 for November.

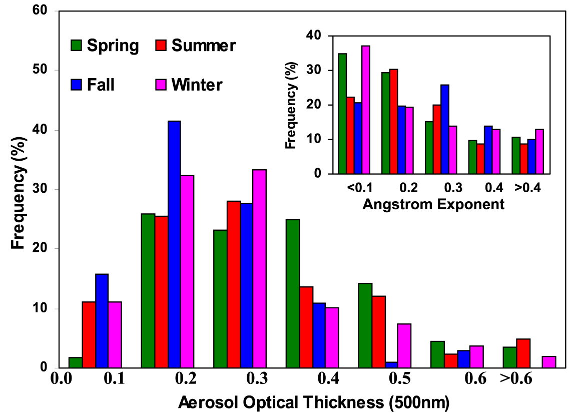

Figure 3: Seasonal frequency distribution of aerosol optical thickness and Angström exponent for different seasons in Dunhuang

sons. The diurnal variations of τ_{SP} and α for four seasons are shown in figure 4a and 4b, respectively. The τ_{SP} (α) is smaller (larger) in the morning (8 $\sim$ 11 a.m. local time) and larger (smaller) during afternoon (12 $\sim$ 4 p.m. local time). In all seasons, the diurnal change of dust AOT is usually more than 10% (equivalent to a change of dust AOT about 0.05), and the change in α is about 30%. The variations of both τ_{SP} and α in one hour could as large as 5% of the daily mean. For instance, during the fall season, the τ_{SP} departure from daily mean at 2 p.m. is about -1% and increases to about 5% one hour later at 3 p.m. Another interesting pattern is that the Angström exponent shows a consistent season-invariant increase in the late afternoon (after 4 p.m., figure 4b), although τ_{SP} does not show any consistent variation patterns at this time (figure 3a). Depending on different seasons, in the last 2 $\sim$ 3 hours before the sunset, the departure of Angström exponent from daily mean could change rapidly from daily minimum values below zero to near zero or daily maximum. Meteorological data sets are needed to study such rapid changes.

3.2 Comparison with MISR AOT

The Sunphotometer continuously observes downward solar radiation with approximately 0.8° field of view at a fixed location, with a narrow wavelength interval of 0.01 μm [*Holben et al.*, 2001]. Compared to single view-angle satellite sensors, the MISR is different because it images the same location from 9 different angles and it takes about 7 minutes for all nine cameras to image a given location [*Diner et al.*, 2001]. In this study, we used the intercomparison procedure outlined in [*Diner et al.*, 2001] by comparing the averaged τ_{SP} within 30 minutes of satellite overpass time with the regional mean τ_{MISR} in 3X3 sets (total 9 sets) of 17.6X17.6km^2 regions centered on the SP location. To minimize the cloud contamination and other retrieval non-ideality, the comparison pair is selected only when the number of valid τ_{MISR} in 3X3 sets is larger than 4 (i.e., at least 5 out of 9).

The MISR instrument has a swath width about 380km and orbits the Earth with 233 distinct orbits that are repeated every 16 days. Only four different satellite orbit paths could cover the SP site (40.09° N, 94.41°E). Totally, 21 coincidence pairs between τ_{MISR} and τ_{SP} are obtained, but only 11 pairs met the comparison criteria mentioned above. Note that the MISR was launched in December 1999 and started to collect data in February, 2000. As shown in figure 5a, τ_{SP} and τ_{MISR} pairs show a good agreement with linear coefficient of 0.94 and root mean square error of 0.06. Their difference generally fall within the expected uncertainties (i.e., maximum of 0.05 or 20% of τ_{MISR}). But figure 5a suggests that τ_{MISR} systematically overestimates τ_{SP} about 0.05,

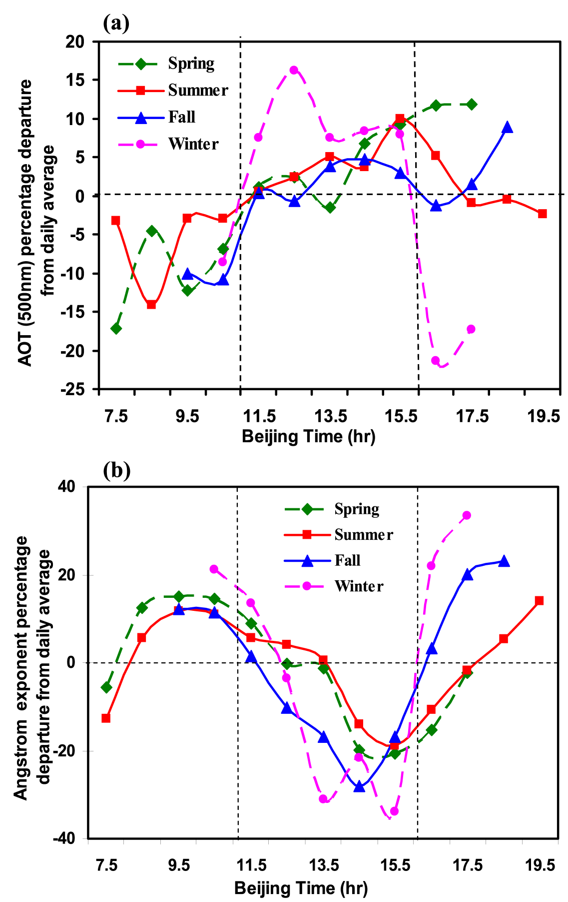

Figure 4: Diurnal variations expressed in terms of percentage departure from the daily mean for different seasons a) aerosol optical thickness at 500nm b) Angström exponent

though such overestimation tends to decrease when AOT becomes larger. Possible reasons for such overestimation could include non-ideality of dust optical properties such as low single scattering albedo or instrument calibration uncertainties.

We finally explore if τ_{MISR} during the time of the satellite overpass is representative of the daily mean dust AOTs near dust source regions. This is an important aspect because MISR dust AOT is essentially an instantaneous quantity. Due to the scarcity of AOT information over the desert region, the MISR dust AOT plays an important role in dust forcing calculations [*Zhang and Christopher*, 2003]. However the instantaneous values would be more meaningful if they can be converted or linked to the diurnally averaged quantities. Therefore, the intent of the intercomparison between τ_{MISR} and daily mean τ_{SP}, is not to evaluate the MISR AOT product and retrieval algorithm itself, but rather to investigate possible uncertainties if we use τ_{MISR} as a daily mean value in the radiative forcing calculations over the East Asian desert regions. Figure 5b showed that τ_{MISR} and the daily mean τ_{SP} are highly correlated (R=0.89); but on the average, the difference between τ_{MISR} and the daily mean τ_{SP} is about 0.09. Accounting for the current τ_{MISR} instantaneous bias of 0.05, the τ_{MISR} would overestimate the τ_{SP} about 0.03 even if the accuracy of τ_{MISR} is improved to within 0.01. The MISR onboard the Terra satellite usually samples the diurnal phase of AOT at 10:45 a.m. local time [*Diner et al.*, 2001]. Therefore, such 0.03 bias of τ_{MISR} (as compared to τ_{SP}) is the sampling error mainly caused by the diurnal variation of dust in its source regions, and cannot be resolved by the refinement of MISR retrieval algorithms alone.

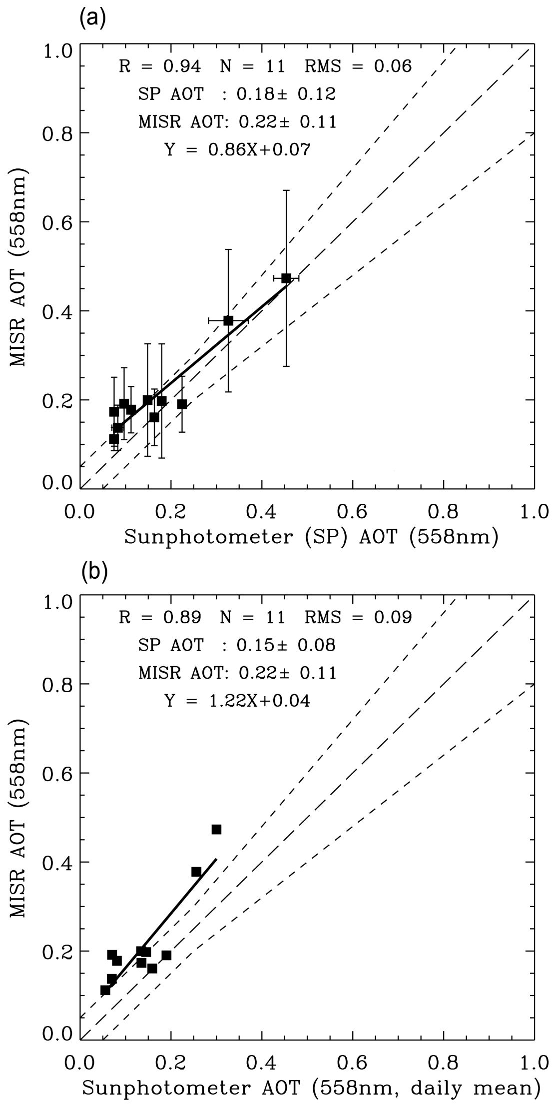

Figure 5: Intercomparison between MISR and Sunphotometer AOT for: (a) pairs that have at least 5 valid MISR AOT values in the 3X3 sets regions; (b) same as (a) except that SP daily-mean AOT values are used in the comparison. The horizontal bar represents the temporal standard deviations and vertical bar the spatial standard deviations. The long-dashed line represents the one-to-one line and the short-dashed line represents the expected MISR AOT uncertainty line (e.g., 0.05 or 20% of SP AOT, whichever is larger)

4 Discussion and Summary

Previous studies [*Kaufman et al.*, 2000; *Smirnov et al.*, 2002] have analyzed of diurnal changes of aerosol optical properties over dozens of Sunphotometer sites around the globe and showed that the diurnal change of AOT is within 5% for most areas where dust is a major component of atmospheric aerosols. However, these studies lack the analysis of aerosol properties in the dust source regions over China mainly because of the scarcity of AOT measurements in this region. In this study, we showed that diurnal change of dust properties over the Chinese dust source region is relatively larger (10% for AOT and 30% for Angström). By comparing MISR AOT with SP AOT, we also showed that MISR AOT are highly correlated with SP AOT and falls within the expected uncertainties, suggesting that MISR AOT is a unique data set for the study of aerosol forcing over the dust source regions. However, further analysis showed that diurnal change of aerosol optical properties in the dust source regions need to be carefully considered when time-averaged computations (such as in regional aerosol forcing studies) or aerosol information with high temporal resolutions (such as air quality studies) are desired.

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