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

Sundar A. Christopher, Jun Wang *, Xiangao Xia

Department of Atmospheric Sciences
University of Alabama in Huntsville
Huntsville, AL, USA, 35805

Institute of Atmospheric Science
Chinese Academy of Sciences
Beijing, China, 10029

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 to 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 summarizes the paper.

2 Data Description

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

*Email: wangjun@nsstc.uah.edu
The excellent agreement between
East Asia. Since the Sunphotometer does not have a
caracterized by two parameters: \( \mu AOT \) at 500nm,
and the Angström exponent (hereafter \( \alpha \)) derived from a
calculated the \( \tau_{SP} \) at 0.558\( \mu m \) based on logarithmic inter-
channel at 0.558\( \mu m \), to compare the \( \tau_{MISR} \) with \( \tau_{SP} \), we
calculated the \( \tau_{SP} \) at 0.558\( \mu m \) based on logarithmic inter-
3.1 Diurnal and Seasonal Change of Dust
Optical Properties

To be consistent with other previous studies [e.g.
Sunphotometer measures the
direct solar radiation centered at 315, 400, 500, 675, 870,
940, 1020 nm. The AOT is then calculated from the mea-
sured radiation based on the Beer-Lambert-Bouguer law.

The MISR level 2 aerosol product on Terra has a
spatial resolution of 17.6 X 17.6 km\(^2\), and due to the nar-
row swath width of the sensor, global coverage can be
obtained only every 7 to 9 days. The product contains
AOT at 0.558 \( \mu m \) 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 \( \tau_{MISR} \)) and SP AOT (hereafter \( \tau_{SP} \))
has been reported for smoke aerosols over South Africa
(Diner et al. 2001) and urban aerosols over the differ-
ent continents [Kahn et al. 2004], but only a few com-
parisons have been made near dust source regions [Mar-
tonchik 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

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.

Figure 2: Monthly mean AOT (solid dots) in Dunhuang. The solid curve is the fit of AOT as a function of month (m): \( \text{AOT} = 0.52 - 0.11m - 1.07\cos(2\pi(0.21m/12 - 0.29)) + 0.05\sin(2\pi(1.09 - 1.84m/12)) \). Note m starts from December, i.e., m= 1 for December, m=2 for January and m = 12 for November.
The diurnal variations of $\tau_{SP}$ and $\alpha$ for four seasons are shown in figure 4a and 4b, respectively. The $\tau_{SP}$ ($\alpha$) is smaller (larger) in the morning (8 ~ 11 a.m. local time) and larger (smaller) during afternoon (12 ~ 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 $\alpha$ is about 30%. The variations of both $\tau_{SP}$ and $\alpha$ in one hour could as large as 5% of the daily mean. For instance, during the fall season, the $\tau_{SP}$ 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 3b), although $\tau_{SP}$ does not show any consistent variation patterns at this time (figure 3a). Depending on different seasons, in the last 2 ~ 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 $\tau_{SP}$ within 30 minutes of satellite overpass time with the regional mean $\tau_{MISR}$ in 3X3 sets (total 9 sets) of 17.6X17.6km² 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 $\tau_{MISR}$ 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 $\tau_{MISR}$ and $\tau_{SP}$ 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, $\tau_{SP}$ and $\tau_{MISR}$ 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 $\tau_{MISR}$). But figure 5a suggests that $\tau_{MISR}$ systematically overestimates $\tau_{SP}$ about 0.05.
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 $\tau_{MISR}$ 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 $\tau_{MISR}$ and daily mean $\tau_{SP}$, is not to evaluate the MISR AOT product and retrieval algorithm itself, but rather to investigate possible uncertainties if we use $\tau_{MISR}$ as a daily mean value in the radiative forcing calculations over the East Asian desert regions. Figure 5 showed that $\tau_{MISR}$ and the daily mean $\tau_{SP}$ are highly correlated ($R=0.89$); but on the average, the difference between $\tau_{MISR}$ and the daily mean $\tau_{SP}$ is about 0.09. Accounting for the current $\tau_{MISR}$ instantaneous bias of 0.05, the $\tau_{MISR}$ would overestimate the $\tau_{SP}$ about 0.03 even if the accuracy of $\tau_{MISR}$ 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 $\tau_{MISR}$ (as compared to $\tau_{SP}$) 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.

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 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.
Acknowledgement

This research is supported by NASA's Radiation Sciences, Interdisciplinary Sciences and ACMAP programs. Dr. Xiang-Ao Xia is supported by Chinese NSF grant 40305002. The MISR data is obtained from the NASA Langley Research Center Atmospheric Sciences Data Center.

References


