Characteristics of Dust Aerosol derived from sky-radiometer over Loess Plateau of Northwest China

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Abstract

This study investigates the characteristics of dust aerosols over Loess Plateu of Northwest China using observation data collected in this region during 2009 and 2010. As the first part of the research, comparison of aerosol optical thickness (AOT) and single scattering albedo (SSA) measured by two independent instruments (SKYNET sky radiometer and AERONET sun photometer) is performed. We find very good agreement of AOT, whereas SSA from the former instrument is systematically higher than the latter on. The possible reasons for such differences are discussed. As the second part of the study, we study the characteristics of dust aerosols in this region. We find that strong dust events can carry high concentration of anthropogenic aerosols, such as black carbon (BC) aerosol, during their transport from the source region. This finding may provide some clues to justify absorptive Asian dust aerosols observed in the Pacific Ocean region in the past studies. The study also suggests that significant dust aerosols may exist in the atmosphere of this region even during no dust event days.

Keywords: dust aerosol, aerosol optical thickness, BC aerosol

1. Introduction

Aerosols are known to alter the atmospheric heat budget and climate by their direct (scattering and absorption of solar radiation) and indirect (modification of microphysical and optical properties of clouds). Despite the importance of aerosols on climate change, the roles of aerosols on climate change phenomenon are still not well understood. This is primarily due to short life time and variability of aerosols on space and time. In order to improve our understanding regarding aerosol effects on climate change, it is necessary to collect information of aerosols of various origins.

Among several types of aerosols, the characteristics of dust aerosols are still subject of debate (e.g.,Nakajima et al. 2007). It is likely that dust aerosols have different optical characteristics depending on geographical location. Moreover, when dust aerosols, originated from arid and semi-arid areas, transport over long distances, they mix with anthropogenic aerosols. Such mixed aerosols can have important effect on both regional and global climate. The observation data collected near the source region of dust aerosols may provide valuable clues to solve climatic effects of such mixed aerosols. As the semi-arid region of northwestern China is close to the Taklamakan and Gobi deserts, data collected at this region are of great importance to study several important aspects of dust aerosols. In view of this recognition, this study is designed to understand the characteristics of dust aerosols over Loess Plateau of Northwest China.

2. Observation site and instrumentation

Sky radiometer (Model POM-01, Manufacture: PREDE Co. Ltd. Japan) has been operated at Semi-Arid Climate Observatory and Laboratory (SACOL) (35.047^0N,104.136^0E) (http://climate.lzu.edu.cn) from March, 2009 as a part of SKYET actives of SKYNET network (http://atmos.cr.chiba-u.ac.jp). Since SACOL is a rural site, and it is located at southeast of Lanzhou city and south edge of Gobi desert, it is possible to observe various types of aerosols, including anthropogenic aerosol, natural dust, relatively background aerosol depending on the atmospheric condition and route of air masses. Due to the special geographical location and good infrastructure, it has become a super site for atmospheric study. In order to further understand the characteristics of dust aerosols in more detail, POM-02 sky radiometer was operated during an intensive field observation conducted from 20 April to 20 June, 2010 at Minqin Desert Control Research Institute (38.607^0N,102.959^0E). This study mainly uses data measured by such sky radiometers. In addition, we also used black carbon (BC) mass concentration measured by

aethalometer (Model AE-31; Manufacturer: Magee Scientific)

The detailed description of the sy radiometer instrument and data retrieval procedures can be found elsewhere (e.g., Nakajima et al., 1996; Khatri and Takamura 2009). In brief, the instrument measures spectral direct solar irradiance and diffuse sky irradiances at predefined scattering angles. Such measured data were inverted using SKYRAD.PACK (version 4.2) software (Nakajima et al., 1996) and calibration constants obtained from improved methods of Nakajima et al. (1996). The retrieved parameters are aerosol optical thickness (AOT), single scattering albedo (SSA), and refractive indices at 400nm, 500nm, 675nm, 870nm, and 1020nm for POM-01 and 340nm, 380nm, 400nm,500nm,675nm,870nm, and 1020nm for POM-02 instrument. In addition, another important retrieved parameter is volume size distribution at 20 size bins for both POM-01 and POM-02. Such retrieved parameters were further processed by using cloud screening algorithm of Khaitr and Takamura (2009).

3. Results and discussion

3.1. Intercomparison of key aerosol optical parameters obtained from SKYNET sky radiometer and AERONET sunphotometer

As SACOL was also equipped with sun photometer of AERONET network (Holben et al., 2003), which measures same optical parameters of sky radiometer of SKYNET network, it was a good opportunity to perform closure study of key aerosol parameters. Figure 1 shows comparison of AOTs at four wavelengths (400nm and 440nm, 675nm, 870nm, and 1020nm). As shown in the Figure, the comparison result is relatively good with data falling around 1:1 line. It is worth to note that the calibration constant for direct irradiances obtained from Improved Langley (IL) method using surface observation data are used for SKYNET sky radiometers (Nakajima et al., 1996), whereas as AERONET sun photometers are relied on calibration constants determined at high mountains using Normal Langley (NL) technique. The latter technique is inconvenient and economically expensive. The observed good agreement in Figure (1) may verify the accuracy of IL method adopted for SKYNET sky radiometers, and may suggest that observed AOTs in this study can be interpreted with much more confidence level. Figure (2) shows comparison of SSAs obtained from two independent instruments. In contrast to AOTs, the differences in instantaneous SSA are considerably large. The possible reasons for such poor agreement may be explained due to the difference in retrieval algorithm and measurement protocol of sky radiances. Since SSA is very sensitive to AOT, surface reflectance etc., some differences on those parameters might have also caused to differ SSA. Despite such discrepancies, two important conclusions can be drawn from Figure 2: (i) Using present versions of algorithms, SSAs from SKYNET sky radiometer are systematically higher than AERONET sun photometer (ii). The average columnar SSAs at all wavelengths are relatively small at this remote site. This indicates the transportation of light absorbing aerosols from urban atmosphere. Taking into account of the fact that this area is often under the influence of dust aerosols with higher concentration during spring season, it can be suggested that such dust aerosols can mix with strongly light absorbing aerosols transported from urban areas. Since the surface reflectance of this area is relatively high, such light absorptive aerosol mixture can trap radiation energy in the atmosphere more significantly. As a result, aerosols of this region can have very significant effect on atmospheric heat budget and regional climate. Such effects can be numerically evaluated using radiative transfer model.

3.2. Optical characteristics of aerosols during dust storm events

Figure 3 shows aerosol optical thickness at 500nm and Angstrom exponent from 22 April 2010 to 20 June 2010 at Minqin observation site. During this observation period, frequent heavy dust events were observed. The observed dust events are denoted in Figure 3(a). As shown in Figure 3(a), during such dust events, AOT at 500nm increased drastically. Such drastically increased AOTs are compensated by low values of Angstrom exponent. The indicates the dominance of coarse mode aerosols in comparison to fine mode aerosols. It is worth to note in Figures 3(a) and 3(b) that dust events are frequently observed within the gaps of few days. Another thing to be noted in Figure 3(a) is the sudden decrease of AOT after dust event. This suggests that dust aerosols are lifted by strong winds, suggesting the possibility of reaching such dust aerosols over the Pacific Ocean and beyond it. As a part of understanding the characteristics of dust aerosols in more detail, volume size distribution of one typical dust event of May 3 is compared with relatively clean observation day of May 22. Table 1 shows geometrical mean radius and volume concentration of fine and coarse mode aerosols for those two observation days. As shown in Figure 4 and Table

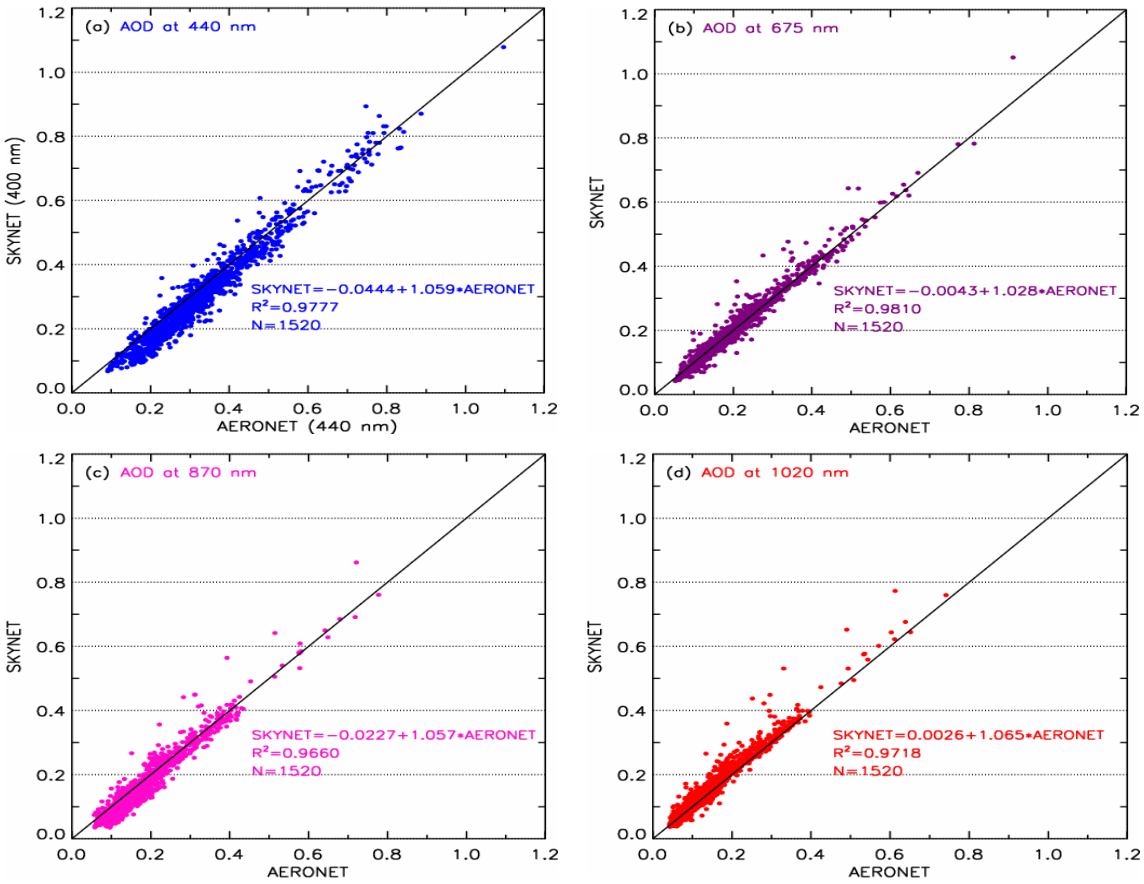

Figure 1. Comparison of AOTs between sky radiometer of SKYNET network and sun photometer of AERONET network at (a) 400nm and 440nm, (b) 675nm, (c) 870nm, and (d) 1020nm during 2009.

1 that during the dust event day of May 3, volume concentration of coarse mode aerosols largely dominate fine mode aerosols. Interestingly, Table 1 shows that coarse mode aerosols contributed more than 99.5% to total volume concentration on dust event day of May 3. Table 1 also suggests the presence of relatively large size ranged dust aerosols on May 3 in comparison to May 22. One pronouncing feature to be noted in Figure 4 and Table 1 is that even during the clear day of May 22, coarse mode aerosols large dominate fine mode aerosols. On this day, coarse mode aerosol contributed nearly 90% to total volume. This finding indicates that existence of considerable dust aerosols in the atmosphere even during no dust event cases in this region. Such result was also previously shown by Takamura et al. (2007) over Jeju island of Korea during spring season.

Another interesting result observed during intensive observation period at Minqin site is shown in Figure 5. As shown in Figure 5, during the typical dust event days, we not only observed very high concentration of dust aerosols but also very high concentration of black carbon aerosols. The very high concentration of BC mass concentration observed on April 24 at around 20 CST (Chinese standard time) is even higher than the values of BC mass concentration found in typical urban atmospheres of the world. This finding has several important implications for atmospheric research communities. There is a strong debate on light absorptive capacity of dust aerosols. Kaufman et al. (2001) suggested that Sarahan are less light absorptive, whereas as Nakajima et al. (2007) argued that Asian dust are more light absorptive. The observed result in this study may empathize that fact light absorbing capacity of Asian dusts are due to the mixture of BC and dust aerosols during the transportation of dust aerosols. Taking into account the fact that Minqin is basically the desert area, if such BC aerosols from urban areas are transported to desert areas, aerosol mixture can be more effective to influence the regional climate in comparison to other locations such as urban areas, ocean etc. Thirdly, such BC aerosols can be uplifted with dust aerosols up to high altitudes. As a result, such absorptive aerosols at high altitudes may have interaction with cloud, which may affect precipitation pattern and efficiency.

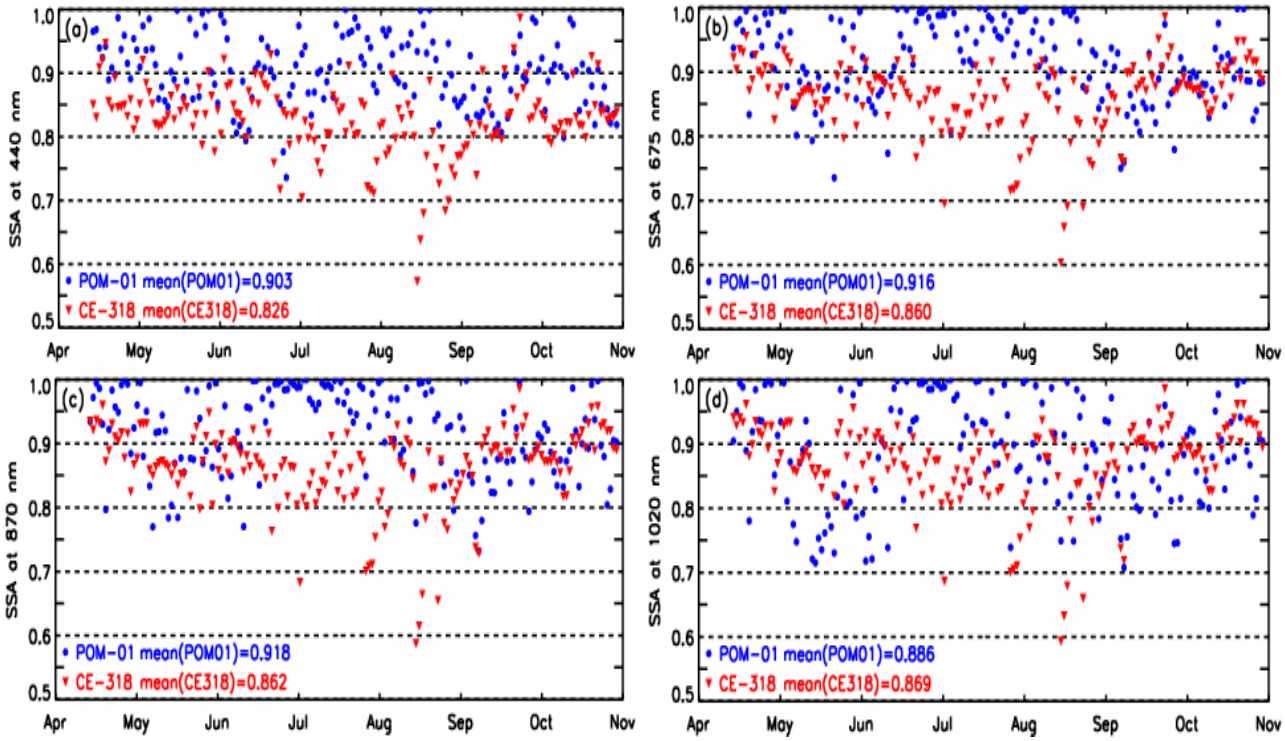

Figure 2. Comparison of aerosol SSAs between sky radiometer of SKYNET network and sun photometer of AERONET network at (a) 400nm and 440nm, (b) 675nm, (c) 870nm, and (d) 1020nm during 2009.

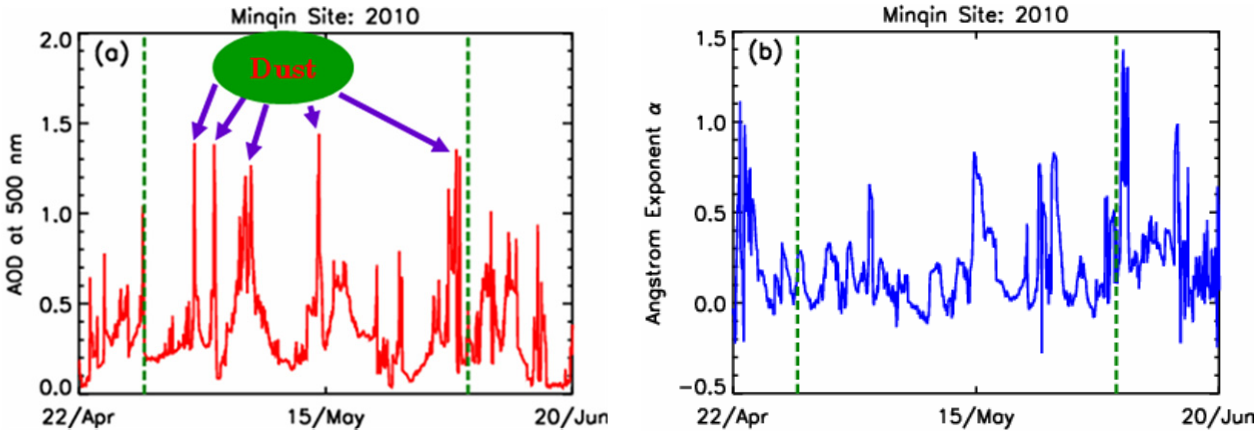

Figure 3. (a) Aerosol opt8ical thickness at 500nm and (b) Angstrom exponent at Minqin site.

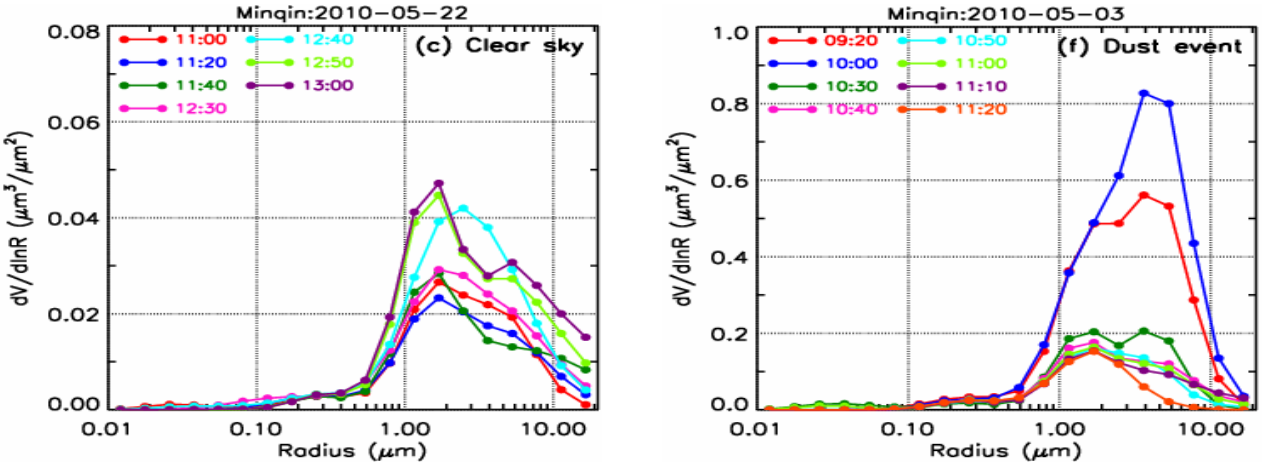

Figure 4. Volume size distribution during (a) clear sky day of 2010-05-22 and (b) dust event of 2010-05-03.

Table 1. Aerosol size distribution parameters for clear sky and dust event days shown in Figure 4.

Obs. day	$R_{m,\,fine}\,(\mu m)$	$R_{m,coarse}\,(\mu m)$	$V_{m,\,fine}\,(\mu m^3/\mu m^2)$	$V_{m,coarse}\,(\mu m^3/\mu m^2)$
Clear sky day (2010-05-22)	0.25	1.69	0.003	0.028
Dust event day (2010-05-03)	0.17	3.62	0.0024	0.83

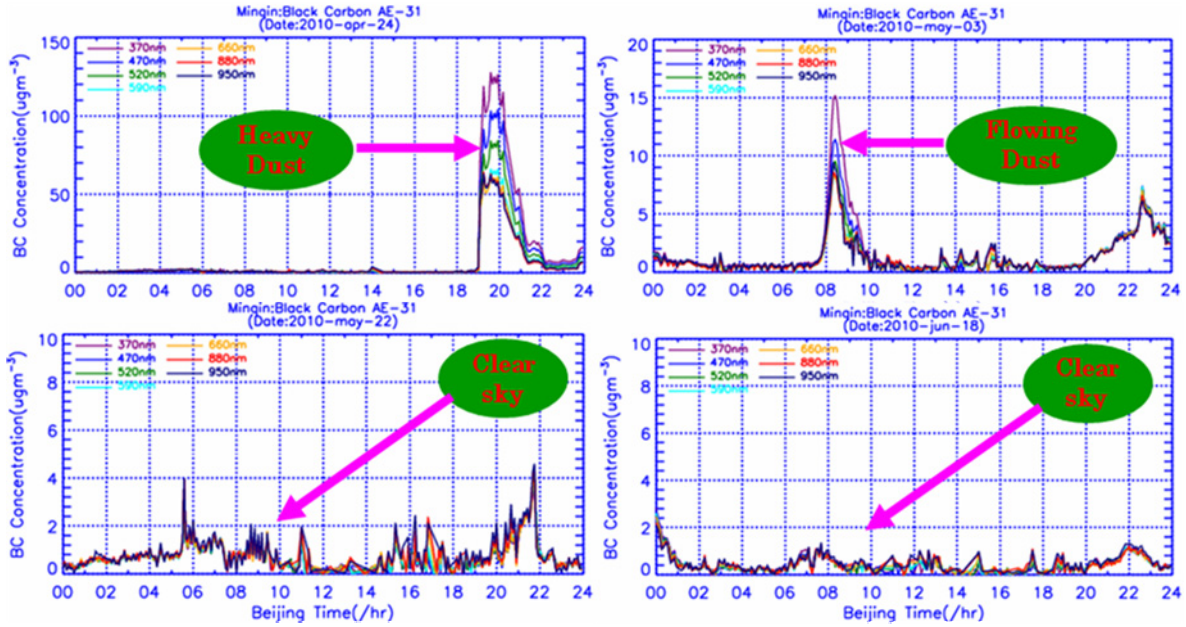

Figure 5. Black carbon mass concentration during dust event day and clear sky day

4. Summary

Dust aerosols originated from the deserts of Asia are known travel long distances around the world. As a result, such dust aerosols have strong impacts on not regional sector, but also on a global scale. This study attempts to characterize the characteristics of Asia dust aerosols near the source region over northwest China. The study mainly analyzes data measured by sky radiometer of SKYNET network. As the first part of the study, we verified by the results measured by our key instrument. After that, we discussed about the characteristics of dust aerosols by using intensive observation data. By using collocated measurements of AOTs from SKYNET sky radiometer and AERONET sun photometer, we discussed that onsite calibration protocol adopted for sky radiometer of SKYNET network is not only convenient and less expensive, but the results are also with reasonably high accuracy. In contrast to AOTs, SSAs from two independent instruments are systematically different. The possible reasons for such discrepancies are highlighted.

During the intensive observation period over Minqin in between 20 April to 20 June 2010, we observed frequent dust events with the time gap of few days. Those dust events were associated with very high AOT, low Angstrom exponent and dominant coarse mode aerosols. For the typical dust event day of May 03, we observed that coarse mode aerosols contributed more than 99.5% of total volume. For the observation days when dust events are not reported, we even observed around 90% of total volume as the volume of coarse mode aerosols. This suggests the existence of dust aerosols in considerable amount in the atmosphere even during no dust storm event. The most interesting finding of this study is the association of extremely high BC mass concentration during strong dust event cases. The observed BC mass concentration during strong dust event case is even higher than values over typical urban atmospheres of the world. The study discusses that such dust aerosols mixed with absorbing BC aerosols can have several important implications on our atmosphere. This also may help to shed light on unsolved mysteries of Asian dust aerosols.

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