Analysis of the Aerosol Extinction Characteristics in Different Areas of China

Zhang Junhua (张军华), Mao Jictai (毛节泰) and Wang Meihua (王美华)

Department of Atmospheric Science, Peking University, Beijing 100871

(Received January 5, 2001; revised October 22, 2001)

ABSTRACT

The multi-wavelength aerosol optical depths and the Angstrom exponent between 450 nm and 900 nm in four locations of China (Miyun, Beijing; Xinfeng, Guangdong; Wulian, Qinghai and Damxung, Tibet) have been observed by sun-photometers. This paper analyzes their characteristics for a one-year period from February 1998 to January 1999. The results show that in the arid and semi-arid locations like Miyun (117°12'E, 40.65°N) and Wulian (100°90'E, 36.29°N), there is a maximum of aerosol optical depth in the spring, it is about twice as large as in any other season. In a humid region like Xinfeng (114°2'E, 24.5°N), the aerosol optical depth also has a maximum in the spring, however is only slightly larger than in other seasons. The Angstrom exponent shows a significant minimum at Wulian in spring, about 0.15, indicating relatively large dust aerosol particles. Large variability of the monthly mean Angstrom exponent is also found in Miyun and Xinfeng, but there is no tendency with seasons. It means that the source of aerosol in these locations is complicated.

Key words: Sun-photometer, Aerosol, Extinction characteristics

1. Introduction

Atmospheric aerosols are important atmospheric component that influences the energy balance of the earth-atmosphere system directly by scattering and absorbing solar radiation and indirectly by changing the property of clouds by acting as condensation nuclei. Recently much concern has been expressed on the effect of aerosols on climate. Several global aerosol distribution models used in climate research have been brought forward. For instance, using the existing observational data and combining it with an aerosol source model, D'Almesda et al. (1991) obtained a model of global aerosol distribution and their radiative characteristics with a 5° x 5° spatial resolution. These aerosol distributions are based on sparse observations and mainly depend on the calculation by source models. Therefore the temporal and spatial resolution and accuracy are limited. More accurate aerosol data with high resolution should depend on satellite remote sensing. In the last two decades, many instruments and methods on remote sensing of aerosols from satellite have been developed (Kaufman et al., 1997; King et al., 1999), and remote sensing of aerosols over the oceans by the NOAA polar-orbiting satellite is in operational use (Stowe et al., 1997). However, the accuracy of these satellite based instruments and methods needs to be verified by ground-based sun-photometer measurements.

This work is supported by the National Natural Science Foundation of China under Grant No 49635200.

Now in Atmospheric Science Program, Department of Physics, Dalhousie University, Halifax, Canada, B3H 3J5.
A high temporal and spatial resolution and accurate aerosol distribution model is also required to study the regional climate in China. This model is mainly based on satellite remote sensing over China. Simultaneously, sun-photometer observation is made in various locations to verify the satellite remote sensing method. The sites selected for sun-photometer measurements are Miyun of Beijing (117.12°E, 40.65°N, altitude 286 m ASL), Xinfei of Guangdong (114.2°E, 24.5°N, altitude 160 m ASL), Waliguan of Qinghai (100.90°E, 36.29°N, altitude 3816 m ASL), and Damxung of Tibet (91.1°E, 30.48°N, altitude 4200 m ASL). They represent different geographic and climatic regions in China. Figure 1 shows the locations of the four sites. The period of the observation is one year, from February 1998 to January 1999 (because of the harsh environment in Damxung, Tibet, there are only two months of observations at this site, May and June 1998). The results of the sun-photometer observations are discussed in this paper to illustrate the aerosol radiative characteristics in different regions of China.

2. Instrument and calibration

2.1 Instrument

The sun-photometers used in the four sites are BB model ten-wavelength sun-photometers produced by the Photoclectric Instrument Institute of Beijing Normal University. The detector of the sun-photometer is a silicon photocell diode with a 3° circular visual field. Center wavelengths of the ten bands are close to 450 nm, 500 nm, 550 nm, 600 nm, 650 nm, 700 nm, 750 nm, 800 nm, 850 nm, 900 nm and the semi-wavelength width is about 10–20 nm. Table 1 summarizes the center wavelengths for the four sun-photometers and Fig. 2 shows the response function of the ten bands for one sun-photometer.
Table 1. Center wavelengths of the sun-photometers (nm)

<table>
<thead>
<tr>
<th>Band</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>444.2</td>
<td>497.7</td>
<td>550.0</td>
<td>610.0</td>
<td>658.2</td>
<td>701.6</td>
<td>767.6</td>
<td>808.7</td>
<td>866.3</td>
<td>910.0</td>
</tr>
<tr>
<td>2</td>
<td>441.4</td>
<td>497.7</td>
<td>550.0</td>
<td>606.8</td>
<td>656.9</td>
<td>700.0</td>
<td>764.3</td>
<td>810.0</td>
<td>862.9</td>
<td>910.0</td>
</tr>
<tr>
<td>3</td>
<td>449.2</td>
<td>499.6</td>
<td>560.0</td>
<td>610.0</td>
<td>653.8</td>
<td>700.0</td>
<td>762.4</td>
<td>810.0</td>
<td>862.0</td>
<td>910.0</td>
</tr>
<tr>
<td>4</td>
<td>440.3</td>
<td>496.6</td>
<td>550.0</td>
<td>610.0</td>
<td>658.8</td>
<td>707.6</td>
<td>763.6</td>
<td>810.0</td>
<td>862.5</td>
<td>910.3</td>
</tr>
</tbody>
</table>

# Calibration

Calibration is essential for sun-photometer measurements. There are mainly two calibration methods: the standard lamp method and the Langley method. Standard lamp method is simple and easy to conduct. However, because different standard lamps exist with 5%–10% relative error (Shaw, 1976), it still has some uncertainty for absolute calibration. Using the sun as the lamp-house, calibration using the Langley method is more accurate than using the standard lamp method. However it has strict requirement for the selection of calibration sites and weather conditions. Therefore it is not convenient for frequent calibration. In our observation period, the sun-photometers are calibrated using both methods.

Before (October 1997) and after (April 1999) the experiment, the four sun-photometers were calibrated twice using the Langley method in Xinglong Observatory, Hebei. During the
Fig. 3. Result of Langley calibration for 450 nm band of the \( \tau \) sun–photometer in four different locations.

Fig. 4. Relative error of standard lamp calibrations for all the four sun–photometers from September 12, 1997.
observations, additional two Langley calibrations were made for the $\approx 2$ sun-photometer in May 1998 and November 1998 in two different sites, Damxung of Tibet (Zhang et al., 2000a) and Huangshan Mountain of Anhui respectively. Figure 3 shows the results of the four Langley method calibrations for the $\approx 2$ sun-photometer's 450 nm band. There is almost no difference between the four calibration times, and the correlation coefficient of the calibration line is larger than 0.999. For all sun-photometers, all correlation coefficients of the calibration lines are larger than 0.995.

Besides the Langley calibration, in the period of observation an RS-10A standard lamp produced by EG&G was used to monitor the stability of the sun-photometers. For the one-year period of observation, the sun-photometers were calibrated four times by the standard lamp. Figure 4 shows all the results of standard lamp calibration starting from September 12, 1997, including the calibrations before and after the observations in addition to the calibrations during the observation. It can be seen from the figure that most of the relative errors of the sun-photometers are less than $\approx 4\%$. Although the relative error of a band sometimes is as large as $\approx 9.2\%$, no systematic error is found in this figure. Thus, the large error is caused by random errors, such as collimation, reading.

3. Data processing

The satellite data used in our study are the visible channel reflectance of the Japanese geostationary meteorological satellite GMS-5 and the remote sensing was done at the same time over China. Considering the time difference between different regions of China, we use the 1330 BST (Beijing Standard Time) GMS-5 data. Therefore the observations of the sun-photometers are between 1200–1400 BST. Every clear day when the sun is not covered by cloud has one observation. Multi-observations per day were only obtained on some days on the site of Damxung, Tibet. The original observational data are processed as described below.

3.1 Aerosol optical depth

According to the Lambert–Beer law, the optical depth of the total atmosphere can be obtained by (Lenoble, 1993)

$$
\tau(\lambda) = - \frac{1}{m(\mu)} \ln \left( \frac{V(\lambda)}{aV_0(\lambda)} \right),
$$

where $V_0(\lambda)$ is the calibration coefficient, $V(\lambda)$ is the measurement of the sun-photometer, $x$ is the sun-earth distance factor, $m(\mu)$ is the atmospheric mass, $\mu$ is the zenith angle of the sun.

The optical depth calculated by (1) includes the aerosol optical depth $\tau_{ae}(\lambda)$, the Rayleigh scattering optical depth of the air molecules $\tau_m(\lambda)$, and absorption optical depth by gases like O$_2$, H$_2$O, O$_3$, etc., $\tau_{ab}(\lambda)$

$$
\tau(\lambda) = \tau_{ae}(\lambda) + \tau_m(\lambda) + \tau_{ab}(\lambda).
$$

The method of calculating $\tau_m(\lambda)$ and $\tau_{ab}(\lambda)$ in each band considering bandwidth and error correction are discussed in detail by Zhang et al. (2000b).

Then the aerosol optical depth is given by

$$
\tau_{ae}(\lambda) = \tau(\lambda) - \tau_m(\lambda) - \tau_{ab}(\lambda).
$$
3.2 Angstrom exponent

According to the research of Angstrom (1964), the dependence of the aerosol optical depth on the wavelength can be expressed as

$$
\tau_{\text{aer}}(\lambda) = \beta \lambda^{-\alpha},
$$

(4)

where \(\beta\) is the turbidity coefficient, which represents the content of the aerosol in the atmosphere; \(\alpha\) is the Angstrom exponent, which is affected by the size distribution of the aerosol particles. Normally, \(0 < \alpha < 2\), with smaller \(\alpha\) associated with larger aerosol sizes.

Although (4) has some limitations (Wang, 1982), it reflects the size of the aerosol. Table 2 summarizes the monthly mean aerosol optical depth (550 nm) and Angstrom exponent for the four sites. Because Xinjiang is located in the humid area of South China, most of the time in summer the sky is covered with clouds and hence no observational data is available in June, July and September.

**Table 2.** Monthly mean aerosol optical depth and Angstrom exponent observed at the four sites

<table>
<thead>
<tr>
<th>Month</th>
<th>Waliugan</th>
<th></th>
<th></th>
<th>Miyun</th>
<th></th>
<th></th>
<th>Xinfeng</th>
<th></th>
<th></th>
<th>Damaung</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>AOD</td>
<td>AE</td>
<td>N</td>
<td>AOD</td>
<td>AE</td>
<td>N</td>
<td>AOD</td>
<td>AE</td>
<td>N</td>
<td>AOD</td>
<td>AE</td>
</tr>
<tr>
<td>Jan</td>
<td>19</td>
<td>0.07</td>
<td>1.14</td>
<td>23</td>
<td>0.14</td>
<td>0.75</td>
<td>11</td>
<td>0.43</td>
<td>0.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb</td>
<td>13</td>
<td>0.13</td>
<td>0.39</td>
<td>8</td>
<td>0.15</td>
<td>0.73</td>
<td>1</td>
<td>0.28</td>
<td>0.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mar</td>
<td>5</td>
<td>0.25</td>
<td>0.57</td>
<td>2</td>
<td>0.13</td>
<td>1.23</td>
<td>5</td>
<td>0.53</td>
<td>0.96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr</td>
<td>11</td>
<td>0.19</td>
<td>0.26</td>
<td>4</td>
<td>0.50</td>
<td>0.54</td>
<td>9</td>
<td>0.60</td>
<td>0.71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>14</td>
<td>0.24</td>
<td>0.15</td>
<td>20</td>
<td>0.40</td>
<td>0.97</td>
<td>6</td>
<td>0.52</td>
<td>0.79</td>
<td>6</td>
<td>0.69</td>
<td>0.55</td>
</tr>
<tr>
<td>Jun</td>
<td>11</td>
<td>0.25</td>
<td>0.32</td>
<td>14</td>
<td>0.56</td>
<td>0.73</td>
<td>18</td>
<td>0.06</td>
<td>0.35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jul</td>
<td>9</td>
<td>0.15</td>
<td>0.33</td>
<td>9</td>
<td>0.24</td>
<td>0.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aug</td>
<td>12</td>
<td>0.12</td>
<td>0.37</td>
<td>14</td>
<td>0.26</td>
<td>0.60</td>
<td>3</td>
<td>0.45</td>
<td>1.06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sep</td>
<td>14</td>
<td>0.15</td>
<td>0.48</td>
<td>14</td>
<td>0.40</td>
<td>0.84</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct</td>
<td>13</td>
<td>0.10</td>
<td>1.19</td>
<td>16</td>
<td>0.19</td>
<td>0.57</td>
<td>6</td>
<td>0.29</td>
<td>0.35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov</td>
<td>23</td>
<td>0.07</td>
<td>1.36</td>
<td>18</td>
<td>0.19</td>
<td>0.84</td>
<td>15</td>
<td>0.30</td>
<td>0.58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec</td>
<td>21</td>
<td>0.07</td>
<td>1.02</td>
<td>22</td>
<td>0.17</td>
<td>0.74</td>
<td>13</td>
<td>0.45</td>
<td>0.81</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.3 Relative standard deviation (RSD) of aerosol optical depth

The temporal variability of the aerosol optical depth at each site is illustrated by the relative standard deviation of the aerosol optical depth for every month observed in that site as shown in Table 3.

**Table 3.** Relative standard deviation of aerosol optical depth in every month observed in the four sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miyun</td>
<td>0.79</td>
<td>0.79</td>
<td>0.02</td>
<td>0.94</td>
<td>0.83</td>
<td>0.79</td>
<td>1.05</td>
<td>1.21</td>
<td>0.88</td>
<td>1.22</td>
<td>0.77</td>
<td>1.05</td>
</tr>
<tr>
<td>Waliugan</td>
<td>0.41</td>
<td>0.35</td>
<td>0.46</td>
<td>0.31</td>
<td>0.39</td>
<td>0.82</td>
<td>0.57</td>
<td>0.45</td>
<td>0.59</td>
<td>0.77</td>
<td>0.63</td>
<td>0.52</td>
</tr>
<tr>
<td>Xinfeng</td>
<td>0.64</td>
<td>0.02</td>
<td>0.62</td>
<td>0.20</td>
<td>0.38</td>
<td>0.19</td>
<td>0.38</td>
<td>0.33</td>
<td>0.33</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damaung</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.33</td>
</tr>
</tbody>
</table>
4. Results and discussion

4.1 General description of geographic and climatic properties of the observation sites

The selected four observation sites represent different geographic and climatic zones of China. Waliguan of Qinghai is located in the arid area of northwestern China, belonging to a continental plateau climate. Here high wind and dust storm often occur in spring. Miyun of Beijing is in the north of China. It has a typical temperate semi–humid continental climate, it is hot and rainy in summer, cold and arid in winter, and is dry in spring. Xinfeng of Guangdong is located in the hot and rainy region of southern China, belonging to a subtropical–tropical moist monsoon climate. Damxung of Tibet is in the Qiangtang prairie in the center of Tibet. It has the plateau temperate monsoon climate with distinct wet and dry seasons.

4.2 Annual variability of aerosol optical depth and Angstrom exponent

Figures 5–7 show the annual variation of monthly mean 550 nm aerosol optical depth and Angstrom exponent in three of the observation sites, Waliguan, Miyun and XinFeng. Because there are only two months of observations in Damxung, the total observed 550 nm aerosol optical depth and Angstrom exponent are shown as a function of Julian day in the scatter diagram as Fig. 8.

As can be seen from Figs. 5, 6, and 7 that there is a maximum of aerosol optical depth in spring in all of the three sites (Waliguan, Miyun and XinFeng), even though they belong to different geographic zone and have much different climates. The maxima at Waliguan and Miyun are significant in spring, the values of the aerosol optical depth in this season are about 2 to 3 times as large as in other seasons. This is caused by the dry and windy weather in spring that uplifts dust aerosols. Furthermore, the trends of the variability of the aerosol optical depth during the year are similar at these two sites. This phenomenon represents the characteristics of the annual variation of the aerosol optical depth in the arid and semi–arid zone. XinFeng belongs to the humid zone of South China. Here the difference of aerosol optical depth between different seasons is not as large as in Waliguan and Miyun. The maximum in the spring is related to relative dry weather and the prevailing wind in this season. In spring, the predominant wind is from the north, carrying the aerosol from inland China; in summer, the wind is mainly from the southeastern ocean where the air is cleaner. It represents the aerosol characteristics in the southeastern humid zone of China.

From Fig. 6 we can see that in Miyun there is a maximum comparable to the maximum of spring in September. It is consistent with the farming activity during this period. The land is bare because of the harvest and cultivation at that time. Dust and farming activity are the reasons for the maximum in this month.

Comparing the values of the aerosol optical depth, we can see that in spring the aerosol optical depth is similar in Miyun and XinFeng, about 0.5 in 550 nm, and both of them are about twice as large as in Waliguan. However, in winter the aerosol optical depth in XinFeng is about twice as large as in Miyun, and in Miyun is twice as large as in Waliguan. This illustrates the different aerosol sources in the different areas and seasons. Miyun and XinFeng are located in the highly developing zone of East China. Besides natural sources, the anthropogenic aerosol is a major source. Waliguan is located in the remote northwestern China where the aerosol mainly originated from natural sources. Thus the aerosol optical depth in Miyun and XinFeng is larger than in Waliguan during the year. In winter, the
Fig. 5. Monthly mean aerosol optical depth (a) and Ångström exponent (b) in Waliguan, Qinghai.
Fig. 6. Monthly mean aerosol optical depth (a) and Angstrom exponent (b) in Miyun, Beijing.
Fig. 7. Monthly mean aerosol optical depth (a) and Angstrom exponent (b) in Xinfeng, Guangdong.
Fig. 8. Daily aerosol optical depth (a) and Ångström exponent (b) in Damxung, Tibet.
prevailing wind in Miyun is from the remote northwestern Mongolia, diluting the aerosol that originated from local pollution. Therefore, the aerosol optical depth in Miyun is smaller than in Xinfeng in winter.

Figure 8 shows that the aerosol optical depth in Damxung is much small during May and June. Most of the aerosol optical depth at 550 nm is below 0.1, and is about half of the value observed in Waliguan at the same time, even though both of the sites are in the Tibetan Plateau. This difference is due to the differences of land surface type and weather conditions in the two sites. Damxung is in the Qiangtang prairie. No dust storms occur in this area. However in Waliguan, dust storms often occur in spring. This figure also shows a tendency for the aerosol optical depth to decrease from May to June in Damxung. This is the result of the changes of weather in this period, from the dry season to the wet season. This transition occurred in the middle of June in that year. Wet deposition decreases the aerosol content in the air.

For the Angstrom exponent shown in these figures, a noticeable property is an annual variation in Waliguan. In spring the monthly mean Angstrom exponent has its minimum (about 0.15) while the aerosol optical depth has its maximum. The maximum of Angstrom exponent is found in September, about 1.36, and the aerosol optical depth reaches its minimum. The observations made by Wang and Qiu (1988) in the Taklimakan desert also showed a similar small Angstrom exponent in spring like in Waliguan. It suggests the occurrence of large aerosol particles in the atmosphere and is consistent with the fact that dust storms often occur around the site in spring. Although the monthly mean aerosol optical depth in Miyun has an evident maximum in spring like in Waliguan, there is no trend of Angstrom exponent over the year. The Angstrom exponent in Xinfeng also does not show an annual trend either. This is because the aerosol at these two sites not only includes large particles like dust but also includes small particles from air pollution.

The daily data of Angstrom exponent in Damxung show that sometime it is negative (abnormal extinction). It means that occasionally the aerosol is composed of very large particles. This phenomenon is also observed at the other three sites, and more frequently in Waliguan where dust is the dominating aerosol component. About 10 percent of the observations in Waliguan the Angstrom exponent are negative. Only a few cases of abnormal extinction are observed in Miyun and Xinfeng over the year.

The difference of the aerosol extinction characteristics at the four sites shows that in the eastern zone of China, the anthropogenic aerosol burden is comparable to the natural aerosol burden. Here the aerosol composition is relatively complete. In the western China, the aerosol mainly originates from natural sources.

4.3 Monthly relative standard deviation of the aerosol optical depth

Figure 9 shows the monthly relative standard deviation of the aerosol optical depth observed at the four sites. Generally, Miyun has the largest relative standard deviation except for March (only two observations which are not sufficient for statistics). It means the temporal variation in Miyun is the largest, and it is two to four times as large as in Xinfeng. The reason for this is Miyun belongs to a fast developing area of China. The aerosol originated from human activities such as industry and agriculture is large. On the other hand, about 150 km north of it is the Inner Mongolia of China where the dominant source of the aerosol is natural. When the wind is from the north, the clean continental air mass can notably decrease the aerosol optical depth in this area when no dust storm occurs. Therefore it has the largest temporal variation. The relative standard deviation in Waliguan is also high, about twice as
large as in Xinfeng. This is related to the variation of the dust aerosol during the year at that site. Compared to Miyun and Waliguan, the source of aerosol in Xinfeng and Damxung is simpler and steadier, so that the relative standard deviations at these two sites are smaller than at the other two sites.

4.4 Daily variation of aerosol optical depth in Damxung

Damxung is the only site that has more than one observation per day. Because of its high altitude (4200 m), the solar radiation is very strong near the ground and the surface temperature increases very quickly in the morning. Thus the developed turbulence in the boundary layer is strong enough to activate deep convection to form lots of cumuli in the late morning. Therefore most of the time the sun is covered by clouds after 1200 BST (1000 local time), and the observations of aerosol optical depth are in the morning. Figure 10 shows the variation of one day's aerosol optical depth in 550 nm (May 29, 1998). It has 17 observations from 0730 to 1330 BST. The aerosol optical depth shows a decreasing tendency from early morning to noon. This phenomenon was also observed during other experiments, for instance Wang and Qiu (1988) observed that in the Taklimakan desert. A possible cause is the influence of the relative humidity on the aerosol optical properties. This was discussed in detail by Zhang et al. (2000a).

Figure 11 shows the change of the multi-wavelength aerosol optical depth on May 29, 1998. As there is a weak and narrow absorption band of $O_2$ near 750 nm that can result in a large relative error if the aerosol optical depth is small, we only used the data observed in 8
Fig. 10. Daily variation of the 550 nm aerosol optical depth observed in Damxung on May 29, 1998.

Fig. 11. Variation of multi-wavelength aerosol optical depth observed in Damxung on May 29, 1998.
Fig. 12. Variation of the surface temperature observed in DAMXUNG on May 29, 1998.

Fig. 13. Variation of the wind velocity observed in DAMXUNG on May 29, 1998.
wavelengths, which are far from 750 nm. It can be seen that the multi-wavelength aerosol optical depth also decreases with time. However, the decrease in short wavelengths is more pronounced than in the long wavelengths. This means the size of the aerosol has a trend to become larger over the course of the day. One possible reason is that the wind velocity increase with the onset of convection, more dust at large sizes is blown into the air. In the meantime the aerosol optical depth decreases with the decrease of the relative humidity. Figures 12 and 13 show the change of surface temperature and wind velocity observed on that day. The surface temperature changed from near 0°C at 0730 (BST) to about 40°C at 1200 (BST). As a result strong convection should occur and the relative humidity should decrease. The wind velocity at 50 cm above ground also increases from about 0.5 m/s to 3.5 m/s during this period.

5. Conclusion

Aerosol extinction characteristics have been observed by sun-photometers at four sites located in different geographic and climatic zones of China. Several conclusions can be drawn from the analysis of the observational data:

1. Aerosol optical depths in arid and semi-arid area show a significant variation with season with a maximum in spring. The 550 nm aerosol optical depth is about 0.4–0.5 in spring in the highly developing site of Miyun, and is about 0.2 in other seasons. Sometime farming activity also has an influence. As a result of advection of the clean air mass from the northwest, the relative standard deviation of aerosol optical depth at this site is the largest among the four sites, about 2 to 4 times as large as in Xinfeng. In the remote continental site of Waliguan, the 550 nm aerosol optical depth is about 0.2 in spring and is about 0.1 in other seasons.

2. There is relative small seasonal variation in the monthly mean 550 nm aerosol optical depth at the humid site of Xinfeng. The 550 nm aerosol optical depth is about 0.5 in spring, similar to Miyun. In the other seasons, it is about 0.3–0.4.

3. The 550 nm aerosol optical depth in May and June in Damxung is about 0.1. Because of the different surface type, it is smaller than the Waliguan site even though both of them are located in the Tibetan Plateau.

4. The Angstrom exponent has a noticeable annual variation at Waliguan. It is very small in spring, the monthly mean minimum of 0.15 occurs in May. The maximum of 1.36 occurs in November. This is characteristic of the arid northwestern area of China where the main source of aerosol is dust. In the area with more human activity like Miyun and Xinfeng, the Angstrom exponent shows no annual trend, probably as a result of the complicated aerosol sources in these areas.

5. The daily change of aerosol optical depth in Damxung is also significant. The minimum occurs near noon, when the relative humidity is the lowest.

The authors thank Professor Chen Jiaji in the Department of Atmospheric Science, Peking University for providing the temperature and wind velocity data in Damxung site. Thanks are given to Dr. Ulrike Lohmann and Dr. Glen Lesins in the Atmospheric Science Program, Department of Physics, Dalhousie University for their kind suggestions on this paper.
REFERENCES


中国不同地区气溶胶消光特性分析

张军华 毛节泰 王美华

摘要

利用多波段太阳光度计在中国四个点（北京的密云、广东的新丰，青海的瓦里关，西藏的当雄）测量了450–900 nm范围中多波长气溶胶光学厚度和Angstrom指数。本文分析了这些参数从1998年2月到1999年1月这一年的特点。结果表明，在干旱和半干旱地区，如密云（117.12°E，40.65°N）和瓦里关（100.90°E，36.29°N），春季出现气溶胶光学厚度的最大值，大约是其他季节的2倍。在湿润地区，如新丰（114.25°E，24.5°N），虽然春季气溶胶光学厚度值也是最大，但只是比其他季节稍大一些。瓦里关春季的Angstrom指数最小值，约0.15，表明有比较大的粒子，密云和新丰的Angstrom指数也有很大的月相变化，但没有明显的季节倾向。这表明，气溶胶粒的离比较复杂。

关键词：太阳光度计，气溶胶，消光特性