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Aerosol monitoring at multiple locations in China: contributions of EC and dust to aerosol light absorption

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ABSTRACT

This paper reports on the analysis of 24-h aerosol data measured during 2006, at 14 monitoring sites in China. Measurements included seven-wavelength Aethalometers, thermal/optical reflectance analyses of filter samples and determination of dust aerosols. Black (elemental) carbon (BC, EC) is found to be the principal light-absorbing aerosol over many parts of China; however, the fraction of apparent light absorption attributed to dust varied from 14% in winter, to 11% in spring, to 5% in summer to 9% in autumn. Aerosol light absorption in urban areas was larger than in rural areas by factors of 2.4 in winter, 3.1 in spring and 2.5 in both summer and autumn. These differences may lead to contrasts in radiative, thermal and cloud modification effects between urban and rural areas. Absorption 'hotspots' were located in the Sichuan Basin, the provinces south of Beijing, the Pearl Delta River regions and the Guanzhong Plain. The mass absorption coefficient for aerosol BC (σ_{BC}) based on Aethalometer data is estimated to be 11.7 $m^2\ g^{-1}$ at 880 nm wavelength (λ) with inverse (λ^{-1}) wavelength scaling, whereas the mass absorption coefficient for dust (σ_{dust}) is 1.3 $m^2\ g^{-1}$ on average without significant wavelength dependence.

1. Introduction

Black carbon (BC) and dust aerosols can absorb substantial amounts of solar energy, thereby increasing solar heating, particularly when aerosol layers are located above cloud layers. These effects have been observed above the Indian Ocean (Ackerman et al., 2000) and over the Amazon Basin (Koren et al., 2004). To improve our understanding of the interactions between aerosols and climate system, we require more accurate measurements of BC, other light-absorbing components such as dust and optically-scattering species such as organic carbon (OC), sulphate, nitrate, etc. Unfortunately, this data is not as widely available as would be required for accurate modelling. The Aethalometer (Hansen et al., 1984) is a widely-used instrument that measures aerosol optical absorption ('attenuation') on a filter and converts it to a mass of BC. These results were derived primarily by comparing the Aethalometer light absorption data with elemental carbon (EC) mass determination by the Thermal/optical reflectance (TOR) method, using the major assumption that all the aerosol absorption is attributable to BC. Actually, although BC may be the principal light-absorbing material in most cases, the contribution of optical absorption by dust may be significant. Under these conditions, the total aerosol optical absorption will depend on its composition in terms of BC and dust.

The material reported by the Aethalometer as 'Black Carbon' is defined by being 'black', that is, optically absorbing broad band. However, in the presence of dust, we must report this as 'absorbing material' (AM) since the Aethalometer measures light absorption, not chemical composition. In thermochemical analyses such as the TOR method, a sample collected on a filter is heated so that carbon leaves the deposit at specified temperature plateaus in oxidizing and non-oxidizing carrier gases. These methods attempt to separate OC from EC, whose properties are presumably similar to those of BC.

In this study, we analysed a 1yr data set of measurements from 14 stations of the China Atmosphere Watch Network (CAWNET), to determine the relationships between optical absorption, EC derived by TOR and dust aerosol mass. The objectives were to: (1) evaluate the relative contributions from dust and BC to the observed aerosol light absorption; (2) determine mass absorption coefficients (σ_{BC} and σ_{dust}) for BC and dust aerosol, respectively, on the AE31 and (3) find an overall value of σ_{abs}

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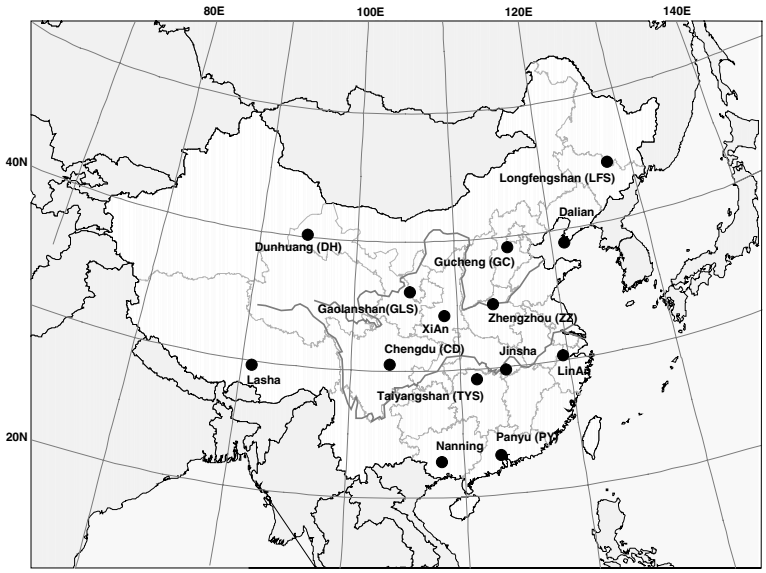

Fig. 1. Locations of 14 CAWNET rural and urban stations in China.

to convert the observed aerosol light absorption from CAWNET stations to BC concentrations.

2. Sample collection and analyses

2.1. Site and filter sampling descriptions

Aerosol samples were collected on filter media during 2006 at representative urban and rural areas of China, from 14 long-term CAWNET stations operated by the Chinese Meteorological Administration (CMA) (Fig. 1). The rural stations are typically located some 100 km away from local sources or nearby major cities, at moderate height above the area's local elevation. At the urban stations, the sampling heights were 50–100 m higher than the city average elevation. This was designed to produce samples representative of the region rather than the immediate locality. Detailed site descriptions are presented in Table 1. 24-h PM10 samples were collected by MiniVol(tm) air sampler (Airmetrics, OR, USA) at flow rates of 5 l min^{-1} from 09:00 to 09:00 the following day. The samples were collected on 47 mm Whatman quartz microfibre filters (QM/A) that were pre-heated at 800 °C for 3 h, before using.

2.2. EC and OC measurements

The 24-h filter samples were collected at each station on a one in every three days basis. Thermochemical analyses for EC and OC were made by the TOR method, following the 'interagency monitoring of protected visual environments' (IMPROVE) protocol (Chow et al., 1993; 2004). The sample filter is heated stepwise at temperatures of 120 °C (OC1), 250 °C (OC2), 450 °C (OC3) and 550 °C (OC4) in a non-oxidizing (He) atmosphere and at 550 °C (EC1), 700 °C (EC2) and 800 °C (EC3) in an oxidizing atmosphere of 2% oxygen and 98% He. Evolved carbon is oxidized to CO_2 and then reduced to CH_4 for detection by FID. The pyrolysed or charred OC is monitored by laser reflectance at λ = 633 nm. The portion of EC1 shown until the laser signal returns to its initial value, is assigned to pyrolysed organic carbon (OP). The total OC is defined by the sum OC1 + OC2 + OC3 + OC4 + OP, whereas the total EC is defined by EC1 +EC2 + EC3 – OP.

2.3. PIXE analyses

Portions of the filter-based samples were also analysed directly, using a proton induced X-ray emission (PIXE) method, to determine elemental concentrations. The PIXE analyses were performed using 2.5 MeV protons with a 50 nA beam current, produced by the 2 × 1.7 MV tandem accelerator at Beijing Normal University (Zhang et al., 1993). The concentrations of twenty elements can be determined through these procedures, after correction for blank filters. In this study, only Fe was used as a surrogate to estimate the dust fractions in the daily filter samples.

2.4. Aethalometer measurement

At each station, an Aethalometer^{TM}, model AE-31 (Magee Scientific, Berkeley, CA, USA), was used to measure optically-absorbing filterable aerosol material on a 5 min time base. These instruments were operated at a sample flow rate of 4 l min^{-1}, collecting the aerosol sample on a quartz fibre filter tape, which is continuously compared optically to a reference portion of the tape. The filter tape is automatically advanced when its optical density attains 0.75. The attenuation of light with wavelength λ transmitted through the particle deposit, relative to the blank

Table 1. Site locations and descriptions

Station name	CAWNET stations descriptions
Chengdu (CD) (30°39′N, 104°2.4′E)	Urban station, 496 m a.s.l., in the centre of Chengdu city, Sichuan province. Aerosol samples collected from a 91 m tall building.
Dalian (DL) (38°54′N, 121°37.8′E)	Urban station, 91.5 m a.s.l., southeast of Dalian city center, at city outskirts. Aerosol samples collected from a 5 m tall building.
Dunhuang (DH) (40°9′N, 94°40.8′E)	Rural station, 1139 m a.s.l., 1.5 km northeast of Dunhuang city, Gansu province. Aerosol samples collected from a 5 m tall sampling container.
Gaolanshan (GLS) (36°0′N, 105°51′E)	Rural station, 5 km north of Lanzhou city (1531 m a.s.l.), Gansu province. Aerosol samples collected from a 544 m tall hill.
Gucheng (GC) (39°7.8′N, 115°48′E)	Rural station but within area of rapid urbanization: 15.2 m a.s.l., 38 km southwest from Baoding city, Hebei province. Aerosol samples collected from a 8 m tall building.
Jinsha (JS) (29°37.8′N, 114°12′E)	Rural station, 416 m a.s.l., 105 km north of Wuhan city, Hubei province. Aerosol samples collected from a 8 m tall building.
Lhasa (LS) (29°40.2′N, 91°7.8′E)	Urban station in remote area, 3663 m a.s.l., within Lasa city, Qinghai-Xizang Plateau. Aerosol samples collected from a several metre tall building.
LinAn (LA) (30°18′N, 119°44′E)	Rural station, 139 m a.s.l., 150 km northeast of Shanghai 50 km west of Hangzhou city, Zhejiang province. Aerosol samples collected from a 10 m tall building.
Longfengshan (LFS) (44°43.8′N, 127°36′E)	Rural station, 331 m a.s.l., 175 km northeast of Harbin city. Aerosol samples collected from a 6 m tall building.
Nanning (NJ) (22°49.2′N, 108°21′E)	Urban station, 84 m a.s.l., in Nanning city, Guangxi province. Aerosol samples collected from a 97 m tall building.
Panyu (PY) (23°0′N, 113°21′E)	Urban station in Panyu district of Guangzhou city (5 m a.s.l.), Guangdong province. Aerosol samples collected from a 140 m tall hill.
Taiyangshan, Changde (TYS) (29°10.2′N, 111°42.6′E)	Rural station, 563 m a.s.l., 18 km northwest of Changde city, Huan province. Aerosol samples collected from a 8 m tall building.
Xian (XA) (34°25.8′N, 108°58.2′E)	Urban station in northern margin of Xian city, but within Jinhe River Industrial District in the Guanzhong Plain, 363 m a.s.l., 20 km north of centre of Xian city, Shaanxi province. Aerosol samples collected from a 4 m tall sampling container.
Zhengzhou (ZZ) (34°46.8′N, 113°40.8′E)	Urban station, 99 m a.s.l., in the centre of Zhengzhou city, Henan province. Aerosol samples collected from a 56 m tall building.

filter, is used to estimate aerosol light absorption, $b_{abs}(\lambda)$. This is divided by a mass absorption coefficient, $\sigma_{abs}(\lambda)$ (in units of $m^2\ g^{-1}$), to obtain the mass concentration in $\mu g\ m^{-3}$. The method is described in detail by (Hansen et al., 1984). We note that the mass absorption coefficients have been reported to be site-specific and variable, even during different seasons (Liousse et al., 1993; Horvath, 1997; Moosmüller et al., 1998; Kirchstetter et al., 2004; Watson et al., 2005), although there is debate as to the constancy of chemical analysis. In normal operation, corrections are not made for filter loading, filter scattering and aerosol scattering (Bond et al., 1999), although the raw signals are available for post-processing, if desired. We also note the possible non-linearities existing in apparent light absorption, with mass loading and aerosol composition as described by (Weingartner et al., 2003). The light absorption values used here are instrumental values and the mass absorption coefficients, likewise, are specific to Aethalometer data. Despite the above cautions, Aethalometer data in general agree extremely well with EC analysis by thermochemical means, as shown (for example) in the 'Harvard Six Cities Study', conducted at diverse locations across the USA in all seasons (Babich et al., 2000). It is also important to note that measurements of optical absorption performed on an aerosol deposit collected on a filter, do not represent the true in situ optical absorption by freely-suspended particles. Collection onto a filter matrix necessarily perturbs the microphysical nature and mixing state of the carbon 'core', whose optical properties in suspension are strongly influenced by other chemical species, humidity, etc. We use the measurement of optical attenuation through a filter deposit to estimate aerosol absorption and carbon mass. In all of the subsequent discussion, the term 'optical absorption' is implicitly understood to represent absorption derived from attenuation measured on the filter tape of the Aethalometer. This AE-31 model Aethalometer measures optical absorption at seven wavelengths of 370, 470, 520, 590, 660, 880 and 950 nm.

3. Results and discussion

3.1. Aerosol light absorption in various regions of China

Aerosol light absorption (b_{abs}) at 880 nm was found to have relatively low values, averaging around 50 M m^{-1} for regionally dispersed aerosols at the rural stations (Zhang et al., 2008). These

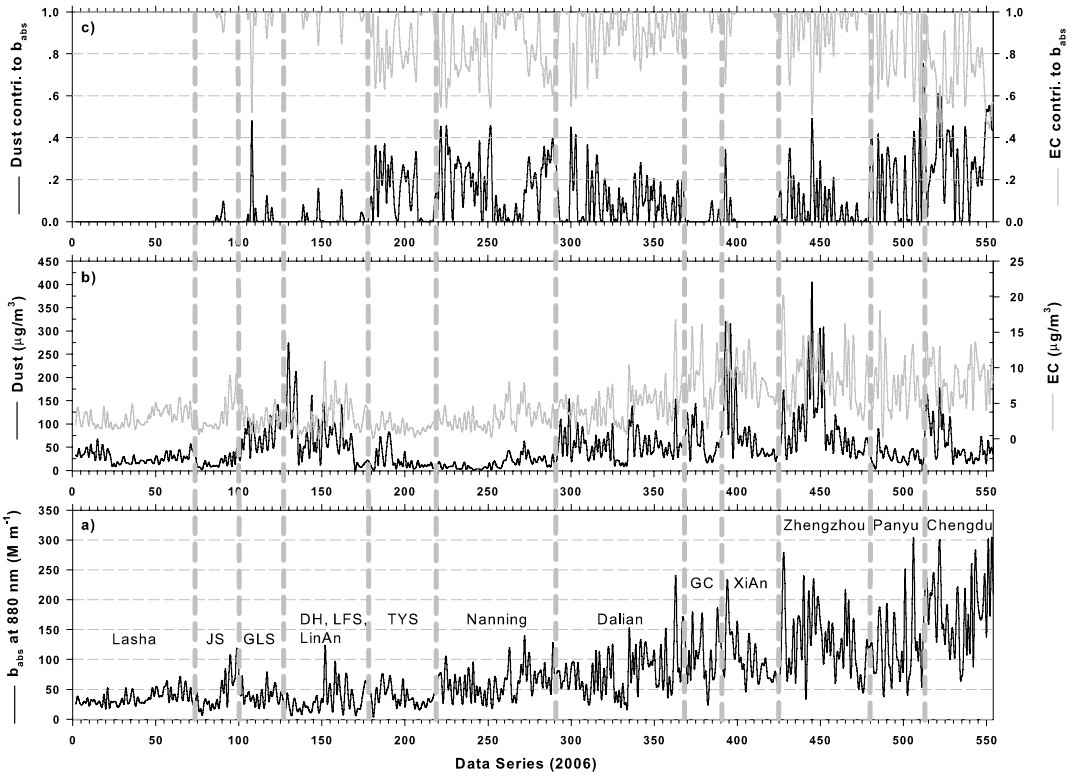

Fig. 2. (a) Series of aerosol light absorption (b_{abs}) at 880 nm, (b) concentration of dust and EC and (c) the relative contributions of EC and dust to the total aerosol light absorption.

stations are shown in Fig. 2a and include Lhasa, Jinsha, Gaolanshan (GLS), Dunhuang (DH), Longfengsha (LFS), LinAn and Taiyangshan (TYS). Gucheng station is rural, but within an area of rapid urbanization in Hebei province (south of Beijing), with heavy local pollutant source influences—it should therefore be classified in the 'urban' group. The rural values of b_{abs} were much lower than the mean values of ∼130 M m^{-1} from the urban stations that include Gucheng, Xian, Panyu, Zhengzhou and Chengdu (Fig. 2a), where high concentrations of carbonaceous aerosols were observed, as described in our accompanying paper (Zhang et al., 2008) and also in Fig. 2b. On average, optical absorption in urban areas is higher than at rural sites by factors of 2.4 in winter, 3.1 in spring, 2.5 in summer and 2.5 in autumn, respectively. This result is also true for absorption, derived from the other six Aethalometer wavelengths. This considerable difference in aerosol absorption between urban and rural areas of China may result in additional thermal or other atmospheric contrasts between these two areas, which may have impacts on the local circulation and other meteorological parameters such as precipitation and cloud covers. The highest average aerosol absorptions were observed at Chengdu in Sichuan basin even though this location did not have the highest EC loading, which suggests that another factor may contribute to the aerosol absorption values. The absorption 'hotspots' are located at the Sichuan Basin site (Chengdu), as well as the sites in provinces south of Beijing (Zhengzhou, GC), site within Pearl Delta River regions (Panyu) and the site in the Guanzhong Plain (Xian) (Fig. 2a).

3.2. Elemental carbon and dust aerosols in various regions of China

The data for EC (Fig. 2b) show a variation very similar to that for aerosol light absorption (Fig. 2a), reflecting a high correlation between the daily averaged aerosol light absorption and EC loading. As with absorption, relatively lower EC concentrations were observed at the rural sites than those found at urban stations—especially at Zhengzhou (Henan province south of Beijing), Chengdu in the Xichuan Basin and Panyu in the Pearl Delta River region (see Fig. 2b). In contrast to the optical absorption data, lower 'rural' concentrations of EC were found at Nanning and Dalian. At these locations, the EC concentrations remained at the typical lower rural level, but the aerosol light absorption was somewhat increased. This implies again the existence of light absorption by other factors.

At all 14 rural and urban stations, substantial and variable amounts of dust were observed (Fig. 2b). The dust concentration is estimated by Fe measured by the PIXE method, using an average composition of Fe in dust of 4% (Zhang et al., 2003).

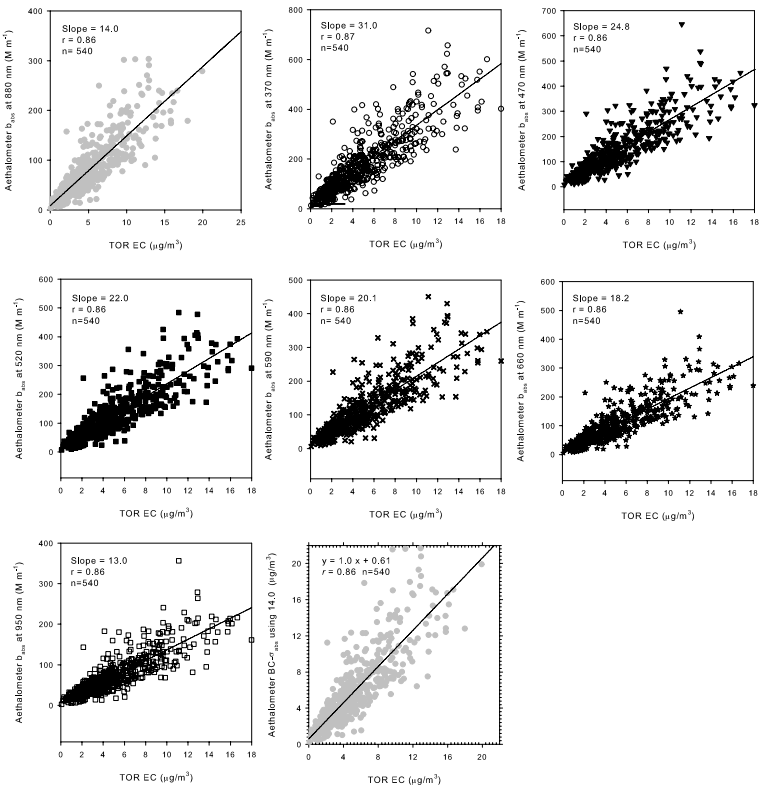

Fig. 3. Correlations between the daily averaged aerosol light absorptions at the seven Aethalometer wavelengths and 24-h TOR EC concentrations for all the samples collected from CAWNET stations during 2006. Last diagram at bottom row is the correlation between TOR EC and BC concentrations estimated using $\sigma_{abs} = 14.0$.

In some periods, especially at rural stations, the dust concentrations show consistent variations with EC, exhibiting the dispersed features for these two different types of aerosol and less local influence. During some periods, these correlations were less consistent, reflecting the influence of local 'dust events' or strong transport events. Relatively low dust concentrations with median values smaller than 10 μg m^{-3} were observed at TYS, LFS, Nanning and LinAn stations. Meanwhile, some peaks in dust loading were found at the GLS, DH, GC and Xian stations, especially during springtime. This reflects the transport of Asian soil dust aerosol associated with sand and dust storm (SDS) events as shown at www.sds.cma.gov.cn. Data from the urban group showed dust concentrations of 20–90 μg m^{-3} at stations such as Panyu, Chengdu and Zhengzhou, where there are no frequent influences by transported Asian mineral dust. The 'dust' at these sites could be 'industrial emission' dust from metal processing, or local coal fly-ash from incomplete combustion, or fugitive dust from construction activities.

3.3. Relationship between aerosol light absorption and TOR EC

The Aethalometer aerosol light absorption ('attenuation') at each wavelength λ is linearly related and highly correlated with TOR EC (Fig. 3). Note that this is related to in situ aerosol optical absorption, but generally larger due to optical effects in the filter fibres. Good correlations ($r \simeq 0.86$) were found for 540 24-h parallel sample data in 14 stations from various regions of China, suggesting the overall absorption is dominated by black (elemental) carbon in China. The correlation between Aethalometer 'attenuation' and EC gives an average slope of $\sigma_{abs} = 14.0\,m^2\,g^{-1}$ at 880 nm. Using this value to estimate EC from any Aethalometer data gives overestimated results by about 22% relative to the TOR data (Fig. 3), suggesting this conversion factor is generally usable in CAWNET of China. Actually this σ_{abs} (14.0, at 880 nm) is larger than the value 12.6 normally used for this conversion (Hansen et al., 2000), inferring that there may be other contributions to aerosol absorption in China, in addition to EC. There may also be an influence from scattering artefact if the mass loadings or overall aerosol composition in different areas are not the same. Actually, the σ_{abs} varied from site to site, with the minimum value of 7.3 found at Gaolanshan to maximum of 18.0 at Taiyangshan, probably because of different aerosol composition and morphology at the different sites, or loading/scattering/shadowing artefact. A range of values of σ_{abs} have been reported by campaigns and investigations from different areas (Liousse et al., 1993; Horvath, 1997; Moosmüller et al., 1998; Kirchstetter et al., 2004; Watson et al., 2005). These are seldom related to the absorption by dust. In our analyses, the compositions of BC (or EC) and dust in aerosol particles are found to contribute to the aerosol absorptions, resulting in the different values of σ_{abs} among the sites.

3.4. Relative contributions of EC and dust aerosols to aerosol light absorption

In general, it is observed that dust particles have very high single scattering albedo (SSA) and low absorption (e.g. Dubovik et al., 2002). However, the light-absorption of dust has also been found in some measurements (Hansen et al., 1993; Kaufman et al., 2001; Fialho et al., 2005). The Aethalometer measurement of aerosol light absorption at a wavelength λ, $b_{abs}(\lambda)$, by a broad-band absorber such as graphitic carbon, would produce an 'attenuation', inversely proportional to the wavelength of the light used. Thus, for a given mass of broad-band absorbing material [AM], the optical attenuation can be written as

$$b_{abs}(\lambda) = \sigma_{abs}(\lambda) \times [\mathrm{AM}], \quad (1)$$

where [AM] is the mass of absorbing material and $\sigma_{abs}(\lambda)$ is the mass absorption coefficient that is wavelength dependent (λ^{-1} for a broad-band absorber).

If the aerosol is a mixture of two absorbing materials—BC and dust—this quantity can be expressed as the result of the additive contribution of each,

$$b_{abs}(\lambda) = \sigma_{BC}(\lambda) \times [\mathrm{BC}] + \sigma_{dust}(\lambda) \times [\mathrm{Dust}] \quad (2)$$

The Aethalometer algorithm assumes that the optical absorption is linearly proportional to the mass of absorbing material, although non-linearities in apparent light absorption, with mass loading and aerosol composition, has also been reported (Weingartner et al., 2003). This assumption is valid under the conditions that the amount of absorbing material in the sample is not so great as to lead to saturation, and (e.g. 'Scattering: Elimination by Filter Matrix') the effect of the embedment of the aerosol particles in a deep matrix of optically-scattering fibres is to eliminate any reduction of the optical transmission through the filter by optical scattering of the particles and to render the measurement sensitive to absorption only. Therefore, data taken during the events of greatly increased OC during January, February and October to December at Dunhuang are not included in our comparisons. The very large concentrations of optically scattering materials at Dunhuang resulted in the Aethalometer operating outside its normal range, as shown by examination of the site-by-site correlation.

To assess the relative contributions of BC and dust, weighted multiple-linear regressions (MLR) were used to estimate the relative contributions of TOR EC and dust to absorption by an aerosol sample, taken over a given 24 h period. This type of statistical analysis has been used to evaluate the relative contribution of different sources to ambient dust concentrations for SDS research (Zhang et al., 1993; 2003). The results show that the contributions of EC to aerosol absorption are present in almost all the samples and dominant in more than half of our samples (Fig. 2c). However, there are substantial contributions from dust during some periods, especially at some of the regional and rural stations (Fig. 2c). Over the entire data set, the overall contributions to the aerosol light absorption are estimated to be ~9% from dust and 91% from EC. During the four seasons, the proportional dust contributions to the apparent absorption of the collected aerosol are calculated to be 14% in winter, 11% in spring, 5% in summer and 9% in autumn.

To obtain values for σ_{BC} and σ_{dust}, we first study aerosol light absorption data during periods of zero contribution from dust and compare it with the corresponding 24-h TOR EC, as shown in Fig. 4. All of the optical absorption can be attributed to black (elemental) carbon only. The results show that b_{abs} has a highly significant correlation ($r \simeq 0.96$) with TOR EC, with a regression slope that provides an estimate of the σ_{BC} applicable to the aerosol under these conditions. For the Aethalometer 'attenuation' data, the value for σ_{BC} at the wavelength of $\lambda = 880$ nm is 11.7 $m^2\ g^{-1}$—very close to the value of 12.6 $m^2\ g^{-1}$ found in the 'Harvard Six Cities' study (Hansen et al., 2000). Values of σ_{BC} at other wavelengths are found in the same way by correlating the TOR EC data with the 'attenuation' $b_{abs}(\lambda)$ at the six different wavelengths; as predicted for broad-band absorbers, σ_{BC} is found to scale with inverse wavelength, λ^{-1}. Using eq. (2), we can insert these values of σ_{BC} to obtain the corresponding σ_{dust} for all the samples, including those with substantial concentrations of dust. The average values of σ_{dust} are 1.2–1.4 $m^2\ g^{-1}$ for the seven λ and do not appear to have a wavelength dependence. We use the median value of σ_{dust}, 1.3 $m^2\ g^{-1}$, to estimate the contribution of dust to aerosol light absorption.

3.5. Other factors influencing optical absorption by dust

An analysis of aerosol optical absorption in terms of dust concentration levels, time series of PM10 and PM1 mass, EC and many meteorological variables, shows that there is a poor overall correlation between the concentrations of dust and its deduced contribution to light absorption. During some episodes of high dust levels, the light-absorption from dust did not increase as expected (see Lhasa and Taiyangshan in Fig. 5). During periods when the dust optical absorption was larger, strong correlations were seen between dust and EC concentrations (Figs. 2b and 5). This suggests that there may be more than one contribution to both dust optical absorption and dust mass, with behaviour varying from one site to another. It is interesting that most of the data exhibiting high optical absorption from dust were reported by the stations with relatively high sampling heights, including Taiyangshan, Nanning, Daliang, Zhengzhou, Panyu and Chengdu (Fig. 2a). At these locations, the aerosol tends to be well mixed (Zhang et al., 2008), containing dust particles with a relatively smaller size that have survived long-range transport. Another important factor correlating with high values of dust optical absorption is relative humidity (RH). The relationship with RH here is based on a visual association. Compare data from Lhasa–TYS—Zhengzhou–Panyu as an example (Fig. 5). Lhasa, a regionally representative station (Zhang et al., 2008), similar or

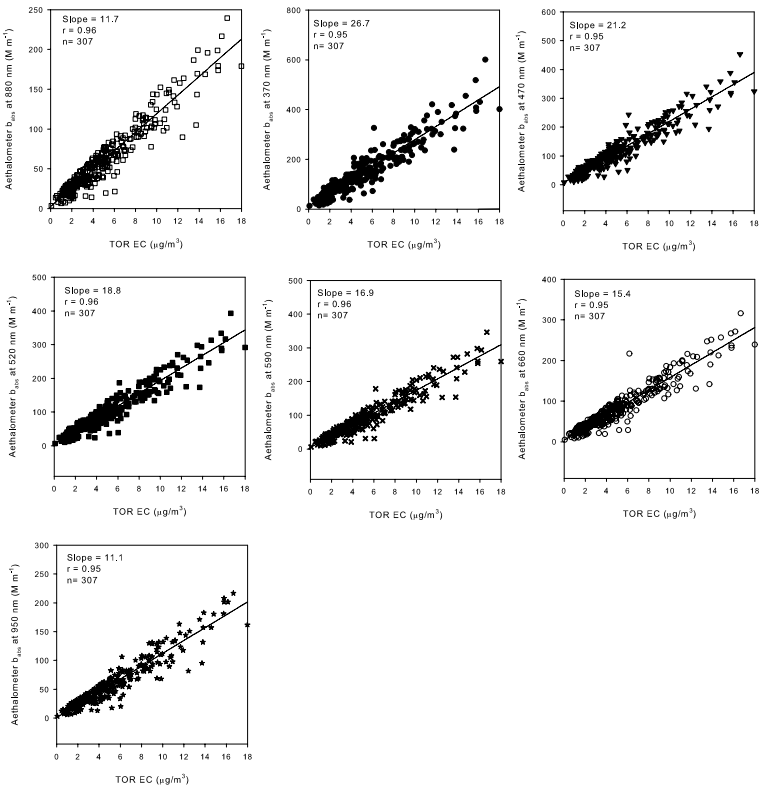

Fig. 4. Correlations between the daily averaged aerosol light absorptions at the seven Aethalometer wavelengths, and 24-h TOR EC concentrations for samples collected from CAWNET stations during 2006, in periods of little or no dust loadings.

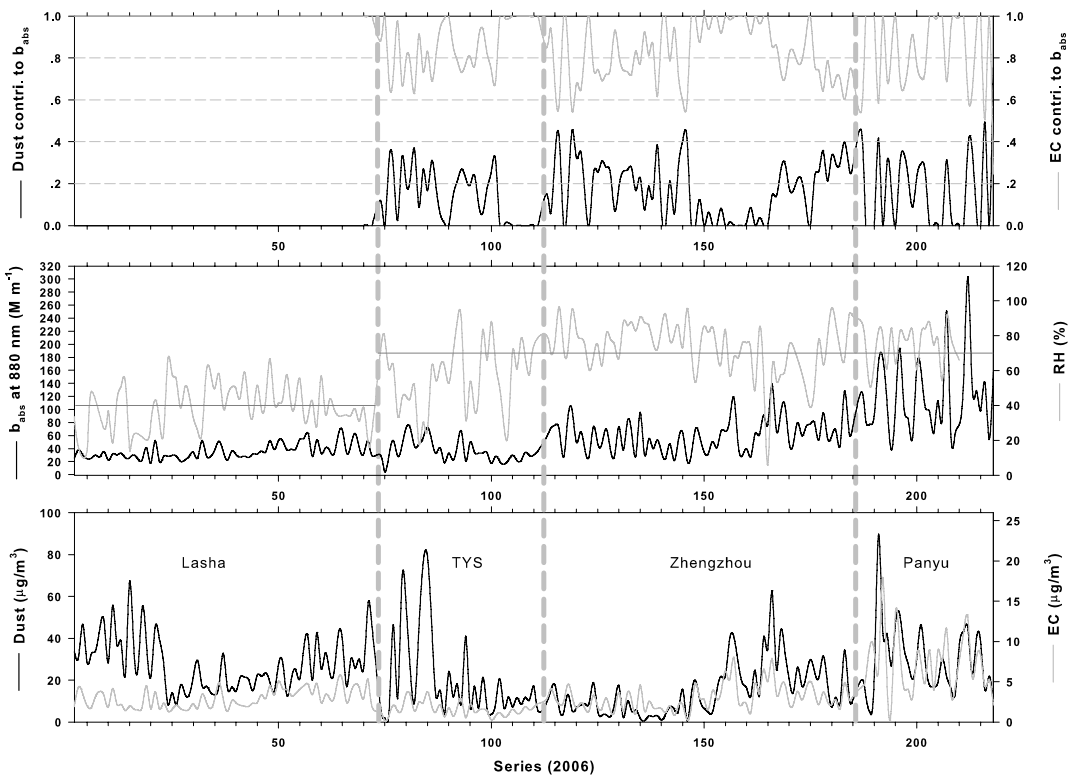

Fig. 5. For data from Lasha, TYS, Zhengzhou and Panyu as examples, the diagram shows the series of concentration of dust and EC, aerosol light absorption (b_{abs}) at 880 nm and RH and the relative contributions of EC and dust to aerosol-light absorptions.

even higher dust mass loadings in some periods and correlation between dust and EC were observed. However, the contribution of dust to optical absorption at Lhasa was much smaller than that at comparing stations, such as TYS, Zhengzhou and Panyu (Fig. 5). The primary differences are the higher relative humidity (RH) and concentrations of other aerosol species observed at TYS, Zhengzhou and Panyu. This suggests that the increased RH leads to an increased light absorption by dust. By analysing GOME and GMS satellite data, Costa et al. (2006) suggested that dust particles from Asia are mixed with pollutants such as sulphate, nitrate and black carbon, during long-range transport from the source region (Costa, et al., 2006), leading to lower scattering efficiency and increased absorption. Mineral dust particles may acquire coatings of sulphate either through heterogeneous uptake of gaseous SO_2 and its subsequent oxidation or through coagulation with cloud or fog droplets. The presence of particles of mixed composition in sulphate droplets also indicates that the aggregation of particles of different origins occurred through cloud processing. The optical properties of sulphate-coated dust particles would be different and would show different behaviour with regard to RH, from the properties of non-coated particles (Kojima et al., 2006; Bauer et al., 2007). This has strong implications for cloud formation, precipitation and chemistry of the free troposphere (e.g. (Levin et al., 1996; Wurzler et al., 2000; Yin et al., 2002). Because the possible contributions to Fe can also come from industrial, construction or combustion sources, especially in urban areas, the relatively high light absorption in high RH conditions may also result from the non-dust Fe at TYS, Zhengzhou and Panyu. Further investigations are needed. Our instruments did not operate with preconditioned sample air, and we therefore need further evaluation to study the effect of RH on collected aerosol material (or filter substrate), in terms of altering the scattering properties of the collected aerosol–filter combination.

We also observed some 'dust storm' periods in which the relationship between EC and dust concentrations were disrupted during periods of high dust absorption, for example, at Xian and Zhengzhou during a dust storm when the dust concentrations rose to more than 200 $\mu g\,m^{-3}$ from the regular level of $<100\ \mu g\,m^{-3}$ (Fig. 2b). This suggests that there may be a considerable contribution to aerosol absorption by Asian dust storm events. There have also been studies (e.g. Claquin et al., 1998; Claquin et al., 1999; Sokolik and Toon, 1999) that emphasize that the mixing of hematite with quartz or clay in dust particles has a strong impact on the resulting optical absorption properties. There may therefore be a dependence of optical absorption on mineralogical composition.

4. Summary

During 2006, the Centre for Atmosphere Watch and Services of CMA operated Aethalometers side-by-side with 24-h quartz-fibre filter samplers, at 14 sites at various locations in China.

Table 2. Calibration factors for the Aethalometer in terms of the 'σ_{BC}-Magee' (new manufacturer's values) and 'σ_{abs}-CAWNET'

Channel	λ	σ_{BC}(Magee)	σ_{abs}(CAWNET)
UV	370 nm	26.7	31
Blue	470 nm	21.2	24.8
Green	520 nm	18.8	22
Yellow	590 nm	16.9	20.1
Red	660 nm	15.4	18.2
IR-1	880 nm	11.7	14
IR-2	950 nm	11.1	13

These filter samples were analysed by the TOR method for EC content according to the generally accepted protocol. The TOR EC results tracked the Aethalometer data very well ($r \simeq 0.86$) at all stations for all seven wavelengths, but with a proportionality constant σ_{abs}(CAWNET) of 14 $m^2\ g^{-1}$ (at $\lambda = 880$ nm) that was higher than the value of 12.6 $m^2\ g^{-1}$ reported by the 'Harvard Six Cities' study.

One interpretation is that in these Chinese data, there is a significant contribution of dust to optical absorption at some (but not all) locations, which was absent in the Harvard study in the United States. Our data show that although EC is found to be the principal light-absorbing aerosol component over China, the contribution of dust to aerosol optical absorption is around 9%, averaged over the entire country, or as much as 20% at locations that are regularly impacted by dust. During periods of high optical absorption by dust, strong correlations are observed between concentrations of dust and EC. This suggests that the aerosol composition during these periods is approximately constant and regionally dispersed. We also observe that higher values of relative humidity are linked to higher optical absorption by dust, suggesting, in turn, that the dust may have a chemical composition that makes it hygroscopic.

The data also allow for a reconciliation between EC (based on thermochemical analysis) and BC (based on optical attenuation). We may derive an empirical calibration factors for the Aethalometer in terms of the 'σ_{BC}-Magee' (new manufacturer's values, see Section 3.4) and 'σ_{abs}-CAWNET' (see Sections 3.3 and 3.4) and use inverse-wavelength proportionality. The σ_{BC} is derived from aerosol light absorption data during periods of zero contribution from dust and comparing it with the corresponding 24-h TOR EC. The results for the correlation between EC and attenuation give cross-section values in Table 2:

The majority of light absorption due to ambient aerosols over many parts of China are attributable to black (or elemental) carbon. On the basis of the relationship between b_{abs} and TOR EC measured from all CAWNET stations, one can use the estimated σ_{abs}(CAWNET; in Fig. 2) to approximately estimate the BC through Aethalometer monitoring data if one doesn't have dust data to separate the dust contribuitons, although dust contribution and uncertainties still exist. The dust mass

absorption coefficient is estimated to be 1.3 m^2 g^{-1}, independent of wavelength. Optical absorption by dust is also influenced by relative humidity, requiring further investigations.

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