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Black carbon aerosols in urban central China

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ABSTRACT

The first ever (to our knowledge), year-round measurements of Black Carbon (BC) aerosols in Hefei, an urban site of central China, from June 2012 to May 2013 are performed. The aim of this paper is to evaluate the black carbon in Hefei in terms of seasonal, monthly and diurnal variations, including their source identification. The annual mean BC mass concentration M_{BC} is found to be 3.5 ± 2.5 μg m^{-3} in Hefei, while the aerosol optical depth shows a yearly average value of ~0.6. The seasonality of M_{BC} depicts minimum values in the summer, moderate levels in the spring and fall, and maximum in the winter. The monthly average values of M_{BC} vary threefold, ranging from the lowest average value of 2.0 ± 1.0 μg m^{-3} in July to the highest 6.0 ± 2.6 μg m^{-3} during January. Diurnal variations exhibit two BC peaks, corresponding to the morning and evening rush hours. Higher median BC concentrations are observed during haze episodes compared with non-haze periods, although low M_{BC} is sometimes observed for high visibility, which is probably indicative of the aerosol scattering dominating diminished visibility. Based on trajectory analyses, the haze BC pollutions are mostly classified into three types from local areas, long-range transport from the Yangtze Delta, and transport from the North China Plain. The median M_{BC} values for haze groups attributed to biomass burning from MODIS wildfire maps are higher than related groups that are not, which is indicative of the significant enhancement of BC aerosols due to agricultural biomass burning. The study suggests that aerosol absorption contributes more to the observed haze episodes in fall compared to other seasons.

1. Introduction

Atmospheric aerosols are the focus of increasing attention, due to their significant involvement in atmospheric processes, especially in the solar radiative balance of the Earth [1–12]. The radiative forcing uncertainty of aerosols, in particular anthropogenic aerosols, is a major obstacle to the accurate prediction of future climate changes [13–15]. Black Carbon (BC) aerosols, mostly produced by anthropogenic activity, are chemically inert, are generally in the submicron size regime, and have a long atmospheric lifetime. As such, BC may be utilized as tracers for the human impact on the atmospheric environment, and the long-range transport of polluted air masses from distinct source regions [16,17].

In urban areas, BC is the dominant aerosol species absorbing radiation in the visible and infrared spectrum [18–20].

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The absorption by BC particles, leading to atmospheric warming [21], can greatly counteract the direct radiative cooling effect of some scattering aerosols [22]. The Intergovernmental Panel on Climate Change [13] recognizes that BC contributed approximately $+0.5\ W/m^2$ to radiative forcing, which is the second most significant contributor to global warming after CO_2. A recent study even reports that BC is responsible for a global heating of $+0.9\ W/m^2$ [23]. Furthermore, BC can have indirect effects on climate by altering cloud properties on regional and global scales [24,25]. The associated brown clouds have been observed from satellites [26,27], in wide polluted tropospheric layers characterized by an anthropogenic aerosol optical depth (AOD) higher than 0.3 and an absorbing AOD more than 0.03 [28]. The BC particulates heat the air, modifying atmospheric stability and affecting large-scale circulation, thereby playing an important role in monsoon rainfall variations, and in the hydrological cycle [23,29]. The BC not only impacts the energy budget of the atmosphere, but deposits on snow surfaces, absorbing light, thus decreasing the albedo of the snow and altering the energy budget of snow surfaces [30,31]. Mikhailov et al. [32] report that coatings of snow on BC aerosols increase their absorption of solar radiation by up to a factor of two. Additionally, BC aerosols are carcinogenic and have adverse effects on human health [33,34].

Spatial and temporal apportionments of BC are also a major concern when modeling aerosol radiative properties [35–40]. The monitoring of BC concentrations in remote regions is necessary to determine emission sources, elucidate the mechanisms of the long-range transport of anthropogenic pollutants, and validate models. Numerous field experiments exist, revealing the impacts of BC on climate, environment, and human health; such as Aerosol Characterization Experiment-Asia (ACE-Asia), Arabian Sea Monsoon Experiment (ARMEX), Integrated Campaign for Aerosol gases and Radiation Budget (ICARB), India Ocean Experiment (INDOEX) and Transport and Chemical Evolution over Pacific (TRACE-P). Black carbon aerosols over China have attracted attention due to anthropogenic emissions from industry, transport, and incomplete fossil fuel combustion, all of which are rapidly rising [41–43]. Urban BC measurements over some megacities in China are known, indicating heavy anthropogenic BC pollutions (e.g., [44–47]). Significant BC burdens even in the high Himalaya, representing the free-tropospheric altitudes, are observed [48,49]. However, real-time continuous BC measurements over central China are still limited, including BC aerosol loading in Hefei.

Here, one-year surface observations of BC characteristics in Hefei, an urban site, from June 11, 2012 to May 31, 2013 are presented. An aethalometer and visibility sensor are used to measure BC properties and atmospheric visibility. Air-mass back-trajectories and images of fire spots are utilized to distinguish the source regions for BC pollution. The relationship between BC, AOD and meteorological parameters are explored. The objective here is to determine BC properties in terms of seasonal, monthly, and diurnal variations, including haze episodes.

2. Data and methodology

Our field experiments are done in an urban site, Hefei, which is illustrated in Fig. 1a. Hefei is an inland city in central China with mountains to the west and south, the Yangtze Delta (YD) to the east, and the North China Plain (NCP) to the north. The background image in Fig. 1a presents the regional distribution of yearly mean AOD obtained from Giovanni maps from the Moderate resolution imaging spectroradiometry (MODIS) satellite [50] from June 2012 to May 2013. In Hefei, a yearly average AOD value of about 0.6 is seen. The mountainous areas to the south and west generally have the values of AOD less

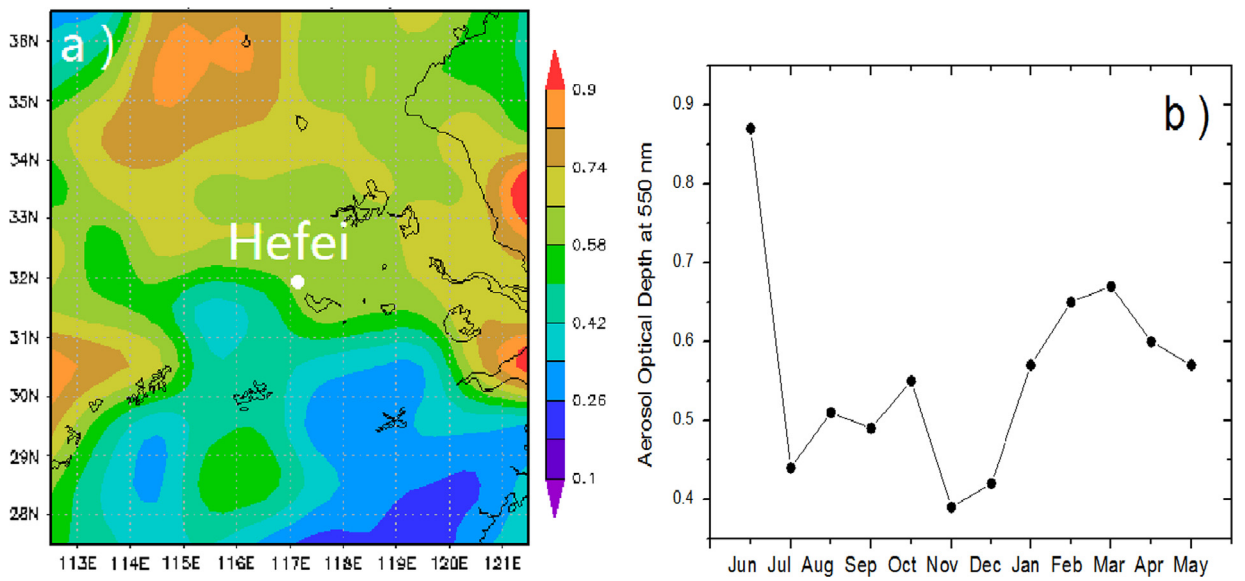

Fig. 1. Aerosol optical depth (AOD) map (a) and monthly mean AOD at 550 nm (b) of area-averaged time series over mid-eastern China (region: 112–122°E, 27–37°N) derived from MODIS-Terra data from June 2012 to May 2013. The white solid circle denotes the sampling site of Hefei.