Science of the Total Environment xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Insights into extinction evolution during extreme low visibility events: Case study of Shanghai, China

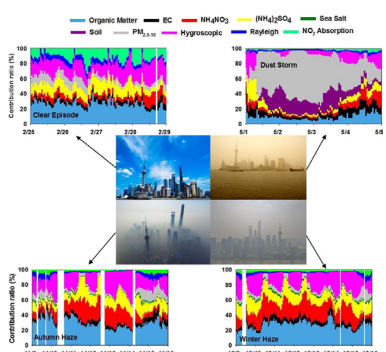
Zhen Cheng [a,b], Shuxiao Wang [b,c,*], Liping Qiao [d,e], Hongli Wang [d,e,**], Min Zhou [d,e], Xiao Fu [b], Shengrong Lou [d,e], Lina Luo [a], Jingkun Jiang [b,c], Changhong Chen [d,e], Xiaoliang Wang [f], Jiming Hao [b,c]

[a] School of Environmental Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
[b] State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China
[c] State Environmental Protection Key Laboratory of Sources and Control of Air Pollution Complex, Beijing 100084, China
[d] Shanghai Academy of Environmental Sciences, Shanghai 200233, China
[e] State Environmental Protection Key Laboratory of the Cause and Prevention of Urban Air Pollution Complex, Shanghai 200233, China
[f] Division of Atmospheric Sciences, Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512, USA

HIGHLIGHTS

- Hourly-resolution apportionment of ambient extinction coefficient was conducted.
- $PM_{2.5}$ soil and coarse particles dominated extinction coefficient during dust storm.
- RH caused the differences of contributors during autumn and winter events.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 July 2017
Accepted 19 August 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Haze
Extinction coefficient
IMPROVE algorithm
Low visibility
Shanghai megacity

ABSTRACT

Apportionment of ambient extinction coefficient is essential for quantifying the causes of visibility degradation. Previous studies focused on either seasonal or episode-average extinction coefficients. The extinction evolution during different types of low visibility events was still unclear and seldom investigated. In this study, hourly-resolution apportionment of ambient extinction coefficient, including dry extinction coefficient and hygroscopic portion, during three low visibility events (i.e., dust storm, autumn and winter haze) and one clear episode was retrieved through online measurement in Shanghai, China. $PM_{2.5}$ soil and coarse particles contributed 90% of PM_{10} mass and 62% of total extinction coefficient throughout the dust storm event. Secondary inorganic aerosol and organic matter dominated the autumn and winter haze events, accounting for 52% and 31% of $PM_{2.5}$ mass, 35% and 27% of extinction coefficient, respectively. Hygroscopic enhancement by inorganic particles contributed another 22–27% of extinction coefficient during the two haze events. However, higher relative humidity elevated the extinction percentage of inorganic aerosol and hygroscopic enhancement during the autumn haze, and the percentage of organic matter decreased correspondingly. In contrast, the extinction of each contributor increased proportionally and the percentages could keep at a stable level during the winter haze. Furthermore, the mass extinction efficiency of major $PM_{2.5}$ chemical components was found to increase with the accumulation of mass loading. These findings indicated the importance of reducing the mass level of organic matter and secondary inorganic aerosol during the

* Correspondence to: S. Wang, State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China.
** Correspondence to: H. Wang, Shanghai Academy of Environmental Sciences, Shanghai 200233, China.
E-mail addresses: shxwang@tsinghua.edu.cn (S. Wang), wanghl@saes.sh.cn (H. Wang).

https://doi.org/10.1016/j.scitotenv.2017.08.202

Please cite this article as: Cheng, Z., et al., Insights into extinction evolution during extreme low visibility events: Case study of Shanghai, China, Sci Total Environ (2017), https://doi.org/10.1016/j.scitotenv.2017.08.202

autumn or winter haze events. The control of precursors of sulfur and nitrogen oxides seemed more effective for visibility improvement during the autumn events with higher relative humidity.

1. Introduction

Ambient fine particulate matter ($PM_{2.5}$) causes horizontal visibility degradation and vertical change of radiative balance through its light extinction effect (Charlson et al., 1992; Watson, 2002). Severe problems of air pollution and radiative forcing will be deduced when $PM_{2.5}$ concentration exceed the threshold of ambient capacity (Bates et al., 2006; Pui et al., 2014). Various $PM_{2.5}$ chemical components are verified to have different levels of extinction efficiencies (Hand and Malm, 2007; Pitchford et al., 2007). Tracking the extinction apportionment from major $PM_{2.5}$ components will help to quantify the causes of visibility degradation and estimate aerosol radiative forcing accurately, which will in turn help the policy makers design effective strategies to improve visibility and address climate change.

The frequent and severe haze pollution in urban China has drawn global attentions as the aerosol concentration and extinction coefficient could be several times as that of clear episodes (Guo et al., 2014; Huang et al., 2014; Li and Zhang, 2014; Tian et al., 2016). Previous studies on the apportionment of extinction coefficient in urban China have been reported intensively. Annual or seasonal average of extinction apportionment were investigated through offline-filter samples at the city of Xi'an, Tianjin, Shanghai, Nanjing and Guangzhou (Cao et al., 2012; Han et al., 2012; Lin et al., 2014; Shen et al., 2014; Tao et al., 2014). As to the studies based on online measurement of super site, Han et al. (2015) compared the extinction contribution by aerosol species between haze days and non-haze days at Shanghai. Tian et al. (2016) also presented the apportionment differences between the days of 20% best visibility and 20% worst visibility at Suzhou. Wang et al. (2015) investigated the extinction contribution of each aerosol species during the nonheating and heating periods by an Aerosol Chemical Speciation Monitor at Beijing. However, seasonal or episode-average results were not sufficient for the evolution process of these extreme low visibility events. Dominant contributors and formation mechanisms might vary with different types of low visibility events. Insights into extinction evolution during different typical low visibility events were seldom reported. Furthermore, only dry ambient extinction coefficient was concerned in the above studies, which only accounting for ~46% of total extinction coefficient (Cheng et al., 2017).

In this study, three typical low visibility events, i.e., dust storm, autumn haze and winter haze, as well as one clear episode were identified and compared based on a one-year online observation campaign in Shanghai, the largest megacity of China. In-situ measurements of aerosol chemical components, ambient visibility and meteorological factors were conducted firstly. Hourly-resolution apportionments of ambient extinction coefficient, including dry extinction coefficient and hygroscopic portion, were retrieved for the above four events then. The distinct characteristics of extinction apportionment findings in this study are expected to enrich the knowledge of evolution towards visibility impairment, as well as efficient strategies towards visibility improvement for these extreme events.

2. Methodology

2.1. Observation site and events time

The observation site was located at the top of main building in Shanghai Academy of Environmental Sciences (121.43°E, 31.17°N), near the inner ring of Shanghai megacity. Shanghai is the largest megacity of China with a permanent population of more than 24 million in the year of 2014 (http://www.stats-sh.gov.cn). It lies in eastern of China as the core city of the Yangtze River Delta city cluster. Its total energy consumption reached 114 million tons equivalent of coal, accompanying an annual $PM_{2.5}$ concentration of 52 μg/m^3 in the year of 2014 (http://www.stats-sh.gov.cn). As shown in Fig. 1, the observation site was in a typical residential and commercial area. There were no major industrial or fugitive dust sources nearby. The site was 130 m north to Caobao Road, and 650 m west to Humin Elevated Road. The sampling height was 15 m above ground level and 23 m above mean sea level.

Shanghai is dominated by the north subtropical monsoon climate, and the seasonal distribution of pollution episodes is significant. Haze events usually occur in the autumn or winter season due to the more stable meteorological dispersion conditions than other seasons (Fu et al., 2016; Hua et al., 2015; Zhou et al., 2012, 2016a, 2016b). In addition, dust storms transported from the northwest China can affect Shanghai during spring season (Fu et al., 2010; Fu et al., 2014; Li et al., 2014). Hence a one-year online observation campaign was conducted from April 1, 2011 to March 30, 2012. Three low visibility events were identified and selected for this study, including a dust storm event in spring (5/1 0:00–5/5 0:00, 2011), an autumn haze event (11/9 0:00–11/16 0:00, 2011) and a winter haze event (12/9 0:00–12/16 0:00, 2011). Meanwhile, a clear episode (2/25 16:00–2/29 16:00, 2012) with high level of visibility was selected for the comparison.

2.2. Online measurement instruments and models

Table 1 summarized the ambient datasets measured or modeled in this study, including PM mass concentration and major chemical components, NO_2 mass concentration and meteorological factors. In detail, $PM_{2.5}$ and PM_{10} mass concentrations were measured by β-ray attenuation with 5-minute resolution. $PM_{2.5}$ water-soluble ions including sulfate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+) and chloride (Cl^-) were measured using a Monitor for Aerosols and Gases in Ambient Air (MARGA) with 1-hour resolution. $PM_{2.5}$ organic carbon (OC) and elemental carbon (EC) were measured by a Semi-Continuous OC-EC Field Analyzer with 30-minute resolution. Ambient relative humidity (RH) and wind speed were measured by a Met One Station with 5-minute resolution. All the above online measurement results were then averaged to hourly resolution.

Hourly concentrations of crustal elements of Al, Si, Ca, Fe and Ti were retrieved from the simulation results at the period of the four events with the model of U.S. EPA Community Modeling and Analysis System (CMAQ). Details of the CMAQ model configuration and input datasets such as emission inventory and meteorological data were described in the previous studies of our group (Fu et al., 2014, 2016). Meanwhile, mixing layer height and precipitation data with the resolution of 3-h were obtained from the Global Data Assimilation System (GDAS) model (Rolph, 2013). The records of mixing layer height corresponded to the instantaneous value of indicated time, while precipitation record was the cumulative results for 3 h.

Table 1 Instruments and their time resolution for real-time measurements used in the field campaign.

2.3. Data processing

Hourly $PM_{2.5}$ mass was reconstructed by eight sets of aerosol species according to the US IMPROVE algorithms (Watson, 2002; Pitchford et al., 2007). Concentrations of ammonium sulfate, ammonium nitrate and sea salt were estimated by multiplying MARGA reported sulfate, nitrate and chloride concentrations by factors of 1.375, 1.29, and 1.8,

Please cite this article as: Cheng, Z., et al., Insights into extinction evolution during extreme low visibility events: Case study of Shanghai, China, Sci Total Environ (2017), https://doi.org/10.1016/j.scitotenv.2017.08.202