1 *Supplement of*

2 **Measurement report: The importance of biomass burning in**
3 **light extinction and direct radiative effect of urban aerosol**
4 **during the COVID-19 lockdown in China**

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Text S1. Absorption Ångström exponent method

In this study, aerosol light absorption coefficient (b_{abs}) at wavelengths of $\lambda = 370$ nm, 470 nm, 520 nm, 590 nm, 660 nm, and 880 nm were measured by a newly developed Aethalometer (model AE33, Magee Scientific, Berkeley, CA, USA). The Absorption Ångström exponent (AAE) describes the wavelength dependence of aerosol light absorption, and can be calculated according to power law fitting of b_{abs} from wavelengths of 370 nm to 880 nm (Moosmüller et al., 2011):

$$b_{\text{abs}}(\lambda) \sim \lambda^{-\text{AAE}} \quad (1)$$

Through the AAE method (Lack and Langridge, 2013), the mass absorption efficiency (MAE) of black carbon (BC) at 520 nm can be obtained as follows:

$$b_{\text{abs}}(520 \text{ nm}) = b_{\text{abs-BC}}(520 \text{ nm}) + b_{\text{abs-BrC}}(520 \text{ nm}) \quad (2)$$

$$b_{\text{abs-BC}}(520 \text{ nm}) = b_{\text{abs-BC}}(880 \text{ nm}) \times \left(\frac{520}{880}\right)^{-\text{AAE}_{\text{BC}}} \quad (3)$$

$$\text{MAE}_{\text{BC}}(520 \text{ nm}) = \frac{b_{\text{abs-BC}}(520 \text{ nm})}{[\text{BC}]} \quad (4)$$

where $b_{\text{abs-BC}}$ and $b_{\text{abs-BrC}}$ in Mm^{-1} are the light absorption coefficients caused by BC and brown carbon (BrC), respectively; AAE_{BC} is the AAE caused by the BC particle, which can vary from 0.8 to 1.4 due to core size, coating materials, and mixing state (Lack and Cappa, 2010; Lack and Langridge, 2013). The linear relationship between the AAEs and the mass concentration ratios of organic aerosol (OA) to BC is investigated to find the realistic AAE_{BC} during the normal and lockdown periods (Figure S13) (Yuan et al., 2016); and $[\text{BC}]$ is the mass concentration of BC in $\mu\text{g m}^{-3}$.

44 **Text S2.** The uncertainty of the element

45 Considering the element concentration measured by the Xact 625 ambient metals monitor with 1 hour
46 sampling interval, the uncertainty of the element (u_e) inputting into the receptor model was estimated as
47 follows (Norris et al., 2014):

48
$$u_e = \sqrt{(c_e \times 10\%)^2 + (0.5 \times \text{MDL})^2}, \text{ for } c_e > \text{MDL} \quad (5)$$

49
$$u_e = \frac{5}{6} \times \text{MDL}, \text{ for } c_e \leq \text{MDL} \quad (6)$$

50 where c_e is the concentration of the element; 10% is the default analytical relative error (Rai et al., 2020);
51 MDL represents method detection limit for the element.

Text S3. Diagnostics of HERM solutions

In this study, factor number from 2 to 8 were selected to run in the HERM software. Each factor solution was performed with completely unconstrained profiles at twenty different seeds to explore the possible sources. Detailed information on how the most interpretable factors were selected is presented below.

As shown in Figure S2, the values of $Q/Q_{\text{exp}} (> 1)$ decreased as the factor numbers increased. The large Q/Q_{exp} values in 2- (21.10 ± 0.03) and 3-factor (12.29 ± 0.01) solutions indicated too few factors were resolved. In the 4-factor solution (Figure S3), Factor 2 identified as biomass burning was characterized by high explained variations (EV) values of POA (56%), LO-OOA (54%), BC (43%), Cl (55%). Factor 3 was regarded as fugitive dust due to significant EV values of Si (100%), Ca (68%), and Fe (35%). For the Factor 4 assigned to secondary source, EV values of NO_3^- , SO_4^{2-} , NH_4^+ , and MO-OOA were larger than 30%. It is noted that Factor 1 was associated with traffic-like source because b_{ext} from this source showed a moderate correlation with NO_x , a tracer of fresh motor vehicle exhaust emission ($R^2 = 0.58$). However, the high EV values of some specific elements (e.g., As (44%) and Se (31%)) in this factor indicated the possible mixture of other fossil fuel source (e.g., coal combustion). When five factors were resolved, except traffic-like source (Factor 1), biomass burning (Factor 2), and fugitive dust (Factor 3), secondary source was split into nitrate plus SOA (Factor 4) and sulfate plus SOA (Factor 5) sources (Figure S4). The increase to 6-factor solution (Figure S5) showed well separation of traffic-related emission (Factor 1) and coal combustion (Factor 3). The stronger correlation between b_{ext} from traffic-related emission and NO_x ($R^2 = 0.72$) was found compared to traffic-like factors resolved in 4- and 5-factor solutions ($R^2 = 0.58$). As shown in Figure S6 and S7, further investigations of unconstrained profile solutions with 7–8 factors resulted in factor split. The extra split factors possibly came from biomass burning and coal combustion, mainly due to high EV values of K (26%–33%), or As (21%). Despite b_{ext} from coal combustion factors in 7- and 8- factor solutions showed the stronger correlation with As ($R^2 = 0.63$ – 0.68), Se ($R^2 = 0.79$ – 0.86), and Pb ($R^2 = 0.60$ – 0.67), the profiles identified coal combustion had no POA contribution. Meanwhile, the values of POA in fugitive dust profiles identified in 7- and 8- factor solutions were higher than 1 (the reference standard of $\text{PM}_{2.5}$). It is indicated that these profiles didn't match the real world.

Therefore, for our analyses of all factor solutions described above, six factors were most interpretable, including traffic-related emission, biomass burning, coal combustion, fugitive dust, nitrate plus SOA source, and sulfate plus SOA source.

Figure S1. The location of sampling site in Xi'an, China.

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85 **Figure S2.** Values of Q/Q_{exp} for the unconstrained profile solutions with 2–8 factors at twenty different
86 seeds.

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93 **Figure S4.** (a) Profiles and (b) time series plots of the resolved source factors in the 5-factor solution.
 94 The columns in each factor is the profile that displaying relative relation of absolute values of variables.
 95 The red dot represents the explained variation of species for different factors. The corresponding time
 96 trends of chemical tracers also are shown.

Figure S5. (a) Profiles and (b) time series plots of the resolved source factors in the 6-factor solution. The columns in each factor is the profile that displaying relative relation of absolute values of variables. The red dot represents the explained variation of species for different factors. The corresponding time trends of chemical tracers also are shown.

Figure S6. (a) Profiles and (b) time series plots of the resolved source factors in the 7-factor solution. The columns in each factor is the profile that displaying relative relation of absolute values of variables. The red dot represents the explained variation of species for different factors. The corresponding time trends of chemical tracers also are shown.

Figure S7. (a) Profiles and (b) time series plots of the resolved source factors in the 8-factor solution. The columns in each factor is the profile that displaying relative relation of absolute values of variables. The red dot represents the explained variation of species for different factors. The corresponding time trends of chemical tracers also are shown.

Figure S8. Hourly variations of light scattering (b_{scat}), absorption (b_{abs}), and extinction (b_{ext}) coefficients, single scattering albedo (SSA), and $\text{PM}_{2.5}$ mass concentrations in Xi'an during the normal (1 to 23 January) and COVID-19 lockdown (27 January to 7 February) periods.

Figure S9. Variations of single scattering albedo (SSA) as a function of (a) secondary inorganic aerosol (SIA = $\text{NH}_4\text{NO}_3 + (\text{NH}_4)_2\text{SO}_4$)/PM_{2.5}, (b) secondary organic aerosol (SOA = LO-OOA + MO-OOA)/OA, and (c) LO-OOA/MO-OOA ratios during the normal and COVID-19 lockdown periods.

Figure S10. Linear relationships between the reconstructed chemical and the measured optical (a) b_{scat} , (b) b_{abs} , and (c) b_{ext} .

Figure S11. Linear relationships between $\text{PM}_{2.5}$ and PM used in reconstruction of aerosol optical coefficients. PM is the sum of NH_4NO_3 , $(\text{NH}_4)_2\text{SO}_4$, fine soil, BC, POA, LO-OOA, and MO-OOA in this study. The slope of linear regression between $\text{PM}_{2.5}$ and PM concentrations (0.79) was close to that between the measured optical b_{ext} and the reconstructed chemical b_{ext} (0.78, see Figure S10c), suggesting that chemical calculation of b_{ext} was a reasonable estimation of aerosol optical coefficients by using chemical components data.

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132 **Figure S12.** Linear relationships between the modeled source and the measured optical (a) b_{scat} , (b) b_{abs} ,
 133 and (c) b_{ext} . The modeled source b_{ext} was strongly correlated linearly with the measured optical b_{ext} (R^2
 134 $= 1.00$, slope $= 1.00$), indicating that the six identified sources can adequately account for the variability
 135 in aerosol b_{ext} .

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137 **Figure S13.** The linear relationships between the AAEs and the mass concentration ratios of organic
 138 aerosol (OA) to BC (OA/BC) during the normal (a) and lockdown (b) periods. The intercept of the linear
 139 regression represents the realistic AAE_{BC} .

Table S1. Summary of chemical and meteorological measurements of in Xi'an before and during the COVID-19 lockdown period.

Parameters	Sampling interval	Instruments and online source	Operation and calibration
Chemical variables			
NO ₃ ⁻ , SO ₄ ²⁻ , NH ₄ ⁺ , Cl ⁻ , and OA	15-min	Quadrupole aerosol chemical speciation monitor (Q-ACSM, Aerodyne Research Inc., Billerica, Massachusetts, USA)	The relative ionization efficiencies (RIEs) for OA, nitrate, and chloride were set to 1.4, 1.1, and 1.3 by default, respectively. The RIE for ammonium (5.8) was determined from the ammonium nitrate aerosol calibration, while the RIE for sulfate (1.9) was estimated by fitting the measured sulfate versus predicted sulfate values. The collection efficiency was set to 0.45.
Si, K, Ca, Cr, Mn, Fe, Zn, As, Se, Ba, Hg, and Pb	1-hour	Xact 625 ambient metals monitor (Xact 625i, Cooper Environmental Services, Beaverton, OR, USA)	Daily advanced quality assurance checks were performed during 30 min after midnight to monitor shifts in the calibration.
PM _{2.5} and NO _x	5-min	The Department of Ecology and Environment of Shaanxi Province (http://sthjt.shaanxi.gov.cn , in Chinese)	
Meteorological variables*			
WS, WD, RH, T, P, and DP	1-hour	Integrated automatic weather station (MAWS201, Vaisala, Helsinki, Finland)	
PBLH	3-hour	Global Data Assimilation System (ftp://arlftp.arlhq.noaa.gov/pub/archives/gdas1)	

*WS, WD, RH, T, P, DP, and PBLH represent wind speed, wind direction, relative humidity, temperature, pressures, dew point, and planetary boundary layer height, respectively.

144 **Table S2.** Summary of output indices from the constructed b_{ext} GAM.

Intercept	6.640	
Adjusted R^2	0.569	
IOA	0.909	
Smoothed parameters*	F value	p value
$f(\text{WS})$	3.194	0.00341
$f(\text{WD})$	6.145	6.81×10^{-5}
$f(\text{RH})$	3.005	0.03216
$f(\text{T})$	2.575	0.0169
$f(\text{P})$	3.268	0.00171
$f(\text{DP})$	14.257	2.00×10^{-16}
$f(\text{PBLH})$	4.249	0.01188

145 *WS, WD, RH, T, P, DP, and PBLH represent wind speed, wind direction, relative humidity,
146 temperature, pressures, dew point, and planetary boundary layer height, respectively.

Table S3. Concurvity indices between each independent smoothed parameter in the constructed GAM.

Smoothed parameters*	$f(\text{WS})$	$f(\text{WD})$	$f(\text{RH})$	$f(\text{T})$	$f(\text{P})$	$f(\text{DP})$	$f(\text{PBLH})$
$f(\text{WS})$	1.00	0.27	0.09	0.03	0.09	0.08	0.23
$f(\text{WD})$	0.16	1.00	0.05	0.08	0.10	0.03	0.07
$f(\text{RH})$	0.08	0.10	1.00	0.04	0.03	0.36	0.33
$f(\text{T})$	0.08	0.07	0.14	1.00	0.12	0.23	0.22
$f(\text{P})$	0.09	0.23	0.07	0.05	1.00	0.07	0.09
$f(\text{DP})$	0.05	0.06	0.36	0.08	0.06	1.00	0.05
$f(\text{PBLH})$	0.13	0.07	0.32	0.06	0.05	0.08	1.00

*WS, WD, RH, T, P, DP, and PBLH represent wind speed, wind direction, relative humidity, temperature, pressures, dew point, and planetary boundary layer height, respectively.

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