Supplementary of
Chemical composition and mixing state of BC-containing particles and their implications on light absorption enhancement

Jiaxing Sun[1,2], Yele Sun[1,2,3], Conghui Xie[1,2, a], Weiqi Xu[1], Chun Chen[1,2], Zhe Wang[1], Lei Li[4,5], Xubing Du[4,5], Fugui Huang[6], Yan Li[1,2], Zhijie Li[1,2], Xiaole Pan[1], Nan Ma[7], Wanyun Xu[8], Pingqing Fu[9], and Zifa Wang[1,2,3]

[1]State Key Laboratory of Atmospheric Boundary Layer Physics and Atmospheric Chemistry, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China

[2]College of Earth and Planetary Sciences, University of Chinese Academy of Sciences, Beijing 100049, China

[3]Center for Excellence in Regional Atmospheric Environment, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China

[4]Institute of Mass Spectrometer and Atmospheric Environment, Jinan University, Guangzhou, 510632, China

[5]Guangdong Provincial Engineering Research Center for On-Line Source Apportionment System of Air Pollution, Guangzhou, 510632, China

[6]Guangzhou Hexin Analytical Instrument Company Limited, Guangzhou, 510530, China

[7]Institute for Environmental and Climate Research, Jinan University, Guangzhou 511443, China

[8]State Key Laboratory of Severe Weather & Key Laboratory for Atmospheric Chemistry, Institute of Atmospheric Composition, Chinese Academy of Meteorological Sciences, Beijing, 100081, China

[9]Institute of Surface-Earth System Science, Tianjin University, Tianjin 300072, China

[a]now at: State Key Joint Laboratory of Environmental Simulation and Pollution Control, College of Environmental Sciences and Engineering, Peking University, Beijing, 100871, China

Correspondence: Yele Sun (sunyele@mail.iap.ac.cn)

Method of estimating the direct radiative forcing

Based on E_{abs} for each factor and the contribution of that factor to $b_{abs,\ BCpure}$, we further simply estimated the direct radiative forcing (ΔF_R) caused by BC-containing particles with their mixing state at the top-of-atmosphere (TOA), suggested by pervious study (Chylek and Wong, 1995; Chen and Bond, 2010). The modified version of the equation is given as below:

$$\Delta F_{R,fi} = \int -\frac{1dS(\lambda)}{4d\lambda}\tau_{atm}^2(\lambda)(1-F_c)[(1-a_s)^2 2\beta\tau_{scat,fi}(\lambda) - 4a_s\tau_{abs,fi}(\lambda)]d\lambda$$

where S is the solar irradiance (W m^{-2}), τ_{atm} is the atmospheric transmission (unitless), F_c is the fractional cloud amount (0.6 unitless), a_s is the surface reflectance (0.19 unitless), β is the backscatter fraction (0.29 unitless) (Charlson et al., 1992; Bond and Bergstrom, 2006; Wang et al., 2019), and τ_{scat} and τ_{abs} are the aerosol scattering and absorption optical depths (unitless), respectively. Wavelength-dependent S(λ) and $\tau_{atm}(\lambda)$ are derived from the ASTM G173-03 reference spectra (Chen and Bond, 2010). τ_{scat} and τ_{abs} can be estimated as $\tau_{scat}(\lambda) = b_{sca}(\lambda) \times$ Heff and $\tau_{abs}(\lambda) = b_{abs}(\lambda)$

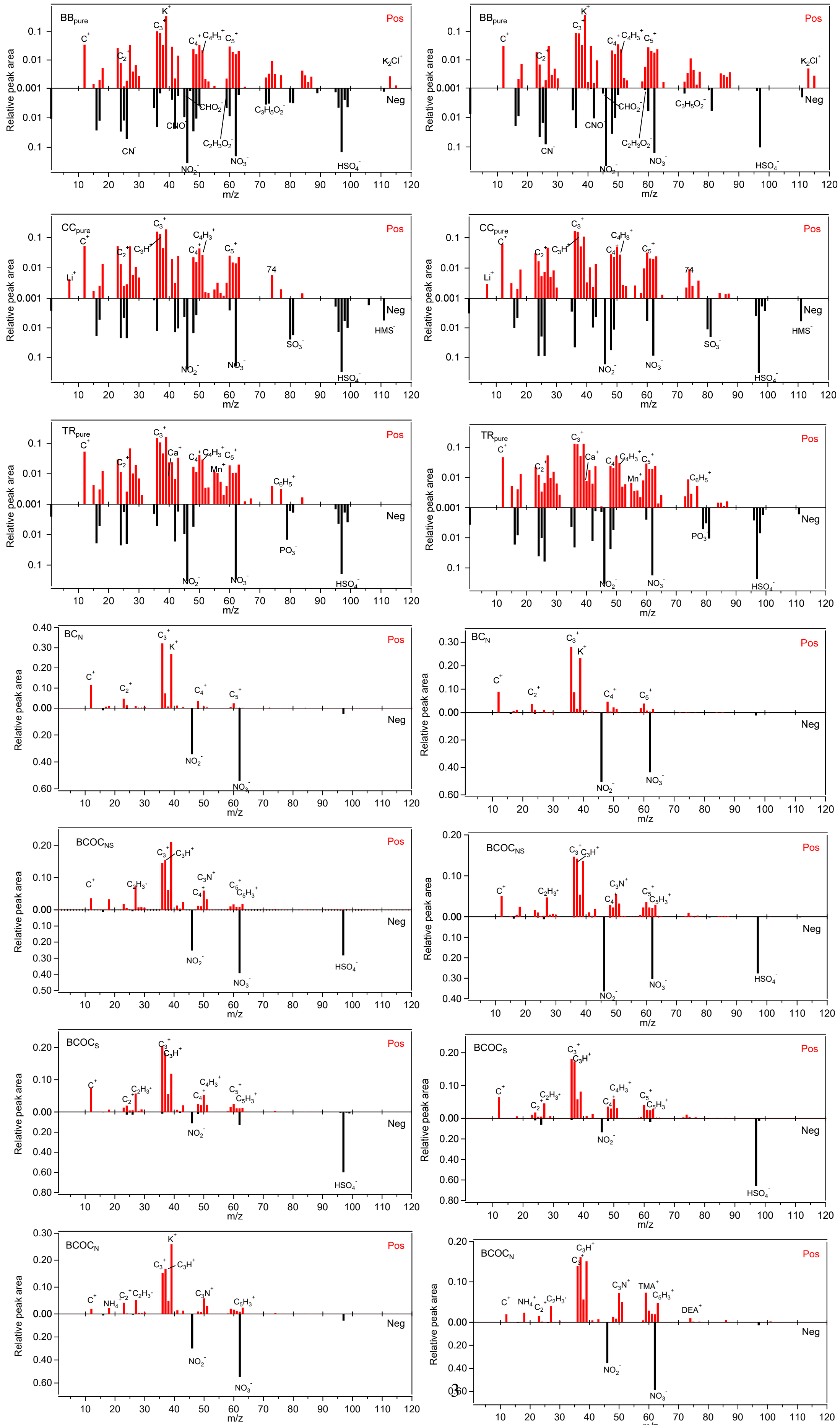
E_{abs} × Heff, respectively, where Heff is effective height (Wang et al., 2019) derived from the relationship between aerosol optical depth τ (= τ_{scat} + τ_{abs}, available from the Aerosol Robotic Network data archive) and light extinction coefficient b_{ext} (= b_{abs} + b_{sca}, derived from PAX), shown in Figure S1. And ΔF_R is the sum of all factor values of $\Delta F_{R,fi}$.

Table S1. A summary of abberviations and descrptions of BC-containing particle types and organic aerosol factors.

Description of type or species	Abbreviation
BC only from biomass burning	BB_{pure}
BC only from coal combustion	CC_{pure}
BC only from traffic emission	TR_{pure}
BC internally mixed more than one sources	MixSource
BC internally mixed with nitrate	BC_N
BC internally mixed with sulfate	BC_S
BC internally mixed with nitrate and sulfate	BC_{NS}
BC internally mixed with OC and nitrate	$BCOC_N$
BC internally mixed with OC and sulfate	$BCOC_S$
BC internally mixed with OC, nitrate, and sulfate	$BCOC_{NS}$
Biomass burning organic aerosol	BBOA
Coal combustion organic aerosol	CCOA
Fossil fuel-related organic aerosol	FFOA
Hydrocarbon-like organic aerosol	HOA
Cooking organic aerosol	COA
Oxygenated organic aerosol	OOA
Aqueous-related organic aerosol	aq-OOA
Less oxidized oxygenated organic aerosol	LO-OOA
More oxidized organic aerosol	MO-OOA

Table S2. A summary of relationship between aerosol optical depth and light extinction coefficient measured by PAX at both sites.

	Beijing	Gucheng
Effective Height (m, slope)	711	554
r	0.73	0.51


BBpure
CCpure
TRpure
BCN
BCOCNS
BCOCS
BCOCN
Pos
Neg
Relative peak area
m/z
C+
C2+
C3+
K+
C4+
C4H3+
C5+
K2Cl+
Li+
C3H+
Ca+
Mn+
C6H5+
74
C2H3+
C3N+
C5H3+
NH4+
TMA+
DEA+
CN-
CNO-
CHO2-
C2H3O2-
C3H5O2-
NO2-
NO3-
SO3-
PO3-
HMS-
HSO4-

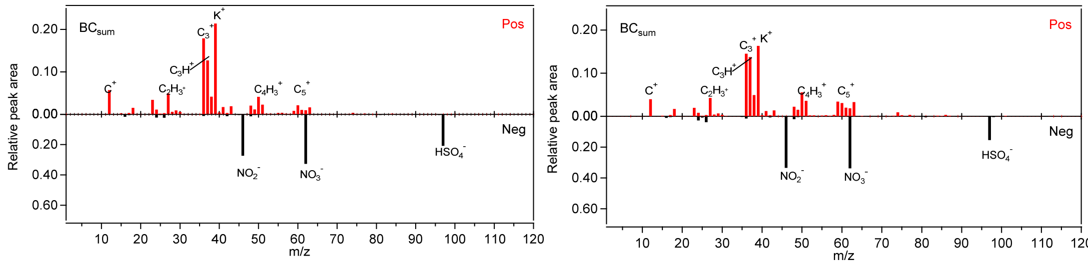


Figure S1. Average mass spectra of six types of BC-containing particles and total BC- containing particles in Beijing (left panel) and Gucheng (right panel).

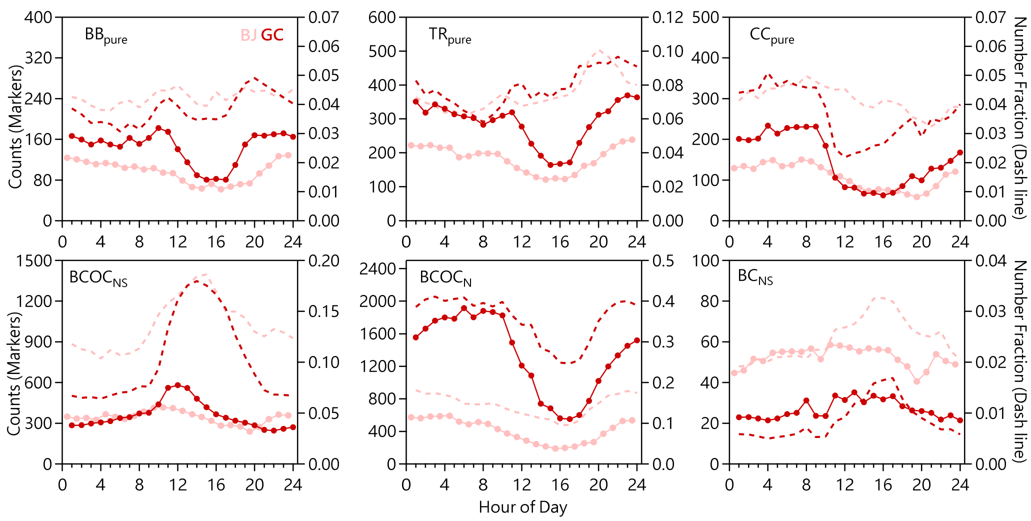


Figure S2. Diurnal variations of six types of BC-containing particles in Beijing and Gucheng.

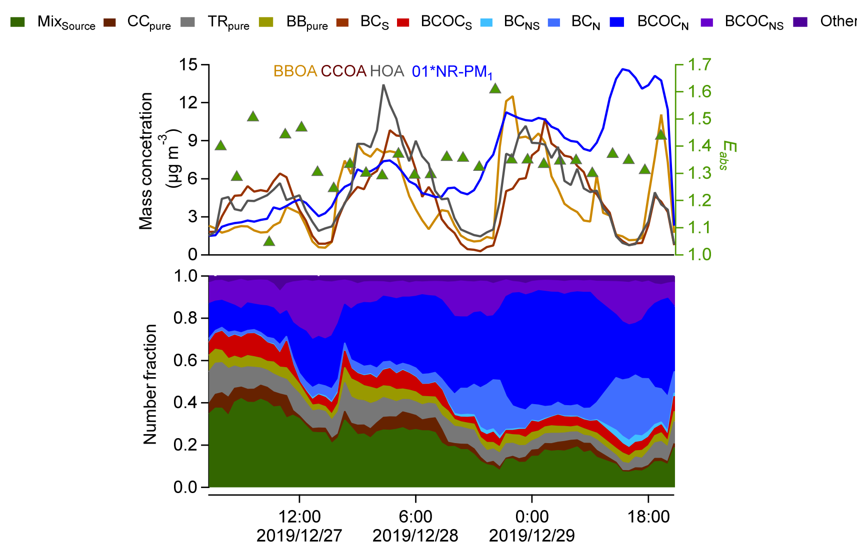


Figure S3. Temporal variations of E_{abs}, number fractions of BC-containing particle types and mass concentration of species during pollution case in GC.

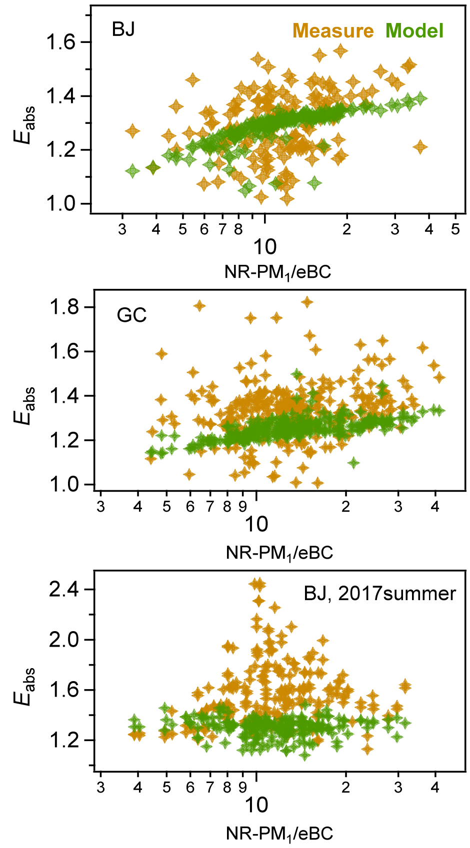


Figure S4. The comparisons between measured data and model results.

References

Bond, T. C. and Bergstrom, R. W.: Light absorption by carbonaceous particles: an investigative review, Aerosol Sci. Technol., 40, 27-67, 10.1080/02786820500421521, 2006.

Charlson, R. J., Schwartz, S. E., Hales, J. M., Cess, R. D., Coakley, J. A., Hansen, J. E., and Hofmann, D. J.: Climate forcing by anthropogenic aerosols, Science, 255, 423-430, 1992.

Chen, Y. and Bond, T. C.: Light absorption by organic carbon from wood combustion, Atmos. Chem. Phys., 10, 1773-1787, 2010.

Chylek, P. and Wong, J.: Effect of aerosols on global budget, Geophys. Res. Lett., 22, 929-931, 1995.

Wang, Q., Ye, J., Wang, Y., Zhang, T., Ran, W., Wu, Y., Tian, J., Li, L., Zhou, Y., Hang Ho, S. S., Dang, B., Zhang, Q., Zhang, R., Chen, Y., Zhu, C., and Cao, J.: Wintertime optical properties of primary and secondary brown carbon at a regional site in the North China Plain, Environ. Sci. Technol., 53, 12389-12397, 10.1021/acs.est.9b03406, 2019.