

# Modelling the Effect of Black Carbon and Sulfate Aerosol on the Regional Meteorology Factors

X Ma<sup>1</sup>, W Wen<sup>2</sup>

1 National Meteorological Center, CMA, Beijing 100081, RP China

2 Institute of Urban Meteorology, China Meteorological Administration, Beijing 100089, China

E-mail addresses: brianwenwei@163.com

**Abstract.** In this study, we focus on the effect of black carbon aerosol and sulfate aerosol on meteorology factors during heavy pollution period and non-heavy pollution period. The version of WRF/chem V3.4 was used in this work, Four Simulation scenarios are applied to simulate the effect of the effect of black carbon aerosol and sulfate aerosol on solar radiation, temperature, PBL high. The analysis results show that the effect of black carbon and sulfate aerosol cause decline on three meteorological factors in both heavy pollution and non-heavy pollution period in both January and July. The influence of two aerosols on meteorological factors are less significant than winter. During heavy pollution, black carbon aerosol cause the loss of solar radiation is 29.1W/m<sup>2</sup>; the warming effect of black carbon aerosol caused temperature to rise 0.05°C; PBL height decreased by an average of 73.1m. Sulfate aerosols cause the loss of solar radiation is 21.5W/m<sup>2</sup>; Temperature fell an average of 0.89°C; PBL height decreased by 66.6m. The change of three meteorological factors due to aerosol feedback in non-heavy pollution period in much smaller than heavy pollution period.

## 1. Introduction

China has become one of the most uncertainty areas in aerosol radiative forcing and climate change due to the severe air pollution. The effect of aerosol radiative force is different among different aerosol species. Sulfate aerosol refers to the form of solid particles suspended in the air of sulfuric acid or sulfuric acid, with cooling effect. Black carbon (BC) aerosol is the main component of soot, by solid fuels (coal, wood, dung and crop residues), biomass combustion and combustion of fossil fuels into the atmosphere, both cooling and heating effect. Global anthropogenic contributions to the concentration of aerosols (primarily sulfate, organic carbon, black carbon, nitrate and dust) together produce a cooling effect with a total (including atmosphere and surface) direct radiative forcing of -0.5 W/m<sup>2</sup> and an indirect cloud albedo forcing of -0.7 W/m<sup>2</sup>[1,2,3,4]. Simulation of the aerosol-radiation interaction and aerosol-cloud interaction of aerosol feedbacks require on-line coupled models [5].

The aerosol-radiation interaction and aerosol-cloud interaction of aerosols on the regional meteorological factor in the short-term are important in the dispersion of pollutants and in secondary organic reactions. A five day period study with Weather Research and Forecasting model with Chemistry (WRF/Chem) with the Model of Aerosol Dynamics, Reaction, Ionization, and Dissolution (MADRID) (referred to as WRF/chem-MADRID) of 2000 Texas Air Quality (TexAQS2000) found that the incoming solar radiation and near-surface temperature decreased due to aerosol-radiation interaction and aerosol-cloud interaction feedbacks, and aerosols led to excessive numbers of cloud condensation nuclei with too low saturation and reduced precipitation via these CCN [6,7].



Among the previously described studies, field experiments have deficiencies in investigating the aerosol radiation interaction and aerosol-cloud interaction of aerosols on regional meteorological factors and air quality over a large region and a long-term (years and decades) period. Although using general circulation models and climate models can focus on the regional and long-term period aerosol feedbacks, but it cannot fully reflect the short-term (hours and days) characteristic of aerosol feedbacks. On-line air quality models are designed for aerosol simulation, which include the accurate simulation of the aerosol concentration and the regional- to global-scale of the feedback between air pollutants and meteorological factors[5]. In this study, we focus on the effect of black carbon aerosol and sulfate aerosol on meteorology factors during heavy pollution period (While  $PM_{2.5}$  concentration higher than  $250\mu g/m^3$  or AQI higher than 150) and non-heavy pollution period (While  $PM_{2.5}$  concentration lower than  $250\mu g/m^3$  or AQI lower than 150). Six typical cities (Beijing, Tianjin, Shijiazhuang, Shanghai, Nanjing and Guangzhou) are selected to analysis the effect in winter and summer in 2010.

## 2. Methodology

Four Simulation scenarios are applied in this study, as shown in table 1. The BASE scenario represent the real atmosphere, both aerosol-radiation interaction and aerosol-cloud interaction processes are included. The Effect\_Non scenario does not calculate any aerosol feedback process. The BC\_Non scenario does not include the effect of BC. The  $SO_4^{2-}$ \_Non scenario does not include the effect of sulfate aerosol. The effect of BC and sulfate aerosol are calculated based on the follow method.

$$\text{Aerosol Effect} = \text{BASE} - \text{Effect\_Non}$$

$$\text{BC Effect} = (\text{BASE} - \text{Effect\_Non}) - (\text{BC\_Non} - \text{Effect\_Non})$$

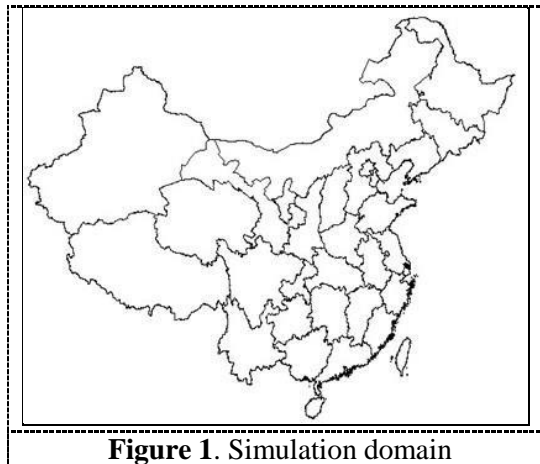
$$\text{Sulfate Effect} = (\text{BASE} - \text{Effect\_Non}) - (\text{SO}_4^{2-}\text{\_Non} - \text{Effect\_Non})$$

Table 1. Simulation scenarios set up

Scenarios	Description
BASE	Real atmosphere scenario, all aerosol feedbacks are included
Effect_Non	No aerosol feedback
BC_Non	No black carbon aerosol's effect
$SO_4^{2-}$ _Non	No sulfate aerosol's effect

## 3. Domain Setting and Model Configuration

The version of WRF/chem V3.4 was applied in this work. The study area is divided into  $92 \times 78$  horizontal grid cells with a 54-km grid spacing. The entire China continent, part of East China Sea and part of Southeast Asia are included. 27 logarithmic structure layers divide the modelling vertical zone, which range from the surface to a fixed pressure of 100mb. The National Centers for Environmental Prediction (NCEP) Final Analysis Reanalysis data are used to generate the meteorology initial conditions and boundary conditions. The INTEX-B emission inventory for Asia in 2006 was used as the anthropogenic emission input[8]. Natural emissions are calculated online based on the U.S. Geological Survey (USGS) land use data. The meteorological observed data come from the Meteorological Information Comprehensive Analysis and Process System (MICAPS).

**Figure 1.** Simulation domain

The summarised performance statistics of the meteorology factors and the  $PM_{10}$  concentration levels are listed in table 2. figure1 compares the simulated and observed hourly T2 at Beijing, Shanghai, Wuhan and Guangzhou, which are located in China in the north, south, central and east, respectively, WRF/chem well captured the variations of T2 at all sites in the four months with correlation coefficients (RC) between 0.78~0.93. Warm bias occurs in some periods, which represent  $-0.50^{\circ}\text{C}$  to  $2.16^{\circ}\text{C}$  MB and  $-1.71\%$  to  $44.08\%$  NMB of four sites in the four seasons, especially in April. The warm bias is caused by the limitations in the PBL scheme, radiation schemes[9] and the land-surface model[10].The moderate to large over-prediction occurred in the hourly WSP10 in all the sites, with a domain wide average bias are 0.77, 1.35, 0.41, 0.69 m/s in January, April, July and October, respectively. The bias is caused by two points. First, analysis nudging (FDDA) was not applied to the meteorological factors to prevent the aerosol-radiation interaction and aerosol-cloud interaction of aerosols on meteorological factors are the suppressed [11]. Second, with a horizontal resolution of 54 km, the model has difficulties in capturing the wind properly. The hourly precipitation is well captured by WRF/chem, but incorrect reports (which represent cases when rain did not occur, but the model reported it and vice versa) of precipitations are found in the north China sites, and under-predictions are found in the south China sites.

$$NMB = \frac{\sum_1^N (c_m - c_o)}{\sum_1^N c_o} \times 100\% \quad (1)$$

$$NMB = \frac{\sum_1^N |c_m - c_o|}{\sum_1^N c_o} \times 100\% \quad (2)$$

**Table 2.** Simulation error analysis of  $PM_{10}$ 

Table 2. Simulation error analysis of PM <sub>10</sub>							
January	City	NMB(%)	NME(%)	July	City	NMB(%)	NME(%)
	Beijing	-68.07	74.44		Beijing	23.28	50.71
	Shijiazhuang	-51.99	52.79		Shijiazhuang	3.62	28.91
	Tianjin	-50.52	50.52		Tianjin	14.89	32.91
	Shanghai	-0.22	35.41		Shanghai	-39.35	42.07
	Zhengzhou	-23.21	30.54		Zhengzhou	26.88	45.19
	Wuhan	-21.68	31.02		Wuhan	-39.77	51.86
	Guangzhou	-41.95	52.44		Guangzhou	-56.24	57.8
	Average	-36.8	46.7		Average	-9.5	44.2

#### 4. Results and Discussion

The result of the effect of BC and sulfate aerosol on meteorological factors is show in figure 2 and figure 3.

##### 4.1. Solar Radiation

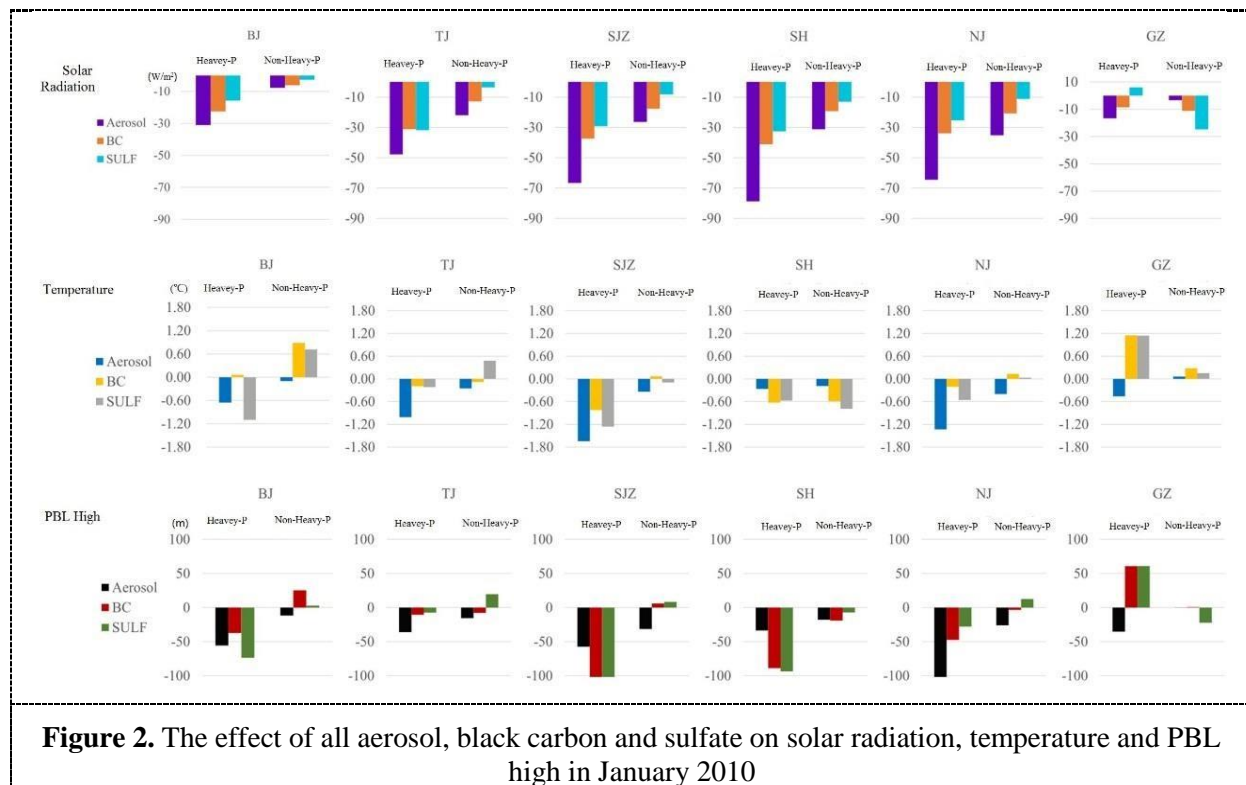
Solar radiation is decreased in six cities due to the effect of aerosol feedback in both winter and summer in 2010 in six cities, as shown in the first row in figure 2 and figure 3. The absorption of BC is stronger than sulfate's scattering on solar radiation in both winter and summer. In January 2010, black carbon aerosol decline solar radiation and the average drop of  $21.9\text{W/m}^2$ , heavy pollution period average drop is  $29.1\text{W/m}^2$ , non-heavy pollution period drop is  $14.6\text{W/m}^2$ . Sulfate aerosols cause the loss of solar radiation and the average drop is  $14.8\text{W/m}^2$ , heavy pollution period is  $21.5\text{W/m}^2$ , non-heavy pollution period drop is  $10.6\text{W/m}^2$ . In July 2010, solar radiation decrease  $12.1\text{W/m}^2$  due to the effect of aerosol. The declining contents are similar during heavy pollution period and non-heavy pollution period. Black carbon aerosol and sulfate aerosols on solar radiation effects are relatively mild, average respectively  $0.15\text{ W/m}^2$  and  $0.9\text{ W/m}^2$

##### 4.2. Temperature

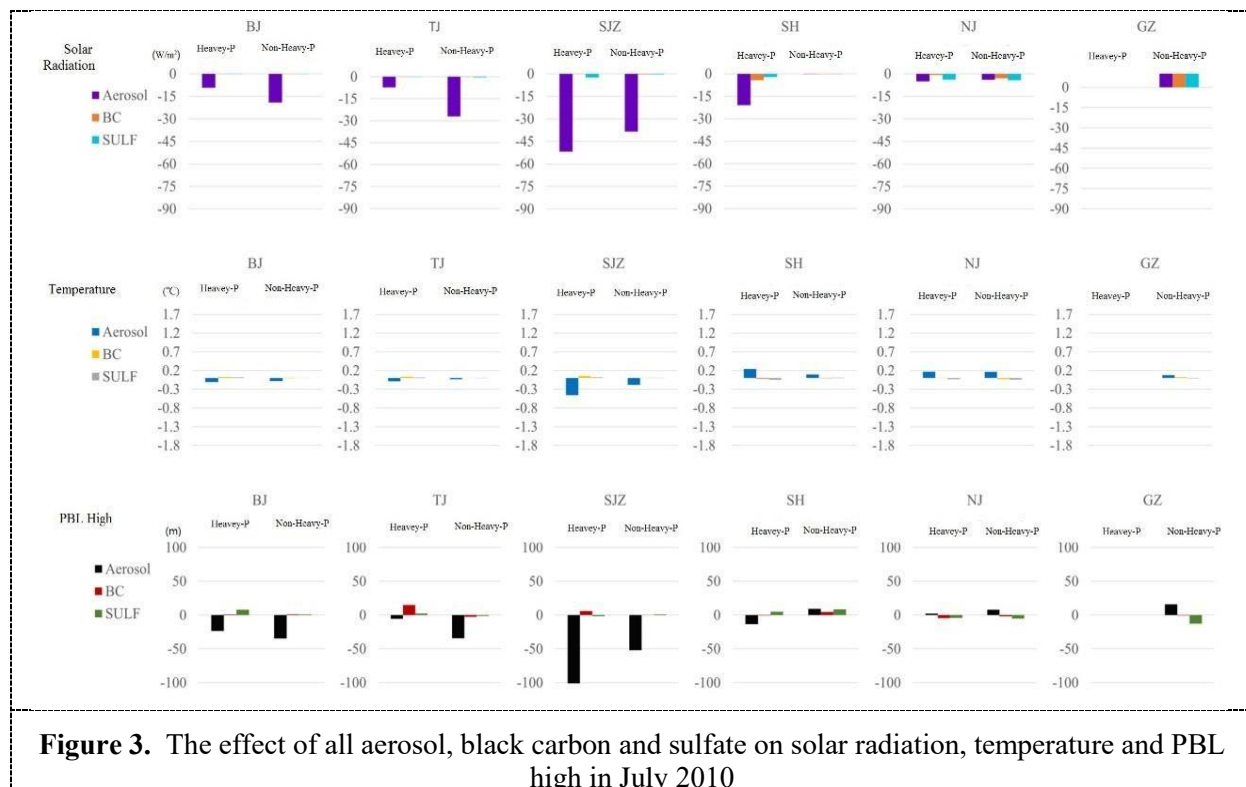
Temperature is declined due to the effect of aerosol in six cities. In January 2010, the temperature fell an average of  $0.89^\circ\text{C}$  in heavy pollution period and fell an average of  $0.2^\circ\text{C}$  in non-heavy pollution period, as shown in the second row in figure 2 and Figure. The warming effect of black carbon aerosol caused temperature to rise  $0.05^\circ\text{C}$ . During the heavy pollution period, the temperature increased by  $0.6^\circ\text{C}$ , and during non-heavy pollution period temperature increased by  $0.34^\circ\text{C}$ , as shown in the right most column in figure 2. The cooling effect of sulfate aerosol resulted in an average reduction of  $0.17^\circ\text{C}$  in six cities, and the temperature during the heavy pollution period was reduced by an average of about  $0.43^\circ\text{C}$  and  $0.08^\circ\text{C}$  during the period of non-heavy pollution. In July 2010, black carbon aerosol makes the temperature in the six cities increase slightly. Compared with January 2010, the effect of aerosol feedbacks on the temperature in the six cities are relatively light, and the effect of black carbon aerosol and sulfate aerosol on temperature are not significant.

##### 4.3. Plant Boundary Layer (PBL) High

In January 2010, the effect of aerosol feedback make the average PBL high in the six cities decreased by  $25.9\text{m}$ , and the PBL high decreased by  $54.6\text{m}$  in the heavy pollution period;  $17.2\text{m}$  in non-heavy pollution period, as shown in the third row in figure 2 and figure 3. Black carbon aerosol made six areas of PBL height decreased by an average of  $36.4\text{m}$ , decreased  $73.1\text{m}$  during the heavy pollution period and decreased  $0.27\text{m}$  during the non-heavy pollution period. Sulfate aerosol made the average height of PBL in six cities decreased by  $32.2\text{m}$ , decreased by  $66.6\text{m}$  during the heavy pollution period, and increased by  $2.3\text{m}$  during the non-heavy pollution period. In July 2010, the aerosol feedbacks makes the height of PBL in the six regions decreased by an average of  $20.6\text{m}$ . In both heavy pollution period and non-heavy pollution period, and the variation of PBL height is not significant. Black carbon aerosol made PBL average height increased by  $1.4\text{m}$ , sulfate aerosol had little effect on the PBL high. Compared with January 2010, the effect of aerosol on the PBL high in six cities are relatively light, the influence of black carbon aerosol and sulfate aerosol on PBL height are not significant too.



**Figure 2.** The effect of all aerosol, black carbon and sulfate on solar radiation, temperature and PBL high in January 2010



**Figure 3.** The effect of all aerosol, black carbon and sulfate on solar radiation, temperature and PBL high in July 2010

## 5. Conclusions

In this paper, the effects of black carbon aerosol and sulfate aerosol on solar radiation, temperature and PBL height in six cities over China in winter and summer are analyzed. According to the classification

standard of air pollution index (AQI), When the  $PM_{2.5}$  concentration is higher than  $250 \text{ g/m}^3$ , it is regarded as the heavy pollution period, lower than  $250 \text{ g/m}^3$  is considered as non-heavy pollution period. The analysis results show that the absorption effect of black carbon aerosol is stronger than the scattering effect of sulfate on solar radiation. The warming effect of black carbon aerosol is significant in both heavy pollution and non-heavy pollution period. Both black carbon and sulfate aerosol are caused PBL height decreased. In this study, we only discuss the effect of black carbon and sulfate aerosol on solar radiation, temperature and PBL high. For further studies, the effect of the change in regional meteorological factors on the formation of secondary aerosols due to aerosol feedbacks.

## 6. Acknowledgments

This research was supported by the youth fund of the development of GRAPES model special fund (GRAPES-FZZX-2016-31) and Beijing Natural Science Foundation (8172051) .

## 7. References

- [1] IPCC, Climate change 2007: Synthesis Report. In: Solomon, S., Qin, D., Manning, M. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. 2007b*
- [2] Ramanathan V., P. J. Crutzen, J. T. Kiehl, D. Rosenfeld. Aerosols, Climate, and the Hydrological Cycle. *Sciences*, 2010. 5549: 2119-2124.
- [3] Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestad, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, Anthropogenic and Natural Radiative Forcing. In: *Climate Change 2013: The Physical Science Basis[R]. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 2013
- [4] Jacobson, M.Z., (2002). *Atmospheric Pollution: History, Sciences and Regulation*, Cambridge University Press, New York, ISBN 0521010446, 399 pp.
- [5] Zhang Y. Online-coupled meteorology and chemistry models: history, current status, and outlook, *Atmos. Chem. Phys.*, 2008, 8, 2895–2932.
- [6] Zhang Y, Ying Pan. Kai Wang. Jerome D. Fast. Georg A. Grellb. WRF/Chem-MADRID: Incorporation of an aerosol module into WRF/Chem and its initial application to the TexAQS2000 episode. *Journal of Geophysical Research-Atmospheres*. 2010, 115, D18202
- [7] Zhuang BL, Jiang F, Wang TJ, Li S, Zhu B. Investigation on the direct radiative effect of fossil fuel black-carbon aerosol over China. *THEORETICAL AND APPLIED CLIMATOLOGY*. 2011, 104, 301–312
- [8] Q.Zhang, D.G.Streets, G.R.Carmichael, K.B.He, H.Huo, A.Kannari, Z.Klimont, I.S.Park, S.Reddy,J.S.Fu, D.Chen, L.Duan, Y.Lei, L.T.Wang, Z.L.Yao. Asian emissions in 2006 for the NASA INTEX-B mission. *Atmos. Chem. Phys.*, 2009, 9, 5131–5153.
- [9] M. García-Díez, Fernández, J, Fita, L, Yaguee.C. Seasonal dependence of WRF model biases and sensitivity to PBL schemes over Europe. *Quarterly Journal of the Royal Meteorological Society*. 2012, 139: 501–514
- [10] Lee, S.-H., Kim, S.-W., Angevine, W. M., Bianco, L., McKeen, S. A., Senff, C. J., Trainer, M., Tucker, S. C., and Zamora, R. J. Evaluation of urban surface parameterizations in the WRF model using measurements during the Texas Air Quality Study 2006 field campaign. *Atmos. Chem. Phys.*, 2011, 11, 2127-2143
- [11] Renate Forkel, Johannes Werhahn, Ayoe Buus Hansen, Stuart McKeen, Steven Peckham, Georg Grell, Peter Suppan. Effect of aerosol-radiation feedback on regional air quality - A case study with WRF/Chem. *Atmospheric Environment*. 2012, 53, 202-211.