Supplement of Atmos. Chem. Phys., 17, 14473–14484, 2017
https://doi.org/10.5194/acp-17-14473-2017-supplement

Atmospheric Chemistry and Physics
Open Access
EGU

Supplement of

Limited production of sulfate and nitrate on front-associated dust storm particles moving from desert to distant populated areas in northwestern China

Feng Wu et al.

Correspondence to: Feng Wu (kurt_wf@ieecas.cn) and Daizhou Zhang (dzzhang@pu-kumamoto.ac.jp)

Table S1. The relative mass ratio (%) of nitrate and sulfate in samples collected under dust conditions at the Gobi Desert reported in previous studies and this study.

Study sites	Size fractions	NO_3^-	SO_4^{2-}	References
Ejin Qi, Badain Jaran desert [a]	TSP	0.04	0.63	Mori et at., 2002
Sonid Youqi-Huade-Zhangbei	TSP	0.025	0.46	Mori et at., 2003
Gobi desert [b]	PM_{10}	0.084	0.47	Dong et al., 2016
Tonggunao'er	TSP	0.12±0.11	1.2±0.1	This study

[a] Estimated from regressions of aerosol chemical composition on distance from the dust source. [b] Based on the local measurement data reported by Huang et al. (2010).

Table S2. Summary of published papers on nitrate and sulfate in Asian dust particles at downwind sites within the continent

(a) Papers: If the samples contained mainly desert dust particles or were mixed with locally-emitted ones cannot be clarified.

Sampling sites	Study periods	Period of sample collection	Sampling methods	Analysis methods	Production of sulfate	Production of nitrate	References	Remarks
Mt. Hua	April 27-29, 2009	April 24	PM_{10}: 3- or 6-h intervals	IC	Significant	Significant	Wang et al., 2011	Vague sample collection records
Mt. Tai	April 27-29, 2009	April 24	PM_{10}: 3- or 6-h intervals	IC	Significant	Significant	Wang et al., 2011	Vague sample collection records
Beijing	March 13 to April 26, 2002	Dust storm days	TSP: 2-h intervals	IC	Significant	Significant	Wang et al., 2005	Vague sample collection records
Beijing	March 9 to April 23, 2004	Dust event days	TSP and $PM_{2.5}$: 24-h intervals	IC	Significant	Significant	Wang et al., 2007	Vague sample collection records
Beijing	March 20, 2002		TSP and $PM_{2.5}$: 12-h intervals	ICP-AES	Significant	No data	Sun et al., 2004	Vague sample collection records
Beijing	March 27 to April 12, 2015	Dust storm days	$PM_{2.5}$ and PM_{10}: 12-h intervals	IC	Significant	Significant	Wang et al., 2017	Vague sample collection records
Qingdao	March, 2002	Dust event days	Single particles	SEM	Significant	no data	Qi et al., 2006	Vague sample collection records
Qingdao	March 9- April 23, 2004	Dust event days	TSP and $PM_{2.5}$: 24-h intervals	IC	Significant	Significant	Wang et al., 2007	Vague sample collection records
Shanghai	March 9- April 23, 2004	Dust event days	TSP and $PM_{2.5}$: 24-h intervals	IC	Significant	Significant	Wang et al., 2007	Vague sample collection records
Shanghai	March 20-April 20, 2007	Dust event days	TSP: 24-h or less intervals	IC	Significant	Limited	Huang et al., 2010	Vague sample collection records

Xiamen	March 20-24, 2010	March 21-22	TSP: 8-h intervals	IC	Significant	Significant	Zhao et al., 2011	Vague sample collection records
Hongkong	April 14-25, 1998	Dust event days	TSP: 24-h intervals	IC	Significant	Significant	Cao et al., 2003	Vague sample collection records

(b) Papers: The sample collection was started before front arrival of fronts, at frontal arrival, or when the front had disappeared.

Sampling sites	**Study periods**	**Period of sample collection**	**Sampling methods**	**Analysis methods**	**Production of sulfate**	**Production of nitrate**	**References**	**Remarks**
Beijing	March 20, 2002	At the peak of aerosol loading	TSP and $PM_{2.5}$: 12-h intervals	IC	Significant	Significant	Yuan et al., 2008	Sample collection started before front arrival
Beijing	February to May, 2002	At the peak of aerosol loading	TSP and $PM_{2.5}$: 12-h intervals	IC	Significant	Significant	Sun et al., 2005	Sample collection started before front arrival
Beijing	March 28 to April 12, 2015	Dust event days	$PM_{2.5}$ and PM_{10}: 10-h or 14-h intervals	IC and ACSM	Significant	Significant	Pan et al., 2017	Front disappeared
Shanghai	March–May 2010	Dust even days	$PM_{2.5}$: 1-h intervals	MAGA	Significant	Significant	Wang et al., 2013	Front disappeared
Mt. Heng (elevated)	April 20-29, 2009	April 24-26	$PM_{2.5}$: 12-h intervals	IC	Significant	Significant	Nie et al., 2012	Sample collection started at front passage

(c) Papers: Results of samples from prefrontal air and samples from postfrontal air can be identified

Sampling sites	Study periods	Period of sample collection	Sampling methods	Analysis methods	Production of sulfate	Production of nitrate	References	Remarks
Xi'an	March, 2013	Dust event days	TSP: 1-h intervals	IC	Limited	Limited Significant	Wang et al., 2014	Postfrontal samples Prefrontal samples
Beijing	March to April, 2002	Dust event days	TSP: 2- or 3-h intervals	IC	Limited Significant	Limited Significant	Zhao et al., 2007	Postfrontal samples Prefrontal samples
Beijing	Springs of 1995 and 1996	After front passage	TSP particles: 2 minute samples	TEM	Limited	Limited	Zhang and Iwasaka, 1999	Postfrontal samples
Qingdao	Spring 2001	After front passage	TSP particles: 2 minutes sample	TEM	Limited	Limited	Zhang et al. 2003	Postfrontal samples
Qingdao	March 20-21, 2002	Before and after front passage	TSP particles: 2 minutes sample	SEM	Limited Significant	Limited	Zhang et al. 2005	Postfrontal samples Prefrontal samples
Xi'an	May 1, 2014	After front passage	TSP: 1- or 2-h intervals	IC	Limited	Limited	This study	

ACSA: Aerosol chemical speciation analyzer; ACSM: Aerosol Chemical Speciation Monitor; ATOFMS: aerosol time- of-flight mass spectrometer; IC: ion chromatography; MAGA: online analyzer for monitoring of aerosols and gases; TEM: transmission electron microscopy; SEM: scanning electron microscopy; PMF2: bilinear positive matrix factorization

References

Cao, J., Lee, S., Zheng, X., Ho, K., Zhang, X., Guo, H., Chow, J. C. and Wang, H.: Characterization of dust storms to Hong Kong in April 1998, Water Air Soil Pollut. Focus, 3(2), 213–229, doi:10.1023/A:1023202926292, 2003.

Huang, K., Zhuang, G., Li, J., Wang, Q., Sun, Y., Lin, Y. and Fu, J. S.: Mixing of Asian dust with pollution aerosol and the transformation of aerosol components during the dust storm over China in spring 2007, J. Geophys. Res., 115(null), 1–13, doi:10.1029/2009JD013145, 2010.

Nie, W., Wang, T., Xue, L. K., Ding, a. J., Wang, X. F., Gao, X. M., Xu, Z., Yu, Y. C., Yuan, C., Zhou, Z. S., Gao, R., Liu, X. H., Wang, Y., Fan, S. J., Poon, S., Zhang, Q. Z. and Wang, W. X.: Asian dust storm observed at a rural mountain site in southern China: Chemical evolution and heterogeneous photochemistry, Atmospheric Chem. Phys., 12(24), 11985–11995, doi:10.5194/acp-12-11985-2012, 2012.

Pan, X., Uno, I., Wang, Z., Nishizawa, T., Sugimoto, N., Yamamoto, S., Kobayashi, H., Sun, Y., Fu, P., Tang, X. and Wang, Z.: Real-time observational evidence of changing Asian dust morphology with the mixing of heavy anthropogenic pollution, Sci. Rep., 7(1), doi:10.1038/s41598-017-00444-w, 2017.

Qi, J., Li, X., Feng, L. and Zhang, M.: Characterization of dust and non-dust aerosols with SEM/EDX, J. Ocean Univ. China, 5(1), 85, doi:10.1007/BF02919381, 2006.

Sun, Y.: Characteristics and sources of 2002 super dust storm in Beijing, Chin. Sci. Bull., 49(7), 698, doi:10.1360/03wb0157, 2004.

Sun, Y., Zhuang, G., Wang, Y., Zhao, X., Li, J., Wang, Z. and An, Z.: Chemical composition of dust storms in Beijing and implications for the mixing of mineral aerosol with pollution aerosol on the pathway, J. Geophys. Res. Atmospheres, 110(D24), D24209, doi:10.1029/2005JD006054, 2005.

Wang, G., Li, J., Cheng, C., Hu, S., Xie, M., Gao, S., Zhou, B., Dai, W., Cao, J. and An, Z.: Observation of atmospheric aerosols at Mt. Hua and Mt. Tai in central and east China during spring 2009 – Part 1: EC, OC and inorganic ions, Atmos Chem Phys, 11(9), 4221–4235, doi:10.5194/acp-11-4221-2011, 2011.

Wang, G. H., Cheng, C. L., Huang, Y., Tao, J., Ren, Y. Q., Wu, F., Meng, J. J., Li, J. J., Cheng, Y. T., Cao, J. J., Liu, S. X., Zhang, T., Zhang, R. and Chen, Y. B.: Evolution of aerosol chemistry in Xi'an, inland China, during the dust storm period of 2013 – Part 1: Sources, chemical forms and formation mechanisms of nitrate and sulfate, Atmospheric Chem. Phys., 14(21), 11571–11585, doi:10.5194/acp-14-11571-2014, 2014.

Wang, L., Du, H., Chen, J., Zhang, M., Huang, X. and Tan, H.: Consecutive transport of anthropogenic air masses and dust storm plume : Two case events at Shanghai , China, Atmospheric Res., 127, 22–33, doi:10.1016/j.atmosres.2013.02.011, 2013.

Wang, Y., Zhuang, G., Sun, Y. and An, Z.: Water-soluble part of the aerosol in the dust storm season -

Evidence of the mixing between mineral and pollution aerosols, Atmos. Environ., 39(37), 7020–7029, doi:10.1016/j.atmosenv.2005.08.005, 2005.

Wang, Y., Zhuang, G., Tang, A., Zhang, W., Sun, Y., Wang, Z. and An, Z.: The evolution of chemical components of aerosols at five monitoring sites of China during dust storms, Atmos. Environ., 41(5), 1091–1106, doi:10.1016/j.atmosenv.2006.09.015, 2007.

Wang, Z., Pan, X., Uno, I., Li, J., Wang, Z., Chen, X., Fu, P., Yang, T., Kobayashi, H., Shimizu, A., Sugimoto, N. and Yamamoto, S.: Significant impacts of heterogeneous reactions on the chemical composition and mixing state of dust particles: A case study during dust events over northern China, Atmos. Environ., 159(Supplement C), 83–91, doi:10.1016/j.atmosenv.2017.03.044, 2017.

Yuan, H., Zhuang, G., Li, J., Wang, Z. and Li, J.: Mixing of mineral with pollution aerosols in dust season in Beijing: Revealed by source apportionment study, Atmos. Environ., 42(9), 2141–2157, doi:10.1016/j.atmosenv.2007.11.048, 2008.

Zhang, D. and Iwasaka, Y.: Nitrate and sulfate in individual Asian dust-storm particles in Beijing, China in spring of 1995 and 1996, Atmos. Environ., 33(19), 3213–3223, doi:10.1016/S1352-2310(99)00116-8, 1999.

Zhang, D., Zang, J., Shi, G., Iwasaka, Y., Matsuki, A. and Trochkine, D.: Mixture state of individual Asian dust particles at a coastal site of Qingdao, China, Atmos. Environ., 37(28), 3895–3901, doi:10.1016/S1352-2310(03)00506-5, 2003.

Zhang, D., Iwasaka, Y., Shi, G., Zang, J., Hu, M. and Li, C.: Separated status of the natural dust plume and polluted air masses in an Asian dust storm event at coastal areas of China, J. Geophys. Res. Atmospheres, 110(6), 1–9, doi:10.1029/2004JD005305, 2005.

Zhao, J., Zhang, F., Xu, Y., Chen, J., Yin, L., Shang, X. and Xu, L.: Chemical characteristics of particulate matter during a heavy dust episode in a coastal city, Xiamen, 2010, Aerosol Air Qual. Res., 11(3), 300–309, doi:10.4209/aaqr.2010.09.0073, 2011.

Zhao, X., Zhuang, G., Wang, Z., Sun, Y., Wang, Y. and Yuan, H.: Variation of sources and mixing mechanism of mineral dust with pollution aerosol-revealed by the two peaks of a super dust storm in Beijing, Atmospheric Res., 84(3), 265–279, doi:10.1016/j.atmosres.2006.08.005, 2007.

Figure S1: Geographical features of North China. The elevation dataset was from NASA Shuttle Radar Topography Mission. (http://vterrain.org/Elevation/SRTM/)

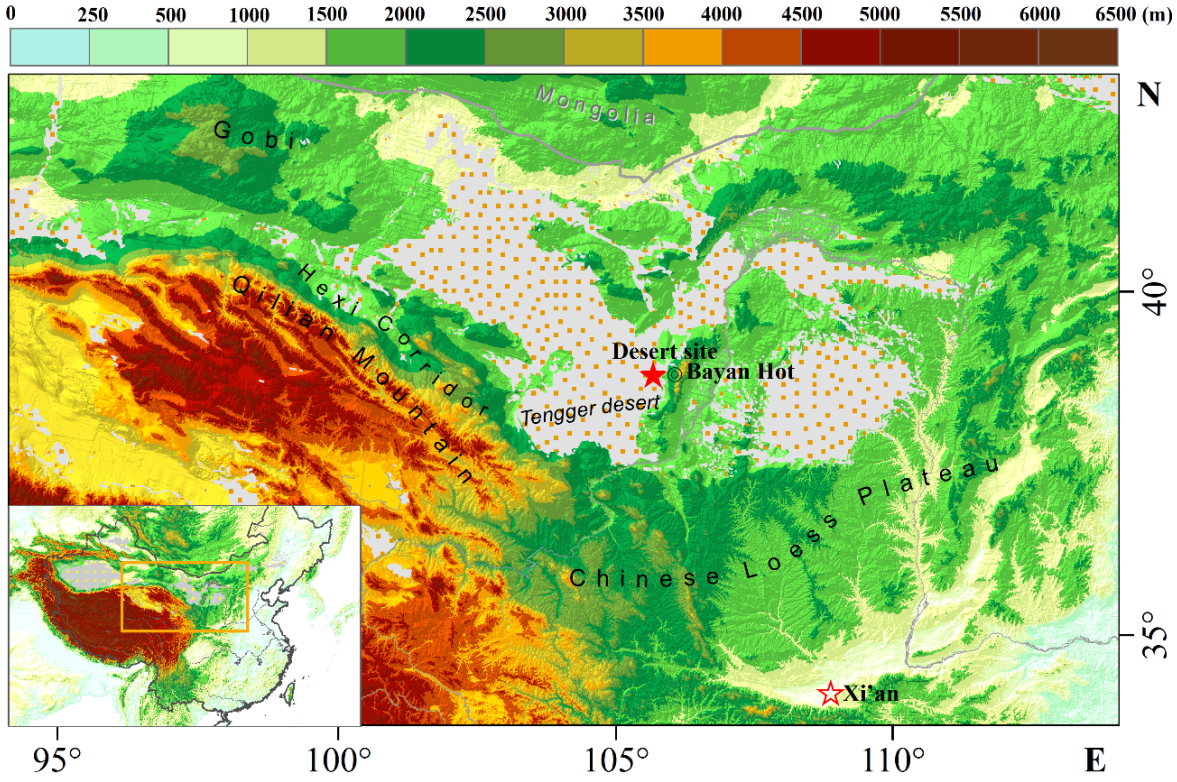

Figure S2: Backward trajectories from the desert site (2014/04/24) and Xi'an site (2014/05/01) from the HYSPLIT model (www.arl.noaa.gov/HYSPLIT.php). (BST = GMT + 08:00)

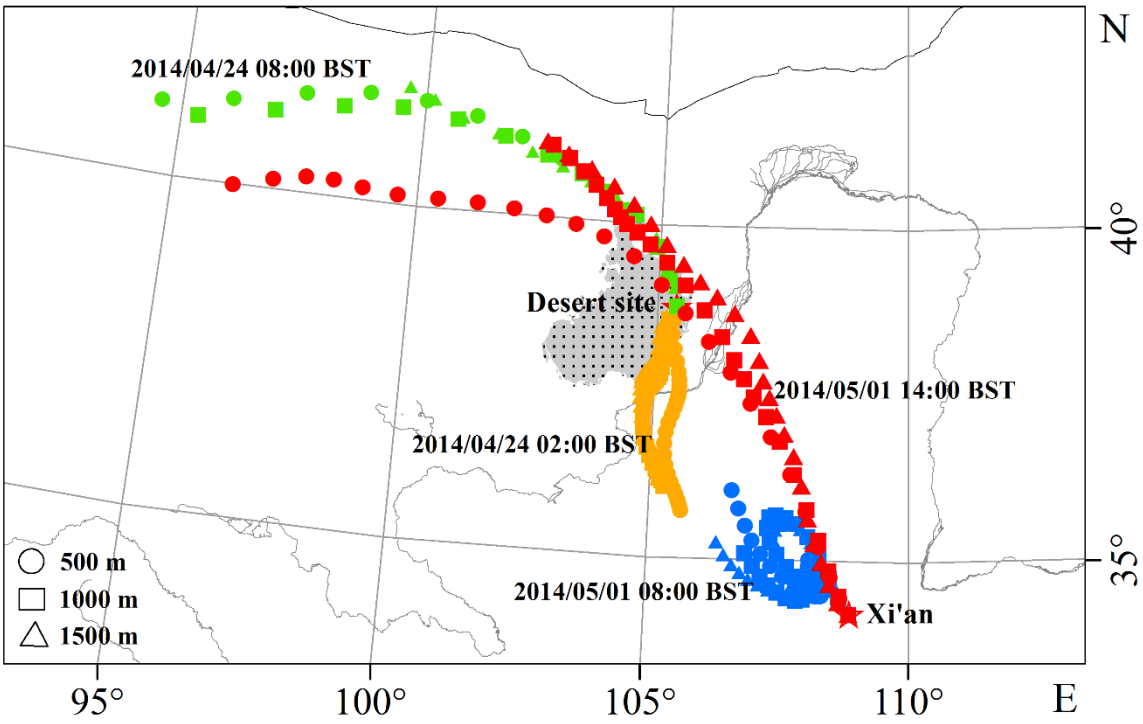

Figure S3: CFORS model output for boundary layer (surface - 1000m) dust concentration (μg/m^3, color in log scale) and wind vector at 1000m of East Asia during the sampling periods at desert site (a) and Xi'an (b). (http://www-cfors.nies.go.jp/~cfors/index-j.html) (JST = GMT + 09:00)

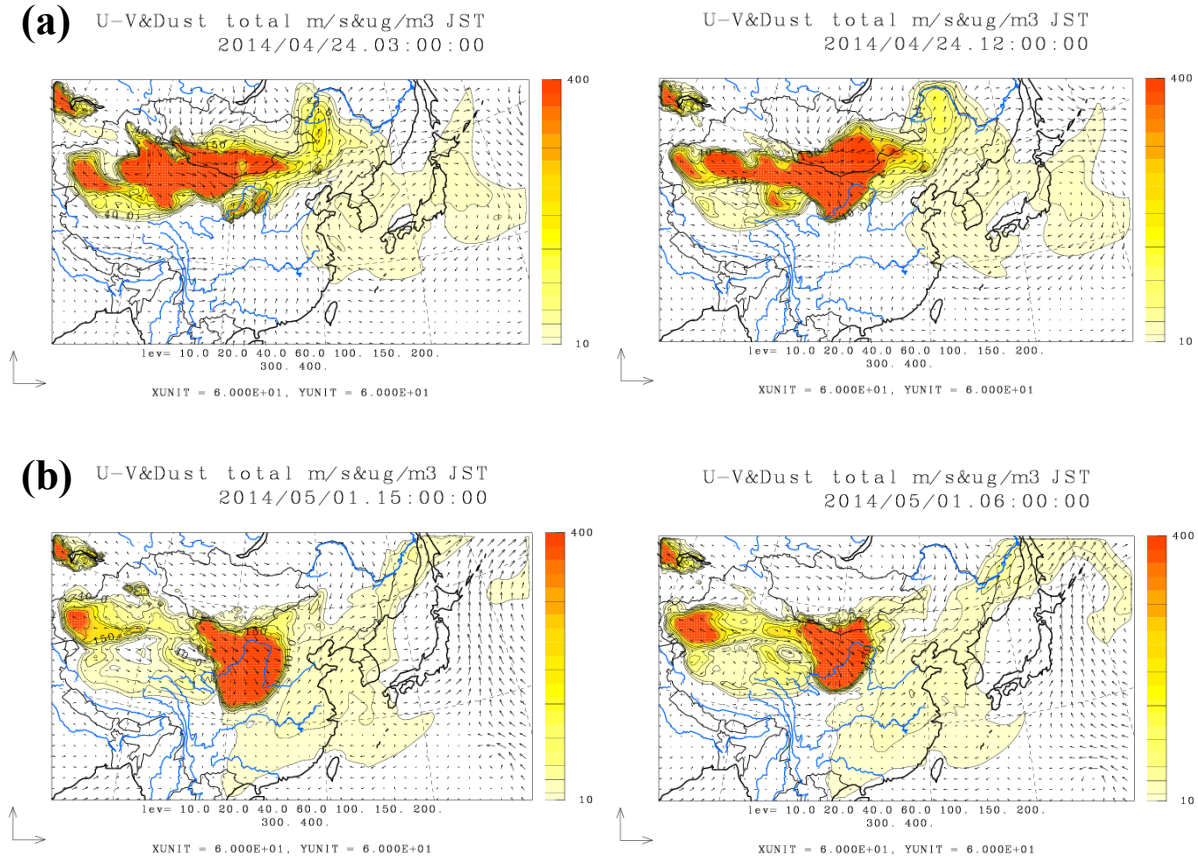

Figure S4: Emission distributions of SO_2 at 0.25º×0.25º resolution during April-May, 2014. Data were from (http://www.meicmodel.org/). The emission sources were composed of four types: industry, power, transportation and residential sources.

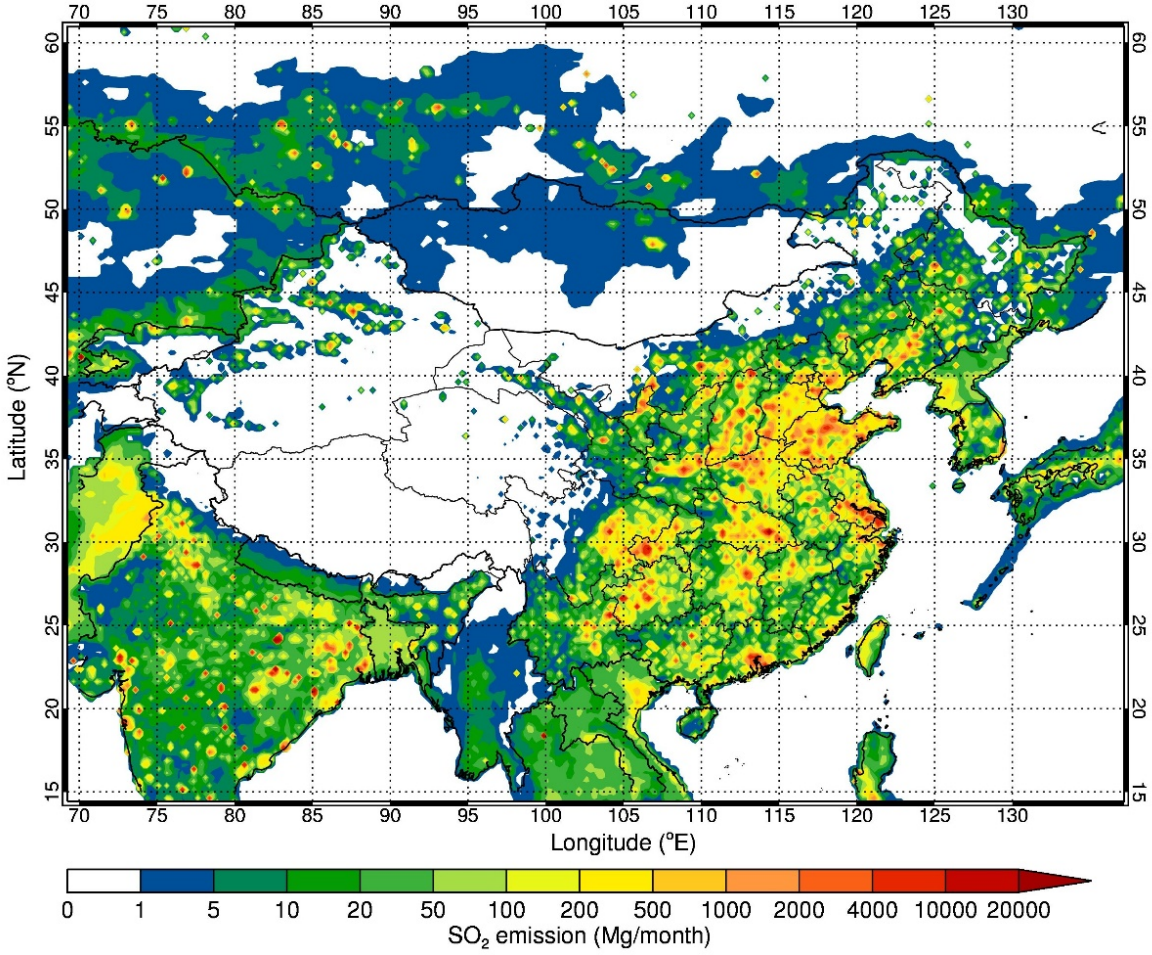

Figure S5: Concentrations of SO_2 and NO_2 at Xi'an site during the dust passage on May 1, 2014.

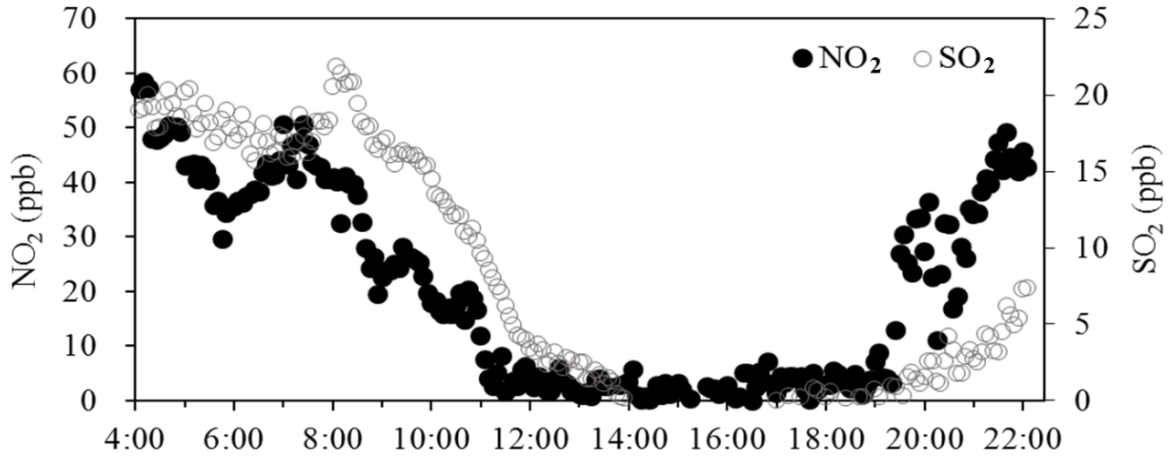

Figure S6: Vertical profiles of virtual potential temperature near the surface at Yinchuan (38.48°N, 106.21°E), the WMO sounding station closest to the desert site, and at Jinhe (34.43°N, 108.97°E), a suburb place of Xi'an, before and after dust occurrence at the two places. The profiles were from the homepage of Atmospheric Soundings of the University of Wyoming (http://weather.uwyo.edu/upperair/sounding.html). Dust occurred at the desert site on the morning of April 24, 2014, and the sample collection was held between 06:30 and 15:00 BST on April 24. Dust occurred at Xi'an site on the morning of May 1, 2014, and the sample collection was held between 07:00 and 19:00 BST on May 1.