Supplement of Atmos. Chem. Phys., 23, 4271–4281, 2023
https://doi.org/10.5194/acp-23-4271-2023-supplement


Atmospheric Chemistry and Physics
Open Access

*Supplement of*

# Coarse particulate matter air quality in East Asia: implications for fine particulate nitrate

**Shixian Zhai et al.**

*Correspondence to:* Shixian Zhai (zhaisx@g.harvard.edu)

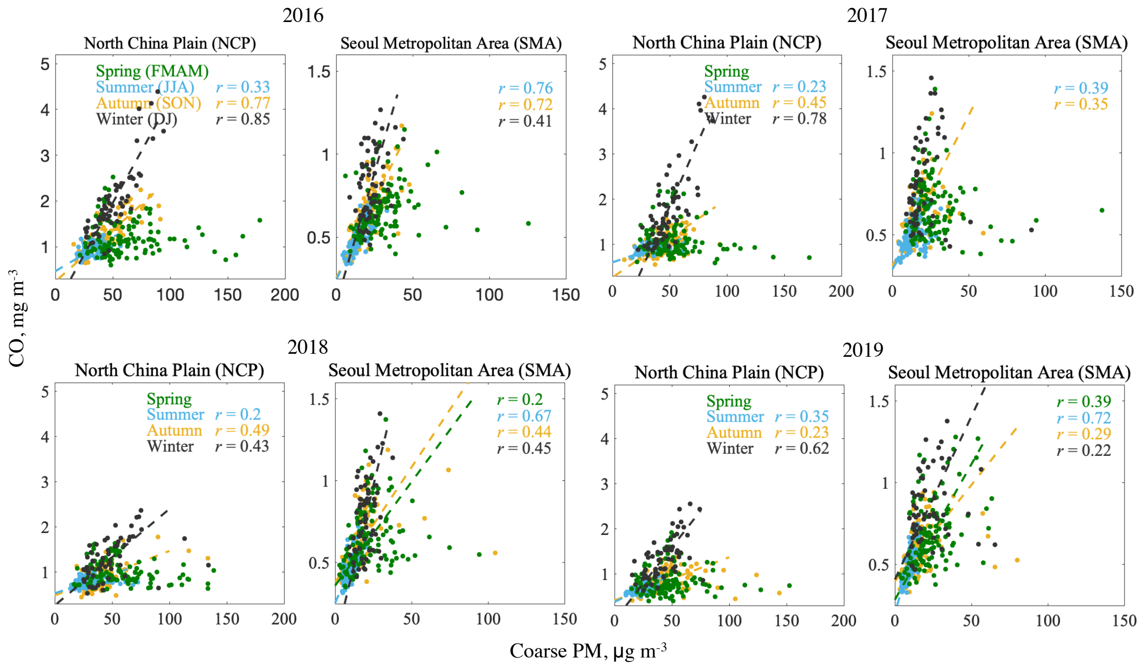


Figure S1. Daily correlations of coarse PM and CO over the North China Plain (NCP) and Seoul Metropolitan Area (SMA). Same as Fig. 3 in the main text but for the years 2016, 2017, 2018, and 2019.

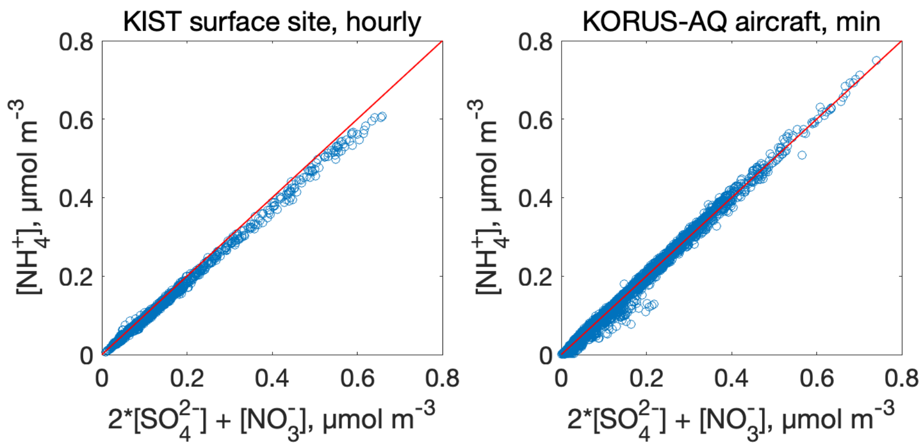


Figure S2. Ionic charge balance of AMS $PM_1$ during KORUS-AQ over SMA. Here the ionic charge balance is represented by scatterplots of 2*[$SO_4^{2-}$] + [$NO_3^-$] and [$NH_4^+$] molar concentrations at the surface KIST site (left) and on the DC-8 aircraft (right). 2*[$SO_4^{2-}$] + [$NO_3^-$] and [$NH_4^+$] are in charge balance, suggesting that AMS measured nitrate is mainly inorganic nitrate that is associated with ammonium.

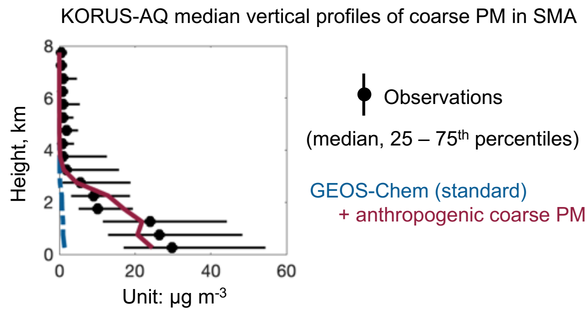


Figure S3. Median vertical profiles of coarse PM over SMA during KORUS-AQ. Data filtering criteria is the same as Fig. 4 in the main text. Aircraft observations of coarse PM are derived from the size distribution measurements by in-situ Aerosol Particles from the DMT CPSPD Probe.

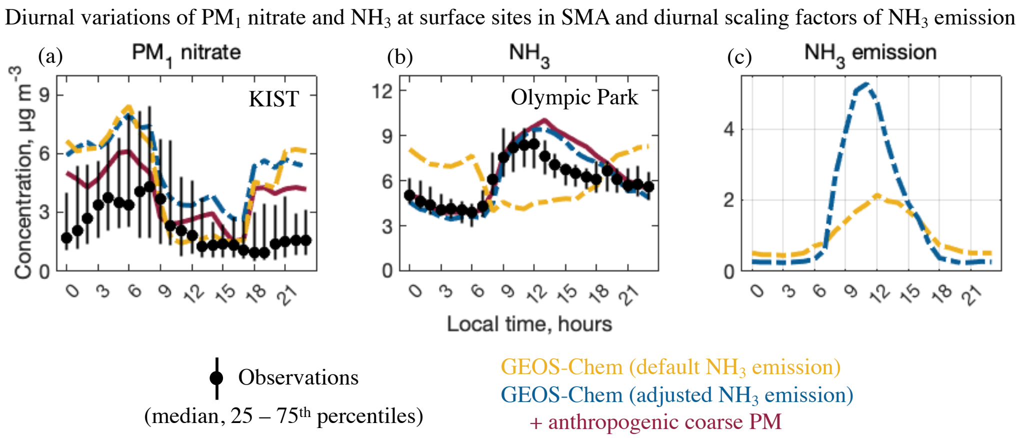


Figure S4. Effects of anthropogenic coarse PM and diurnal variations of $NH_3$ emission on $PM_1$ nitrate and $NH_3$ over Seoul Metropolitan Area (SMA) during KORUS-AQ. Same as Fig. 4a in the main text but with the diurnal profiles of $NH_3$ at the Olympic Park site in SMA, diurnal scaling factors of $NH_3$ emission, and GEOS-Chem model results with default and adjusted $NH_3$ emissions added. $NH_3$ was measured by ion chromatography at the Olympic Park site in SMA, ~7 km to the southeast of KIST. The default diurnal scaling factors of $NH_3$ emission is provided by the Multi-resolution Emission Inventory for China (MEIC) agriculture emission sector.

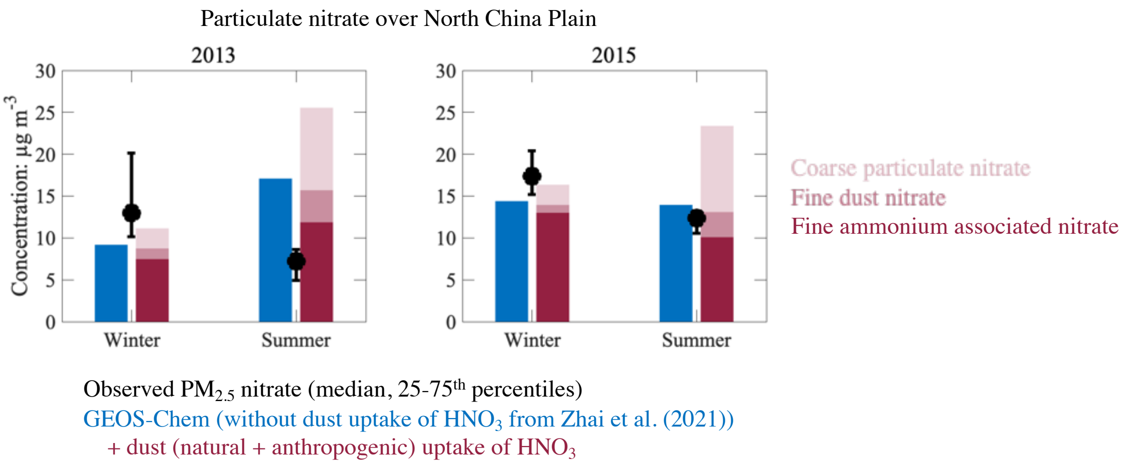


Figure S5. Effects of dust uptake of $HNO_3$ on winter and summer mean particulate nitrate over the North China Plain. Observed $PM_{2.5}$ nitrate at sites in NCP and the GEOS-Chem model results without considering dust uptake of $HNO_3$ are from our previous study (Zhai et al., 2021). GEOS-Chem model results are sampled at NCP observation sites.

Table S1 Concentrations of multi-year winter and summer mean[a] fine particulate nitrate observed in Beijing and Seoul, Unit: μg $m^{-3}$. Data is visualized in Fig. 5 in the main text.

| | Winter | | | | | Summer | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | IAP[b] | Tsinghua[c] | PKU[d] | NIER[e] | KIST[f] | IAP | Tsinghua | PKU | NIER | KIST |
| 2015 | 14.6 | | 14.6 | 9.2 | | 5.0 | 8.4 | 12.3 | 0.4 | |
| 2016 | | | | 7.9 | 6.6 | | | | 1.3 | 1.4 |
| 2017 | | 16.5 | | 9.4 | 8.9 | | 7.7 | | 0.8 | |
| 2018 | 14.7 | 11.5 | | 6.7 | 5.2 | 8.6 | 9.0 | | 0.7 | 0.5 |
| 2019 | 11.4 | 12.8 | | 10.3 | 10.5 | 6.1 | 7.6 | | 0.7 | |
| 2020 | 13.8 | 15.8 | | | | 7.2 | 8.5 | | | 0.3 |
| 2021 | | 19.2 | | | | 3.0 | 6.8 | | | |

[a] Winter mean are December-January-February averages and summer mean are June-July-August averages unless otherwise noted.

[b] Winter mean fine particulate nitrate at the Institute of Atmospheric Physics (IAP) site are January-February-March averages (Lei et al., 2021). Winter data for year 2015 and year 2018 are Q-ACSM NR-$PM_1$. Winter data for year 2019 and 2020 are ToF-ACSM NR-$PM_{2.5}$. Summer data for year 2015 (1 June - 3 July and 15 August - 31 August) are AMS NR-$PM_1$. Summer data for years 2018, 2019, 2020, and 2021 are ACSM NR-$PM_{2.5}$.

[c] $PM_{2.5}$ nitrate at Tsinghua campus from 2017 to 2021 are measured by Monitor for AeRosols and Gases (MARGA, Metrohm Ltd., Switzerland) (Xu et al., 2019). Winter mean are January-February-March averages. $PM_1$ nitrate in summer 2015 is from Li et al. (2018).

[d] Data is from ref Liu et al. (2019).

[e] Data is measured by an ambient ion monitor (AIM, URG-9000D/USA)(Jo et al., 2020; Jeong et al., 2022).

[f] $PM_1$ nitrate at the Korea Institute of Science and Technology (KIST) site is HR-ToF-AMS NR-$PM_1$ (Kim et al., 2017). Winter mean concentration are averaged from 5 December 2015 to 21 January 2016 for year 2016 (Kim et al., 2017), from 1 January 2017 to 10 February 2017 for year 2017, from 17 January 2018 to 22 February 2018 for year 2018, and from 22 February 2019 to 2 April 2019 for year 2019 (Kim et al., 2020). Summer mean concentration are averaged from 27 July to 31 August for year 2016, from 6 August to 31 August for year 2018, from 13 August to 31 August for year 2020.

## References

Jeong, J. I., Seo, J., and Park, R. J.: Compromised Improvement of Poor Visibility Due to PM Chemical Composition Changes in South Korea, Remote Sens., 14, 5310, https://doi.org/10.3390/rs14215310, 2022.

Jo, Y.-J., Lee, H.-J., Jo, H.-Y., Woo, J.-H., Kim, Y., Lee, T., Heo, G., Park, S.-M., Jung, D., Park, J., and Kim, C.-H.: Changes in inorganic aerosol compositions over the Yellow Sea area from impact of Chinese emissions mitigation, Atmos. Res., 240, 104948, https://doi.org/10.1016/j.atmosres.2020.104948, 2020.

Kim, H., Zhang, Q., and Sun, Y.: Measurement report: Characterization of severe spring haze episodes and influences of long-range transport in the Seoul metropolitan area in March 2019, Atmos. Chem. Phys., 20, 11527-11550, https://doi.org/10.5194/acp-20-11527-2020, 2020.

Kim, H., Zhang, Q., Bae, G. N., Kim, J. Y., and Lee, S. B.: Sources and atmospheric processing of winter aerosols in Seoul, Korea: insights from real-time measurements using a high-resolution aerosol mass spectrometer, Atmos. Chem. Phys., 17, 2009-2033, https://doi.org/10.5194/acp-17-2009-2017, 2017.

Lei, L., Zhou, W., Chen, C., He, Y., Li, Z., Sun, J., Tang, X., Fu, P., Wang, Z., and Sun, Y.: Long-term characterization of aerosol chemistry in cold season from 2013 to 2020 in Beijing, China, Environ. Pollut., 268, 115952, https://doi.org/10.1016/j.envpol.2020.115952, 2021.

Li, H., Zhang, Q., Zheng, B., Chen, C., Wu, N., Guo, H., Zhang, Y., Zheng, Y., Li, X., and He, K.: Nitrate-driven urban haze pollution during summertime over the North China Plain, Atmos. Chem. Phys., 18, 5293-5306, https://doi.org/10.5194/acp-18-5293-2018, 2018.

Liu, M., Huang, X., Song, Y., Tang, J., Cao, J., Zhang, X., Zhang, Q., Wang, S., Xu, T., Kang, L., Cai, X., Zhang, H., Yang, F., Wang, H., Yu, J. Z., Lau, A. K. H., He, L., Huang, X., Duan, L., Ding, A., Xue, L., Gao, J., Liu, B., and Zhu, T.: Ammonia emission control in China would mitigate haze pollution and nitrogen deposition, but worsen acid rain, Proc. Natl. Acad. Sci. USA, 116, 7760-7765, https://doi.org/10.1073/pnas.1814880116, 2019.

Xu, Q., Wang, S., Jiang, J., Bhattarai, N., Li, X., Chang, X., Qiu, X., Zheng, M., Hua, Y., and Hao, J.: Nitrate dominates the chemical composition of $PM_{2.5}$ during haze event in Beijing, China, Sci. Total Environ., 689, 1293-1303, https://doi.org/10.1016/j.scitotenv.2019.06.294, 2019.

Zhai, S., Jacob, D. J., Wang, X., Liu, Z., Wen, T., Shah, V., Li, K., Moch, J. M., Bates, K. H., Song, S., Shen, L., Zhang, Y., Luo, G., Yu, F., Sun, Y., Wang, L., Qi, M., Tao, J., Gui, K., Xu, H., Zhang, Q., Zhao, T., Wang, Y., Lee, H. C., Choi, H., and Liao, H.: Control of particulate nitrate air pollution in China, Nat. Geosci., 14, 389-395, https://doi.org/10.1038/s41561-021-00726-z, 2021.