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# Sources of emission and their impacts on $PM_{2.5}$ in Nanjing and Shanghai

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**Abstract.** Emission is a key factor to govern the mass concentrations of air pollutants including $PM_{2.5}$, but currently remains large uncertainties. In this study, we firstly analyzed a commonly used emission invertory-MECI10, to understand the situations of emissions from the different major sources such as industry, power, transportation, residential, and agriculture in Nanjing and Shanghai. The analysis shows that industry contributes the most to PM and most gases in both Nanjing and Shanghai, and power contributes more to NOx than industry at Shanghai, while agriculture dominates $NH_3$ emission. The modeled meteorology including temperature, wind speed (direction) and precipitation is then evaluated against the observations during the same time periods, and shows the overall good agreement with the observations. The simulated $PM_{2.5}$ exhibits quite consistent seasonal variations compared to the observed, though the magnitudes are overall higher in the model. The impacts of emissions from various sources on $PM_{2.5}$ was finally investigated and the results indicate that the contribution from industry contributes more than 40% to the total $PM_{2.5}$ during April, July and Fall, with slightly higher percentage in Shanghai than in Nanjing. Different from other seasons, residential contributes the most due to heating in winter. Agriculture is the second largest contributor to the total $PM_{2.5}$ throughout the year, while the contributions from residential and transportation are the least.

## Introduction

With the rapid economic growth in China, emissions of air pollutants increased dramatically in the past few decades, which caused complex air pollution events occurring more frequently. Particular matter (PM) mass concentrations become very high as a result of severe haze events, of which $PM_{2.5}$ (particulate matter with diameter equal to or less than 2.5 μm) is a major concern due to its adverse health effects, including severe respiratory system related symptoms and deceases [1,2] and significant decrease in visibility [3,4]. To understand the situations of air pollution, the emission inventories of air pollutants is a fundamental necessity, which provides the basic information on air pollutants for a specific geographic domain and during in a certain time period. Therefore emission inventories have been commonly used as a input for air quality modeling to simulate the status of air pollutants, investigating the formation and evolution of pollutants, and making emission control polices [5,6]. As one of the fastest economically growing regions around the world during the past few decades, Yangze River Delta (YRD) is currently one of the most seriously polluted regions in China, and has been experiencing haze events more severely and more frequently. According to earlier study [7], 21% days for the year 2014 in Shanghai didn't meet the National Ambient Air Quality Standard (NAAQS) Grade II.

### Model description and observations

In this study we use a fully coupled weather forecasting and chemistry model WRF-Chem version 3.6 [8] to simulate the impacts of different sources of emissions $PM_{2.5}$ mass concentrations over Yangze River Delta (YRD) region, and focus our analysis on two mega cities in the region: Nanjing and Shanghai. There are 27 layers in the vertical and the horizontal resolution is 21km×21km in the model. The National Centers for Environmental Prediction (NCEP) 1°×1° reanalysis data are used for the meteorological initial and boundary conditions. The chemical initial and boundary conditions are provided by the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4) [9].

The gas-phase chemical mechanism CBMZ[10], 4-bin MOSAIC aerosol mechanism, and aqueous chemistry [11] are used in the simulations. MOSAIC treats all the important aerosol species, including sulfate, nitrate, chloride, ammonium, sodium, BC, primary organic mass, liquid water and other inorganic mass. Some other physics configuration parameterization options include Lin cloud-microphysics [12], RRTM long wave radiation [13], Goddard short wave radiation [14]. Table 1 summarizes the physical and chemical mechanisms used in the simulations.

The meteorological condition is a key factor to control the simulated air pollutants concentrations and their temporal and spatial distribution, so it is essential to evaluate the modeled meteorological variables. The variables such as 2 meter temperature, 10 meter wind speed for Shanghai and Nanjing from Meteorological Information Comprehensive Analysis and Process System (MICAPS) are used for evaluation. The hourly $PM_{2.5}$ concentrations are collected from surface observations provided by the China National Environmental Monitoring Center (CNEMC, http://www.cnpm25.com), which includes 76 cities in mainland China, and the data presented the mean values are from different observation stations distributed in various downtown, suburb, and suburban areas of each city.

Table 1. Physical and chemical parameterization schemes

| Schemes | options |
|---|---|
| **Cloud microphyics** | Morrison 2-moment |
| **Longwave radiation** | RRTMG |
| **Shortwave adiation** | RRTMG |
| **Land surface** | Noah |
| **Boudary layer** | YSU |
| **Cumulus cloud** | Grell 3D |
| **Chemistry** | CBM-Z |
| **Photo-chemistry** | Fast-J |
| **Aerosol** | MOSAIC_4bin |

### Emission inventory and simulations

The Multi-resolution Emission Inventory for China (MEIC: http://www.meicmodel.org/) is developed by Tsinghua University, which is a bottom-up air pollutant EI with more than 700 emission sources and production categories. The MEIC model is an improvement and update of the previous work from the same group, compiled from detailed statistical data, technology information, and emission factors [15]. The major improvements include a unit-based power plant emission database [16,17], a high-resolution vehicle emission modeling approach [18], an explicit NMVOC speciation assignment methodology, and unified on-line framework for emission calculation, data processing, and data downloading. The MEIC inventory includes both gaseous and particle species such as $SO_2$, $NO_x$, CO, NMVOC (non-methane volatile organic compounds, $NH_3$, $PM_{2.5}$, $PM_{10}$, BC, OC and $CO_2$. The monthly MEIC 2010 (NEIC10) emission at 0.25°× 0.25° horizontal resolution is used as input for the simulations in this study.

The emissions of MEIC10 come from five major sources, such as industry, power, residential, transportation and agriculture In order to investigate the contributions to $PM_{2.5}$ from different sources of emissions (industry, power, residential, transportation, and agriculture), we run a base experiment in which emissions from all sources are included, and a few of sensitivity experiments in which one of sources is turned off, therefore the contribution of each source to $PM_{2.5}$ can be deduced from the differences of base experiment and sensitivity experiments. Four single month (Janurary, April, July, and October) simulations for the year of 2014 are conducted to represent the seasonal variations.

## Results and Discussions

The emissions of chemical gases and particular matter ($PM_{2.5}$ and $PM_{10}$) from different sources in Nanjing and Shanghai are shown in Fig.1. Apparently industry dominates the total emissions for PM and gases in both cities, contributing more than 65% for PM and $SO_2$, 60% for CO, 50% for BC, 30% for OC, and 70% for VOC. An exception was found for $NO_x$ at Shanghai, where power contributes slightly more to NOx than industry. As the largest city in China, energy consumption in Shanghai is quite high and produces a large amount of emissions, which are clearly shown in Fig.1. For both PM and gases, the magnitudes of emissions in Shanghai are significantly higher than in Nanjing, especially for $SO_2$, $NO_x$, and VOC. The precursor gases (e.g. $SO_2$ and $NO_x$) become secondary particles through the chemical reactions and physical processes, and finally contribute to total $PM_{2.5}$ mass concentrations together with primary particles.

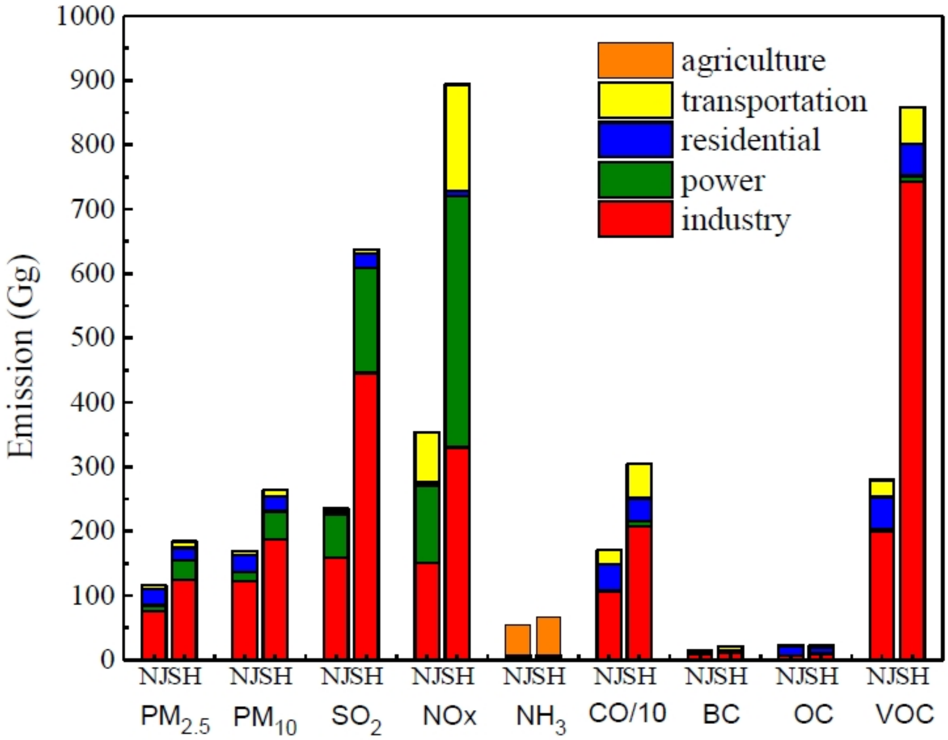


Fig. 1. The total emissions from five sources (industry, power, residential, transportation, and agriculture) based on MIEC10 inventory in Nanjing (NJ) and Shanghai (SH). Unit: Gg.

Meteorological fields especially wind speed, wind direction, temperature, and precipitation, etc., are the major elements to influence the transport, diffusion, depositions and chemical processes of air pollution, so it is necessary to evaluate the modeled meteorology by using the observational data. In this study, the simulated temperature, wind speed, wind direction, and precipitation are evaluated by comparing with the observations for the same time period in Nanjing and Shanghai (Figs omitted). Overall, the model can reasonably well capture the variations of surface temperature, and reproduce the observed wind direction and wind speed. Although the model can capture the time series of precipitation, it generally underestimates the magnitude, especially the peaks with heavy precipitation.

Fig.2 shows the seasonal variations of simulated $PM_{2.5}$ mass concentrations, and comparisons with the observations collected at the monitoring sites. It is indicated that the model can generally capture the observed seasonal variations of $PM_{2.5}$ mass concentrations, with the maximum in winter maximum in winter. Wintertime increases peak are possibly attributable to a combination of persistent temperature inversions near surface and increases in emissions related to heating [19,20]. Overall the model overestimates the $PM_{2.5}$ mass concentrations by more than 30%, and up to 70% at Nanjing for different seasons. The discrepancies between the modeled and observed at Shanghai are generally lower than in Nanjing, but still have about 30% overestimations. The results in autumn at Shanghai are quite close to the observations. The overall overestimations can be attributed to various aspects. Firstly, emission inventory still remains large uncertainties, which can induce the biases of precursor gases and primary emissions of $PM_{2.5}$. Secondly, some chemical mechanisms of precursor gases forming as secondary particles are far from well understand, and physical processes and their parameterizations still need further improvements, both of which all contribute to the differences of $PM_{2.5}$ between the simulations and observations. Finally, although the evaluations of meteorology is overall acceptable, some discrepancies still exist, which also add some differences to the results.

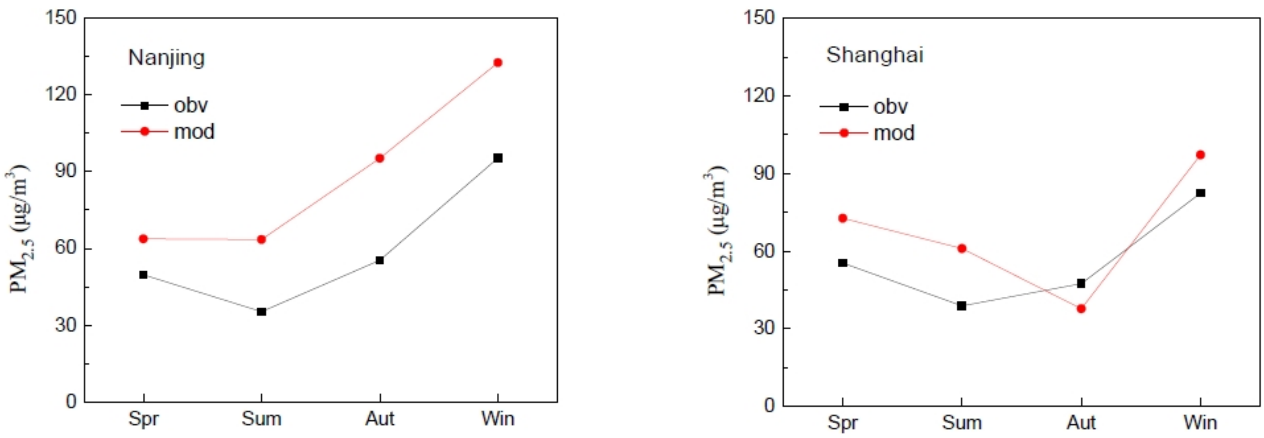


Fig. 2. The simulated $PM_{2.5}$ mass concentrations for four seasons (spring, summer, autumn, and winter), and comparisons with the observations during the same time periods at Nanjing and Shanghai. Unit: $\mu g/m^3$.

In order to investigate the contributions from different sources to the total $PM_{2.5}$ mass concentration, a base experiment and a few of sensitivity experiments are conducted as mentioned above. The contributions from industry, power, transportation, residential, and agriculture presented in Fig. 3 shows a distinct seasonal variation. During winter season, the contribution from residential account for 49% and 37% to the total $PM_{2.5}$ mass in Nanjing and Shanghai, respectively, due to the increase emissions from heating. For other seasons, the contributions from industry are the most, with the percentages of about 40% in Nanjing, and 45% in Shanghai, while the contributions from residential and transportation are the least, only having about 10% or less than 10% contributions. Agriculture is the second largest contributor to the total $PM_{2.5}$ mass throughout the year at both Nanjing and Shanghai, indicating that $NH_3$ plays a key role on the formation of sulfate, nitrate and ammonia aerosols. The contributions from power normally take up about 10% to the total $PM_{2.5}$ mass, with minor seasonal variation.

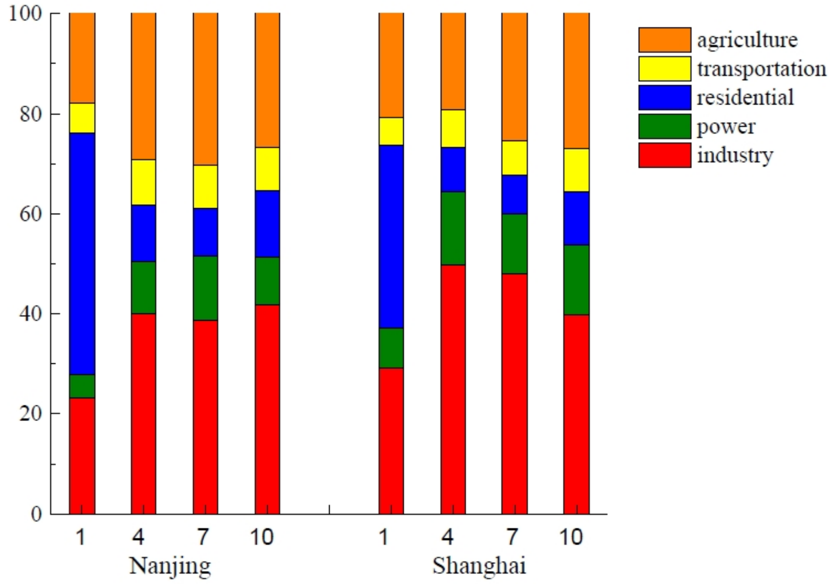


Fig. 3. The percentages of contribution from five sources in the MEIC10 inventory to the total $PM_{2.5}$ for four months at Nanjing and Shanghai. Unit: %.

## Conclusions

The emissions of five major sources to air pollutants gases and particular matter in Nanjing and Shanghai from MEIC10 inventory are firstly analyzed in this study, in order to understand the initial status of emission data and their impacts on the simulated $PM_{2.5}$ mass concentrations. It is found that industry contributes the most to PM and most gases in both cities, and power contributes more to NOx than industry at Shanghai, while agriculture dominates $NH_3$ emission. The modeled meteorology was then evaluated by comparing with the observations and overall showing a good agreement. The simulated seasonal variations of $PM_{2.5}$ are generally consistent with the observed, but the magnitudes are overall higher in the simulations. The impacts of emissions from different sources indicate a strong seasonal variability. In winter, the contribution from residential account for 49% and 37% to the total $PM_{2.5}$ mass in Nanjing and Shanghai, respectively. For other seasons, the contributions from industry are the most, while the contributions from residential and transportation are the least, Agriculture is the second largest contributor to the total $PM_{2.5}$ mass throughout the year at both Nanjing and Shanghai, indicating that $NH_3$ plays a key role on the formation of sulfate, nitrate and ammonia aerosols.

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## References

[1] Pope, C.A., 3rd, Burnett, R.T., Krewski, D., Jerrett, M., Shi, Y., Calle, E.E., Thun, M.J., 2009. Cardiovascular mortality and exposure to airborne fine particulate matter and cigarette smoke: shape of the exposure-response relationship. Circulation 120, 941-948.

[2] Cao, C., Jiang, W., Wang, B., Fang, J., Lang, J., Tian, G., Jiang, J., Zhu, T.F., 2014. Inhalable microorganisms in Beijing's PM2.5 and PM10 pollutants during a severe smog event. Environmental science & technology 48, 1499-1507.

[3] Chang, D., Song, Y., Liu, B., 2009. Visibility trends in six megacities in China 1973–2007. Atmospheric Research 94, 161-167.

[4] Gao, L., Jia, G., Zhang, R., Che, H., Fu, C., Wang, T., Zhang, M., Jiang, H., Yan, P., 2011. Visual Range Trends in the Yangtze River Delta Region of China, 1981–2005. Journal of the Air & Waste Management Association 61, 843-849.

[5] Che, W., Zheng, J., Wang, S., Zhong, L., Lau, A., 2011. Assessment of motor vehicle emission control policies using Model-3/CMAQ model for the Pearl River Delta region, China. Atmospheric Environment 45, 1740-1751.

[6] Li, L., Chen, C.H., Fu, J.S., Huang, C., Streets, D.G., Huang, H.Y., Zhang, G.F., Wang, Y.J., Jang, C.J., Wang, H.L., Chen, Y.R., Fu, J.M., 2011. Air quality and emissions in the Yangtze River Delta, China. Atmospheric Chemistry and Physics 11, 1621-1639.

[7] Ma, X, Jia, H., 2016. Particulate matter and gaseous pollutions in three megacities over China: Situation and implication. Atmos. Environ. 140, 476-494.

[8] Grell G A, Peckham S E, Schmitz R, et al. Fully coupled “online” chemistry within the WRF model[J]. Atmospheric Environment, 2005, 39(37):6957-6975.

[9] Emmons L K, Walters S, Hess P G, et al. Description and evaluation of the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4)[J]. Geoscientific Model Development, 2010, 3(1):43-67

[10] Zaveri, R.A., Peters, L.K., 1999. A new lumped structure photochemical mechanism for large-scale applications. Journal of Geophysical Research: Atmospheres 104, 30387-30415.

[11] Zaveri, R.A., Easter, R.C., Fast, J.D., Peters, L.K., 2008. Model for Simulating Aerosol Interactions and Chemistry (MOSAIC).Journal of Geophysical Research 113.

[12] Lin Y L. Bulk parameterization of the snow field in a cloud model[J]. Journal of Applied Meteorology, 1983, 22(6):1065-1092.

[13] Mlawer, E.J., Taubman, S.J., Brown, P.D., Iacono, M.J., Clough, S.A., 1997. Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave. Journal of Geophysical Research: Atmospheres 102, 16663-16682.

[14] Chou M D, Suarez M J. A solar radiation parameterization for atmospheric studies, NASA TM-104606[J]. Nasa Tech.memo, 1999, 15.

[15] Zhou, Y., Zhao, Y., Mao, P., Zhang, Q., Zhang, J., Qiu, L., Yang, Y., 2017. Development of a high-resolution emission inventory and its evaluation and application through air quality modeling for Jiangsu Province, China. Atmospheric Chemistry and Physics 17, 211-233.

[16] Liu, T., Li, T.T., Zhang, Y.H., Xu, Y.J., Lao, X.Q., Rutherford, S., Chu, C., Luo, Y., Zhu, Q., Xu, X.J., Xie, H.Y., Liu, Z.R., Ma, W.J., 2013. The short-term effect of ambient ozone on mortality is modified by temperature in Guangzhou, China. Atmospheric Environment 76, 59-67.

[17] Zhao, Y., Wang, S., Duan, L., Lei, Y., Cao, P., Hao, J., 2008. Primary air pollutant emissions of coal-fired power plants in China: Current status and future prediction. Atmospheric Environment 42, 8442-8452.

[18] Zheng, B., Huo, H., Zhang, Q., Yao, Z.L., Wang, X.T., Yang, X.F., Liu, H., He, K.B., 2014.High-resolution mapping of vehicle emissions in China in 2008. Atmospheric Chemistry and Physics 14, 9787-9805.

[19] Chan, C.K., Yao, X., 2008. Air pollution in mega cities in China. Atmos. Environ. 42, 1-42.

[20] Wang, L.T., Wei, Z., Yang, J., Zhang, Y., Zhang, F.F., Su, J., Meng, C.C., Zhang, Q., 2014. The 2013 severe haze over southern Hebei, China: model evaluation, source apportionment, and policy implications. Atmospheric Chemistry and Physics 14, 3151-3173.