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A Study of High Spatial Resolution Source Apportionment by Using CAMx-PSAT

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Abstract. The objective of this paper was to apply CAMx-PSAT to obtain the high spatial resolution source apportionment results of $PM_{2.5}$ in the city of Tangshan. By using this method, a detailed source region and emission category contribution is obtained in Tangshan. The source apportionment showed that the metallurgy industry was the biggest contribution source to $PM_{2.5}$, followed by the coal-fired boilers, vehicles and soil dust. The region analysis ranked the relative importance of source regions and emission categories. Fengnan, Kai Ping and Fengrui are the ones that have a large impact to the urban $PM_{2.5}$ concentration. The average concentration contribution ratios of $PM_{2.5}$ from Tangshan surrounding regions were calculated which were 31.1%, 24.7%, 15.1%, and 26.5% for January, April, July, and October, respectively.

Keywords: CAMx-PSAT, $PM_{2.5}$, source apportionment, high spatial resolution.

1. Introduction

$PM_{2.5}$ pollution has become a severe environmental challenge facing China in the past decades. It can not only make the sky ‘grey’ or ‘brown’, bring unpleased feelings, but also pose a great threat to the human heath due to its chemical composition [1]. The city of Tangshan is located on the northeast part of Hebei Province. The city has experienced rapid industrialization and urbanization processes in the past three decades, which has led to a dramatic increase of local air pollutant emissions and thus deteriorated local ambient air quality. In the 2013 annual air quality report released by the Ministry of Environmental Protection of China, the city of Tangshan was one of the top ten poorest air quality cities in China among a total of 74 reported cities [2]. The strictest air pollution control plan requires the city of Tangshan to reduce its annual average $PM_{2.5}$ concentrations by 33% in 2017 [3]. Currently, it is in their desperate need of $PM_{2.5}$ studies by the city of Tangshan for helping the municipal government achieve their Action Plan control targets.

As one of the effective tools for supporting $PM_{2.5}$ emission control strategy decision making, the source apportionment can identify the potential sources of $PM_{2.5}$. It has been widely used by the researchers and governments to help make the air pollutant emission control strategies. However, the previous studies have focused on very coarse resolution results, which only provided the source contributions from a specific region. In this study, Particulate Source Apportionment Technology (PSAT) was implemented in studying the high spatial resolution source apportionment results. It is possible not only to analyze the source contributions from emission categories, but also to provide the source contribution from different regions. It is expected that the high spatial resolution results obtained from this study will be useful for regional air quality management practices.

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2. Domain Setting and Model Configuration

2.1. Modeling Description

The 3D CAMx model is an Eulerian photochemical dispersion model. The Version 6.0 had been used in this study which released in 2013. The particulate source apportioning technology (PSAT) has been developed for CAMx to provide PM source apportionment. Sulfate, particulate nitrate, ammonium, particulate mercury, secondary organic aerosol, Six categories of primary PM can be apportion and traced in CAMx by PSAT [4].

The meteorological circulation was simulated by the Weather Research Forecast model (WRF, v3.3). The physical options used in this study include WRF single Moment 3-class microphysics scheme, RRTM (rapid radiative transfer model) long wave radiation scheme [5], Dudhia shortwave radiation scheme [6], NOAH land surface model [7], Yonsei University Planetary Boundary Layer scheme [8], and Kain-Fritsch cumulus parameterization scheme [9]. The initial and boundary conditions for the WRF simulation were prepared using the $1^{o}\times1^{o}$ resolution final global tropospheric analyses data (FNL) which was produced by NCEP's (National Centers for Environmental Prediction) Global Forecast System (GFS).

2.2. Model Application

In this study, a two-level nested-grid architecture (as shown in Fig. 1) was designed for the implementation of the coupled modeling system. The modeling domain 1 (i.e., Do1) was with a spatial resolution of 27 km. The modeling domain 2 (i.e., Do2) was with a spatial resolution of 9 km, which covers the Beijing-Tianjin-Hebei region and parts of its surrounding provinces (including the provinces of Shanxi, Shandong, Henan, Liaoning, and Inner Mongolia). The vertical dimension of CAMx simulation was divided into fourteen layers from the ground surface to planetary boundary layer (PBL). The corresponding sigma levels are 1.00000, 0.99300, 0.98300, 0.97000, 0.95400, 0.93400, 0.90900, 0.82958, 0.67830, 0.32385, 0.22827, 0.12129, 0.06938, and 0.00000. The CB05 (Carbon Bond Mechanism) was chosen as the gas-phase chemistry mechanism. The PPM (Piecewise Parabolic Method) and EBI (Euler Backward Iterative chemistry solver) were chosen as the horizontal advection solver and gas phase chemistry solver, respectively. The original data in the emission inventories were provided by various environmental protection bureaus in the Beijing-Tianjin-Hebei region. Extensive efforts have been performed to process the raw emission data to make the data adequate and in right formats as the inputs for the CAMx-PSAT simulation. The emission inventories of other provinces outside the Beijing-Tianjin-Hebei region came from the MEIC (Multi-resolution Emission Inventory for China) which was developed by Tsinghua University [10]. The simulation period was January, April, July, and October of 2013. In this study, each sampling period was used to represent a specific season of a year in some occasions, i.e., July for summer, October for fall, January for winter and April for spring.

PSAT methodology is designed $PM_{2.5}$ components are attributed to different source groups, and geographical regions. Urban regions are always the places related with high population density. It’s very meaningful to look at the source apportionment at urban regions. So the urban region (i.e. Lunan, Lubei, Kaiping) are used as receptor regions. The source regions are defined based on their geographic borders, which consist of Lunan, Lubei, Kaiping, Guye, Fengnan, Fengrun, Luanxian, Qianan, Tanghai, Luanan, Leting, Yutian, Zunhua and Qianxi (as shown in Fig. 2). In this study, the source groups were divided into metallurgical industry, cement production, vehicle, coal-fired boiler, power plants, and others emission source.

2.3. Model Verification

In this study, the normalized mean bias (NMB) and normalized mean gross error (NME), were used to assess the performance of the CAMx-PSAT simulation [11]. The simulated monthly concentrations of $PM_{2.5}$ were compared with the monitoring data collected from the monitoring stations for each target month. The model verification results are presented in Table 1.

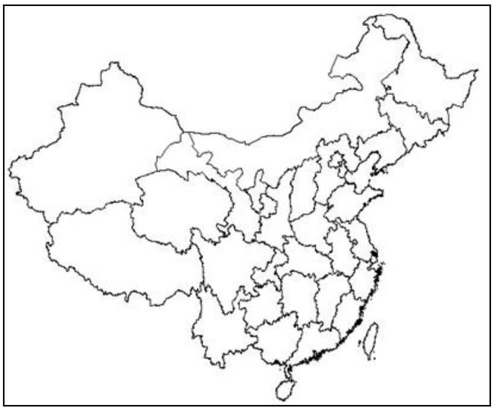

Fig. 1: Two –level nested modeling domain system

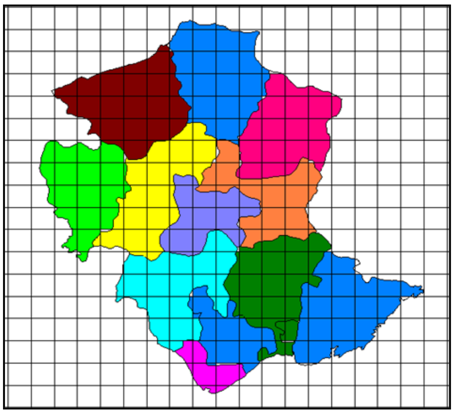

Fig. 2: Source regions setting of PSAT

Table 1: Comparison of simulated results with observation data

Species	Statistical Performance	January	April	July	October
$PM_{2.5}$	Mean sim($\mu g/m^3$)	219.07	56.35	67.64	84.80
	Mean obs($\mu g/m^3$)	214.11	78.88	77.07	96.21
	NMB(%)	2.32	-28.55	-12.23	-11.86
	NME(%)	42.19	43.2	31.9	32.21

Table 1 gives the statistical results through comparing the simulated and monitored 24h average concentrations of $PM_{2.5}$. Specifically, the NMB values for the simulation of $PM_{2.5}$ were 2.32%, -28.55%, -12.23%, and -11.86%. The NME values from the simulation were generally large. The uncertainties might be from: (1) emission inventories could be highly uncertain at individual sites, which would affect the accuracy of simulation results; (2) the uncertainties associated with the meteorology simulation could also affect the results. Comparing with other related studies, the simulation results in this study were acceptable [12]-[14]. CAMx simulations result can be used for further source apportionment analysis.

4. Results and Discussion

4.1. Source Apportionment of $PM_{2.5}$

Based on the CAMx-PSAT simulating results, the source apportionment results for the $PM_{2.5}$ at TANGSHAN could be obtained, as shown in Fig. 3. Among all the identified sources, the metallurgy industry was the biggest contribution source to $PM_{2.5}$, with an annual average contribution of 24.31%, followed by the coal-fired boilers (12.20%), soil dust (13.16%) and vehicles (11.14%). Other methods had been applied in Tangshan for $PM_{2.5}$ source apportionment. The metallurgy industry and cement production emission contributions to the $PM_{2.5}$ were 22.6% and 8.4% in pervious study [15]. The contribution of other-source category to $PM_{2.5}$ was still largest, and these other sources included non-specified sources such as agricultural activities, biomass combustion, residential emissions, et al. In spring, soil dust always plays a major role in contributing to local $PM_{2.5}$ level due to more windy days in spring. The contribution of vehicles to $PM_{2.5}$ at TANGSHAN was 11.14%. The annual average vehicles emission contribution to $PM_{2.5}$ in Beijing was 22.5% [16]. Comparing with Beijing, the stationary pollution was the main source to $PM_{2.5}$ in Tangshan.

Table 2: Source apportionment results of $PM_{2.5}$ at Tangshan (%)

	Soil Dust	Metallurgical Industry	Vehicles	Power Plants	Coal-fired Boiler	Cement Production	Other Sources
Spring	19.95	22.91	12.72	7.34	9.68	6.38	21.02
Summer	10.70	26.33	10.43	10.33	13.78	7.79	20.65
Autumn	13.44	23.29	11.04	7.60	10.55	8.12	25.96
Winter	8.55	24.70	10.39	10.15	14.77	9.59	21.84
Annual	13.16	24.31	11.14	8.86	12.20	7.97	22.37

4.2. High Spatial Resolution Source Apportionment Results

In this study, the analysis for high spatial resolution source apportionment results was performed by CAMx-PSAT. The high spatial resolution source apportionment results could provide the local authorities the useful information and scientific bases to identify the major $PM_{2.5}$ contribution sources in the city, and thus sound decisions could be made to better control the $PM_{2.5}$ pollution. Fig. 3 lists annual high spatial resolution results of $PM_{2.5}$ in Tangshan.

Urban is more affected by the adjacent regions, especially FengNan, FengRun, Kai Ping, Gu Ye, are the ones that have a large impact. Several possible reasons cause the high percentage contribution. Firstly, the distance from urban is close, leading to large regional impact. Secondly local emission is large. Feng Nan is one of the major emission source regions in the TANGSHA. The metallurgical production contribution was 7.75%.The coal-fired boiler and metallurgical industry form KaiPing is also strongly affected urban $PM_{2.5}$ concentration, which contribution were 3.65% and 5.22% respectively. The FengRun was the third largest contribution source contribution region. It's coal-fired and power plant contribution were 2.38% and 3.25%. The industry category form surrounding countires have large contribution percentage. However in urban, contributions from vehicle and soil dust are domain emission category which contribution to $PM_{2.5}$ are about 2.49 % and 2.36%.

Overall, the urban need further control management to reduce vehicle and soil dust emission. For the suburb region need pay more attention to manage industrial emission source. Reductions on this two emission types could potentially see larger reduction in $PM_{2.5}$ concentration.

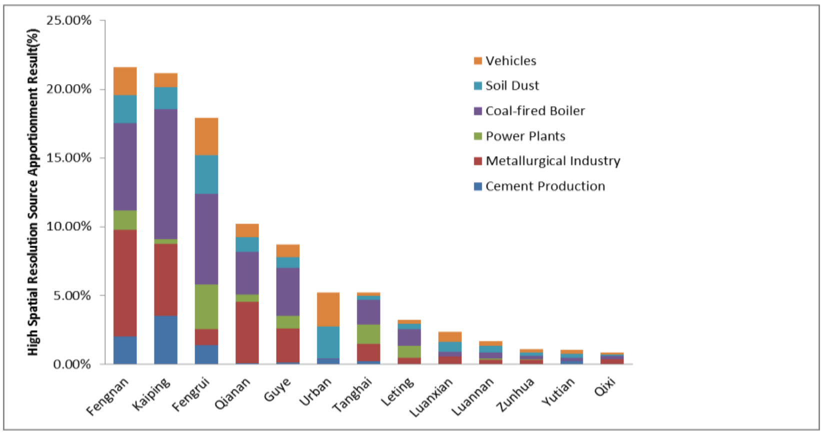

Fig. 3: Source apportionment results of $PM_{2.5}$ at Tangshan (%)

4.3. Region Transport for Surrounding Region

The monthly average contributions to $PM_{2.5}$ from Tangshan surrounding regions were calculated. It can be found that significant monthly variations of the contribution ratios exist for each month. It can be found that the monthly average emission contribution ratios from all of Beijing's surrounding regions were 31.1%, 24.7%, 15.1%, and 26.5% for January, April, July, and October, respectively. The annual average concentration contribution ratios of $PM_{2.5}$ from Tangshan surrounding regions were 24.35%. The trans-boundary transport from TANGSHAN's surrounding regions had a much higher contribution ratio in January as compared to the three other months. In this paper, the MICAPS (Meteorogical Information Comprehensive Analysis and Processing System) data were calculated the prevailing wind direction of TANGSHAN in each month. In winter, North China is mainly under the control of Siberian cold high pressure, the prevailing wind direction is northwest. In this case, the $PM_{2.5}$ transport is mainly from the Hebei, Tianjin and Beijing where there has a higher $PM_{2.5}$ emission. In summer, it is mainly under the control of temperate oceanic air mass. The prevailing wind directions are south and southwest. But the east of Tangshan has lower $PM_{2.5}$ emission where located BOHAI sea. However, in spring and autumn, the wind directions are relative even, resulting in the intermediate level of $PM_{2.5}$ transport boundary contribution ratios between summer and winter. The control of $PM_{2.5}$ pollution needs coordinated efforts in TANGSHAN and its surrounding region.

5. Conclusions

In this study, CAMx-PSAT modeling approaches were used to deal with the source apportionments of $PM_{2.5}$ for the city of Tangshan. By using this technology, it is possible not only to simultaneously analyze the source contributions, but also to provide the relative importance of different source regions and emission categories. It is the first time the regional air quality model has been used to study the apportionment of both emission category and source region for $PM_{2.5}$ in this region. From the results of this study, emission control strategy from local government can have a large effect on the reduction of $PM_{2.5}$ concentrations in the region.

The source apportionment results show that the metallurgy industry was the biggest contribution source to $PM_{2.5}$ followed by the coal-fired boilers, soil dust and vehicles. The industry emission form surrounding suburb region have larger impact on urban $PM_{2.5}$ contribution, while the soil dust and vehicle are domain emission category in urban. The annual average concentration contribution ratios of $PM_{2.5}$ from Tangshan surrounding regions were 24.35%. The high resolution source apportionment results could help the local government make regulations to control $PM_{2.5}$ pollution. Meanwhile for further reduction, cooperation and prioty control between different regions should be taken into account.

6. References

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