Supplementary Information

Source Apportionment of $PM_{2.5}$ in a Chinese Megacity During Special Periods: Unveiling Impacts of COVID-19 and Spring Festival

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Text S1

Figure S1-S5

Table S1-S3

Text S1. Detailed description of chemical analysis and quality assurance/quality control (QA/QC)

OC and EC were analysed based on a hole with 0.588 cm^2 of the quartz filter. OC_1, OC_2, OC_3, and OC_4 were sequentially measured in pure helium at 140 ℃, 280 ℃, 480 ℃, and 580 ℃. Subsequently, EC_1, EC_2, and EC_3 were analyzed in a 2% O_2 atmosphere at 540℃, 780℃, and 840℃, respectively. The organic pyrolyzed carbon (OPC) would also be detected after adding oxygen. Finally, the OC and EC concentrations were calculated as Eq. (S1) and Eq. (S2), respectively.

$$OC = OC_1 + OC_2 + OC_3 + OC_4 + OPC \quad \text{(S1)}$$

$$EC = EC_1 + EC_2 + EC_3 - OPC \quad \text{(S2)}$$

To determine ion concentrations (F^-, Cl^-, NO_3^-, SO_4^{2-}, Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}), Teflon membranes were analyzed by ion chromatography. Samples were ultrasonicated for 30 minutes in 10 mL deionized water within beakers pre-cleaned vis ultrasonication (three times). The supernatant was then filtered (0.22 μm) into vials for IC analysis. Method reliability was assessed through computational ion chromatography, evaluating the cation-anion charge balance. Results showed excellent agreement (R^2 = 0.98) between total cation and anion charge concentrations, with a cation-to-anion slope ratio near 1.02.

For elemental analysis, the concentrations of 26 metals (Na, K, Ca, Mg, Al, Fe, V, Ti, Mn, Co, Ni, Cr, Cu, Zn, Mo, Ba, Cd, Pb, Tl, Th, As, Se, P, Sr, Bi and U) were subjected to analysis via inductively coupled plasma mass spectrometry. A mixed digestion solution was added to digest sample pieces, afterwards the digestion

solution would be transferred into a PET bottle, and the solution to 25ml with deionized water for further analysis.

Strict Quality Assurance/ Quality Control measures (QA/QC) were implemented throughout the entire analytical process. Quartz filters were calcined in a muffle furnace at 550°C for 5 hours prior to removing background carbonaceous substances. Teflon filters were balanced for 24 hours under constant temperature (21±1 °C) and humidity conditions (45±5%) in a laminar flow hood before weighing. Collected samples were stored wrapped in a layer of aluminium foil in a freezer at -20 °C until weighing and analysis. Before sampling, flow calibration was performed on the sampling instrument, and blank sample analysis was conducted prior to formal sampling procedures. Blank filter mass differences (-3 to 20 μg) indicated minimal contamination. Blank OC levels (3.5-8.5 μg C) and near-zero EC confirmed low carbon interference. Analysis of ions in blank samples shows low background concentrations (0 - 0.4 mg L^{-1}), confirming that ultrapure water, syringes, and filter tips used in the extraction process met analytical requirements. Quality control measures included multi-point calibration curves (with correlation coefficients exceeding 0.999) for OC/EC and ion analyses. Spike recovery tests for elemental determinations demonstrated satisfactory recovery rates within acceptable error margins. Furthermore, the sum of the component-derived $PM_{2.5}$ concentrations will be compared with the gravimetrically determined $PM_{2.5}$ mass concentration, as shown in Figure S5 to ensure the validity of the sample analysis.



Figure S1. Location of the sampling site.

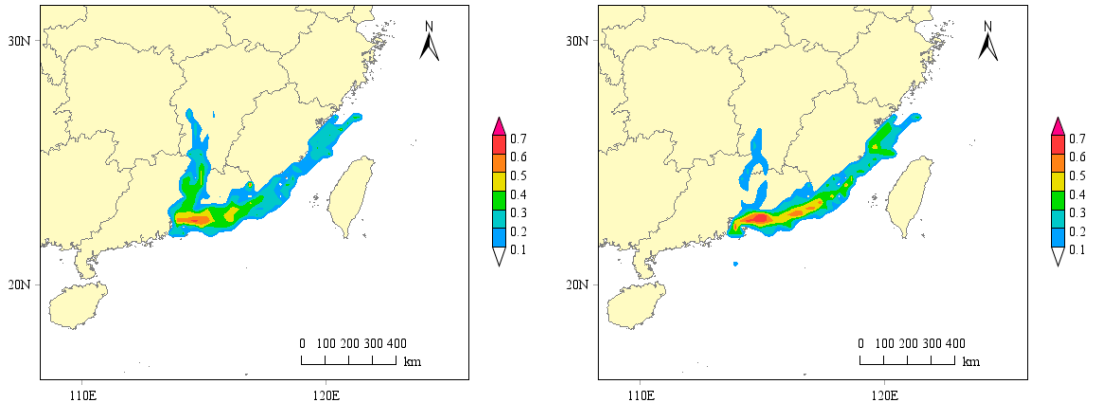


Figure S2. The Potential Source Contribution Function (PSCF) results of secondary sulfate (left) and aged sea salt (right).

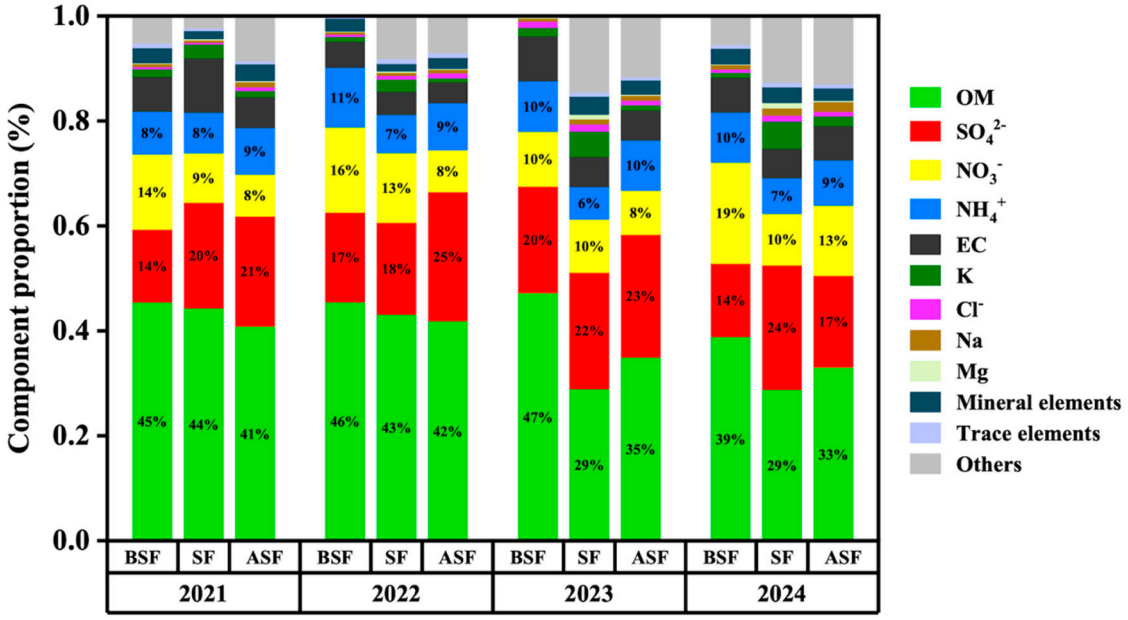


Figure S3. The proportion of $PM_{2.5}$ components during the BSF, SF and ASF periods from 2021 to 2024 in Shenzhen.

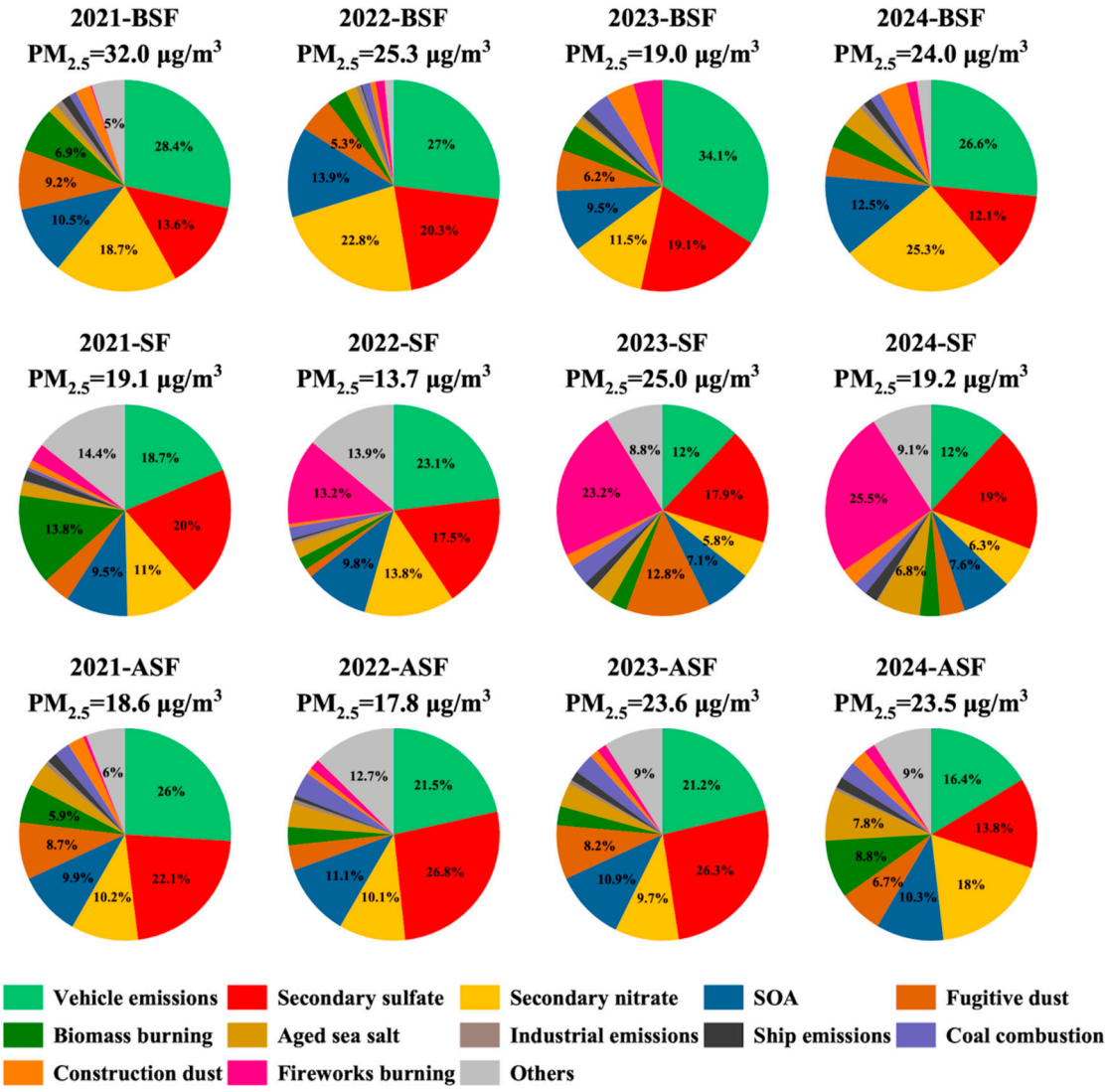


Figure S4. $PM_{2.5}$ source contributions during the BSF, SF and ASF periods from 2021 to 2024 in Shenzhen.

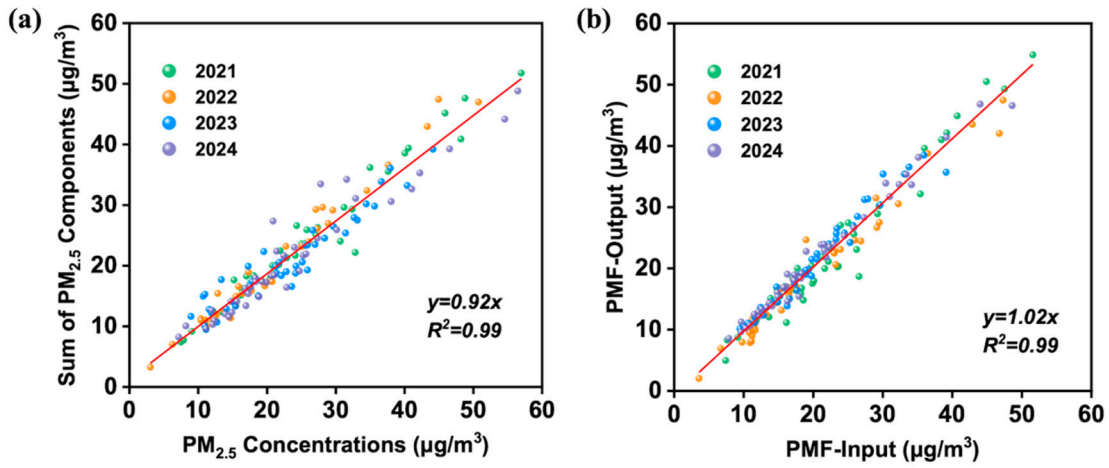


Figure S5. Data quality assessment: (a) Comparison between gravimetric $PM_{2.5}$ concentrations and reconstructed component concentrations; (b) Comparison of input and output mass of $PM_{2.5}$ concentrations in the PMF model. (red solid line: linear fit curve)

Table S1. Error estimation summary results for the 11 solutions

DISP Diagnostics												
Error Code:	0											
%dQ:	-1.06											
Swaps by Factor:	0	1	0	0	0	1	0	0	0	0	0	
BS Mapping												
	Base Factor 1	Base Factor 2	Base Factor 3	Base Factor 4	Base Factor 5	Base Factor 6	Base Factor 7	Base Factor 8	Base Factor 9	Base Factor 10	Base Factor 11	Unmapped
Boot Factor 1	100	0	0	0	0	0	0	0	0	0	0	0
Boot Factor 2	0	87	0	0	1	1	5	0	0	0	6	0
Boot Factor 3	0	0	100	0	0	0	0	0	0	0	0	0
Boot Factor 4	0	0	0	99	0	0	0	0	0	0	1	0
Boot Factor 5	0	3	0	7	84	0	4	1	0	0	1	0
Boot Factor 6	0	8	1	4	2	75	6	0	0	0	4	0
Boot Factor 7	0	0	0	0	0	0	100	0	0	0	0	0
Boot Factor 8	0	0	1	1	0	1	1	94	0	0	2	0
Boot Factor 9	0	0	0	0	0	0	0	0	100	0	0	0
Boot Factor 10	0	0	0	0	0	0	0	0	0	100	0	0
Boot Factor 11	0	1	0	0	0	0	0	0	0	0	99	0

Table S2. Mean values of major meteorological parameters, January to March 2021–2024

Time		Temperature（°C）	Precipitation（mm）	Relative humidity（%）	Wind speed（m/s）	Prevailing wind direction
2021	January	15.6	0	54.4	1.0	ENE
	February	19.5	55.7	69.4	0.9	NNW
	March	21.9	16.7	74.5	1.1	NNW
	Average	19.0	24.1	66.1	0.9	/
2022	January	17.8	7.7	68.8	0.9	NNE
	February	14.2	37.1	71.0	0.9	NE
	March	21.9	42.4	67.8	0.9	N
	Average	18.0	29.1	69.2	0.9	/
2023	January	15.8	4.9	61.3	1.0	ENE
	February	19.0	0.7	62.7	1.0	N
	March	21.1	83.7	63.9	1.0	N
	Average	18.6	29.8	62.6	1.0	/
2024	January	17.1	2.2	60.9	0.9	ENE
	February	18.7	1.7	66.7	1.0	N
	March	20.9	14.5	67.0	1.1	N
	Average	18.9	6.2	64.9	1.0	/

(Wind direction is abbreviated as the 16th cardinal direction)

Table S3. Comparison of $PM_{2.5}$ Sources: BSF vs. SF (Independent Samples t-tests)

Source	BSF	SF	*t*	*p*
Vehicle emission	7.40±4.40	3.01±2.60	5.96	<0.001*
Secondary nitrate	5.43±4.65	1.66±1.55	5.76	<0.001*
SOA	3.08±2.09	1.61±0.83	4.81	<0.001*
Fugitive dust	1.74±1.78	1.20±1.82	1.34	0.186
Industrial emissions	0.22±0.19	0.04±0.04	7.64	<0.001*
Construction dust	0.73±0.48	0.31±0.24	5.34	<0.001*

*indicates a statistically significant difference($p < 0.05$)