Supplemental Material

Evolution and meteorological causes of fine particulate explosive growth events in Beijing, China, from 2013 to 2017

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This file includes:
Supplementary Text, Figures S1–S2 and Table S1

1. Instruments and operation

1.1 Aerosol mass concentration, gaseous species, and meteorological parameters

PM\textsubscript{2.5} mass concentrations (aerodynamic particle size less than or equal to 2.5 μm) were measured using a tapered element oscillating microbalance (TEOM 1405-DF, Thermo Scientific, USA) with a Filter Dynamic Measurement System. The FDMS-TEOM is designed to measure mass concentrations of ambient particulate matter at 30°C and thus provide information on volatile (at 30°C), non-volatile, and total aerosol mass concentrations (Grover
et al. 2005). The minimum detection limit of the instrument is 0.06 μg m\(^{-3}\) h\(^{-1}\), with a mass resolution of 0.10 μg m\(^{-3}\) and an accuracy of ±1.50 μg m\(^{-3}\) h\(^{-1}\).

Trace gas pollutants (SO\(_2\), CO, NO\(_2\), and O\(_3\)) were monitored using Thermo Scientific™ i-series gas analyzers. NO\(_2\) was measured using a chemiluminescence NOx analyzer (Model 42i, Thermo-Fisher Scientific, USA), the minimum detection limit of which is 0.5 μg m\(^{-3}\), with an accuracy of ± 0.4 × 10\(^{-9}\) μg m\(^{-3}\). O\(_3\) was measured using a UV photometric O\(_3\) analyzer (Model 49i, Thermo-Fisher Scientific, USA), the minimum detection limit of which is 2 μg m\(^{-3}\), with an accuracy of ± 1 × 10\(^{-9}\) μg m\(^{-3}\). SO\(_2\) was measured using a pulsed fluorescence SO\(_2\) analyzer (Model 43i, Thermo-Fisher Scientific, USA), the minimum detection limit of which is 5.7 μg m\(^{-3}\), with an accuracy of ± 1 × 10\(^{-9}\) μg m\(^{-3}\). CO was measured with a nondispersive infrared analyzer (Model 48i, TE), the minimum detection limit of which is 0.04 μg m\(^{-3}\), with an accuracy of ± 1 × 10\(^{-9}\) μg m\(^{-3}\). The installation and maintenance of the above instruments were performed in accordance with China National Environmental Monitoring Center specifications, as described in our previous study (Xin et al. 2015).

Meteorological variables, including temperature (T), relative humidity (RH), pressure (P), wind speed (WS), and wind direction (WD), were measured simultaneously by automatic meteorological observation instruments (Vaisala, Milos 520, Finland) installed on the roof of the same building. In addition, in order to eliminate the influence of buildings on the wind, this study selected the 120-m WD of the 325-m meteorological observation tower and 8-m WS as references. All data in this study are based on Beijing time (UTC + 8).

1.2 Quality assurance and quality control
TEOM 1405-DF and Thermo Scientific™ i-series gas analyzers are installed in a specially designed observation box with air conditioning to keep the temperature inside the box at 26°C. The instrument sampling tube is wrapped with an insulating pipe, so that the gas production is not affected by the air conditioning in the box. The R&P TEOM 1405DF is equipped with a gas–water separator, and other instruments use a silica gel tank to filter water vapor. During the R&P TEOM 1405DF observation period, the possibility of instrument malfunction was checked every day, and the separator filter and silica gel were checked regularly to eliminate the potential for instrument failure and calibrate the instrument once a month. For FDMS-TEOM, a monthly flow rate check and leak check were performed. The original data record is the average value of 5 min. The data used in the paper are the hourly average after quality control. The data quality control was based on a zero-point inspection each month and multi-point calibration results of the calibration instrument, and the original data were corrected according to the daily operation of the instrument, and then the mean and daily mean values were calculated (Xin et al. 2015).

The study is based on the analysis of the monitoring data of particulate matter from 2013 to 2017. The total observation time is 1826 days, 43 824 hours, except during instrument failure and regular maintenance of the instrument (calibration, cleaning, etc.), when the instrument stopped running. The effective hourly data of PM$_{2.5}$ accounted for 98% of the total hourly data; the effective hourly data of gaseous precursors accounted for 91% of the total hourly data; and the effective hourly data of meteorological parameters (WS, WD, T, RH) accounted for 99% of the total hourly data. Effective data of 120-m WD hours accounted for 96% of all hours.
References
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Figure S1. Yearly and seasonal variation of PM$_{2.5}$ and gaseous precursors in Beijing during 2013–2017.
Figure S2. Radar chart of wind direction–velocity–PM$_{2.5}$ mass concentration for four months (January, February, November, December) of 6-h events.
Table S1. Yearly and seasonal mean values of gaseous precursors and meteorological elements for FPEG events from 2013–17.

| Year | CO  | NO₂ | O₃  | SO₂ | T  | RH  | P    | WD  | WS  | PM₂.₅ |
|------|-----|-----|-----|-----|----|-----|------|-----|-----|-------|
| 2013 |     |     |     |     |    |     |      |     |     |       |
| 3h   | 3.2 | 93.5| 33.1| 36.1| 9.7| 55.8| 1010.9| 178.4| 1.5 | 152.5 |
| 6h   | 1.7 | 82.0| 48.2| 31.8| 14.4| 45.1| 1007.2| 156.5| 0.9 | 165.4 |
| 9h   | 1.8 | 88.5| 22.6| 43.6| 7.8 | 39.2| 1016.5| 173.8| 1.0 | 139.5 |
| 3h   | 3.0 | 119.1| 19.7| 72.7| 8.0 | 46.6| 1017.0| 125.9| 1.1 | 165.1 |
| 2014 |     |     |     |     |    |     |      |     |     |       |
| 6h   | 1.4 | 65.6| 29.2| 32.7| 8.1 | 29.4| 1016.9| 189.8| 1.5 | 126.0 |
| 9h   | 1.7 | 96.6| 28.9| 39.2| 10.4| 34.3| 1014.1| 144.0| 1.0 | 136.3 |
| 3h   | 1.6 | 66.0| 48.3| 39.5| 7.1 | 33.7| 1017.7| 163.3| 1.2 | 142.1 |
| 2015 |     |     |     |     |    |     |      |     |     |       |
| 6h   | 3.0 | 103.7| 47.7| 18.5| 9.3 | 47.1| 1013.0| 152.3| 1.0 | 179.4 |
| 9h   | 1.8 | 74.0| 62.2| 19.9| 14.9| 51.2| 1011.2| 163.6| 1.0 | 129.7 |
| 3h   | 2.1 | 95.5| 12.3| 23.1| 5.7 | 31.9| 1018.8| 134.5| 1.4 | 134.7 |
| 2016 |     |     |     |     |    |     |      |     |     |       |
| 6h   | 2.7 | 94.4| 34.0| 16.8| 8.9 | 42.0| 1012.9| 154.6| 1.1 | 152.3 |
| 9h   | 2.0 | 83.4| 60.5| 22.6| 13.8| 41.8| 1010.2| 149.2| 0.9 | 141.4 |
| 3h   | 1.0 | 70.1| 110.0| 4.7 | 12.1| 55.8| 1010.5| 186.7| 0.4 | 109.6 |
| 2017 |     |     |     |     |    |     |      |     |     |       |
| 6h   | 1.2 | 76.8| 64.8| 10.1| 12.2| 42.5| 1017.0| 157.6| 1.1 | 111.5 |
| 9h   | 1.3 | 59.9| 105.0| 18.3| 22.2| 39.6| 1005.2| 118.7| 1.5 | 116.2 |