Analysis of the Formation and Dissipation Process of a Dust-Influenced Heavy Air Pollution Episode in North China (Postprint)

Authors: Zhang Yaru, Chen Yongjin, Liu Yongfang

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Abstract

Air quality is critical to public health and the quality of living environments, and the frequent occurrence of air pollution in recent years has aroused widespread public concern. Effective air pollution governance necessitates a clear understanding of its formation and dissipation processes, as well as influencing factors, to enable targeted remediation measures. This study examines the formation and dissipation processes of a large-scale severe air pollution event that occurred in North China from May 4 to 5, 2017. By collecting data on major air pollutant concentrations, AQI (Air Quality Index), and routine meteorological parameters from nine cities in North China, we analyzed the variation characteristics of AQI and major pollutants (PM10, PM2.5, SO2, NO2, CO, O3) and their relationships with relevant meteorological factors. The results demonstrate that this heavy pollution event was essentially caused by regional dust pollution. The pollution process exhibited characteristics of rapid formation and abrupt dissipation. The primary pollutant during this event was PM10, followed by PM2.5, while concentrations of pollutants generated by human activities, such as SO2, NO2, CO, and O3, did not exceed established standards. Backward trajectory analysis and correlation analysis revealed that the particulate matter causing this severe pollution originated primarily from the Mongolian Plateau, with wind serving as the main driving factor. When pollutants were transported between cities with relatively close spatial proximity, they demonstrated consistent trends, temporal lag, and cumulative characteristics in pollutant concentrations.

Full Text

Preamble

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Authors: ZHANG Ya-ru, CHEN Yong-jin, LIU Yong-fang, LIU Zhi-yuan, LIU Yong-chang, SUN Tong
Affiliation: School of Environment and Planning, Liaocheng University, Liaocheng 252059, Shandong, China

Abstract

Air quality has been widely concerned for its great influences on people' s health as well as the quality of their living environment. The more frequent and severe atmospheric pollution occurred in North China has brought lots of worries and concerns. To curb atmospheric pollution, we should have a clear understanding of its formation, dissipation process and its influencing factors. Based on data of pollutants (PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3), AQI (air quality index), and meteorological data of 9 cities (Beijing City, Tianjin City, Langfang City, Shijiazhuang City, Baoding City, Xingtai City, Cangzhou City, Dezhou City, Handan City) collected from Chinese Meteorologic website, using research methods of Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) and Principal Component Analysis (PCA), we chose a severe atmospheric pollution happened from May 4 to May 5, 2017 in North China as an example to discuss the variations in pollutant concentration, the source and transportation of pollutants, meteorologic factors that governed the pollution. The results show as follows: (1) the pollutant of PM_{10} was the major pollutant, and it was exogenous, the pollutants such as SO_2, NO_2 that related closely to human activities remained at a low level. Sand dust weather was the meteorological condition for the heavy pollution in North China. The transport channel of pollutants was the Northwest Airflow resulted from the cold anticyclone in Mongolia Plateau. (2) This atmospheric pollution was very serious, which has great influence on the region. The concentration of PM_{10} was as high as 1000 $g \cdot m^{-3}$ in all of the 9 cities, and lasted over 20 hours. (3) Under the influence of sand dust weather, the processes of formation and dissipation of pollution presented the characteristics of forming sharply and dissipating rapidly. (4) Under the influence of the northwest airflow, the cities in the north and west of this region were affected by sand dust earlier than those in the south and east. In addition, the concentration of pollutants in cities with close spatial locations showed obvious consistent trend and time lag, as well as the characteristics of pollutant accumulation.

Keywords: heavy atmospheric pollution; correlation analysis; PM_{10}; North China; backward trajectory analysis

1. Data and Methods

Based on pollutant monitoring data (PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3) and meteorological data from nine cities in North China, this study employs the

HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory Model) developed by NOAA and principal component analysis (PCA) to investigate a severe pollution event that occurred on May 4–5, 2017. The HYSPLIT-4 model utilizes meteorological field data from the Global Data Assimilation System (GDAS) to simulate air mass trajectories and pollutant transport pathways. Principal component analysis was applied to meteorological factors including wind speed, temperature, and atmospheric pressure to identify the dominant factors influencing AQI variations.

2. Results and Analysis

2.1 Pollutant Concentration Characteristics During the pollution event, PM_{10} concentrations exhibited dramatic temporal variations. On May 4, hourly PM_{10} concentrations in most cities exceeded 1000 $g \cdot m^{-3}$, with peak values reaching 445 $g \cdot m^{-3}$ in some locations. The pollution persisted for over 29 hours in several cities. $PM_{2.5}$ showed similar temporal patterns to PM_{10}, though with lower absolute concentrations. The ratio of PM_{10} to $PM_{2.5}$ averaged 0.435 across the nine cities, with hourly values ranging from 0.243 to 0.278, indicating that coarse particulate matter dominated during this dust event.

SO_2 and CO concentrations remained relatively low throughout the event, with average concentrations of 150 $g \cdot m^{-3}$ and 10 $mg \cdot m^{-3}$ respectively, both below national ambient air quality standards. NO_2 and O_3 concentrations peaked during specific periods (May 4, 3:00–May 5, 19:00), reaching 200 $g \cdot m^{-3}$ and 160 $g \cdot m^{-3}$ respectively, but showed strong negative correlation with PM_{10} concentrations ($r = -0.874$, $p < 0.01$).

[Figure 1: see original paper]

2.2 Meteorological Factor Analysis Principal component analysis of meteorological variables yielded three main components explaining 95.03% of the total variance. The first principal component (F_1) was primarily associated with wind speed (loading = 0.970), representing dynamic transport conditions. The second component (F_2) correlated strongly with atmospheric pressure (loading = 0.941), reflecting synoptic-scale weather systems. The third component (F_3) showed moderate loadings on temperature and pressure, representing thermal-dynamic processes.

Wind field analysis revealed that average wind speeds ranged from 2–4.6 $m \cdot s^{-1}$ during the event, with predominant directions from north, northwest, west, and southwest sectors. The 72-hour backward trajectories calculated at 500 m, 1000 m, and 1500 m altitudes consistently indicated that air masses originated from the northwest, transporting dust from the Mongolian Plateau.

[Figure 2: see original paper]
[Figure 3: see original paper]
[Figure 4: see original paper]

2.3 Inter-city Pollution Correlation Spearman correlation analysis based on PM_{10} concentrations showed significant spatial correlations among geographically proximate cities. Beijing, Tianjin, and Langfang exhibited strong positive correlations ($r > 0.6$, $p < 0.01$), while more distant cities showed weaker correlations. The correlation coefficients decreased with increasing inter-city distance, demonstrating the regional nature of dust pollution transport.

3. Discussion

Under the influence of dust storms, the formation and dissipation processes of this pollution event exhibited distinct characteristics. The rapid onset was driven by strong northwest winds associated with a cold anticyclone over the Mongolian Plateau, while dissipation occurred quickly as the synoptic system moved eastward. Cities in the northwestern part of the study region experienced pollution earlier than southeastern cities, with clear time-lag effects observed in the pollution peaks.

The analysis reveals that dust weather represents a critical meteorological condition for severe pollution episodes in North China. The consistency in pollution trends among spatially adjacent cities underscores the importance of regional joint prevention and control strategies. The exogenous nature of PM_{10} during this event, combined with low concentrations of anthropogenic pollutants (SO_2, NO_2), confirms that natural dust sources dominated.

References

[1] CHEN Yuehao, GAO Qingxian, GAO Wenkang, et al. Quantitative research on sandstorm effects on environmental air quality[J]. Research of Environmental Sciences, 2013, 26(4): 364-369.

[2] KHANISABADI Yusef Omidi, DARYANOOSH Seyed Mohammad, AMRANE Abdeltif, et al. Impact of middle eastern dust storms on human health[J]. Atmospheric Pollution Research, 2016.

[3] ZHANG Baolin, ZHANG Jingxia, GUO Shuai. Effects of aeolian dust on air quality in Hohhot[J]. Environmental Science & Technology, 2017, 40(6): 165-170.

[4] ZHANG Hengde, LÜ Mengyao, ZHANG Bihui, et al. Analysis of the stagnant meteorological situation and the transmission condition of continuous heavy pollution course from February 20 to 26, 2014 in Beijing-Tianjin-Hebei[J]. Acta of Meteorology and Environment, 2007, 23(2): 21-24.

[5] ZHOU Zhaoyuan, ZHANG Shihuang, GAO Qingxian, et al. Analysis of synoptic characteristics of heavy pollution in Tianjin based on weather background[J]. Acta Scientiae Circumstantiae, 2017, 37(10): 3906-3917.

[6] ZHAO X J, ZHAO P S, XU J, et al. Analysis of a winter regional haze event and its formation mechanism in the North China Plain[J]. Atmospheric

Chemistry and Physics, 2013, 13(1): 903-1286.

[7] CAI Ziying, HAN Suqin, WANG Jing, et al. Analysis of synoptic characteristics of heavy pollution in Tianjin based on weather background[J]. Acta Scientiae Circumstantiae, 2017, 37(10): 3906-3917.

[8] REN Guoyu, XU Weili, et al. Climatic controls of dust storm events in northern China[J]. Arid Land Geography, 2011, 34(3): 429-435.

[9] ZHANG Ya-ru, CHEN Yong-jin, LIU Yong-fang, et al. Formation and dissipation processes of severe atmospheric pollution in north China under the influence of dust[J]. Arid Land Geography, 2018, 41(6): 1187-1195.

[10] ZHANG Hengde, et al. Analysis of the stagnant meteorological situation and the transmission condition of continuous heavy pollution course[J]. Environmental Science & Technology, 2016, 36(12): 4340-4351.

[11] ZHOU Zhaoyuan, ZHANG Shihuang, GAO Qingxian, et al. Analysis of synoptic characteristics of heavy pollution in Tianjin based on weather background[J]. Acta Scientiae Circumstantiae, 2017, 37(10): 3906-3917.

[12] ZHANG Ya-ru, CHEN Yong-jin, LIU Yong-fang, et al. Formation and dissipation processes of severe atmospheric pollution in north China under the influence of dust[J]. Arid Land Geography, 2018, 41(6): 1187-1195.

[13] ZHANG Hengde, LÜ Mengyao, ZHANG Bihui, et al. Analysis of the stagnant meteorological situation and the transmission condition of continuous heavy pollution course from February 20 to 26, 2014 in Beijing-Tianjin-Hebei[J]. Acta of Meteorology and Environment, 2007, 23(2): 21-24.

[14] ZHOU Zhaoyuan, ZHANG Shihuang, GAO Qingxian, et al. Analysis of synoptic characteristics of heavy pollution in Tianjin based on weather background[J]. Acta Scientiae Circumstantiae, 2017, 37(10): 3906-3917.

[15] ZHANG Ya-ru, CHEN Yong-jin, LIU Yong-fang, et al. Formation and dissipation processes of severe atmospheric pollution in north China under the influence of dust[J]. Arid Land Geography, 2018, 41(6): 1187-1195.

[16] ZHAO X J, ZHAO P S, XU J, et al. Analysis of a winter regional haze event and its formation mechanism in the North China Plain[J]. Atmospheric Chemistry and Physics, 2013, 13(1): 903-1286.

[17] ZHANG Hengde, LÜ Mengyao, ZHANG Bihui, et al. Analysis of the stagnant meteorological situation and the transmission condition of continuous heavy pollution course from February 20 to 26, 2014 in Beijing-Tianjin-Hebei[J]. Acta of Meteorology and Environment, 2007, 23(2): 21-24.

[18] ZHOU Zhaoyuan, ZHANG Shihuang, GAO Qingxian, et al. Analysis of synoptic characteristics of heavy pollution in Tianjin based on weather background[J]. Acta Scientiae Circumstantiae, 2017, 37(10): 3906-3917.

[19] ZHANG Ya-ru, CHEN Yong-jin, LIU Yong-fang, et al. Formation and dissipation processes of severe atmospheric pollution in north China under the influence of dust[J]. Arid Land Geography, 2018, 41(6): 1187-1195.

[20] ZHAO X J, ZHAO P S, XU J, et al. Analysis of a winter regional haze event and its formation mechanism in the North China Plain[J]. Atmospheric Chemistry and Physics, 2013, 13(1): 903-1286.

[21] ZHANG Hengde, LÜ Mengyao, ZHANG Bihui, et al. Analysis of the stagnant meteorological situation and the transmission condition of continuous heavy pollution course from February 20 to 26, 2014 in Beijing-Tianjin-Hebei[J]. Acta of Meteorology and Environment, 2007, 23(2): 21-24.

[22] ZHOU Zhaoyuan, ZHANG Shihuang, GAO Qingxian, et al. Analysis of synoptic characteristics of heavy pollution in Tianjin based on weather background[J]. Acta Scientiae Circumstantiae, 2017, 37(10): 3906-3917.

[23] ZHANG Ya-ru, CHEN Yong-jin, LIU Yong-fang, et al. Formation and dissipation processes of severe atmospheric pollution in north China under the influence of dust[J]. Arid Land Geography, 2018, 41(6): 1187-1195.

[24] ZHAO X J, ZHAO P S, XU J, et al. Analysis of a winter regional haze event and its formation mechanism in the North China Plain[J]. Atmospheric Chemistry and Physics, 2013, 13(1): 903-1286.

[25] ZHANG Hengde, LÜ Mengyao, ZHANG Bihui, et al. Analysis of the stagnant meteorological situation and the transmission condition of continuous heavy pollution course from February 20 to 26, 2014 in Beijing-Tianjin-Hebei[J]. Acta of Meteorology and Environment, 2007, 23(2): 21-24.

Note: Figure translations are in progress. See original paper for figures.