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Analysis of Meteorological Causes of a Severe Pollution Process in Beijing in 2016

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Abstract

In this paper, the atmospheric circulation characteristics, the causes of pollution formation and dissipation during a heavy pollution process from December 15 to December 22, 2016 were analyzed based on AMDAR data from aircraft and hourly observation data from the monitoring station of Beijing Environmental Protection Bureau. The results showed that the pollution process is characterized by gradual accumulation, high concentration and rapid dissipation. The weather cause of the heavy pollution process is that the atmospheric junction is stable under the influence of the homogeneous pressure field and weak high pressure, accompanied by the formation of low-level temperature inversion, and the vertical diffusion ability of pollutants is weak.

Keywords

Beijing; Severe pollution; Meteorology; Causes

Introduction

At present, severe pollution frequently occurs in the central and eastern regions of China, which not only reduces visibility, but also affects the wide spatial range of regional haze pollution, affecting the climate, ecological environment and people's health [1]. This is mainly caused by high pollution emissions and stable weather patterns. Beijing is surrounded by mountains and the sea, with a vast hinterland. The plains are surrounded by mountains to the west, north and northeast. The ridges form an arc-shaped barrier of about 1,000 meters, and the terrain is like a dustpan. The unique terrain features block the flow of atmosphere, making it difficult for atmospheric pollutants to be transported outward and the self-purification capacity of the atmosphere is not strong.

Many scholars at home and abroad have studied the heavy pollution process and its influencing factors in different regions. The Beijing Meteorological Science Institute reclassified the ground weather conditions that affect the diffusion of pollutants and divided them into 18 weather conditions based on the characteristics of the Beijing area [3]. Davis et al. [4] pointed out that large-scale circulation conditions and local meteorological conditions in a short period of time play a decisive role in the heavy pollution process; Flocas et al. [5] analyzed the impact of four types of atmospheric circulation conditions and five types of local circulation on pollution conditions; Su Fuqing pointed out that the gradient distribution of meteorological factors in the boundary layer affects the convergence, transportation and diffusion of pollutants; Ren Zhenhai et al. [6] found that persistent inversion layers and dry warm air caps are important causes of pollution.

The persistent P that occurred in Beijing from December 15 to 23, 2016 as an example. Taking the $PM_{2.5}$ severe pollution process as the research object, this paper conducts a comprehensive and systematic analysis of the case from multiple aspects, such as the evolution of the pollution process, the influence of meteorological conditions, the

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evolution of the spatial distribution of pollution levels and its relationship with the ground wind field. It also analyzes the causes and main influencing factors of this severe pollution process in order to deepen the understanding of the $PM_{2.5}$ pollution problem in Beijing.

1. Basic analysis of heavy pollution process

1.1 Changes in pollution process

From December 15 to 23, 2016, Beijing experienced a severe pollution process. On December 15, the average AQI in Beijing was 54, and the air quality level was Level 2 Good; on December 16, the pollution level rose to Level 3 Light Pollution, and the $PM_{2.5}$ mass concentration rose to 114 μg/m^3; on December 17, the pollution level rose sharply, the $PM_{2.5}$ mass concentration reached 196 μg/m^3, and the quality level rose to Level 5 Severe Pollution; on December 18 and 19, the $PM_{2.5}$ mass concentration rose slightly to 223μg/m$^{3;}$ on December 20, the $PM_{2.5}$ mass concentration surged to 379 μg/m^3, an increase of 70%, reaching Level 6 Severe Pollution; on December 21, the $PM_{2.5}$ mass concentration was 396 μg/m^3, reaching Level 6 Severe Pollution for two consecutive days, indicating that this process was severely polluted. On December 22, affected by the obvious cold air, the pollution diffusion conditions improved significantly, and this severe pollution process ended.

During the heavy pollution process, $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO and AQI index showed the same trend of change, rising synchronously before the 21st, reaching the highest point on the 21st, and falling synchronously after the 21st; the 8-hour concentration of ozone was higher when the mass concentration of $PM_{2.5}$ was low, and lower when the mass concentration of $PM_{2.5}$ was high, and the overall trend was "M" type. This heavy pollution process has the characteristics of long duration, high pollution level and fast dissipation speed, which is a very rare heavy pollution process even in autumn and winter.

1.2 Time series analysis

During this pollution process. The pollutant concentration growth process can be seen as two stages. The first stage was from December 15 to 19, when pollutants gradually accumulated and had obvious day and night changes. The second stage was from the evening of the 19th to the 21st, when pollutants accumulated rapidly and remained high for a long time.

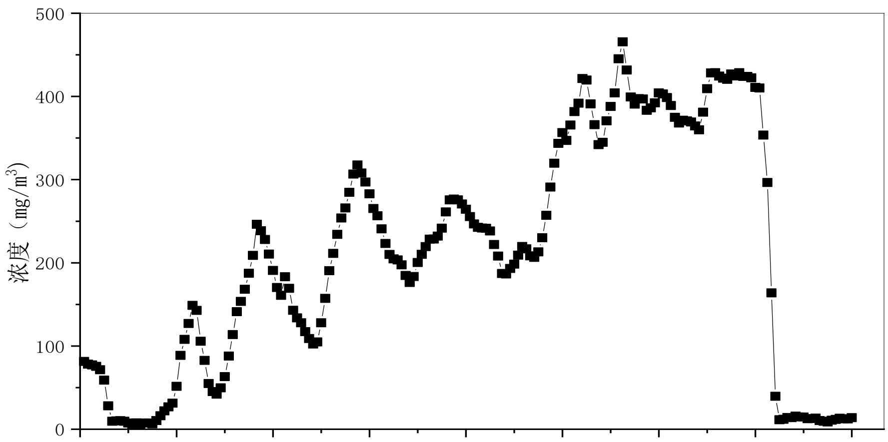

Figure 1. Hourly mass concentration of $PM_{2.5}$ during heavy pollution.

Concentration was at a low value on December 15. From the evening of the 15th, pollutants began to accumulate and the concentration increased, reaching a high value in the early morning of the 16th. The air quality level turned to good within 5 hours. From then on to the 19th, the pollution situation was basically that the pollutant concentration increased at 10 am and reached the highest value of the day at 22:00. The $PM_{2.5}$ concentration reached the maximum value of 317 μg/m^3 in this stage at 20:00 on the 17th. The second stage began at 17:00 on the 19th, and pollutants accumulated rapidly, increasing from 213 μg/m^3 to 419 μg/m^3, and remained at this concentration for 2 days. In the early morning of the 22nd, a high-speed northwest wind swept Beijing, and the pollutants quickly dissipated, and the pollution process ended.

2. Boundary layer structure analysis

Stratification of warm at the top and cold at the bottom can significantly inhibit the diffusion of pollutants and cause continuous accumulation of pollutants. Figure 2 shows the temperature distribution in the vertical structure of the atmosphere at 8 o'clock every day during this heavy pollution process. Taking the 16th, 17th, 18th, 19th and 20th as the polluted days and the 21st as the clean day, the temperature at the same height in the vertical direction shows that the clean days are higher than the polluted days. The temperature on the clean days continues to decrease with the increase of altitude, while the temperature on the polluted days continues to decrease. On the day, there are varying degrees of temperature inversion. On the 16th, the temperature continued to decrease with height below 300m to the ground. A weak inversion layer appeared at 300-670m, which inhibited the vertical diffusion of $PM_{2.5}$ and caused pollutants to accumulate near the ground. On the 17th, the bottom height of the inversion layer remained unchanged, the top of the inversion layer increased to 944 m, and the inversion intensity increased significantly, reaching 4.26 °C/100 m. On the 20th, there was a ground-to-ground temperature inversion from the ground to 540 m. The inversion layer was like a cover, covering pollutants near the ground and inhibiting the diffusion of pollutants. During this period, the mass concentration of $PM_{2.5}$ surged and remained at high concentrations. When the inversion layer is destroyed on the 21st, the vertical diffusion ability of pollutants is enhanced, and pollutants diffuse upward, causing the concentration of ground pollution to decrease.

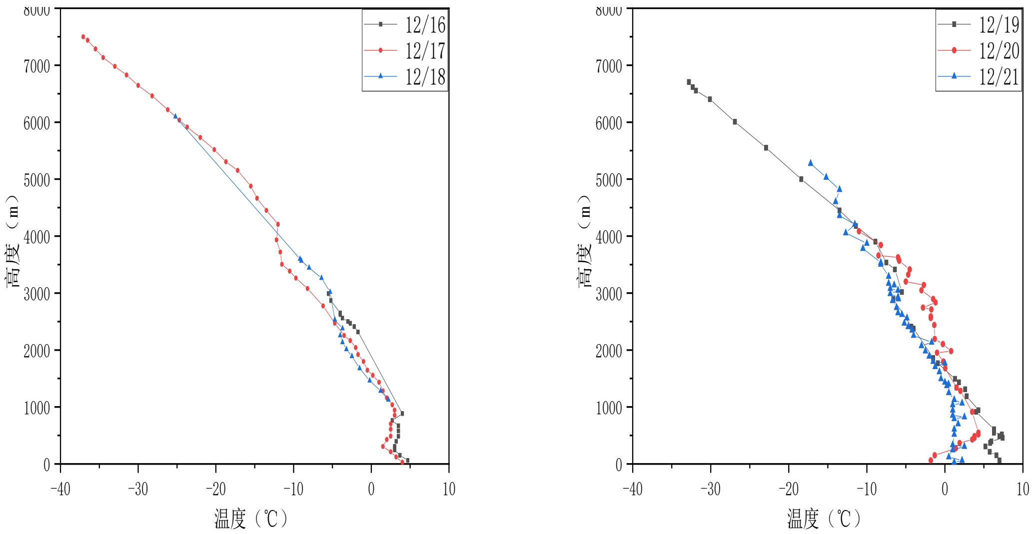

Figure 2. Hourly wind profiles in Beijing from December 15 to 22, 2016.

3. Analysis of meteorological elements

Based on the analysis of the evolution of the local circulation situation and the local flow field, the impact of the changes in local meteorological elements on air pollution is discussed, and the meteorological causes of the $PM_{2.5}$ heavy pollution process are further explored. As shown in the figure below, the change trends of the dew point temperature, that is, absolute humidity and $PM_{2.5}$ concentration are relatively consistent. When the pollutant concentration began to rise on the 15th, the dew point temperature was lower than -15 °C. In the process of increasing pollution, the dew point temperature gradually increased, and the water vapor concentration in the air increased. After the 20th, the pollution concentration reached its peak and remained at a high value of the dew point temperature until 0:00 on the 22nd. After that, the pollutants dissipated rapidly. At 5:00, the $PM_{2.5}$ concentration dropped to 10 μg/m^3, and the pollution process ended, corresponding to the dew point temperature dropping sharply from -2 °C to -11 °C. Therefore, higher humidity is an important condition for promoting the formation of $PM_{2.5}$.

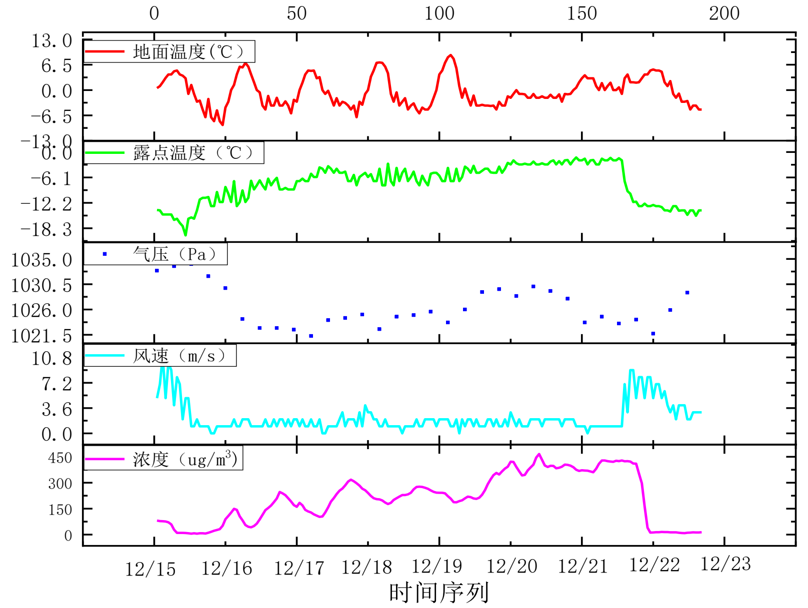

Figure 3. Changes of meteorological elements in Beijing from December 15 to 22, 2016.

The continuous growth of pollutants corresponds to a lower wind speed, with an average wind speed of 1.5 m/s, and even calm weather on the ground. The wind direction on the ground is southerly and southeasterly, bringing higher concentrations of pollutants; the removal process corresponds to a higher wind speed, with the highest wind speed reaching 9 m/s. It can be seen that the lower wind speed near the ground and the control of southerly winds will cause pollutants to stagnate in Beijing and be difficult to transport out, leading to the appearance of polluted days. The higher wind speed has a clearing effect on pollutants, especially under the control of northerly winds, which completely evacuates and removes pollutants from the Beijing area.

Combined with the changes in regional air pressure during the pollution period, it can be seen that during the accumulation of pollutants, the ground is controlled by low pressure, and the radiation effect of low pressure brings enough water vapor to allow the polluted particles that were originally difficult to diffuse to continue to develop; after December 19, a weak high pressure passed through the Beijing area. The high-pressure system brought vertical downward airflow, making it difficult for pollutants to diffuse, and transported pollutants from high altitudes to low altitudes, aggravating the pollution situation.

From the changes in near-ground temperature, we can see that the temperature difference between day and night on the 16th, 17th, 18th and 19th was large, which led to a strong radiation inversion layer at night and a stable boundary layer structure, which was conducive to the accumulation of pollutants at night. On the 20th, 21st and 22nd, when the pollution level was heavier, the temperature difference between day and night was small. This may be because the high concentration of aerosols scattered the short-wave radiation from the sun, preventing the solar radiation from heating the surface, so that the temperature during the day was not too high. At the same time, the heat loss rate at night was slow, and the high concentration of aerosols feedback effect led to a small temperature difference between day and night.

4. Conclusion

During this pollution process, fine particulate matter gradually accumulated in the early stage, with pollutant concentrations increasing from 10 to 22:00 during the day and falling from the night to 10:00 the next day, but overall showing a trend of gradual accumulation. In the later stage, pollutants accumulated rapidly and remained at high concentrations, and finally dissipated rapidly, ending the pollution process.

The weather causes of this severe pollution process are: the westerly jet stream in Beijing is weak, resulting in a weak divergence situation; the near-ground wind speed is relatively small, which is not conducive to the diffusion of pollutants; the southeast wind brings a large amount of water vapor, the relative humidity increases, the pollutants absorb moisture and grow, and accumulate in large quantities; the atmospheric stratification is stable during the pollution process, accompanied by the formation of low-altitude inversion, and the vertical diffusion ability of pollutants is weak.

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