A CASE STUDY OF POLLUTION PROCESS IN NORTH CHINA REGION USING REANALYSIS METEOROLOGY

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ABSTRACT:

Haze pollution events have been a hot topic in recent year due to their serious impacts on human health, environment, and even climate, particularly over East Asia regions. A special pollution process occurred in January 2017 is analyzed in this study based on reanalysis meteorolgoy data and surface $PM_{2.5}$ observations. Based on mesoscale and local meteorology, along with the surface $PM_{2.5}$ observations, this study investigates the formation, accumulation, and disperse of a haze events occurred in Baoding, China during the period from January 27 to 29 in 2017. It shows that the fast accumulation of $PM_{2.5}$ mass concentration at the early stage of haze formation is highly related to the weak southwest winds behind the high pressure system on January 27. On January 28, Baoding lied between the high pressure and low pressure systems, the convergence of winds made aerosols accumulate in this region, causing very heavy pollution with high $PM_{2.5}$ mass concentrations. Moreover, the vertical profile of temperature measured in Beijing shows that the temperature lapse rate decreased on January 28, making the aerosol particles more difficult to disperse. On January 29, when the high pressure dominates with strong north winds, the haze disappeared.

1. INTRODUCTION

Haze events have become a focus issue in east Asia with the rapid development of economy, causing serious impacts on health, environment, weather and even climate (Zhang et al., 2015; Wang et al., 2016). Frequent haze events have been found in many Chinese cities, including Beijing, Nanjing, Xi’an, Shijiazhuang, Baoding, and so on (Zhao et al., 2013; Wang et al. 2014; Zhang et al. 2014; Sun et al., 2014). Many studies have used different method to study the haze characteristics, the haze process, and the source analysis of haze pollution. The particulate matter with aerodynamic diameters less than 2.5 μm ($PM_{2.5}$) are believed as the major source of haze events. Various studies have examined the characteristics of $PM_{2.5}$ during haze events. Liu et al. (2014) studied a heavy haze process occurred in Beijing during the period January 24 and 31 in 2013 using two surface site observations. They analyzed the characteristics of $PM_{2.5}$, including the chemical composition and temporal variation. Guo et al. (2018) analyzed a 11-day haze events occurred in Chengdu in December 2015 based on a few surface site observations. They compared the $PM_{2.5}$ mass concentrations among these surface sites. Li et al. (2017) analyzed the sources of $PM_{2.5}$ and the heights of mixed boundary layer based on surface observations over 16 sites in Chongqing in 2013.

Baoding is a city with frequent haze events in Hebei, China. It lies in the middle west of Hebei province, close to the Taihang Mountain, with Beijing in the north, Shijiazhuang in the south, and Langfang in the East. The typical topography, along with the heavy emission sources, makes this city often polluted. Actually, Baoding is among the most polluted cities in China.

In this study, based on averaged surface observation of $PM_{2.5}$ mass concentrations in Baoding in January 2017, we analyze the characteristics of meso-scale and local meteorology during a heavy haze events. With the case study, this study can help people understand the potential roles of meteorology in the formati[1]on, accumulation and dispersion of haze events.

2. DATA

2.1 $PM_{2.5}$

The $PM_{2.5}$ mass concentration over Baoding is obtained from the website (https://www.aqistudy.cn/), which provides the observation data measured by China Environmental Monitoring Stations. Only valid data have been used here. Considering there are certain uncertainties in the measurements of $PM_{2.5}$ mass concentration, we mainly identify the rough pollution status using the $PM_{2.5}$ mass concentration in this study. Other variables, such as PM_{10}, CO, SO_2, NO_2, and O_3, have also been observed but not analyzed here. Only one haze event is identified and analyzed as shown in section 3.

2.2 Meteorology

The meteorology data is obtained from the National Meteorological Center (NMC), China. It is provided by the Global/Regional Assimilation and PrEdiction System (GRAPES) . The spatial resolution is 15 km. The wind fields from GRAPES at selected time are analyzed to understand the impacts of meteorology during the formation, accumulation and dispersion of haze events.

In addition to wind fields from GRAPES, the surface site observed winds in Baoding, and the temperature profile measured by radiosonde at one Beijing site are used for further investigation of meteorology during the study period.

3. ANALYSIS

3.1 Haze Case

Figure 1 shows the temporal variation of $PM_{2.5}$ mass concentration for the period from January 27 to January 29 in 2017. It shows that there is a heavy haze event during this period, which formed on the afternoon of January 27,

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accumulates and reached the maximum value in $PM_{2.5}$ mass concentration on January 28, and dispersed on January 29. The maximum $PM_{2.5}$ mass concentration was 793 μg/m^3. Before the formation of this haze event, the $PM_{2.5}$ mass concentration was as low as 35 μg/m^3 at 16:00 local time (LT) on January 27, 2018. After 17:00 LT on that day, the $PM_{2.5}$ increased quickly from 42 μg/m^3 to 622 μg/m^3 within 5 hours.

The $PM_{2.5}$ mass concentration increased very fast during this haze event. It reached the maximum value of 793 μg/m^3 at 01:00 LT on January 28, after which the $PM_{2.5}$ mass concentration decreased step by step, with other three peaks of 702 μg/m^3, 450 μg/m^3, and 293 μg/m^3 at time 09:00 LT (January 28), 21:00 LT (January 28) and 03:00 LT (January 29), respectively. After 07:00 LT on January 29, the $PM_{2.5}$ mass concentration decreased fast from 271 μg/m^3 to 17 μg/m^3 within 7 hours. Thus, the haze event studied here experienced less than 2 days.

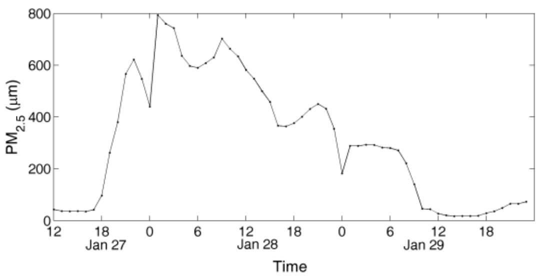

Figure 1. The temporal variation of $PM_{2.5}$ mass concentration during a haze event over Baoding, China for the period from January 27 to 28, 2017.

3.2 Mesoscale Meteorology

As indicated in section 3.1, the have event began on the afternoon of January 27. Figure 2 shows the meteorology conditions at 850 hPa altitude in China on 00:00 UTC (08:00 LT) of January 28, 2017. The red triangle represents the Baoding City. On the afternoon of January 27, the surface high pressure system moved eastward, and the city Baoding lied slightly behind the high pressure system. Correspondingly, the wind changed from north to southwest, and the pollution emitted from the south area was transported to the city, contributing to the increasing $PM_{2.5}$ mass concentration. Of course, the local emission of pollutants is another important source, which is not analyzed here. At 0800 LT of January 29, the pollution became heavier again as shown in Figure 1, which should be also related to the change of meteorology. At that time, the city lied between the high and low pressure system near surface, the convergence of winds made pollution accumulate at this location. The pollutants from both the north and south accumulated here, causing high $PM_{2.5}$ mass concentration. The dispersion of haze pollutants on January 29 should be associated with the coming of Mongolia high pressure, which brought cold high winds.

The meteorology maps at 850 hPa show that the high pressure over the Baoding moved eastward on January 27. On January 28, the low pressure over Sichuan basin moved eastward and brought warm Southwest winds with large amount of moisture. At the same time, on the north of Baoding, there was another low pressure center near Mongolia. The dominant winds were Southwest over Baoding on January 28. At 2000 LT of January 28, the high pressure center over Lake Baikal became stronger and moved southward, making the winds change from Southwest to Northwest over Baoding. On January 29, the low pressure over Mongolia disappeared and the high pressure became stronger over Baoding, making cold north winds dominate.

Similar wind patterns can be seen from the meteorology map at surface, as shown in Figure 3. This meteorology characteristics helped the formation, accumulation and dispersion of $PM_{2.5}$ during this haze event. The convergence of winds on the evening of January 27 helped the fast formation of haze event; the dominant low pressure systems with southwest winds made the pollution keep high on January 28; and the intrusion of high pressure system with strong cold north/northwest winds helped the dispersion of aerosol particles on January 29.

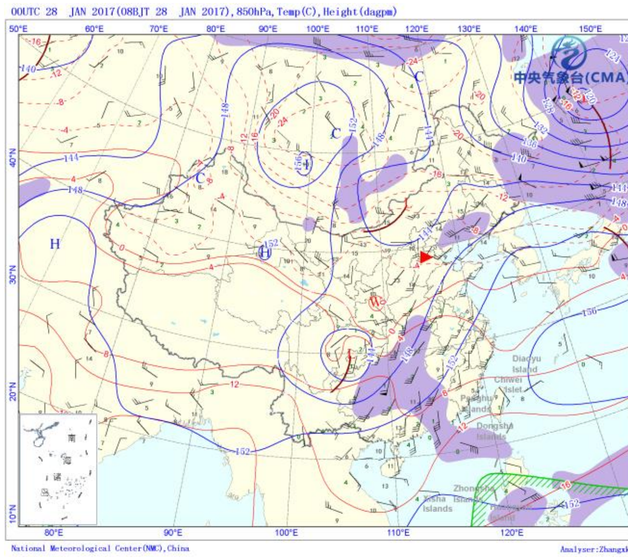

Figure 2. The map of potential heights along with winds, temperature, and pressure at 850 hPa altitude in China on 0000 UTC (0800 LT) of January 28, 2017. The red triangle represents the Baoding City. The figure is downloaded from National Meteorological Center, China.

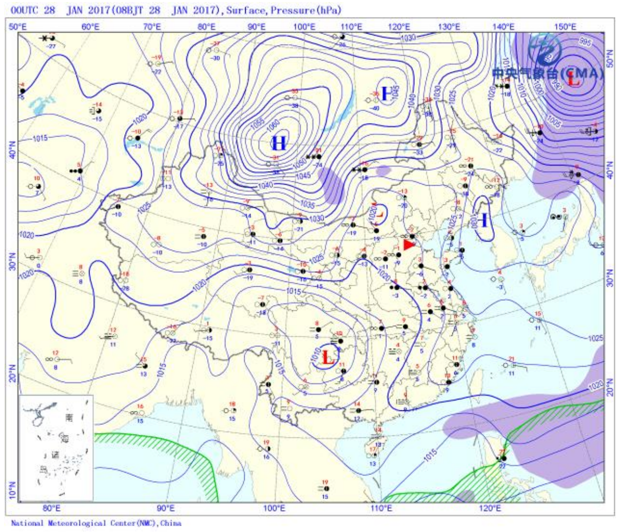

Figure 3. The map of pressure along with winds and temperature at surface in China on 00:00 UTC (08:00 LT) of January 28, 2017. The red triangle represents the Baoding City. The figure is downloaded from National Meteorological Center, China.

3.3 Local Meteorology

Section 3.2 has shown that the pollution process is closely related to the meso-scale meteorology, particularly the wind fields. Here we further analyze the local meteorology based on surface site observations. There was no precipitation during the study period. Figure 4 further shows the site observed winds at

03:00 LT and 10:00 LT in Baoding, when $PM_{2.5}$ mass concentrations are large. Figure 4 shows clear convergence of winds for both time. Moreover, the wind speed is generally less than 2 m/s. At 03:00 LT on January 28, the convergence formed clearly, which should be one significant reason for the accumulation of aerosols at that time. At that time, the winds came from northeast, north, southeast and south, making the pollutants around the city accumulate together. At 10:00 LT on January 28, the wind convergence still existed. Particularly, there were north winds in north of the city and south winds in south of the city at that time. This could explain why the $PM_{2.5}$ mass concentrations were very high for most time of January 28.

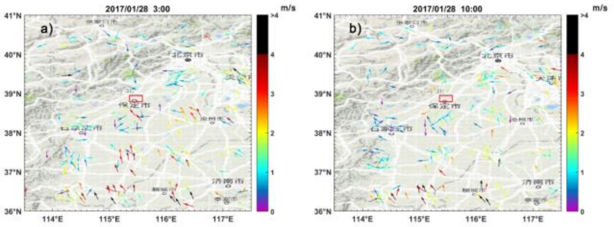

Figure 4. The wind direction measured at surface sites. The red rectangle is the city of Baoding, the color represents the wind speed, and the arrows represent the wind direction.

In addition to winds, the atmospheric stability can also affect the formation of haze events. Since we do not have the radiosonde profile observations in Baoding, we here use the radiosonde observations from a close site at Beijing with latitude 39.8°N and longitude 116.47°E. The distance between the radiosonde observation site and Baoding is 135 km. Figure 5 shows the profiles of temperature measured during the period from January 27 to 29, 2017. We can see that the temperature profiles were rather stable for this haze period. Particularly, the temperature profiles were almost the same between 08:00 and 20:00 LT on the same day, except January 29. On January 27, there was an inversion layer near 950 hPa, which can help the buildup of aerosol particles. On January 28, the lapse rate of temperature was rather small for the altitudes between surface and 700 hPa at 08:00 LT. Moreover, there was a weak temperature inversion layer around the heights between 800 and 700 hPa at 08:00 LT. Both the weak lapse rate and temperature inversion layer inhibited the vertical convection, making the fine aerosol particles difficult to transport outside. At 20:00 LT on January 28, a temperature inversion layer occurred near surface, and there was an almost isothermal layer between 950 hPa and 850 hPa, making the transport condition even worse than that in the morning time. On January 29, the high pressure system intruded and dominated the whole North China plain region. Correspondingly, we can see that the near surface inversion layer disappeared at 08:00 and 20:00 on January 29. Furthermore, the lapse rate of temperature profiles increased with time, making the aerosol particles easier to transport outside. Correspondingly, the $PM_{2.5}$ mass concentration had a quick decrease on that day. The $PM_{2.5}$ mass concentration even became 17 $\mu g/m^3$ at 14:00 LT on January 29.

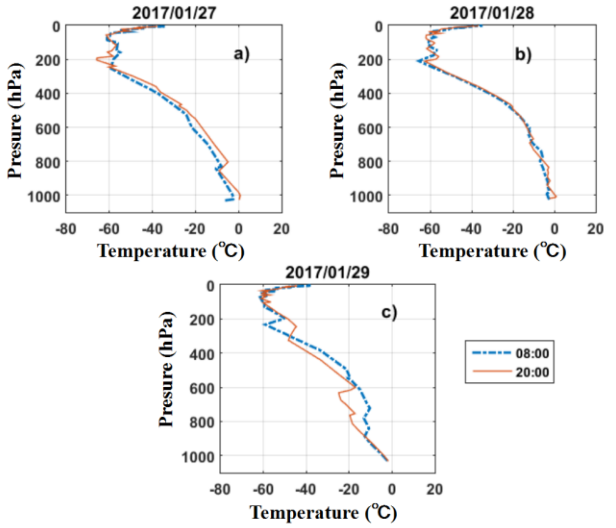

Figure 5. Profiles of temperature from radiosonde observations at a Beijing site, which is 135 km away from Baoding on January 27, 28 and 29.

4. SUMMARY

Using $PM_{2.5}$ and winds from ground surface measurements, temperature profiles from radiosonde observations, and meso-scale meteorology from reanalysis data, this study analyze the characteristics of a haze process. Particularly, this study focuses on the variation of meteorological conditions and analyzes their potential role to $PM_{2.5}$ mass concentrations.

It shows that during this heavy haze event occurred in Baoding from January 27 to 29, the meteorology could play important roles. It favors the formation and accumulation of fine aerosol particles on January 27 and 28, and helps the dispersion of haze events on January 29. Specially, on January 27 and 28, the large scale high pressure systems and low pressure systems around the city made the winds converge around Baoding, causing the pollutants accumulate there. This convergence also made the local emissions hard to transport outside horizontally. Moreover, the existence of near surface temperature inversion layer, along with the weak temperature lapse rate, even the isothermal temperature structure within low atmosphere, made the fine aerosol particles difficult to transport outside vertically. They can also make the fine aerosol particles concentrate within a lower mixed layer. On January 29, the change of meteorology system by a high pressure system, made the dominant weather as strong cold winds with high mixed layer heights, which help the transport of fine aerosol particles. Accordingly, the haze disappeared fast on January 29.

While statistical results can not be obtained here, the case study demonstrates the potential importance of mesoscale and local meteorology to the development of haze event. They provide the favorable meteorology for fine aerosol particles to accumulate. Of course, the emission and formation of fine aerosol particles are the other necessary factors to form the haze. We here did not analyze the emissions from local sources and the potential secondary formation of fine particles, which could be done with models in future.

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