

The Influence of Urban Planning Affected Static and Stable Meteorological Field on Air Pollution

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Abstract. Accompany with the rapid urbanized and industrialized process, the built-up area and the number of high-rise buildings increased fast. Urban air quality is facing with the challenge caused by the rapid increase in energy consumption, motor vehicles owned, and the city construction. Long term high precision analysis on Beijing-Tianjin-Hebei region has been conducted in this article, so as to explore the influence of rapid increase in urban size and tall building amount on occurrence frequency of urban static and stable meteorological conditions as well as the contribution to urban PM_{2.5} pollution.

1. Introduction

The urban air pollution in China has been increasingly deteriorative due to rapid urbanized and industrialized process, which leads to severe threats to residents on physiology and psychology. Although air pollutants mainly come from industrial emission, motor vehicle exhaust and flying dust in construction sites, emerging tall buildings in cities give rise to increased underlying surface height of cities and roughness degree, leading to increased urban atmospheric stability and reduced average wind velocity^{1, 2}. According to research findings, the changes on pollutant concentration are mainly restrained by atmospheric diffusion conditions in condition of limited changes on atmospheric pollutant emission in short time, with the most important factors of atmospheric stability degree and stratification structure within the boundary layer³⁻⁵. In regional static and stable meteorological conditions, severely deteriorated pollutant diffusion conditions lead to very high air pollution development speed, giving rise to severe haze^{6, 7}. Support and guidance are needed to improve atmospheric pollution, which are not provided sufficiently at present.

According to research findings of WHO, air pollution has been the fourth severe threat to people health in China, leading to healthy-year loss to 12 million people every year⁸. PM_{2.5}, the fine particulate matter with grain size less than 2.5 micrometer, is the primary air pollutant for main cities and city agglomerations in China. The air quality standard in China at present: 35 $\mu\text{g m}^{-3}$ annually and 75 $\mu\text{g m}^{-3}$ daily (GB 3095-2012, 2012). It is planned to control the annual average of PM_{2.5} within 56 $\mu\text{g m}^{-3}$ in Beijing in 2020, 30% declined compared to that of 2015. In order to realize this target in 2020, it is necessary to further improve the control method to pollutants.

Regional scale atmospheric pollution is mainly caused by industrial emission, but the vehicle emission in cities and the daily activities of residents leads to influence on further deterioration of the pollution. Beijing is one of the most prosperous regions in economy in China. During the past five



years, the number of motor vehicles in Beijing has been increased by more than 500 thousand although with strict control on license plate, and the population density of central areas is as high as 23953 per km². Other cities in Beijing-Tianjin-Hebei region also face with similar problems, with higher growth rate on population and motor vehicles as well as increased urban size and energy consumption. It is very difficult to improve atmospheric environment in these cities due to the urbanization process with high speed development.

Therefore, two problems are mainly researched in this article:

(1) If the rapid growth of urban size and tall building amount lead to significant increase in occurrence frequency of statistic and stable meteorological conditions?

(2) How do static and stable meteorological conditions affect urban atmospheric pollution?

2. Methodology

The Beijing-Tianjin-Hebei region is the research range in this article. In which Beijing is the capital of China, with dense population and prosperous economy, surrounded by 10 large-scale cities with population of more than 4 million such as Tianjin, Tangshan, Baoding, Cangzhou, Shijiazhuang, Xingtai, etc. With a general name of Beijing-Tianjin-Hebei region, it is one of the regions with the densest industrial enterprises and population in China, with total regional population of more than 100 million and total GDP amount of more than 6.6 trillion yuan (2014). Beijing-Tianjin-Hebei region is one of the regions with the most prominent haze problem, and the industrialization, urbanization and mechanization in this region is related to the atmospheric environment in North China, giving rise to the situation of co-existence of multiple pollutants including fire coal, motor vehicles and industrial waste gas emission.

The static and stable atmospheric condition is defined as:

When $t \in (t_0 - 3, t_0 + 3)$ if

- 1) Wind speed $< 3.3 \text{ m s}^{-1}$;
- 2) No precipitation;
- 3) The height of CML is lower than 500 m.

Then t_0 belong to the static and stable atmospheric condition.

3. Result and Discussion

The population in Beijing was increased to 215.16 thousand in 2014 from 160.1 thousand in 2006, with annual average compound growth rate of 3.7%. During the same period, the amount of the vehicle number was increased to 55.91 thousand from 28.76 thousand, with annual average compound growth rate of 8.7%. The urban built-up area was increased to 1385.6 km² from 1254.2 km², with annual average compound growth rate of 1.2%. The total amount of GDP was increased to 2.1 trillion yuan from 0.8 trillion yuan, with annual average compound growth rate of 12.8%. The indexes of main peripheral cities on economy, urban development and population are similar to that of Beijing; i.e., with the rapid development on economy and population, main cities in Beijing-Tianjin-Hebei region have rapid increase in urban built-up areas and high-rise buildings. At the same time, urban air quality is facing with the challenge caused by rapid increase in energy consumption and motor vehicles owned.

During 2006-2014, the duration for the static and stable meteorological field in Beijing and main peripheral cities (Tangshan and Xingtai are selected as representatives of peripheral cities of Beijing in Figure 1) was increasingly grown; in addition, the atmospheric pollution showed a deteriorated trend during the same period based on the visibility data (quoted from the news of the Ministry of Environmental Protection). Figure 1 illustrate that during 2006-2014, the duration proportion of the static and stable atmospheric conditions in Beijing, Tangshan and Xingtai was increasingly grown, with annual increment of 1.7%, 0.3% and 1.3%, respectively. At the same time, the annual average visibility of the three cities showed a descending trend of 0.37 km yr⁻¹, 0.78 km yr⁻¹ and 0.06 km yr⁻¹, respectively. There was an obvious negative correlation between the duration proportion of static and

stable meteorological conditions in Beijing, Tangshan and Xingtai and the visibility, with correlation coefficient of -0.73, -0.48 and -0.32, respectively. According to long term changing trend, the increasingly improved urban wind environment stability degree gives rise to the decline in visibility, indicating that the rapid development of cities gives rise to the increase in atmospheric particulate pollutants, which is not effectively controlled.

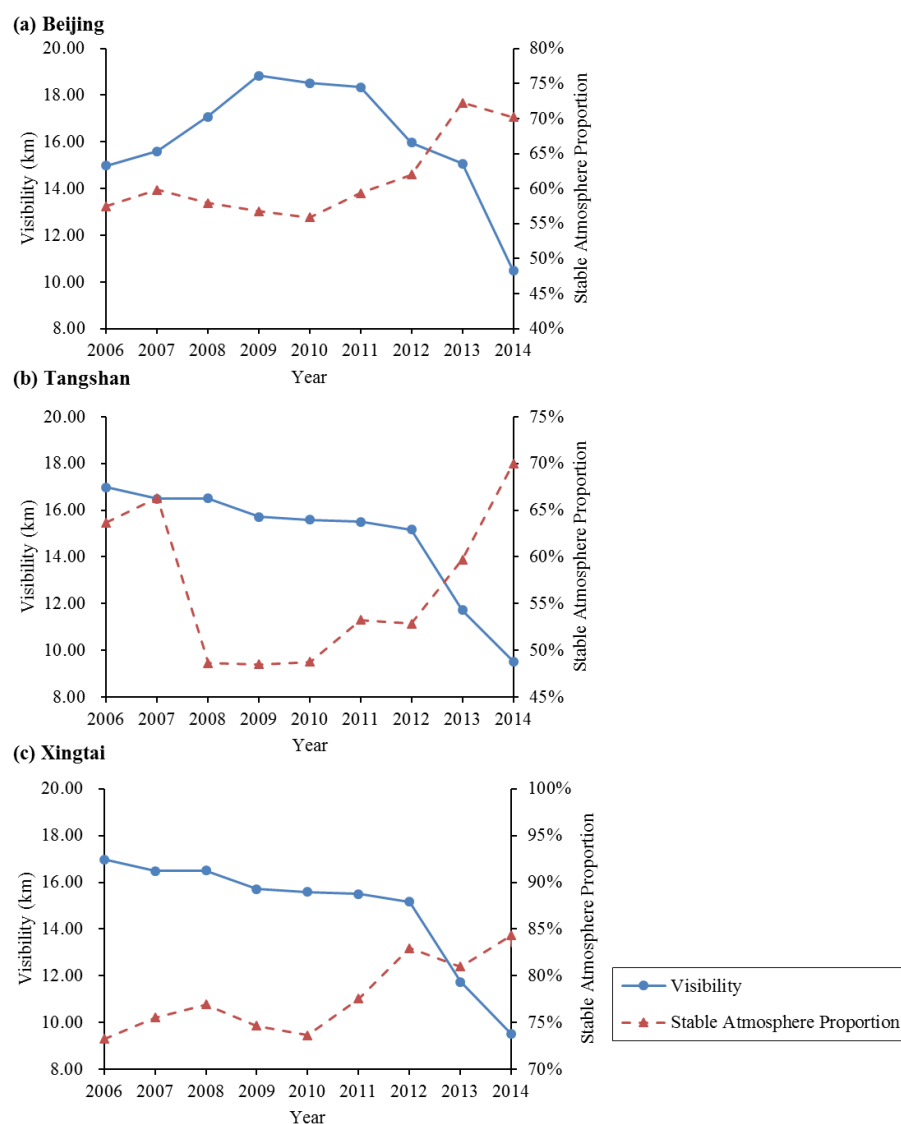


Figure 1 Duration Proportion of Static and Stable Meteorological conditions and Changing Trend of Visibility in Beijing, Tangshan and Xingtai during 2006-2014

According to the long term observation, the rapid increase in occurrence frequency of urban static and stable meteorological conditions has given rise to severe obstructions to air governance since 2006. In order to further verify the influence of the static and stable meteorological conditions on formation and development of $PM_{2.5}$ pollutants, we conduct high precision time analysis on the formation of the heavy dust haze weather by taking January of 2014 as an example, as shown in Figure 2.

There were 3 heavy dust haze events in Beijing during January 2014 (with $PM_{2.5}$ mass concentration peak $> 250 \mu g m^{-3}$), as shown in the grey part in Figure 2. During the formation and development process of heavy dust haze, the atmospheric environment is in the extremely static and

stable conditions (with CML height of fewer than 500 m, no precipitation and with wind speed of lower than 3.3 m s^{-1}).

In condition that the wind speed on the earth's surface of cities is extremely low, the convection current on horizontal direction and vertical direction in high altitude may still be strong, accompanied with certain pollutant transmission. However, it is observed that the wind speed on the earth's surface during the dust haze development period in the winter is extremely low, and there is also continuous low wind speed state at the altitude of 33 m, indicating further deterioration of urban diffusion conditions. In which the heavy dust event happened on January 15 was the most typical one. In the extremely static and stable meteorological field, with earth's surface and high altitude wind speed of less than 2.0 m s^{-1} , the mass concentration of $\text{PM}_{2.5}$ was rapidly increased to $592 \mu\text{g m}^{-3}$ from $87 \mu\text{g m}^{-3}$ within only 6 hours, giving rise to severe dust haze.

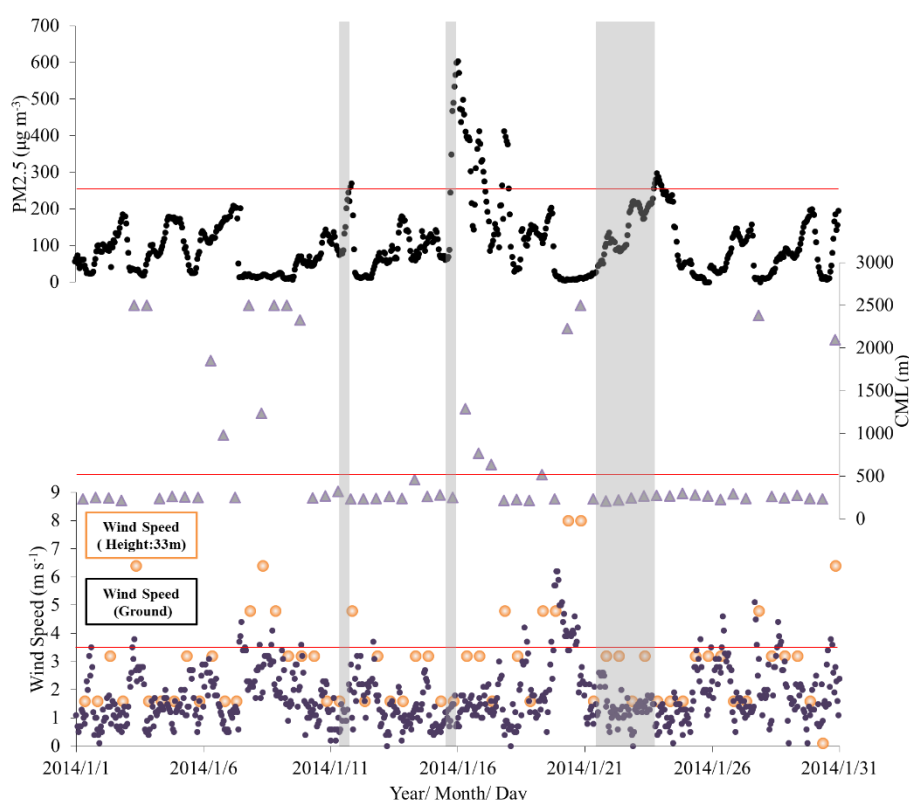


Figure 2 $\text{PM}_{2.5}$ Concentration and Meteorological Conditions of Beijing in January 2014

This month was during the heating period, with high and stable daily pollutant emission amount, which was the internal cause for frequent occurrence of dust haze meteorological conditions. The increase in high-rise buildings gave rise to improvement on underlying surface roughness and air velocity, leading to frequent occurrence of static and stable meteorological conditions, which provided favorable external environment for the accumulation of pollutants and secondary chemical reactions. Due to extremely poor diffusion and transmission conditions, urban pollutants were accumulated more rapidly, leading to rapid increase in $\text{PM}_{2.5}$ pollutant concentration, which resulted in severe atmospheric pollution, and that was the external cause and inducement of heavy dust haze events.

4. Conclusion

Long term high precision analysis on Beijing-Tianjin-Hebei region has been conducted in this article, so as to explore the influence of rapid increase in urban size and tall building amount on occurrence

frequency of urban static and stable meteorological conditions as well as the contribution to urban PM_{2.5} pollution, with the following main conclusions:

1) By taking Beijing, Tangshan and Xingtai as examples, this article conducts analysis on the influence of the rapid development of urban size and tall buildings amount on the duration of urban static and stable meteorological conditions and the air pollution. According to research findings, during 2006-2014, the duration of the static and stable meteorological conditions in the three cities was rapidly increased; at the same time, the visibility was rapidly declined, and there was a significant negative correlation between them with the average correlation coefficient of -0.51.

2) The increase in duration of the static and stable meteorological conditions plays a significant role in frequent occurrence of heavy dust haze meteorological conditions in the winter of Beijing. According to the analysis, urban meteorological conditions have been the important inducement for occurrence and rapid development of dust haze in Beijing or even the Beijing-Tianjin-Hebei region.

3) The amount of urban tall buildings and distribution state is closely correlated with urban wind field and PM_{2.5} pollution. In order to further reduce the PM_{2.5} concentration to achieve the target of 30% reduction of PM_{2.5} concentration in 2020, it is necessary to take urban size and the tall building amount into consideration of urban planning, so as to consider about the influence of urban buildings on atmospheric pollution.

Acknowledgments

The current work was supported by the project of Basic Work of the Ministry of Science and Technology (No. SB2013FY112500).

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