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Environmental and Dynamic Conditions for the Occurrence of Persistent Haze Events in North China

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ABSTRACT

This paper presents a concise summary of recent studies on the long-term variations of haze in North China and on the environmental and dynamic conditions for severe persistent haze events. Results indicate that haze days have an obviously rising trend over the past 50 years in North China. The occurrence frequency of persistent haze events has a similar rising trend due to the continuous rise of winter temperatures, decrease of surface wind speeds, and aggravation of atmospheric stability. In North China, when severe persistent haze events occur, anomalous southwesterly winds prevail in the lower troposphere, providing sufficient moisture for the formation of haze. Moreover, North China is mainly controlled by a deep downdraft in the mid-lower troposphere, which contributes to reducing the thickness of the planetary boundary layer, obviously reducing the atmospheric capacity for pollutants. This atmospheric circulation and sinking motion provide favorable conditions for the formation and maintenance of haze in North China.

1. Introduction

In recent years, regional persistent haze pollution events have happened frequently in North China, the Pearl River Delta, and the Yangtze River Delta [1–3], with the most typical region being North China [4]. The frequent occurrence of haze events has become one of the most severe environmental problems in North China.

Regarding the reasons for frequent haze events, rapid economic development and urbanization in China have resulted in the discharge of a large amount of pollutants in recent years. In addition, it is very possible that changes in climatic conditions resulting from climate warming due to human activities are one of the reasons for haze events [3,5–7]. Pollutant dilution and diffusion capacity varies largely under different meteorological conditions. Local meteorological conditions and the planetary boundary layer (PBL) structure may change under different large-scale circulations, thus having a significant influence on the formation of atmospheric pollution [8–13]. Therefore, one of the approaches to understanding the occurrence of haze events—and persistent haze events in particular—is studying the effect of circulation conditions and related environmental and dynamic factors on haze formation. This paper summarizes the recent study results on the long-term characteristics of haze and on the environmental and dynamic conditions for severe persistent haze events in North China.

2. Spatial-temporal characteristics of haze days in North China

North China is the region with the most prevalent haze in China. From the spatial distribution of annual haze days, shown in Fig. 1(a) [3], it can be seen that haze zones mainly exist in economically developed and densely populated regions, such as Beijing, Tianjin, and southwest Hebei Province, where there are over 30 annual haze days. In particular, there are over 50 annual haze days in downtown Beijing, the north of Tianjin, Shijiazhuang, Xingtai, and Tangshan.

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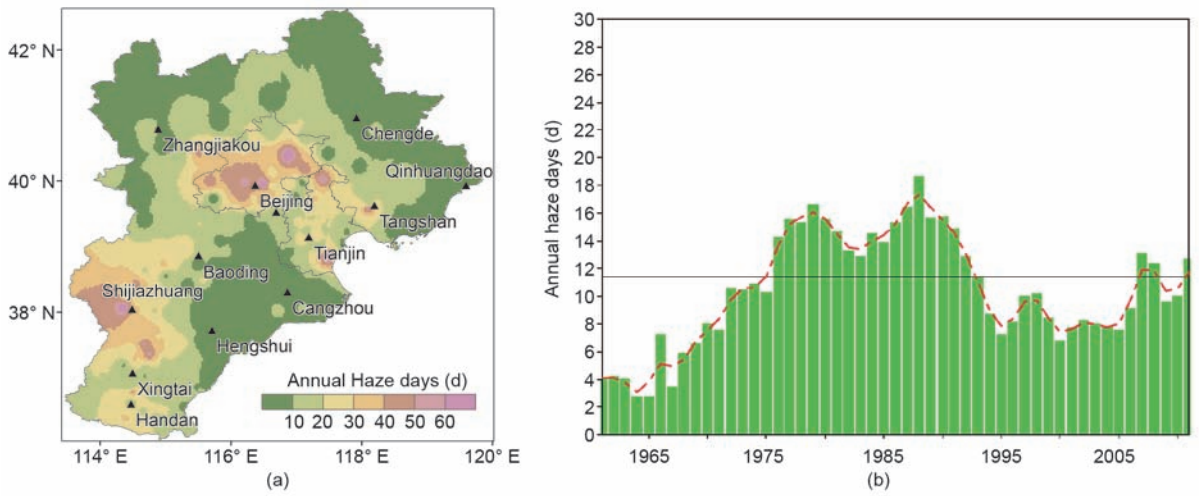

Fig. 1. (a) Spatial distribution and (b) long-term variation of annual haze days in North China. Adapted from Ref. [3].

As shown in Fig. 1(b) [3], the haze frequency in North China rose quickly before 1979 and peaked during 1976–1991, with an average of about 14–15 annual haze days. The frequency then decreased significantly; however, it has risen again since 2005 [3]. Based on the quarterly distribution, haze mainly occurs in the winter, then in the spring and autumn, and occurs at its lowest frequency in the summer [5,11].

In recent years, haze days in China have shown the significant characteristics of longer duration and larger impacted range. Once a haze occurs, it often lasts for several days or even longer, resulting in severe harm to human health. Wu et al. [14] found that most of the persistent haze events that lasted for three or more days in North China occurred in the autumn and winter. From the mid-1990s until now, the frequency of persistent haze events has clearly increased (figure not shown here). Zhang et al. [15] defined a haze event lasting for two or more days as a "persistent haze event," and found that the increase of persistent haze days is the main reason for the increase of total haze days in the past 30 years in North China. Areas with an obviously increasing trend of persistent haze days are mainly concentrated in Beijing, Tianjin, and southwest Hebei Province (Fig. 2) [15]. The range of regions with persistent haze events has an inter-decadal growth trend, with particularly significant aggravation since 2000.

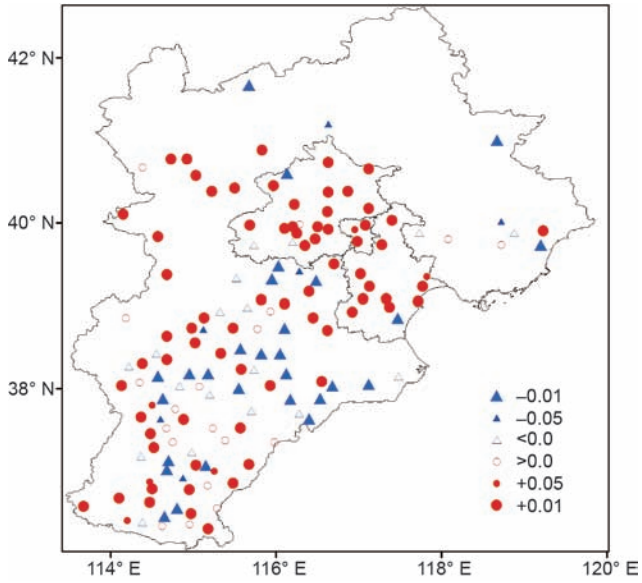

Fig. 2. Varying trends in persistent haze days in North China from 1981 to 2013. Solid/hollow circles represent increasing trends while solid/hollow triangles indicate decreasing trends; a big solid circle/triangle indicates a trend that has passed the 0.01 significance level test; a small solid circle/triangle indicates a trend that has passed the 0.05 significance level test; a hollow circle/triangle indicates a trend that has not passed the significance level. Adapted from Ref. [15].

3. Environmental conditions for haze days in North China

Generally speaking, there are two main conditions for the formation of haze weather. The first condition is a large amount of pollutants in the atmosphere, and the second is stable atmospheric stratification and low wind speed. When there is a large amount of pollutants in the air, and when the atmospheric stratification is stable, the pollutants cannot be quickly diffused, leading to the formation of haze weather. Therefore, the reasons for the increase of haze days include human activity and climatic change. Over the past 50 years, winter temperature in North China shows a rising trend, while surface wind speed has an obviously decreasing trend (Fig. 3) [7]. The increase of temperature may lead to an increase of water vapor in the atmosphere, and water vapor is an important factor for the formation of haze, due to the hygroscopic growth characteristic of haze particles. In addition, a decrease of surface wind speed can weaken the diffusion of pollutants [5]. Thus, rises in temperature and decreases in surface wind speed may cause more haze days. A haze day with a daily maximum wind speed equal to or lower than 6 $m \cdot s^{-1}$ is defined as a "weak wind day," and a haze day with a daily maximum wind speed of higher than 6 $m \cdot s^{-1}$ is defined as a "strong wind day." It is found that in North China, weak wind days are obviously increasing, while strong wind days are obviously decreasing in most cases (Table 1) [7]. These trends have a strong negative impact on the diffusion of air pollutants and a positive impact on the occurrence of haze. It is notable that the most significant influence on the increase of winter haze days in North China is the decrease of days with a daily maximum wind speed of 7–8 $m \cdot s^{-1}$.

A change in atmospheric stratification stability influences the vertical exchange capacity of air, with more stable atmospheric stratification enabling the formation of haze weather. The *A* index can be used to express the atmospheric thermal stability. The *A* index is calculated by the following equation:

$$A = (T_{850} - T_{500}) - [(T - T_d)_{850} + (T - T_d)_{700} + (T - T_d)_{500}] \quad (1)$$

where T is the temperature; T_d is the dew point temperature; and the numbers 500, 700, and 850 indicate different pressure levels.

The bigger the value of the *A* index, the more unstable the atmosphere will be. The variation curve of the winter *A* index