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#### Research Article

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# Dynamic analysis of particulate pollution in haze in Harbin city, Northeast China

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**Abstract:** Based on the air quality data of Harbin in winter from 2015 to 2017, the national winter straw combustion data from 2016 to 2017 and the mixed single particle Lagrange comprehensive track model, Hybrid Single-Particle Lagrangian Integrated Trajectory Model (HYSPLIT), dynamic analysis of Harbin's winter air quality status and influencing factors. The air quality data were analyzed; it was found that the main pollutants in winter in Harbin were SO<sub>2</sub>, NO<sub>2</sub>, PM<sub>10</sub> (particles with aerodynamic diameter ≤10 µm), and PM<sub>2.5</sub> (particles with aerodynamic diameter ≤2.5 µm); the annual air pollution situation deteriorated sharply from November and continued until March of the following year. Through the research on straw fire prevention points in Harbin, the spatial pattern characteristics and causes of persistent haze in Harbin from 2015 to 2017 were dynamically analyzed. Combining the backward trajectory model to trace the source and trend of air mass in pollution, it is found that the air mass trend is consistent with the distribution of straw-burning points. The research results show that (1) during the winter from 2015 to 2017, the overall air quality situation in Harbin improved, the number of serious pollution days decreased year by year, and the main atmospheric pollutants were PM<sub>10</sub> and PM<sub>2.5</sub>. In October

**Keywords:** haze, particulate pollution, air quality, straw incineration, Harbin

#### 1 Introduction

With the rapid development of China, air pollution has become an environmental catastrophic phenomenon that cannot be ignored [1]. Harbin city has experienced severe persistent haze weather in the winter in recent years. The severe air pollution and air quality problems that have occurred during the period have caused the visibility of the atmosphere to decline, which has a major impact on the social economy, the ecological environment, and human health [2-4]. Analyzing the changes and characteristics of air quality during haze in Harbin is of great significance for accurately observing and forecasting haze weather, reducing disaster losses, and ensuring traffic safety and environmental quality.

The deterioration of air quality has brought about many social and environmental problems. The increasing number of diseases caused by air quality problems have caused more and more people to pay attention to air environment problems [5-8]. Many scholars have conducted research on the effects of air pollution on human health to increase public awareness of air pollution [9–12]. In recent years, China has adopted many policies to strengthen environmental management [13], and the Ministry of Environmental Protection and Environmental Protection of China promulgated the latest environmental quality standards

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and November, the pollution concentration peaked, and after December, the pollution concentration showed a downward trend until the next spring reached the valley and (2) the most obvious time of haze in Harbin is from November to December, and it is concluded that haze events are closely related to the large number of pollutants caused by the burning of straw around Harbin, and because the northwest monsoon climate affects the air quality, the transportation of fine particles caused by the burning of straw in winter in the surrounding areas of Harbin is the main cause of serious pollution in Harbin.

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(GB3095-2012) in 2012, and redefined PM<sub>2.5</sub> (particles with aerodynamic diameter  $\leq 2.5 \,\mu\text{m}$ ), PM<sub>10</sub> (particles with aerodynamic diameter ≤10 µm), sulfur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>), carbon monoxide (CO), and ozone (O<sub>3</sub>) concentration grade [14].

At the same time, many scholars at home and abroad have studied the factors affecting air quality from different perspectives. Some scholars have studied the concentrations of PM<sub>2.5</sub>, PM<sub>10</sub>, and NO<sub>2</sub> from the perspective of their atmospheric composition concentration to explain the phenomenon of urban visibility reduction [15]; some scholars have studied the concentration changes of PM<sub>2.5</sub> and PM<sub>10</sub> in different seasons and found that the concentration of PM<sub>2.5</sub> is higher in winter [16,17]; and some scholars have also analyzed the effects of haze weather on air quality. Seinfeld has conducted in-depth research on the relationship between atmospheric aerosols and air pollution and the effects of particulate matter (PM) on humans [18]; Gautam has used remote sensing image data to study the phenomenon of heavy haze in a certain area and to study the corresponding early warning system to reduce the impact of haze on society [19]; Sánchez de la Campa has taken a copper smelter in the southwest as an example to analyze the use of clean technology to contain particulate pollutants [20]; and Viana has assessed the impact of marine emissions on coastal air quality in Europe [21]. In view of the particularity of China's environment, domestic scholars have studied air pollution from different dimensions and explored the formation mechanism and homogeneity of air pollution from national to urban agglomerations and specific cities [22–25]. Considering the differences of air quality in different regions, many scholars at home and abroad have explored factors closely related to changes in air quality, such as urbanization [26], meteorological conditions [27], changes in surface cover [28,29], urbanization and economic development [30–32], transportation methods [33-35], and other factors. Domestic scholarly research on air quality in specific cities mainly studies the specific causes of air quality pollution in different regions and cities, such as analyzing the sources and treatment measures of Beijing's air pollution [36,37] and analyzing the difference of air pollution between China and North Korea [38], and it can be found that the main factors leading to air pollution vary from region to region, so the analysis of air quality deterioration needs to be combined with the actual situation of the study area.

Taking Harbin city as an example, this article analyzes the characteristics and causes of haze pollution in the winter period from 2015 to 2017. This study analyzes the air quality during the pollution period with air quality data and uses the backward trajectory model to simulate the movement trajectory of the air mass at different

altitudes and the transport of pollutants and to trace the source of pollutants. Furthermore, this article also combines the distribution of straw-burning fire points in the surrounding provinces and cities of Heilongjiang Province and Harbin, and the main reasons for haze formation are discussed.

### 2 Study area

As a typical heavy industrial northern ice city in China. Harbin is also one of the most densely populated cities in Northeast China with a population of 9.95 million. It is located between 125°42'-130°10' east longitude and 44°04'-46°40' north latitude. Harbin is located in Northeast China and the center of Northeast Asia. It is the political, economic, and cultural center of Northeast China. It is known as the pearl of the Eurasian Continental Bridge. The starting point of Qi Industrial Corridor, a central city along the border development and opening up strategically positioned by the country. The annual temperature difference is as high as 60°C, and the annual heating period is more than half a year. It is a typical temperate monsoon climate. In recent years, with the acceleration of industrial progress and rapid urbanization, air pollution has continued to be serious.

## 3 Data, model, and methods

#### 3.1 Sources of data

The major air pollutants include PM, SO<sub>2</sub>, NO<sub>2</sub>, CO, and O<sub>3</sub>. The measurement area is Harbin, Heilongjiang Province, and the unit of data is microgram per cubic meter. The air quality data come from the Ministry of Ecology of the People's Republic of China. (http://www.zhb.gov.cn/) and the Heilongjiang Provincial Environmental Protection Agency (http://www.hljdep.gov.cn/) and are used to analyze the air quality during the haze pollution in Harbin during the past 3 years in winter periods.

#### 3.2 Model

The pollutant source trajectory calculation uses the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model [39] jointly issued by the National Oceanic and Atmospheric Administration and the Australian Bureau of Meteorology [40]. The backward trajectory model traces the path origin and direction of air mass during the pollution period; it can handle the meteorological transmission, diffusion, and settlement of different-height layers. There are many meteorological input fields and physical processes, and the trajectory calculation time is world unified time (Coordinated Universal Time), referred to as UTC; meteorological data for the simultaneous Global Data Assimilation System (GDAS) are provided by the National Environmental Forecast Center [41].

#### 3.3 Data-processing method

The comprehensive index of ambient air quality is a dimensionless index that describes the comprehensive status of urban air quality. It comprehensively considers the pollution levels of six pollutants,  $SO_2$ ,  $NO_2$ ,  $PM_{10}$ ,  $PM_{2.5}$ , CO, and  $O_3$ , and the comprehensive index of ambient air quality. The larger the degree of comprehensive pollution, the more serious it is [14].

The calculation process is as follows: first, we calculate the individual index of each pollutant, and then add the six individual pollutants to a single index, which is performed to get the comprehensive index of ambient air quality. The monthly assessment of the ambient air quality index of the city is calculated as follows:

# 3.3.1 Calculate the statistical concentration of each pollutant

Monthly average concentrations of  $SO_2$ ,  $NO_2$ ,  $PM_{10}$ , and  $PM_{2.5}$  in each city were calculated, and the 95th percentile of the daily average value of CO and the 90th percentile of the maximum 8 h value of  $O_3$  were counted.

#### 3.3.2 Calculate the individual index of each pollutant

The individual quality index of pollutant i,  $I_i$  is calculated as follows:

$$I_i = \frac{C_i}{S_i},\tag{1}$$

where  $C_i$  is the concentration of pollutant i – when i is  $SO_2$ ,  $NO_2$ ,  $PM_{10}$ , and  $PM_{2.5}$ ,  $C_i$  is the monthly mean value, whereas when i is CO and  $O_3$ ,  $C_i$  is the specific percentile concentration value – and  $S_i$  is the daily average secondary standard for pollutant i (for  $O_3$ , the secondary standard for the 8 h average).

## 3.3.3 Compute the ambient air quality composite index $I_{sum}$

The calculation of the air quality index needs to cover all six pollutants. The calculation method is as follows:

$$I_{\text{sum}} = \sum_{i} I_{i}, \tag{2}$$

where  $I_{\text{sum}}$  is the air quality composite index and  $I_i$  is the individual quality index of pollutant i. i includes all six indicators, namely SO<sub>2</sub>, NO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>, CO, and O<sub>3</sub>.

According to the requirements of ambient Air Quality Standard (GB3095-2012), the concentration limit of six pollutants is 24 h mean concentrations for two classes are 35 and  $75\,\mu g/m^3$  for  $PM_{2.5}$ , 50 and  $150\,\mu g/m^3$  for  $PM_{10}$ , 50 and  $150\,\mu g/m^3$  for  $SO_2$ ,  $80\,\mu g/m^3$  for  $NO_2$ ,  $4\,m g/m^3$  for CO, and  $1\,h$  values  $O_3$  are 160 and  $200\,\mu g/m^3$ , respectively.

#### 4 Results

# 4.1 Dynamic analysis of air quality during smog

The air quality comprehensive index of Harbin from 2015 to 2017 is calculated, the maximum index of individual pollutants is obtained, and the main pollutants are further obtained. The results are shown in Table 1; it can be clearly seen that, from 2015 to 2017, Harbin's air quality index began to rise rapidly from October, and by the spring of the second year, the air quality index fell rapidly. During this period, Harbin's winter and spring air quality composite index remained high, and the main pollutants were all PM<sub>2.5</sub>. From May to September, major pollutants were replaced by other sources of pollution.

According to the Table 1, the most significant time period of haze in Harbin is in the winter. Starting from October every year, the comprehensive air quality index shows a sharp upward trend. Therefore, this article will focus on the analysis of air quality in Harbin during the past 3 years in winter. The interception time will be November until the next January.

It can be seen from Table 1 that the main pollution sources in the city of Harbin are  $SO_2$ ,  $NO_2$ ,  $PM_{10}$ , and  $PM_{2.5}$ , whereas CO and  $O_3$  are in a secondary position among the six major pollution sources. Therefore, this study mainly analyzes the winter air quality pollutants of  $SO_2$ ,  $NO_2$ ,  $PM_{10}$ , and  $PM_{2.5}$ .

Table 1: Harbin 2015/2016/2017 air quality index

Year	Month	Composi- te index	Single largest index	Major pollutants
2015	1	10.9	3.5	PM <sub>2.5</sub>
	2	10.2	3.3	PM <sub>2.5</sub>
	3	6.2	1.8	PM <sub>2.5</sub>
	4	5.2	1.5	PM <sub>2.5</sub>
	5	3.6	1.0	$PM_{10}$
	6	4.0	1.0	PM <sub>2.5</sub>
	7	4.0	1.0	03
	8	3.0	0.8	$NO_2$
	9	3.2	0.9	$NO_2$
	10	5.2	1.6	PM <sub>2.5</sub>
	11	10.0	4.3	PM <sub>2.5</sub>
	12	11.0	4.1	PM <sub>2.5</sub>
2016	1	8.0	2.8	PM <sub>2.5</sub>
	2	6.3	1.9	$PM_{2.5}$
	3	5.7	1.6	PM <sub>2.5</sub>
	4	4.5	1.2	$PM_{10}$
	5	3.8	0.9	03
	6	3.3	0.8	$NO_2$
	7	3.3	0.8	$NO_2$
	8	3.2	0.8	$NO_2$
	9	3.1	0.9	$NO_2$
	10	4.2	1.3	PM <sub>2.5</sub>
	11	7.4	2.8	PM <sub>2.5</sub>
	12	7.6	1.2	PM <sub>2.5</sub>
2017	1	9.7	3.5	$PM_{2.5}$
	2	6.9	2.1	PM <sub>2.5</sub>
	3	5.9	1.6	PM <sub>2.5</sub>
	4	6.4	1.9	PM <sub>2.5</sub>
	5	4.4	1.3	$PM_{10}$
	6	3.7	1.1	03
	7	3.6	1.0	03
	8	2.8	0.8	03
	9	3.1	0.8	$NO_2$
	10	7.1	2.7	$PM_{2.5}$
	11	6.9	2.9	$PM_{2.5}$
	12	6.3	2.1	$PM_{2.5}$

#### 4.2 Analysis of air quality in winter 2015

In 2015, there were 361 days of effective air quality monitoring in Harbin, and the proportion of air quality standards reached 63.10%. The proportion of days with excellent air quality is 24.1%, the proportion of days with good air quality is 39.10%, the proportion of days with mild pollution is 19.6%, the proportion of moderate pollution days is 5.5%, and the proportion of severe pollution days is 8.6%.

The average concentration of air pollutants in each month of 2015 was plotted, as shown in Figure 1. In January, all pollutants were in a small peak period.  $SO_2$ 

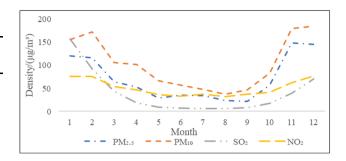


Figure 1: The distribution per month of major air pollutant concentrations in Harbin in 2015.

rose rapidly during the winter and reached its maximum value in January, followed by a rapid decline with time; although there were small ups and downs, it overall exhibited a downward trend. In the months of May, June, July, and August, the concentration of all pollutants was at the lowest stage of the year; since September, the concentration of various pollutants increased. In October,  $PM_{10}$  and  $PM_{2.5}$  increased sharply, and the average monthly concentration was 100%. The peak value was reached in December and  $SO_2$  and  $NO_2$  also increased, with  $NO_2$  fluctuations throughout the year. The details are as follows:

The average monthly  $PM_{2.5}$  concentration ranged between 22 and  $149 \,\mu\text{g/m}^3$ , with an average monthly concentration of  $70.75 \,\mu\text{g/m}^3$ .

The average monthly  $PM_{10}$  concentration ranged between 37 and  $145 \,\mu g/m^3$ , with an average monthly concentration of  $103.42 \,\mu g/m^3$ .

The average monthly  $SO_2$  concentration ranged between 6 and  $157 \,\mu\text{g/m}^3$ , with an average monthly concentration of  $39.67 \,\mu\text{g/m}^3$ .

The average monthly  $NO_2$  concentration ranged between 32 and  $77 \,\mu\text{g/m}^3$ , with an average monthly concentration of  $50.75 \,\mu\text{g/m}^3$ .

Figure 2 shows the statistics of air quality during haze in Harbin in 2015. During November, heavy pollution and above pollution occurred continuously in Harbin, mainly concentrated in early November; the number of days for air quality compliance was only 8 days, mainly in the middle of November. In December, there was a serious decline in air quality, with severe pollution and above days reaching 13 days, concentrated in the middle and end of the month stages. The number of days to reach the standard was less than in November, at only 6 days. During January 2016, there was a phenomenon of "returning to temperature" in the air quality, no severe pollution occurred, the number of days of heavy pollution decreased, and the number of days of compliance increased significantly.

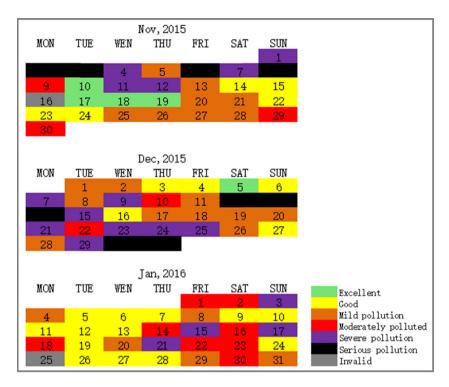


Figure 2: Calendar distribution of 2015 winter air quality.

#### 4.3 Analysis of air quality in winter 2016

In 2016, there were 358 days of effective air quality monitoring in Harbin, and the ratio of air quality to standard days was 77.7%. The proportion of days with excellent air quality was 28.8%, the proportion of days with good air quality was 48.9%, the proportion of days with light pollution was 15.6%, the proportion of moderate pollution days was 4.2%, and the proportion of severe pollution days was 2.2%.

The average concentration of air pollutants in each month in 2016 are finished and mapped as shown in

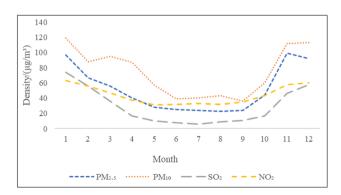


Figure 3: The distribution per month of major air pollutant concentrations in Harbin in 2016.

Figure 3. In January, all pollutants were in the peak period, and the  $PM_{2.5}$  increased sharply, while the  $PM_{10}$  monthly average concentration surpassed 100.  $SO_2$  increased rapidly during the winter and peaked in January, followed by a rapid decline; over time there were small ups and downs, but the overall trend is declining. In June, July, and August, the concentration of all pollutants was at the lowest stage of the year. Since September, the concentrations of various pollutants showed an upward trend, and in November,  $PM_{2.5}$  increased sharply. The average concentration of  $PM_{10}$  exceeded 100,  $SO_2$  and  $NO_2$  also increased, and  $NO_2$  fluctuated little year-round. The details are as follows:

The average monthly  $PM_{2.5}$  concentration ranged between 23 and 99  $\mu g/m^3$ , with an average monthly concentration of 51.58  $\mu g/m^3$ .

The average monthly  $PM_{10}$  concentration ranged between 36 and  $119 \,\mu\text{g/m}^3$ , with an average monthly concentration of  $74.10 \,\mu\text{g/m}^3$ .

The average monthly  $SO_2$  concentration ranged between 6 and  $74 \,\mu\text{g/m}^3$ , with an average monthly concentration of  $29 \,\mu\text{g/m}^3$ .

The average monthly  $NO_2$  concentration ranged between 31 and  $63 \,\mu\text{g/m}^3$ , with an average monthly concentration of  $43.92 \,\mu\text{g/m}^3$ .

The air quality statistics during the winter of 2016 are shown in Figure 4. It can be seen that compared with the same period in winter 2015, Harbin's days of heavy

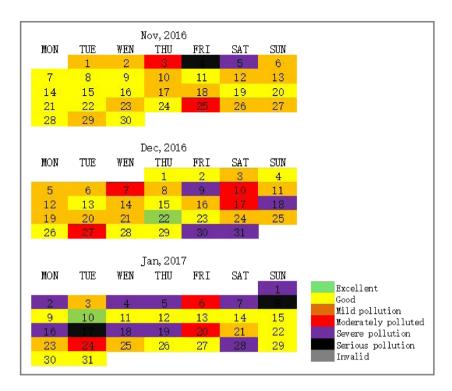


Figure 4: Calendar distribution of 2016 winter air quality.

pollution decreased from 25 to 17 days, a decrease of 32%, and the number of days of compliance increased from 27 to 37 days, an increase of 27.1%, meaning that the air quality has greatly improved. In November and December, nearly half of the days met targets, but by January 2017, the days above severe pollution increased, and the concentration of all pollutants reached the maximum mainly in early January and late mid-January.

#### 4.4 Analysis of air quality in winter 2017

In 2017, Harbin city monitored 365 days of effective air quality, and the proportion of air quality standards reached 74%. The proportion of days with excellent air quality was 25.5%, the proportion of days with good air quality was 48.5%, the proportion of days with mild pollution was 13.4%, the proportion of moderate pollution days was 4.4%, and the proportion of severe pollution days was 5.8%.

The average concentration of air pollutants in each month in 2017 is finished and mapped as shown in Figure 5. In 2017, the concentration of air pollutants fluctuated greatly compared with the previous 2 years. In January, all pollutants were in the peak period, and the monthly average concentration of  $PM_{2.5}$  and  $PM_{10}$  exceeded 100, reaching the highest peak in January; then, there was a small decrease, which fell during the period. However, the

concentration reached a small peak in April and then declined rapidly. In June, July, and August, the concentration of all pollutants was at the lowest peak of the year; since September, the concentrations of various pollutants increased rapidly. In October, the concentrations of  $PM_{2.5}$  and  $PM_{10}$  increased rapidly and reached the next highest peak, followed by a downward trend.  $SO_2$  and  $NO_2$  increased during the winter period, and the fluctuations were small.

The average monthly  $PM_{2.5}$  concentration ranged between 16 and  $123 \,\mu\text{g/m}^3$ , with an average monthly concentration of  $58.2 \,\mu\text{g/m}^3$ .

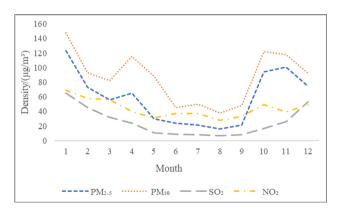


Figure 5: The distribution per month of major air pollutant concentrations in Harbin in 2017.

The average monthly  $PM_{10}$  concentration ranged between 38 and  $148\,\mu g/m^3$ , with an average monthly concentration of  $86.58\,\mu g/m^3$ .

The average monthly  $SO_2$  concentration ranged between 7 and  $65 \,\mu\text{g/m}^3$ , with an average monthly concentration of  $25.42 \,\mu\text{g/m}^3$ .

The average monthly  $NO_2$  concentration ranged between 28 and  $69 \,\mu\text{g/m}^3$ , with an average monthly concentration of  $43.83 \,\mu\text{g/m}^3$ .

To sort out the air quality during the winter of 2017, as shown in Figure 6, compared with the same period in the winter of 2015, Harbin's severe pollution and above days decreased from 25 to 9 days, a decrease of 64%, and the number of days of compliance increased from 27 to 56 days, an increase of 51.8%. Compared with the same period in winter 2016, severe pollution and above days decreased from 17 to 9 days, a decrease of 47.1%, and the number of days of compliance increased from 37 to 56 days, an increase of 34%, meaning that the air quality has obviously improved. In the winter of 2017, the most serious pollution of air quality was concentrated in the beginning of November. The air quality in the week was more than severe pollution.

Combined with the above chart, from the winter of 2015 to the winter of 2017, the overall air quality situation in Harbin has improved, and the number of severe pollution days has decreased year by year. The main air pollutants in winter are  $PM_{10}$  and  $PM_{2.5}$ . In October and November, the pollution concentration peaked, and after December, it showed a downward trend until the spring reached the valley in the following spring.

#### 5 Discussion

# 5.1 Analysis of the back trajectory of air masses

In this article, the HYSPLIT-4 model uses the GDAS meteorological data and UTC time to target the Harbin urban area (45.64°N–45.86°N, 126.47°E–126.81°E). The analysis of air quality in the past 3 years lasted for three consecutive years with severe conditions. The trajectories starting from 8 November 2015, 8 January 2017, and 7 November 2017 were selected as the starting point of the trajectory, and the 3 day (72 h) backward transportation trajectory was calculated by the model. The specific air mass trajectory is shown in Figure 7. The height of the air mass trajectory is selected from three different height

levels. The red trajectory represents the altitude of 100 m, the blue trajectory represents the height of 1,000 m, and the green trajectory represents the air mass transport trajectory at a height of 1,500 m.

Figure 7a is an analysis of the backward trajectory at 09:00 AM on 8 November 2015 (UTC time is 01:00 on 8 November). It can be seen that the three air masses are affected by the northwest monsoon, starting from the high altitudes of Mongolia and entering China's Inner Mongolia at about 6:00 on 6 November; the air flow is relatively stable. Before 7 November, the air flow moved above 3,000 m altitude. Since 06:00 on 7 November, the air flow began to fluctuate. At the same time, air masses at different heights decreased. At 18:00, they stabilized, and the three air masses returned to their corresponding heights. At this time, the air masses moved to Mudanjiang city and were affected by surface air flow. The air masses entered the city of Harbin from east to west.

Figure 7b is an analysis of the backward trajectory at 09:00 AM on 8 January 2017 (UTC time 1 January, 01:00), as the picture shows; The air masses at 500 and 1,500 m heights moved from northwest to southeast, and the 1,500 m high air flow activity is active, starting from a 600 m altitude in Russia to move southeast; at about 18:00 on 5 January, it quickly rose to an altitude of 3,000 m, and then gradually decreased again. At 18:00 on 6 January, the air mass stabilized at an altitude of 1,500 m and arrived at the northern side of Harbin in the early morning of 7 January. During the daytime on 7 January, the air mass moved to the west side of Harbin, and then returned to Harbin. The 500 m air mass began to move from a height of 2,000 m, the airflow was weakening, and the height of the air mass continued to decrease. On 6 January, the air mass dropped to 1,500 m. At this time, the air mass entered the Greater Khingan Range and then moved from the northern side of Heilongjiang Province to the southeast. On the morning of 7 January, the air mass returned to the 500 m altitude and reached the east side of Harbin and entered Harbin from east to west. The air mass at a height of 1,000 m moved around Harbin from 6 to 8 January. During the period from 5 to 6 January, the air masses moved around the surface. On the morning of 7 January, the air mass began to rise and gradually returned to the altitude of 1,000 m.

Figure 7c shows an analysis of the backward trajectory at 08:00 on 7 November 2017 (UTC time is 00:00 on 7 November). As can be seen from the figure, this time, the air mass trajectory starts from the southwest of Harbin and moves from southwest to northeast. The air mass at the altitude of 1,500 m began to move from Inner Mongolia to Liaoning Province and Jilin Province, and finally

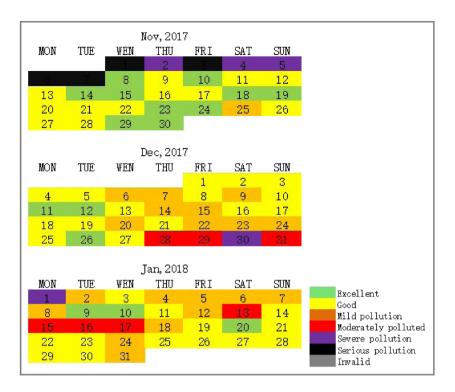


Figure 6: Calendar distribution of 2017 winter air quality.

entered Harbin City from the southwest side. The air masses had been moving at a high altitude near 500 m before 5 November, and they had risen to 1,000 m at 18:00 on the 5 November and then dropped to 500 m. At 12:00 on the 6 November, the air mass began to rise and gradually returned to 1,500 m. The air mass trajectories at the altitudes of 500 and 1,000 m were basically the same. On the morning of 4 to 12 November, the air mass moved southward from northern Jiangsu and then entered Harbin through Anhui, Shandong, Henan, Hebei,

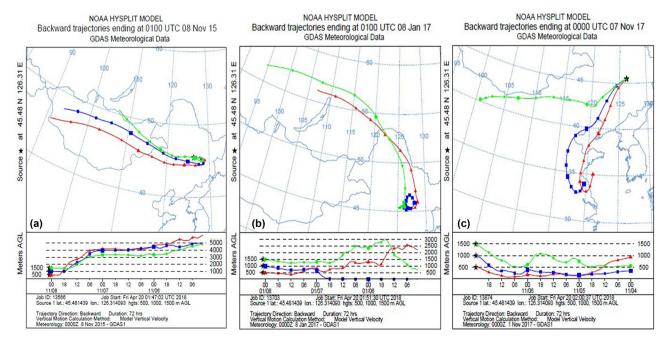


Figure 7: 72 h trail of Harbin city: (a) 2015.11.08 UTC 01:00, (b) 2017.01.08 UTC 01:00, and (c) 2017.11.07 UTC 00:00.

Shenyang, Jilin, and other provinces. The air mass at the height of 1,000 m began to move at a height of 500 m, during which the air flow was relatively stable. From 12:00 on 6 November, the air mass rose and gradually returned to 1,000 m. The air masses at a height of 500 m began to move from an altitude of 1,000 m, then fell to surface movement, and the air flow was always stable.

## 5.2 Analysis of straw incineration around Heilongjiang Province

In the northern provinces of China, there are many strawburning phenomena in autumn, which combine with the climate characteristics and farming system of Heilongjiang Province, as well as the hysteresis of the pollution effect

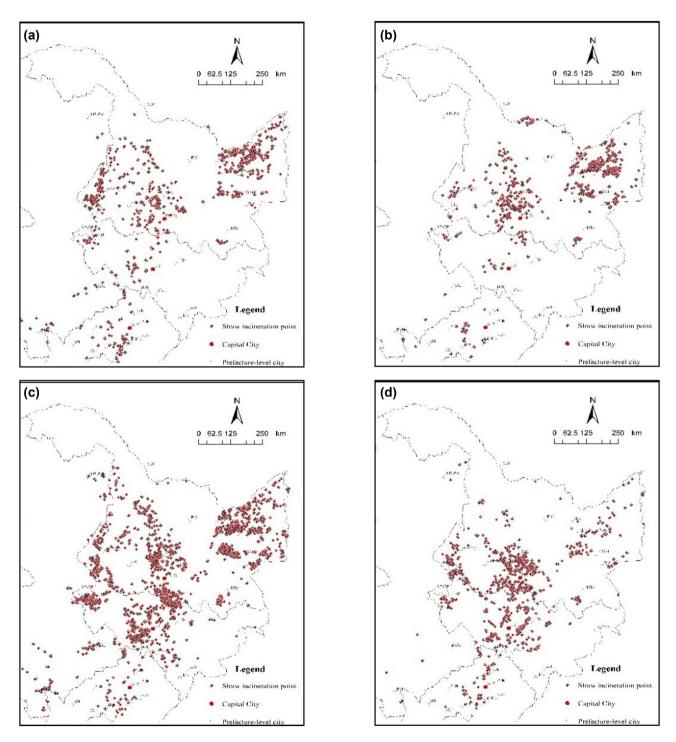


Figure 8: Distribution of straw-incineration points: (a) 2016.10, (b) 2016.11, (c) 2017.10, and (d) 2017.11.

caused by straw burning. An analysis of straw burning in October and November in the past 2 years (due to the missing 2015 straw-burning data, this year is not analyzed) is shown in Figure 8.

Figure 8a shows the situation of straw burning around Heilongjiang Province in October 2016. It can be seen that the straw burning in October is mostly distributed in the northeastern region and North China and is more serious the northeastern region. Among them, Heilongjiang Province has the most concentrated burning, and the central and western regions are mostly concentrated in Harbin, Daging, Suihua, and Oigihar, Burning in the east is mostly concentrated in Jiamusi city and Shuangyashan city. The burning points in Jilin Province are concentrated in the surrounding areas of Baicheng and Changchun, and the burning points in Liaoning Province are concentrated around Panjin and Liaoyang. Figure 8b shows the situation of straw incineration around Heilongjiang Province in November 2016. It can be seen from the figure that the situation of straw burning in the northeast region has improved compared with that in October, Jilin Province and Liaoning Province have significantly decreased, and Heilongjiang Province has decreased. However, the approximate distribution is basically similar to that in October. Figure 8c shows the situation of straw burning around Heilongjiang Province in October 2017. Compared with October 2016, the straw burning in the northeast region has intensified, and straw burning has occurred in nearly half of Heilongjiang Province and Jilin Province. The straw burning in Heilongjiang Province is divided into two major regions, and the central and western regions are mostly distributed in Harbin, Suihua, Daqing, and Qiqihar. In the eastern region, there are different degrees of straw burning, among which Jiamusi city and Hegang city are the most serious. Figure 8d shows the situation of straw burning around Heilongjiang Province in November 2017. Compared with October 2017, it can be clearly seen that the number of straw-burning points in Northeast China has decreased.

By analyzing the distribution of straw incineration points, it can be found that the backward trajectory path partially overlaps with the distribution range of straw incineration sites in the surrounding areas of Heilongjiang Province. The air mass movement transported pollutants from straw incineration to Harbin, and because Harbin was located in the Mongolian high-pressure zone in winter, the air mass affected by surface and weather was likely to gather in the sky, causing the easy formation of smog.

#### 6 Conclusion

In recent years, the smog phenomenon in Harbin has occurred frequently in winter, which has caused great problems for the living environment of local residents. To trace the causes of smog, the Ministry of Ecology and Environment of the People's Republic of China and the Environmental Protection Department of Heilongijang Province have used air quality data and straw-burning data based on the latest environmental quality standard (GB3095-2012) promulgated by the Ministry of Environmental Protection and Environmental Protection in 2012: the formula calculates the monthly major pollutants according to the 74 city air quality status reports issued by the Ministry of Ecology and Environment of the People's Republic of China. Finally, the concentration changes of four pollutants of PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, and NO<sub>2</sub> in the past 3 years were analyzed. It was found that the concentration of each pollutant increased sharply from November and began to decline in March of the following year. It is found that air pollution is the most serious in November every year and is most prone to continuous pollution at the beginning of the month.

The HYSPLIT-4 model was used to analyze the cause of the sharp increase in pollutant concentration. The atmospheric movement of the most severe period of pollution in Harbin was selected. It was found that the trajectory of the air mass was affected by the northwest monsoon. The air mass mainly entered from the west side of Harbin. Taking into account the current situation of agricultural activities in the northeast region, the corn stalk-burning period occurs at that time, and the national straw-burning point is transferred through the Ministry of Ecology and Environment of the People's Republic of China, focusing on the distribution of straw-burning points in the northeast region, and it is found that the burning of straw in Heilongjiang Province is serious. The time period is concentrated in October and November, and the distribution of straw-burning points on the west side of Harbin is relatively concentrated, which coincides with the air tracking.

Using the air quality index, straw-burning point, and HYSPLIT-4 model to analyze the air pollution causes of Harbin in the past 3 years, it is found that the main pollutant in winter is PM<sub>2.5</sub>. One of the causes of smog is straw burning in October and November each year. In addition, the winter in Harbin is affected by the northwest monsoon in winter. It is located on the edge of the

high-pressure area of the mainland, and the air movement of pollution and the transportation of goods to low altitudes has aggravated the haze phenomenon in Harbin. Therefore, one of the causes of the serious haze in winter in Harbin in recent years is the transport of fine particles produced by the burning of surrounding straw.

In the next research process, the effects of hot spot distribution will be analyzed and an exhaust gas emissions analysis of haze will be conducted in Harbin.

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