Climatic Characteristics and Synoptic Situations of Regional Haze in Liaoning Province

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Abstract. Based on the climatic statistical characteristics of haze data from 1961 to 2013 in Liaoning province, the results show that the number of days of haze weather in Liaoning province shows a rising trend year by year. The number of days increases obviously after the 1980s. It shows a steady trend of growth in the 1990s. The growth trend in the early years of this century is obvious again, especially in the nearly 5 years. The changes of haze days coincide with the actual situation of industrial economy, rapid urban development and high energy consumption in Liaoning province in the last 30 years. There is the high incidence area of haze in the central cities in Liaoning. Winter (December to February) is the high incidence season of haze in a year, and haze days account for 30%-40%. During a day, haze weather mainly occurs between 2 a.m. to 8 a.m. accounting for 44.5%, 2 p.m. to 8 p.m. account for 25.9%, however other times less. Through comprehensive analysis of synoptic situations and meteorological factors of haze, five kinds of weather forecasting models for haze weather in Liaoning province are established, which provides basis for the forecast of haze weather.

1. Introduction

Haze is a kind of weather phenomenon, which is large number of extremely fine dry dust particles that float evenly in the air, so that the horizontal visibility is less than 10km and the air is generally turbid [1-4]. Haze will not only aggravate air pollution, worsen air quality, reduce visibility, seriously affect air and sea transportation, but also cause respiratory diseases and seriously harm human health. The 19th congress of the communist party of China put forward building beautiful China, and bring the construction of ecological civilization into the five-in-one entire distribution of socialism with Chinese characteristics, which puts forward higher requirements to optimize and improve the human living environment. With the improvement of people's living standard, the need for healthy environment is becoming more and more urgent. But with the rapid development of industrialization and urbanization in China, haze is frequent. How to do well in the forecast of haze, provide timely and accurate forecast information for the masses, so that it can effectively avoid or prevent the harm caused by haze to health becomes an urgent task to be completed. Domestic scholars [5-10] have carried out a lot of research works on the climate characteristics, which can cause the relationship with meteorological elements of haze. Liaoning is a heavy industry province. During the winter heating period, it mainly focuses on coal burning. The number of haze days is increasing year by year, and the disasters caused by haze are becoming more serious. In this paper, by analyzing the synoptic and climate
characteristics of haze weather in Liaoning province, the climate characteristics of Liaoning regional haze weather were combed, the synoptic concept model of regional haze weather were established and refined prediction technical indicators. It can provide technical support to improve the accuracy of haze forecast warning.

2. Climatic characteristics of haze in Liaoning province

2.1 Decadal variations

Haze days in Liaoning province has been increasing year by year because of climate change and urban development in recent decades (fig 1-3). The average haze days of the whole province were 6.9 days in the 1960s, 19.6 days in the 1970s, 36.5 days in the 1980s, and 33.5 days in the 1990s, and 76 days after 2000. The cities with the largest number of haze days are Shenyang, Anshan, Fushun, Benxi and other Liaoning central cities (Shenyang economic zone), and the number of haze days increases rapidly after 2002. In Shenyang, for example, the average number of haze days in the 1960s and 1970s was about 6 days per year. After the 1980s, the number of haze days increased rapidly, averaging about 20 days per year. The 1990s showed a steady trend of growth, which has increased to an average of about 60 days a year by the beginning of this century, with an obvious trend of growth. The increase is even more pronounced in the past five years, with an average of about 120 days a year, and the number of haze days accounts for 30-40% of the total now. The number of haze days in the coastal areas of Liaoning, including Dalian, Dandong and Panjin, is relatively small. The change of haze days coincides with the actual situation of the industrial economy, rapid development and energy consumption in Liaoning province in the last 30 years.

Fig.1 Haze days change of central city of Liaoning in recent 50 years (1961-2010)

Fig.2 Haze days change of coastal city of Liaoning in recent 50 years (1961-2010)
2.2 Monthly variation
The number of haze days in different months in Liaoning province is obviously different. Taking the central city Shenyang as an example (fig.4), winter (December to February) is the high season of haze occurrence, and the number of haze days accounts for 30% to 40% of the whole year. Autumn accounts for 21% to 26%, and autumn and winter accounts for more than 60% of the total haze days. The number of haze days in summer (June to August) accounts for 18% to 22% of the whole year. It shows that there are more haze days in autumn and winter, and less in spring and summer.

2.3 Diurnal variation
In a day, haze has emerged mostly from 2 a.m. to 8 p.m., accounts for 44.5% of a day and at the time of 2 p.m. to 8 p.m. accounts for 25.9%, but other times less. In the early morning and early evening, it is a time for haze to occur, and it is not easy to have long time haze during the daytime.

3. Synoptic types of haze in Liaoning

3.1 Data and Definitions
If there is more than 5 national meteorological stations in which haze occurred in one day, it is defined as a regional haze. The ground observation data of 56 national meteorological observation stations in Liaoning province from 1961 to 2016 were selected, and the data of surface pressure field, wind speed, temperature and dew point were analyzed. Surface pressure field data using NCEP reanalysis data, the resolution is $2.5 \times 2.5 ^\circ$, according to the defined standards, there are 174 cases of regional haze weather.
3.2 Synoptic typing of haze

The haze statistic instance shows that the weak pressure field and homogeneous pressure situations can lead to regional haze weather under the static stability weather situation. There is no obvious high weather system occurring when regional haze happening. So for regional haze weather, it is given priority to the ground field situation. It can be divided into five types, which are the uniform pressure field in the high pressure front type, the uniform pressure field in the high pressure internal type, the uniform pressure field in the low pressure front type, the northwest trough northeast high pressure type, the low pressure back or the passage of a cold front type. In the 174 regional haze events, the uniform pressure field in the high pressure front type was 52 times, accounting for 29.5%. The uniform pressure field in the high pressure internal type was 23 times, accounting for 13.1%. The uniform pressure field in the low pressure front type was 71 times, accounting for 40.3%. The northwest trough northeast high pressure type was 10 times, accounting for 5.7%. The low pressure back or the passage of a cold front type was 18 times, accounting for 10.2%.

**The uniform pressure field in the high pressure front type:** This type of regional haze occurs mostly in winter and spring. On the surface weather chart, there is a complete high pressure in the western Xinjiang or Baikal region, with a central strength of more than 1040 hPa and a maximum of 1065hPa. When Liaoning province is in the front of high pressure, the pressure field is weak, the northern airflow control, most of the time the weather is given priority to clear, the wind is not big which is 2 m/s or less, sometimes even to calm wind, a few for 2-4 m/s, the relative humidity is 60% to 75%, wind speed generally 8 m/s or less corresponding to 850 hPa. There has more temperature inversion in the near ground layer.

**The uniform pressure field in the high pressure internal type:** On the surface weather chart, within the scope of 35-55°N, 115-135°E, Liaoning province is controlled by a closed high atmospheric pressure, and sometimes it is divided into several centres. Liaoning province locates in the center of high-pressure, in the bottom of high pressure and in the top of high pressure, the weather is given priority to clear, the ground wind speed is small, most of the case speed is 1 m/s or

![Fig. 5 Statistics of synoptic typing of haze in Liaoning](image)

![Fig. 6 The uniform pressure field in the high pressure front type](image)
less, other wind speed is about 2 m/s, the ground relative humidity is 60% to 80%. Corresponding to 850hPa, the wind speed is also small, generally less than 6m/s.

![Fig7. The uniform pressure field in the high pressure internal type](image)

**The uniform pressure field in the low pressure front type:** There is a complete low pressure on the surface weather chart, which is located in the 40-55°N, 110-110°E. Liaoning province is in the control of front of low pressure. In most cases, the weather is cloudy or overcast, minority situation for sunny, wind speed of half the number is 2 m/s or less, partly for 2-4 m/s, less for > 5 m/s, relative humidity is 70% to 85%. Corresponding to 850hPa, the wind speed is generally about 8 m/s, and sometimes the southwest wind is slightly larger, which can reach 10-12m/s. There are near 5 percent of the cases with inversion weather in ground layer.

![Fig8. The uniform pressure field in the low pressure front type](image)

**The northwest trough northeast high pressure type:** On the surface weather chart, there is a inverted trough from the southwest to the north China area, the northeast region is the high pressure, the high pressure center is generally located in the east of Inner Mongolia to the western part of Heilongjiang province. The sky condition is generally cloudy or overcast. The wind speed on the ground is generally 2-4 m/s. The relative humidity is about 50-80%. Corresponding to 850 hPa, wind speed is 4 to 8 m/s, mostly with inversion, the intensity of inversion for 2-4 °C or more.
The low pressure back or the passage of a cold front type: On the surface weather chart, Liaoning province is in the rear of the low pressure, and there is a low-pressure cold front moving over Liaoning province. The sky condition is cloudy or cloudy to clear. The ground wind speed is generally 2-4 m/s, and the relative humidity is 50-80%. Corresponding to 850hPa, the wind speed varies greatly, between 4-12 m/s. Most of the situation is in the control of cold advection of the cold flow, and there has not inversion weather.

4. Statistical characteristics of meteorological elements in haze days
From the previous analysis, there is most haze weather occurring from 2 a.m. to 8 a.m. in a day. Meteorological observation data of 8 a.m. is selected as statistical standards, which make climate probability and statistics of several meteorological elements which is conducive to haze. The results are as follows:

4.1 Ground wind field
When haze occurs, the surface wind speed is generally small in 8 a.m., with a maximum of 1-2m/s. When the wind speed is greater than 5m/s, it is more favorable for atmospheric diffusion, and the occurring probability of haze is less.

4.2 Stratification condition
When the near ground layer is relatively stable or has the inversion temperature, it is beneficial to the accumulation of water vapor and dust impurities. When using the temperature difference between 500 hPa (or 925 hPa) to ground at 8 a.m. to reflect approximated atmosphere stratification condition, the statistics show that appearance of haze generally have accompanied by inversion, inversion generally in more than 2 °C, sometimes more than 8 °C, even stronger.

4.3 Relative humidity
When the haze occurs, the relative humidity of the ground is generally between 50% and 80%. When the relative humidity is less than 80% or less than 50%, the haze hardly appear.

4.4 Visibility
In the case of haze, the ground visibility at 8 a.m. is between 5 and 8km, and there is a low probability of haze when visibility is greater than 8km.

4.5 Other weather phenomena
Haze is often accompanied by light fog, smoke, smoke screen and other weather phenomena. In summer, there is high probability of occurrence of haze and light fog at the same time, and the morning of haze days usually have fog or light fog. In winter, there is high probability of occurrence of haze and smoke or smoke screen. The main reason is the winter heating in Liaoning province being mainly coal burning, with more particulates emission.

5. Cause of haze in Liaoning province
The formation of haze is mainly the result of a large number of particles suspended in the air and meteorological conditions. There are three causes.

1) Increase of static wind in horizontal direction. In recent years, with the rapid development of urban construction, the building is more and more high, blocking and frictional effect makes the flow of the wind significantly weakened when it flow through the cities. The increase of static wind is not conducive to the diffusion dilution of atmospheric pollutants, but it is easy to accumulate particles in urban areas and near suburbs.

2) Inversion occurs in the vertical direction. The inversion reduces cross-ventilation of the upper and lower air. In particular, the near-surface inversion is like a "big lid" that makes it difficult for particulate matter and harmful gases suspended in the atmosphere to diffuse to up level. In general, the inversion is generated around 6 p.m., and disappears around 8 a.m. in the next day, corresponding to the occurring time of haze.

3) Increase of atmospheric particulate concentration. Due to large amounts of pollutants such as smoke, black carbon, sulfur dioxide and nitrogen oxides produced by coal burning, and automobile exhaust contains a large number of hydrocarbons, nitrogen oxides, sulfur dioxide and fuel dust particles, sulfur dioxide and nitrogen oxides through chemical reaction produce sulfate and nitrate particles, these pollutants lead to the increasing of dry dust, smoke, sulfate, nitrate, black carbon, hydrocarbons and other atmospheric fine particles in the air.

6. Conclusions and discussions.
(1) The haze weather days in Liaoning province show the trend of rising year by year, and increase obviously after the 1980s. It shows a steady trend of growth in the 1990s. The growth trend in the early years of this century is obvious again, especially in the nearly 5 years. The changes of haze days coincide with the actual situation of industrial economy, rapid urban development and high energy consumption in Liaoning province in the last 30 years.

(2) There is the high incidence area of haze in the central cities in Liaoning. Winter (December to February) is the high incidence season of haze in a year, and haze days account for 30%-40%. During a day, haze weather mainly occurs from 2 a.m. to 8 a.m., accounting for 44.5%, and 2 p.m. to 8 p.m. account for 25.9%, however other times less.

(3) The regional haze weather in Liaoning province can be divided into five types, which are the uniform pressure field in the high pressure front type, the uniform pressure field in the high pressure internal type, the uniform pressure field in the low pressure front type, the northwest trough northeast high pressure type, and the low pressure back or the passage of a cold front type.

(4) In the context of large-scale weather conditions that is conducive to haze, and the wind speed that is relatively small, and inversion occurring, there is a high probability of haze. In recent years, due to the increase of atmospheric particulate concentration, the frequency of horizontal static wind has
increased, and the vertical inversion has caused haze weather to occur, which has shown an increasing trend.

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