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LONG-TERM VARIATIONS OF FOG AND MIST IN MAINLAND CHINA DURING 1951-2005

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Abstract: Fog is an important indicator of weather. Long-term variations of fog and mist were studied by analyzing the meteorological data from 743 surface weather stations in mainland China during 1951-2005. In climatology, there are more foggy days in the southeast than in the northwest China and more in the winter half of the year than in the summer half. The decadal change of foggy days shows regional variation. Southwest China is the region with the most foggy days, and more than 20 foggy days occur in Sichuan Basin in one year. Persistent heavy fog usually appears in winter and spring over the North China Plain and Northeast China Plain. Misty days are much more frequent in the provinces south of the Yangtze River than in the regions north of it, and there is an obvious increase of misty days after the 1980s. Southwest China is the area with the most number of misty days, and more than 100 misty days occur in Sichuan Basin in a year.

Key words: mainland China; fog; mist; long-term variation

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1 INTRODUCTION

Globally, the scientific community, the general public and governments have paid more and more attention to the global environmental problems induced by climate warming. Recent studies show that a global warming trend is evident and closely related with human activities. In the 100 years of the 20th century, the global surface air temperature rose by 0.4 to 0.8 °C on average. According to the different scenarios from climatic simulation, it is estimated that the global mean temperatures will rise by 1.4 to 5.8 °C in the next 100 years. In the 20th century, China showed a warming trend similar to the global one. In the past 100 years, the average temperature of China has risen by 0.5 to 0.8 °C, which is slightly higher than that of the globe[1-3].

Under the background of global warming related with human activities, the haze in urban areas in China has significantly increased[4-6] while the foggy days in China have significantly decreased[7]. Many studies have focused on the fog of China, but many of them refer to a single foggy process or the regional and local characteristics of fog[8-15]. Only a few studies have addressed the long-term variation of fog. Liu et al.[16] analyzed the climatic characteristics and variation of fog in China using 30-year data from 1971 to 2000. Wang et al.[7] discussed the influence of climate change on fog using 43-year data from 1961 to 2003. This paper analyses the long-term trends of fog and mist during 1951 to 2005 using the data from 743 surface weather stations in mainland China.

Both reducing visibility and leading to disastrous weather, fog and haze are composed of particles suspending in the atmosphere, but their compositions and forming processes are completely different. Fog is an aerosol system composed of a large number of tiny water droplets or ice crystals suspending in the air near the ground surface, a product resulting from condensation or sublimation of water vapor there. Almost all meteorological textbooks emphasize that fog is composed of water droplets or ice crystals,

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which contributes to saturated relative humidity. The appearance of fog will reduce air transparency and deteriorate visibility. If horizontal visibility is less than 1,000 m, the weather phenomenon of condensation or sublimation of water vapor suspended in the air near ground surface is called fog and it is known as mist if the horizontal visibility is between 1,000 and 10,000 m (used to be called brume before the founding and earlier years of the People's Republic of China). These droplets obstruct the vision because of its strong scattering effect to the visible light. It can be divided into radiation fog, advective fog and frontal fog, depending on the formation mechanism. The relative humidity is saturated when the fog occurs (saturation can occur in the presence of a large number of condensed nuclei, with relative humidity still below 100%). Like clouds, fogs are separated from the fine sky by well-defined boundary. As fog droplets distribute unevenly, the visibility is quite heterogeneous. The size of a fog droplet is relatively large, about 3 to 100 μm, and the average diameter is about 5 to 10 μm, which can be seen by the naked eye as it is suspending in the air. Because the fog droplet is much larger than the visible light in wavelength, it scatters panchromatic light, making the fog look like greenish white color. Heavy foggy weather has become a severe disastrous weather phenomenon in the developed area of eastern China.

2 DATA AND METHODS

This paper used meteorological data from 743 national basic (benchmark) stations of a meteorological ground observation network in China for the period between 1951 and 2005. This dataset contains the most comprehensive observation data for ground meteorological elements, which all pass the quality check by archiving experts from the National Meteorological Center.

Long-term climate data used as fog statistics need to be quantified against unified standards first and no weather phenomenon records can be used directly for this purpose. During the routine practice of observation at weather stations across China, thresholds have long been inconsistent in distinguishing fog from mist, offering no comparability between records from different stations. There has not been a single unified criterion to refer to in China and it is quite common that relative humidity, which was set at values lower than it should, was employed in southern China to assist in actual identification. Therefore it is necessary to use visibility, weather phenomena and relative humidity for comprehensive judgment and to eliminate other obstacles within visual ranges, instead of directly using daily data of fog and mist from observation reports[17-23], in order to have objective determination.

In the study on long-term climate change of fog, there are two commonly used methods to process the large number of historical data. One method is correcting the data based on the observational records. A day is statistically determined as a foggy (misty) day as long as it meets the standard of fog (mist) at any time of the day. The other method is to define based on the daily mean value. Excluding the weather events of precipitation, blowing snow, blizzards, duststorms, sandstorms and other situations that can lead to low visibility, a day is defined as a misty (foggy) day if the daily mean meteorological optical range (MOR) is less than 10 km (1 km) and the daily mean relative humidity (R_H) is greater than 90%[5]. This work used daily mean values.

3 CLIMATIC CHARACTERISTICS OF FOG

The occurrence of fog shows considerable variation across geographical locations. In general, fog occurs frequently in the regions at high latitude. Fog is a common and continuous phenomenon in the polar region, with about 80 to 100 days falling into foggy days annually. On the contrary, the occurrence of fog is relatively rare in the low-latitude region. Due to the lack of water vapor in the interior of the continent, the frequency of fog is smaller as it is further inland. Fog is more frequent in the coastal areas where cold ocean currents meets warm ones, such as the coasts of North and South America, and African and southeastern Asian coasts. Moreover, there is more fog in the mountainous area than the plain.

Figure 1 is the geographical distribution of foggy days using 743 surface weather stations in mainland China. In China, fog is more frequent because of the vast area of rivers, which produce abundant water vapor. For example, the southwest China is the region with the most fog occurrence in the country. There are more than 20 foggy days in one year in Sichuan Basin, with more than 100 foggy days in one year in Jinfo Mountain which is 3000 meters above sea level. There are also many foggy days in the areas south of the Yangtze River and the coastal regions, and the foggy weather in Hunan and Jiangxi is most typical. What is more, persistent heavy foggy weather usually appears in winter and spring over the North China Plain and Northeast China Plain. These characteristics show little decadal variation.

Among the 743 ground stations, those with annual foggy days ranking at the top 10 are Jingfo Mountain in Sichuan, Jiuxian Mountain in Fujian, Emei Mountain in Sichuan, Hengshan Mountain in Hunan, Kuocang Mountain in Zhejiang, Huangshan Mountain in Anhui, Tianmu Mountain in Zhejiang, Lvcongpo in Hubei, Qixian Mountain in Fujian, and Lushan Mountain in Jiangxi. All the top 10 stations are located to the south of the Yangtze River and have more than 27 foggy days in one year. In addition, the stations with more than 10 annual foggy days are located in Tai Mountain in Shandong, Changbai Mountain in Jilin, Wutai Mountain in Shanxi, Pingbian in Yunnan, Chengshantou in Shandong, Huajialing in Gansu, and Huashan Mountain in Shaxi. Most of the stations with only a few foggy days a year are located in the western areas of China, such as Xiaojin in Sichuan, Guide and Lenghu in Qinghai, where the average annual foggy days are zero, indicating there is no foggy weather in 50 years.

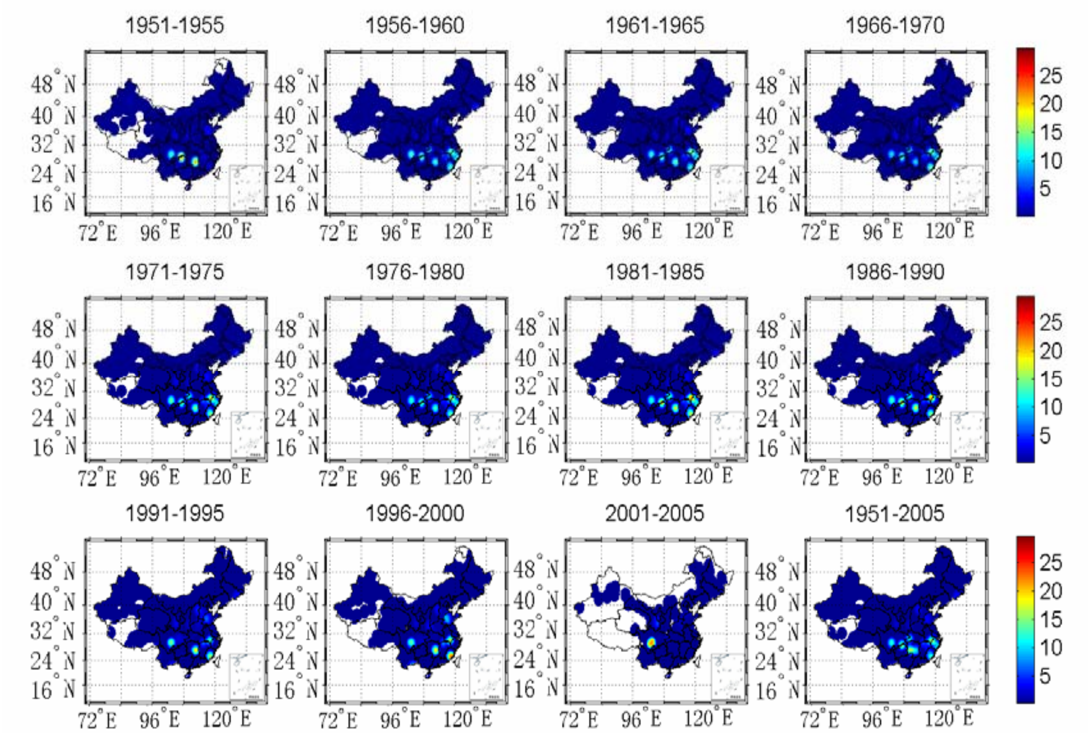

Figure 1. Distribution of foggy days averaged for 1951-2005 (the right, bottom panel) and every five years in mainland China.

On the whole, the geographic distribution of climate foggy weather in mainland China is characterized by more foggy days in the southeastern China but much less in the northwestern China. All the indices reflecting the temporal distribution, including the number of monthly foggy days, the most monthly foggy days and the seasonal distribution of foggy days, show discrepancies between the northern and the southern regions, the eastern and western regions, and significant local features. On the whole, the average annual foggy days have shown an increasing trend in the middle and eastern China but a decreasing trend in the northwestern China, which reflects the annual variation of fog. The number of annual foggy days changes insignificantly. The number of foggy days in China reduced significantly after 2000, though with varying extent in different regions. For instance, there are differences among Beijing, Chongqin and Guiyang. The overall number of annual foggy days in Beijing has changed little. In the 1960s, the foggy days were less and the visibility was the best. During the late 1970s and early 1980s, when the economy developed quickly in Beijing, the foggy days increased significantly and the visibility reduced sharply. In recent years, there were always more than two consecutive days of foggy weather in Beijing in October to December, which brought threats to the traffic, civil aviation, major activities and livelihood of the citizens, drawing heightened concerns from all walks of life. Because of its special valley environment, Chongqing used to be known as the "city of fog", but its number of foggy days is now showing a decreasing trend. In contrast, the number of annual foggy days in Guiyang has significantly increased from 5 days in the 1980s to 28 days in 2005.

For most stations, the most monthly foggy days appear from October to December, except for the regions of Heilongjiang, northern-central part of Inner Mongolia region, Shandong Peninsula, Jiangsu and Zhejiang coasts, Guangxi, Guangdong and some areas in the west, where the most monthly foggy days appear in February to August. For the coastal areas, it may be related to the causes of fog. In these areas, the most common type of fog is the advection fog, which forms when the warm air reaches the cold sea surface off the coast and then condenses. As a result, it often appears when a cold season changes to a warm one. For inland areas such as Heilongjiang and the northern-central part of Inner Mongolia region, fog mainly appears in the warm season. It is probably the high humidity in warm seasons that makes it easy for the radiation fog to form at night.

The panel at the right corner of Figure 1 shows the distribution of the 55-year average foggy days in mainland China. Overall, there are more foggy days in the southeast than in the northwest of China. Most parts of the southwestern China have 15 to 50 foggy days in a year but less than 15 days in most of the northwestern China. Areas with more than 30 foggy days in a year include Daxinganling Mountains, northern Heilongjiang, Jilin and eastern Liaoning in the northeastern China, regions near Tianshan in the northwestern China; the coastal areas in Jiangsu and Zhejiang, the northwestern mountainous area of Fujian, Sichuan Basin, areas bordering Hunan and Guizhou and southwestern Yunnan in the eastern and southern China. The areas with more than 60 annual foggy days are concentrated on the coasts of eastern Liaoning, Shandong Peninsula, Jiangsu and Zhejiang, northwestern and coastal Fujian, Sichuan Basin, and southwestern Yunnan. The northwestern Fujian and southwestern Yunnan are the foggiest places with more than 100 foggy days. For example, Jinghong, Lancang and other areas in Yunnan have about 100 foggy days a year. The main reason of so much fog is that these places are located in basins and river valleys where radiation fog tends to form in the winter half of the year. Since the emergence of fog is caused by the condensation of water vapor, a certain degree of humidity and the weather condition leading to saturated humidity are necessary factors for the formation of fog. Thus, the total annual precipitation in one place directly influences the local dry and wet conditions. In climatology, the total annual precipitation is larger in the east than in the west of China. The isohyet of 400 mm starts from the Daxinganling Mountains, extending all the way to the southwest, and terminates in the valley of the Brahmaputra River. The climate in the areas east of this isohyet is moist or relatively moist while that west of it is dry where the steppes and deserts are. The northern Xinjiang is the place with most rainfall in the western China because of the water vapor coming from the Atlantic and Arctic. Correspondingly, there is an average of 4 to 8 foggy days annually in some areas of northern Xinjiang. Being consistent with the topography in China of being higher in the west than in the east, the fog appears more in the eastern low-lying plains and hilly areas than in the western plateau areas with higher altitude.

4 CLIMATIC CHARACTERISTICS OF MIST

Figure 2 shows the geographical distribution of mist in China. It can be seen that the misty days are much more in the provinces south of the Yangtze River than those north of it. There were more misty days in the early 1950s than in the late 1970s and there was an obvious increase of misty days after the 1980s. Southwestern China is the part of the country which has the most misty days and Sichuan Basin has more than 100 misty days in a year, with more than 200 days in the Jinfo Mountain, which is 3000 m above sea level. During 2001–2005, the number of misty days all over the country significantly decreased. It could be related to the urbanization near the stations, which changes the humidity condition. Among the 743 ground stations, stations with annual misty days ranking at the top 10 are Jingfo Mountain in Sichuan, Jiuxian Mountain in Fujian, Emei Mountain in Sichuan, Kuocang Mountain in Zhejiang, Lvcongpo in Hubei, Tianmu Mountain in Zhejiang, Huangshan Mountain in Anhui, Xishui in Guizhou, and Lushan Mountain in Jiangxi. All of these stations are located to the south of the Yangtze River, with more than 84 misty days in a year. In addition, misty days are also quite common in Changbai Mountain in Jilin, Qixian Mountain in Fujian, Fuling in Chongqing, Luzhou in Sichuan, Chenzhou in Hunan, Taining in Fujian, Yichun in Jiangxi, Wugang in Hunan, Pingbian in Yunnan, where the mist is recorded for more than 70 days annually.

5 LONG-TERM VARIATIONS OF FOG AND MIST IN URBAN AREAS

As urban areas are where population and economic activities are highly concentrated and the loads exerted by human being, materials and traffic transportation are much larger than those in the rural and remote areas, foggy weather-related disasters also cause heavier losses. Figure 3 exhibits the long-term variations of annual foggy and misty days in typical cities. It can be seen that in the cities where heavy industries are based in the northern China, represented by Shenyang, Beijing, Xingtai, Taiyuan and Zhengzhou, the foggy (misty) days tend to vary insignificantly over the 55 years and mainly reflect on the interannual and interdecadal scales. In Chongqing, Chengdu, Guiyang, Nanjing, Hangzhou, Changsha and Guangzhou, the number increases mildly or periodically. While Xi'an shows a decreasing trend, the southern cities of Shenzhen and Haikou’s trends are not obvious.

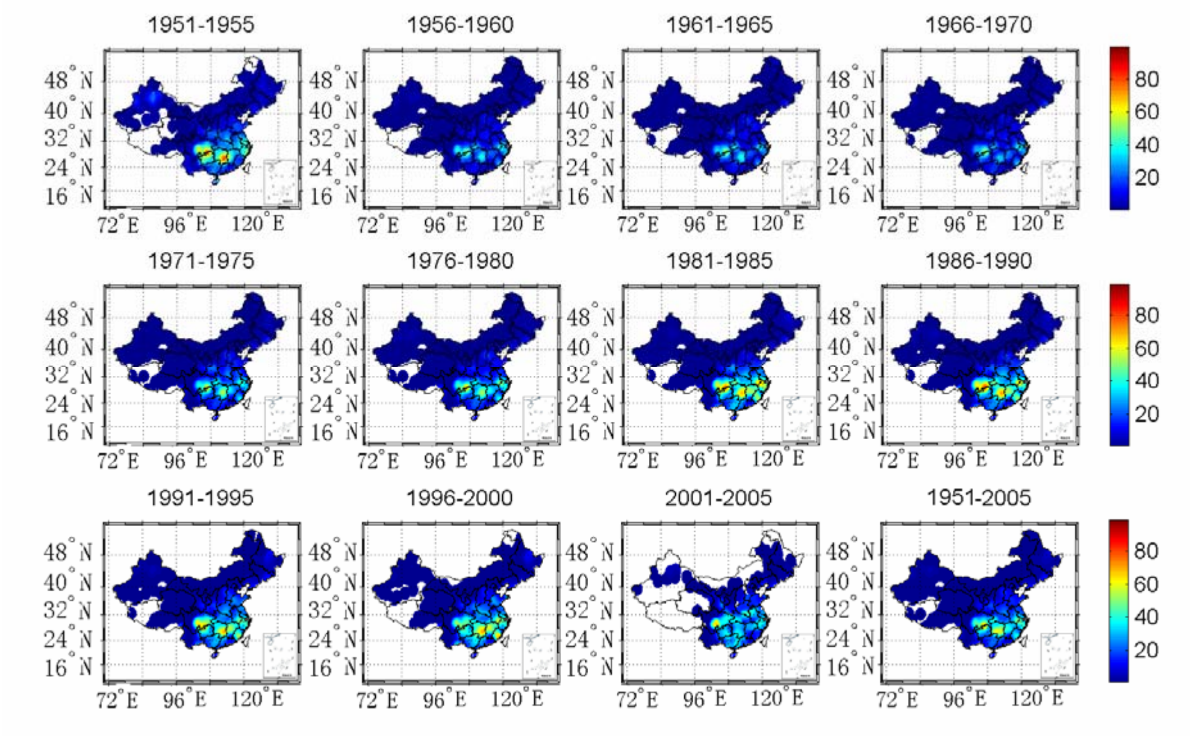

Figure 2. Same as Figure 1 but for the distribution of misty days.

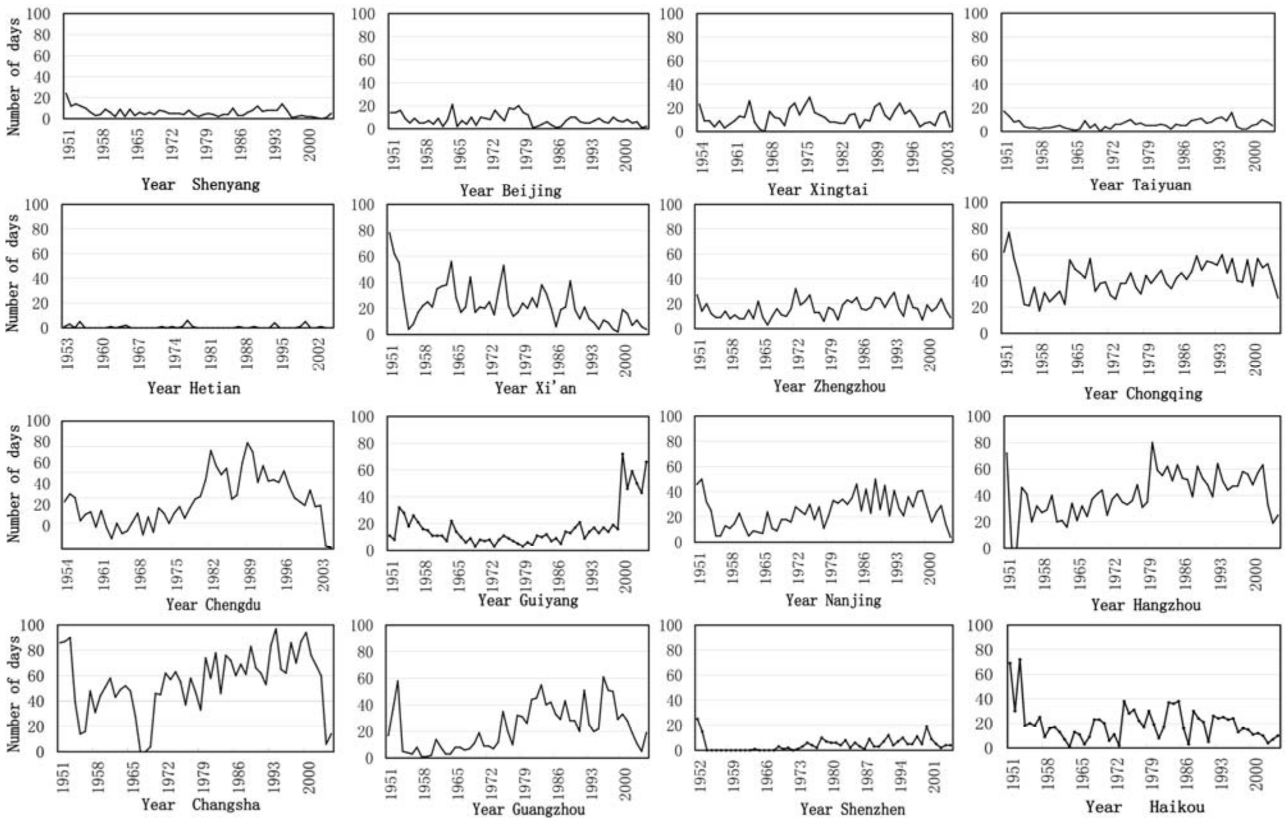

Figure 3. Long-term variations of annual foggy and misty days in typical cities.

Figure 4 shows the long-term variations of monthly foggy and misty days in typical cities. It is noted that the foggy (misty) days in the northern cities are obviously less than in the southern ones, which mainly occurs in late summer and autumn, because of the dry climate there. In Hetian of Xinjiang, for its extremely dry climate, foggy (misty) weather rarely occurs. There are more foggy (misty) days in Xi'an and Zhengzhou than the cities in the northern cities but less than those in the southern cities. It mainly appears in summer and autumn, and winter as well. Foggy (misty) weather in the southern cities of

Chongqing, Chengdu, Nanjing, Hangzhou and Changsha is much more than in other cities, and it appears all the year round. The foggy (misty) weather in Chongqing, Chengdu and Guiyang appear more in autumn and winter, while appearing more in winter and spring in Hangzhou and Changsha. Particularly, the foggy (misty) days are more in spring in Guangzhou, which is closely related to a condition called "Back to the Southerly" during the local pre-flood period[18]. Foggy (misty) weather occurs less frequently in the southern coastal cities of Shenzhen and Haikou. This is somewhat related to the continuous presence of coastal northeasterly winds during the local foggy season, making the foggy (misty) weather difficult to maintain[24, 25].

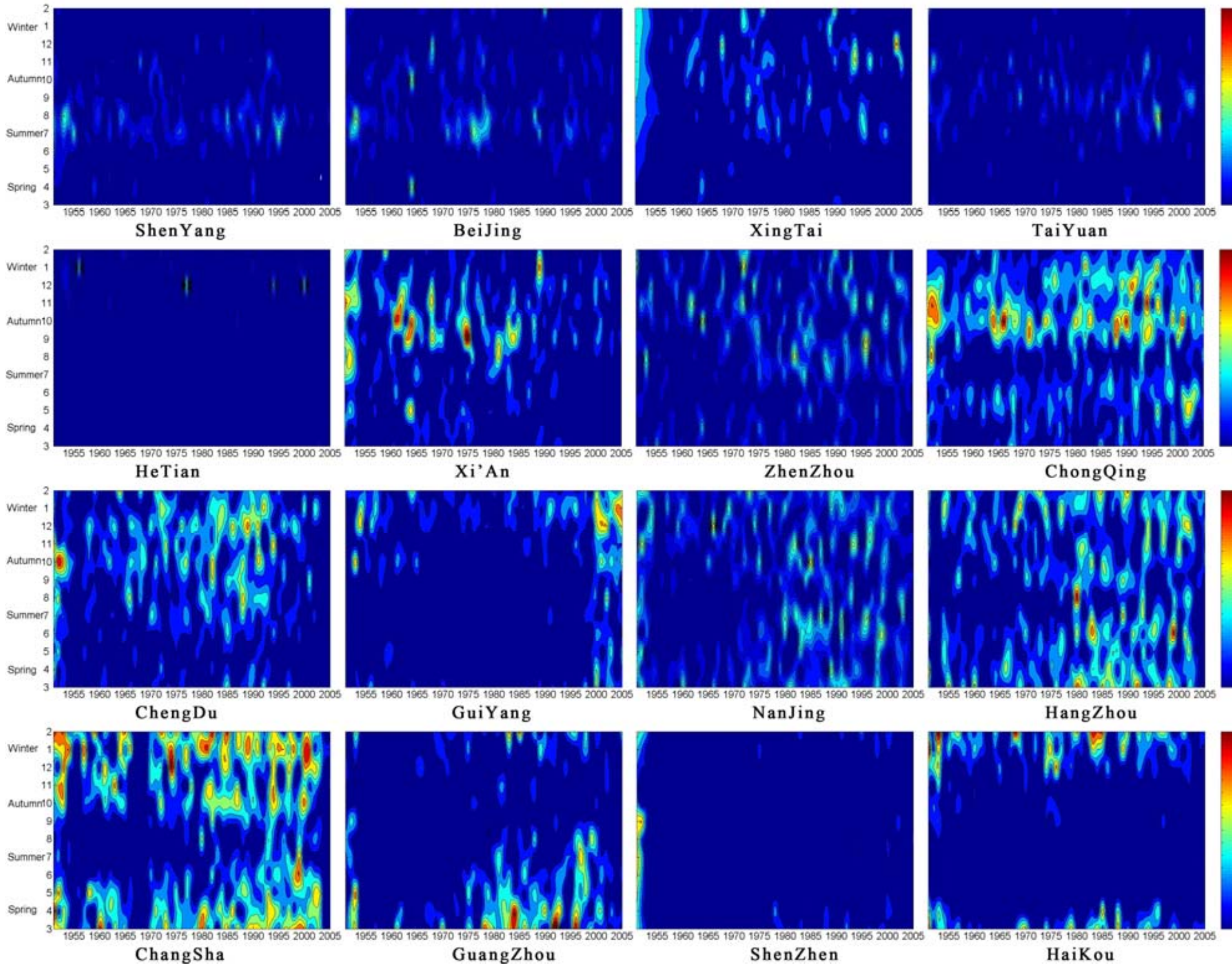

Figure 4. Same as Figure 3 but for monthly foggy and misty days.

6 CONCLUSIONS

The long-term trends of fog and mist variation are studied by analyzing the meteorological data from 743 surface weather stations in mainland China for the period from 1951 to 2005.

Overall, the geographic distribution of climate foggy days in mainland China is characterized by more in the southeastern than in the northwestern part and most in the southwestern part. Annually, there are more than 20 foggy days in Sichuan Basin, with more than 100 days in JinFo Mountain which is 3000 meters above sea level. There are also many foggy days in the south of the Yangtze River, especially in Hunan and Jiangxi. Fog appears more in coastal regions, and persistent, heavy fog usually appears in winter and spring over North China Plain and Northeast China Plain. Differences are insignificant between decades.

Most of the stations have more foggy days in the winter half of the year than in the summer half. In most parts of China, foggy days mainly occur in winter, i.e. from October to January, which accounts for 12.8% of the foggy days in the whole year, with the most in December.

Misty days occur much more frequently in the provinces to the south of the Yangtze River than those to the north and there is an obvious increase after the 1980s. Southwestern China is the part of the country which has the most misty days and Sichuan Basin is misty for more than 100 days in a year.

The variation of foggy (misty) days in the heavy industry cities in northern China, represented by such typical cities as Shenyang, Beijing, Xingtai, Taiyuan and Zhengzhou, shows insignificant trends over the 55 years and mainly presents interannual and interdecadal variations. The foggy (misty) days in Chongqing, Chengdu, Guiyang, Nanjing, Hangzhou, Changsha and Guangzhou increase mildly or periodically while Xi'an shows a decreasing trend, and Shenzhen and Haikou, which are located on the southern coast, show no obvious trends.

The foggy (misty) weather in the northern cities is less than that in the southern cities, which mainly occurs in late summer and autumn. The fog (mist) in the southern cities appears more in autumn and winter. The foggy (misty) days in Guangzhou mainly appear in spring while the coastal cities, including Shenzhen and Haikou, have relatively few occurrences.

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