The Analysis of the Weather Conditions of a High Visibility Heavy Pollution Event in Shenyang

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Abstract. There was a high visibility heavy pollution event in Shenyang on October 21st, 2014. This paper analyzes the formation and maintenance of the heavy pollution weather from the aspects of weather situation, meteorological elements, atmospheric stability and pollutants transportation. The results show that the heavy pollution weather process is due to the surface layer atmosphere transports local atmospheric pollutants into the air by turbulent motion, and the inversion of the upper block pollutants diffuse into the sky, plus the northeaster wind transport, the heavy pollution occurs in Shenyang area. In the event of heavy pollution, the relative humidity is relatively low, and the moisture absorption effect of particulate matter in the atmosphere is limited, so the atmospheric visibility is not reduced to a lower level.

1. Introduction
In general, when heavy pollution weather occurs, it is often affected by adverse weather conditions, and with a period of low wind speed[1-5], relatively high relative humidity and low visibility[6-7]. On October 21st, 2014, there was a heavy pollution event in Shenyang, the outstanding characteristic of the heavy pollution weather process is that when the pollution is serious, the wind speed is high, high visibility, which mostly between the 5 to 10 km. Heavy pollution in such weather conditions is not typical and is often overlooked by forecasters. Based on the analysis of meteorological conditions and physical quantity during the heavy pollution period, this paper looks for the causes of the formation and development of the pollution weather, so as to accumulate forecast experience for such weather.

2. Weather condition
On October 21st, 2014, there was a pollution weather in north-central of Liaoning area( Shenyang, Anshan, Fushun, Benxi, Liaoyang and Tieling ), air quality in such cities reach in moderate to severe pollution. During the period of severe pollution, which appeared at 0 a.m. to 9 a.m. 21st, the concentration of PM$_{2.5}$ and PM$_{10}$ was above 200 ug/m$^3$, and the major pollutant was PM$_{2.5}$, which was mainly primary fine particulate matter. Visibility in the air pollution period is 4 to 11 km, which is a high visibility pollution process.
3. Meteorological conditions analysis

By using conventional meteorological observation data, sounding data, the wind profile radar data, and atmospheric visibility observation data from the roof of the Shenyang Regional Meteorological Center, and at the same time period relative humidity observation data of Shenyang, a detailed analysis of the meteorological conditions is given during the pollution event.

3.1 Circulation situation analysis

During 20th to 21st, at 500 hPa level, Liaoning is located at the bottom of the upper air low vortex of the okhotsk sea, controlled by the west to northwest air flow. When at 8 a.m. 20th, the 850 hPa front area is located in 45 ° N, frontal zone is stronger; at 8 p.m., the 850 hPa front area press south around 44 ° N zone; at 8 p.m. 21st, the 850 hPa front area arrives at the north of Liaoning, the northeaster wind is big; at 925 hPa level, wind speed of Shenyang station reach 12 m/s. With the high-altitude front area press south, the ground has a front crossing and the temperature front and humidity front are moving southward. From the time evolution of the temperature front, it can be seen that at around 8 p.m. 21st, the high-altitude front has just passed through the north-central part of Liaoning, and the wind force reaches 4 to 5 levels, which corresponds to the heavy pollution period.
3.2 Physical quantity analysis

From 8 p.m. 20th to 8 a.m. 21st, the ground relative humidity of Shenyang station is always relatively small, between 20 to 30 %, the air is relatively dry. From the vertical distribution of relative humidity in Shenyang station, it can be seen that the relative humidity between the lower and the upper levels is all between 10 to 36 %, indicating that the whole air above Shenyang is relatively dry. Visibility is maintained at 4 to 11 km.

From the vertical distribution of temperature in Shenyang station, it can be seen that at 8 p.m. 20th, there is the relatively shallow inversion layer from the ground to 1000 hPa level, the inversion difference value is 1 °C. At 8 a.m. 21st, the height of inversion layer is raising, and the thickness of inversion layer is thickening, and the top of inversion layer is up to 850 hPa level, and the thickness of inversion layer is stretching from 925 hPa to 850 hPa level, and the inversion difference value is 3 °C. At 8 p.m. 21st, the temperature did not change from the ground to 1000 hPa level, and there was an approximate inversion layer. The existence of the inversion layer is not conducive to the diffusion of pollutants into the air.
From the vertical motion of Shenyang station, it can be seen that from 8 p.m. 20th to 8 a.m. 21st, Shenyang station has prevailed sinking airflow under 700 hPa level, sinking motion is against for the spread of pollutants, the strongest subsidence movement is at 8 a.m. 21st, in conformity with the serious pollution time.

From the sounding curve of Shenyang station, October 21, 2008, it can be seen that, from 1 to 1.9 km, it is very deep inversion layer, and under 1 km, atmosphere is unstable, there is the condition of thermal turbulent motion happening, the temperature and temperature-dewpoint spread are all above 10°C, atmosphere is dry, and it is bigger and bigger increased with height. The unstable atmosphere and dry atmosphere are conducive to the production of ascending motion, which causes the ground pollution to be transmitted to the air. However, the above inversion prevents the upward diffusion and accumulates the pollution.
From the data analysis of the wind-profiling radar in Shenyang station, it can be seen that from 8 p.m., October 20th, the whole atmosphere of Shenyang station under 2000 m is affected by the north to the northeast wind. At 8 a.m., August 21st, the wind is strong between 1000 and 2000 m, reaching 12-18 m/s, and the northeast ground wind reach 6 m/s.

Main pollutants transport channels are controlled by topography and weather type [8], within the scope of the front zone control, there is northeast wind in Liaohe River Basin, coupled with the influence of the low-lying terrain in Liaohe River Basin, wind funnelling is obvious, resulting in 4 to 5 level northeast wind in Liaohe River Basin. October 20th, there are pollution weather occurring in Fushun and Tieling area, especially in Tieling, the pollution is more severe than Shenyang, under the action of northeast wind, it is conducive to pollutants transportation from Fushun and Tieling area to Shenyang region.

4. Air mass backward trajectories analysis

From Shenyang, 200 m, 500 m and 1000 m level, three air mass backward trajectories after 48 hours at 3 p.m. on October 21, 2014 (BJT) also can see (fig. 10), at 3 p.m. 19th cyclonic deflection occurred into the northeast. As can be seen from the MODIS satellite cloud pictures, along this path, there are many fire points in Jilin province and north-central Liaoning province(fig. 11, pink highlight on the figure are fire points), fire points may be caused by the autumn harvest burning. Due to the northeast air flow, pollutants produced by combustion ignition area of Jilin province are transported to the north-central Liaoning area with the
northeast wind, coupled with pollutants produced by the north-central Liaoning area burning grass, which leads to north-central Liaoning appeared moderate to severe pollution weather on October 21st.

5. Conclusion and Discussion

With comprehensive analysis of the meteorological conditions during heavy pollution, the results showed that when the heavy pollution weather occurred, it is sinking movement under the 3 km(below 700 hPa level). There is a deep inversion layer from 1 to 1.9 km above Shenyang, which prevents pollutants diffusion. It is affected by the low-level cold air invasion at the same time, below 1km in unstable stratification atmosphere, which made conditions for turbulence motion of occurrence and development in surface layer atmosphere, turbulent motion carry local pollutants into the air by updrafts, and the upper inversion block pollutants to spread more high, causing air pollution. Lower layer(925 hPa) wind is bigger, reaching 12 m/s, and has been in vogue northeast wind. The pollutants
are produced by combustion ignition area of Jilin province transported to north-central Liaoning area as the northeast wind, coupled with the pollutants produced by burning grass in north-central Liaoning area. In the northeast of Shenyang, such as Fushun and Tieling area, there has a high concentration of pollutants, under the action of wind advect, and it is conducive to pollutants transportation from Fushun and Tieling area to Shenyang region and worsen air pollution in Shenyang area.

The reason of that visibility has maintained 5 and 10 km during heavy pollution weather is that, according to research, the main factors affecting the atmospheric visibility are particle concentration and relative humidity, particles in the atmosphere can significantly change the refractive index of particulate matter and particle size distribution by particles hygroscopic growth. The contribution of hygroscopic growth for reducing atmospheric visibility may exceed the extinction effect of particulate matter. On October 21, the particle concentration in Shenyang is higher, but the relative humidity is low, which has been maintained at between 20 to 30 %. The hygroscopic growth effect of particulate matter in the atmosphere is limited, and this may be one of the reasons that the atmospheric visibility is not down to a lower level.

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