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Analysis of Observed Ozone Episode in Urban Jinan, China

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Abstract Using a trajectory model (HYSPLIT) analyzed the ozone episodes observed at urban Jinan in 2005. There were 84 h (in 24 days) of ozone episodes (>100 ppbv) observed during the study. June was the most polluted month in the year. The earliest episode observed in May 4 was mainly caused by the favorable meteorological condition for ozone production and accumulation. A multi-day episode from 6 to 8 June was related to the passage of typhoon Nesat. 39 h (in 11 days) of ozone episodes were observed from June 10 to 24. Large scale stagnation, recirculation of air mass, intense solar radiation, high temperature and long-rang transport of pollutants were the main reason for the ozone episodes during this period.

Keywords Ozone episode · Meteorological condition · Trajectory analysis · Jinan

Surface ozone is the most abundant photochemical oxidant in the troposphere and often is considered to be the most important photochemical pollutants affecting public health, agriculture, and forest (e.g., Fuhrer and Booker 2003; Karnosky et al. 2007). In the lower troposphere, ozone is mainly formed by the action of UV light from the sun on nitrogen oxides, and the ozone level is significantly influenced by Meteorological conditions, such as solar radiation, temperature, precipitation, wind speed, and wind direction, which could affect ozone formation, accumulation, and transport (e.g., Thompson et al. 2001). Many studies have shown that, both local photochemical production and pollutant transport could arouse high ozone pollution episode (e.g., Lam et al. 2005; Lee et al. 2002).

Jinan, a medium-sized provincial capital city in East China, located between highly polluted Yangtze Delta and Beijing–Tianjin Region, like other rapidly developing cities in China, faces severe air pollution problems. As our previous studies, ozone concentrations exceeding the Chinese National Ambient Air Quality Standard for common urban area (hourly average concentration 0.20 mg/m^3, about 100 ppbv) were often observed in Jinan, especially in summer (Shan et al. 2008). In this study, we will present surface ozone episodes observed in 2005 at urban Jinan. Surface meteorological data and the HYSPLIT (Version 4.8) model were used to the analysis of ozone episodes.

Materials and Methods

Measurements were carried out on the campus of Shandong University (36°42′N, 117°08′E, 34.5 m a.s.l.), which is in the eastern area of Jinan, lying in the second ring road. Ozone was continuously measured by TE model 49C ozone analyzer. The limit of detection is 2 ppbv and the precision is ±2 ppbv. The height of the air intake was 8.5 m above the ground. More information about the observational site

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and Jinan city could be found in Shan et al. (2008). The interval of each measurement was 1 min and the data presented in this paper are mainly based on hourly averaged values. The data capture rates were 97.9% and 100%, respectively, during the whole year of 2005 and the selected typical episodes.

Local meteorological data used in this study were obtained from China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). The HYSPLIT model (Version 4.8), used to compute the backward trajectories used in this study, was developed by the National Oceanic and Atmospheric Administration Air Resources Laboratory (NOAA ARL). The meteorological input for the trajectory model was the FNL dataset (reprocessed from NOAA's National Centers for Environmental Prediction Final Analysis data by Air Resources Laboratory). Each backward trajectory was calculated for 96-h duration (i.e., 4 days) with 100m-agl vertical levels and labeled with triangles at 02:00, 08:00, 14:00, and 20:00 local time, respectively.

Results and Discussion

There are totally 84 h (in 24 days) ozone episodes with the concentrations exceeding the Chinese Standard level of 0.20 mg/m^3, about 100 ppbv, were observed from May to September, with the maximum 1 h value of 147.83 ppbv. The photochemical pollution in 2005 is more severe than that in 2004, which has 65 h (in 23 days) ozone episodes with the maximum 1 h value of 143.76 ppbv (Shan et al. 2008). Generally speaking, June was the most polluted month with 54 h (in 14 days) episodes, more than half of the episodes in the year. In addition, the maximum 1h value of 147.83 ppbv and the maximum daily value of 91.15 ppbv were observed on 19 and 8 June, respectively. The severe photochemical pollution in June might be associated with some meteorological conditions, such as high temperature (28.56°C), sufficient sunshine duration (8.5 h/d), and less days with rainfall (7 days).

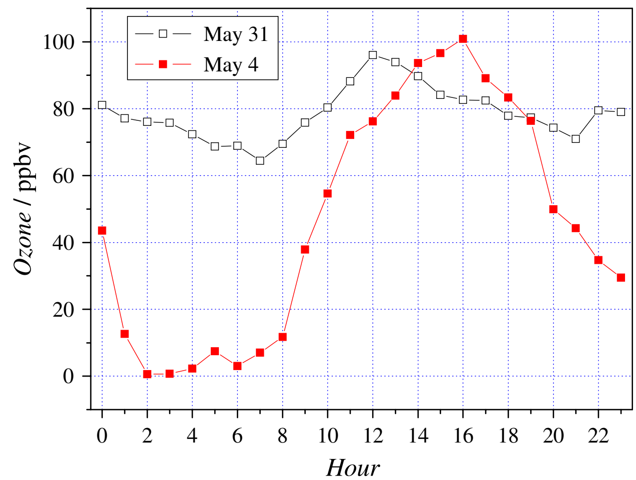

Fig. 1 Hourly averaged ozone concentrations for May 4 and 31

Then, we will analyze some typical ozone episode cases, especially the episodes in June, using the HYSPLIT model and surface meteorological data.

The earliest episode was observed in May 4. Figure 1 presents the time series of hourly averaged ozone concentrations in this episode day. The diurnal variation of ozone shows regular variation in the day, with a slightly exceeding the standard ozone level by 0.86 ppbv at 16:00. Ozone concentrations keep low level in the night, increase rapidly after sun rise from morning to afternoon, and then decrease gradually. Backward trajectory for 14:00 May 4 (local time) is shown in Fig. 2a. The trajectory came from northeast China, and spent about 2 days passing over the lower marine atmosphere before reaching Jinan. We also analyzed the trajectory for the previous day (3 May, not shown). Trajectories for the 2 days are quite similar besides trajectory for May 3 spending more time in lower continental atmosphere, which might be related to the lower relative humidity in May 3 (see Table 1).

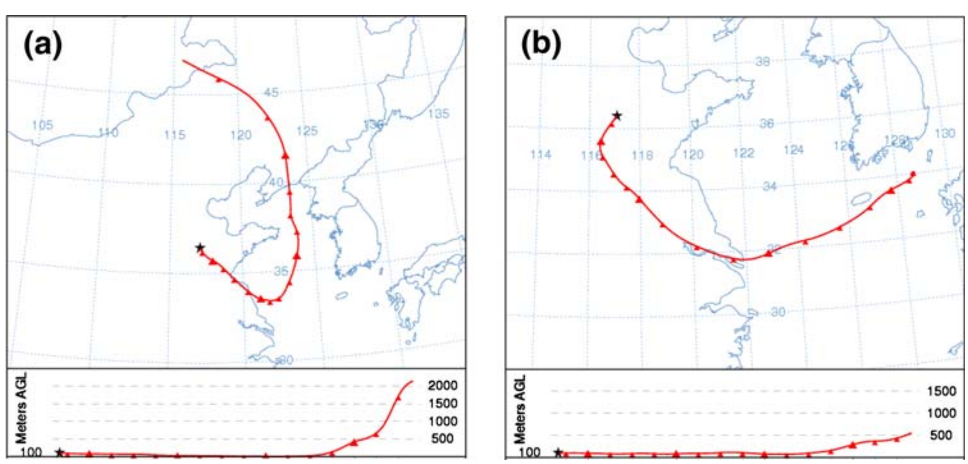

Fig. 2 The 96 h backward trajectories of air masses for 14:00 May 4 (**a**) and 31 (**b**)

Table 1 Meteorological conditions of Jinan for May 3, 4, and 31

Date	RF (mm)	T (°C)[a]	SD (h)	WS (m s^{-1})	RH (%)
5-3	0	23.9/30.6	11.7	6.1	23
5-4	0	23.6/28.9	8.3	1.6	44
5-31	0	26.8/31.6	8.0	6.0	52

RF Rainfall, *T* temperature, *SD* sunshine duration, *WS* wind speed, *RH* relative humidity

[a] Daily averaged temperature/daily maximum temperature

Comparison of the meteorological conditions in the 2 days shows that, the temperature and sunshine were both more favorable for photochemical production in May 3. However, high wind speed (6.1 m/s) dispersed the produced ozone quickly, so no episode observed in May 3. Low wind (1.6 m/s) in May 4 accumulated the produced ozone, resulting in a slight episode.

Diurnal variation of ozone concentrations in May 4 shows a typical pattern for polluted urban area, characterized by high concentrations during afternoon, low concentrations during late night and early morning, and big variation magnitude between daytime and nighttime. This variation pattern is obviously different from the pollution caused by pollutant transport, such as the pollution in May 31. On that day, ozone shows high nighttime level and small variation magnitude between daytime and nighttime in May 31 (see Fig. 1). Backward trajectory for May 31 shows that, the air mass had passed over the highly polluted Yangtze Delta and its surrounding areas (see Fig. 2b) and might take plenty of pollutants form this region since there was no rainfall on the way of transport, resulting in high ozone levels both in the daytime and nighttime on May 31 at Jinan. However, due to the high wind speed (6.0 m/s) no episode was observed on that day, despite the favorable temperature and sunshine.

There is a multi-day episode observed from June 6 to 8 (see Fig. 3). During this period, ozone shows high nighttime level and significant variation magnitude between daytime and nighttime. Trajectory for June 6 shows that, the air mass came from the nearby area and hovered in the lower atmosphere over Jinan from the previous day, indicating large-scale stagnation of the regional meteorology (see Fig. 4a). Due to the approaching of typhoon Nesat (see Fig 5), the origination of the trajectory moved from Shandong Peninsula to South Korea gradually and the ozone concentration shows irregular variation in June 7, with high ozone levels observed at 18:00 and 19:00. On June 8, the influence of typhoon Nesat was still effective. The trajectory mainly came from southeast Korea and south Japan and passed over the eastern coastal region of China in the lower atmosphere (see Fig. 4b). In addition, the meteorological conditions were all favorable for photochemical production (see Table 2). Therefore, this multi-day episode might be related to both local photochemical production and the pollutant transport/recirculation caused by the passage of typhoon.

The low ozone level observed at 7:00 June 7 and 8 might be caused by the rush-hour traffic in the early morning since NO from car exhausts can deplete ozone rapidly. On the other hand, since there was no ozone production at that time due to the lack of solar radiation, a sharply decrease of ozone concentration was observed. The

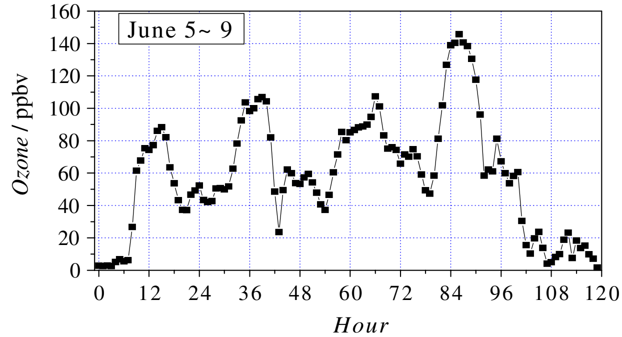

Fig. 3 Hourly averaged ozone concentrations from June 4 to 9

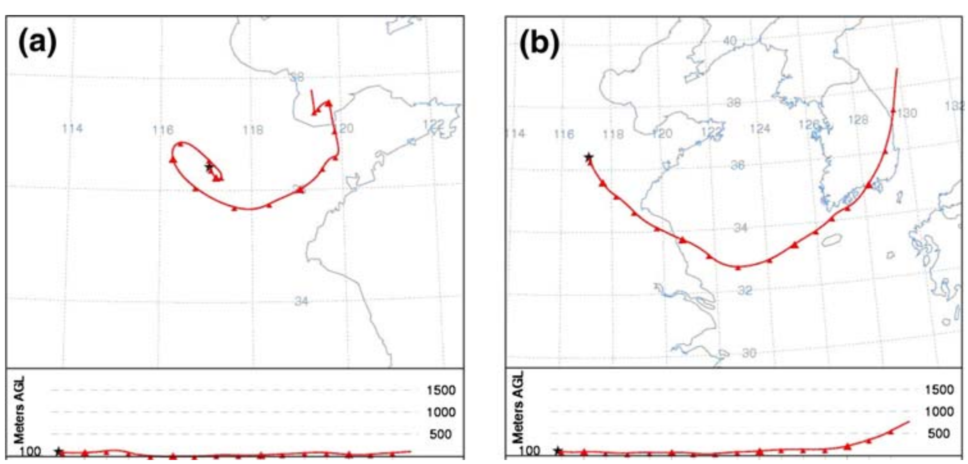

Fig. 4 The 96 h backward trajectories of air masses for 14:00 May 4 (**a**) and 31 (**b**)

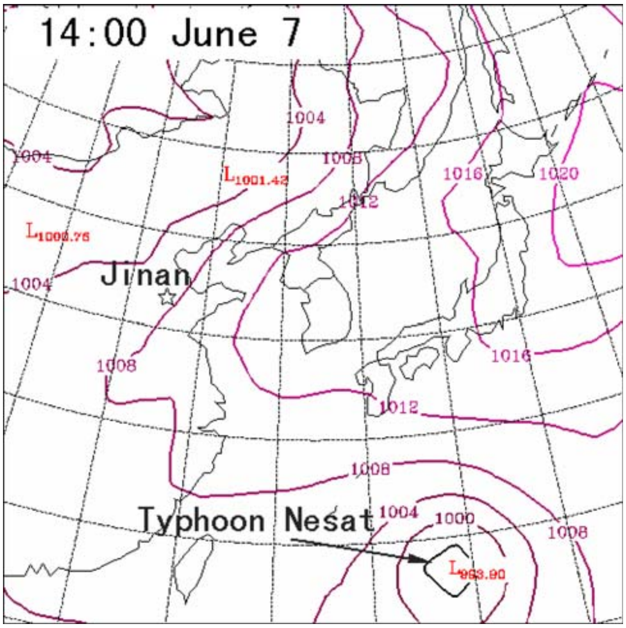

Fig. 5 Synoptic chart for 14:00 June 7

Table 2 Meteorological conditions of Jinan for May 3, 4, and 31

Date	RF (mm)	*T* (°C)	SD (h)	WS (m s^{-1})	RH (%)
6-6	6	25.1/31.3	9.4	3.0	56
6-7	0	26.1/31.9	10.7	4.1	43
6-8	0	27.8/33.8	8.3	3.9	41

RF Rainfall, *T* temperature, *SD* sunshine duration, *WS* wind speed, *RH* relative humidity

sunshine duration was zero due to rainfall on June 9, so the ozone concentration kept lower than 30 ppbv.

The time series of hourly averaged ozone concentrations from June 10 to 24 is shown in Fig. 6. Because June 9 was cloudy, ozone precursors might accumulate in the regional atmosphere. Therefore, ozone concentration increased rapidly after sun rise and exceeded the standard level at 14:00 and 15:00 in June 10. A sharp increase of ozone level

Table 3 Meteorological conditions of some cities along the trajectories

Site	Date	RF (mm)	*T* (°C)	SD (h)	WS (m s^{-1})	RH (%)
Jinan	6-19	0	29.8/38.5	11.3	2.5	50
Ganyu	6-17	0	28.2/35.9	12.6	1.5	65
Nanjing	6-16	0	28.3/35.1	11.4	1.2	49
Shanghai	6-15	0	26.2/30.1	8.8	3.5	76

RF Rainfall, *T* temperature, *SD* sunshine duration, *WS* wind speed, *RH* relative humidity

from 02:00 to 04:00 June 11 was observed, which could not be related to photochemical production since there was no solar radiation on that time. The trajectory for 03:00 June 11 is shown in Fig. 7a, which was originated from the Pacific Ocean, so the original air mass might be clean and moist. However, the trajectory had stayed about 2 days in the lower atmosphere around Jinan before ending at the site. Therefore, transport of pollutants from the surrounding areas might be the reason for the nighttime increase of ozone level. Although there was high temperature (37.1°C) and abundant sunshine (10.8 h) in June 12, high wind speed (6.1 m/s) dispersed the produced ozone quickly. Therefore, no ozone episode was observed in the daytime. However, a nighttime ozone episode was observed from 20:00 to 22:00. Trajectory analysis show that, the air mass traveled over the highly industrialized and urbanized southeastern region all through the 96 h, so the nighttime episode might be associated with the transport of pollutants from this region.

From June 13 to 20, trajectories all came from the highly polluted Yangtze Delta and its surrounding areas, and the episodes were associated with both pollutant transport from this region and local photochemical production. For example, June 19, the most severe episode day with the maximum 1 h ozone value of 147.83 ppbv observed in the year. The trajectory originated from Yangtze Delta, at the western region of Shanghai, and passed by the vicinity

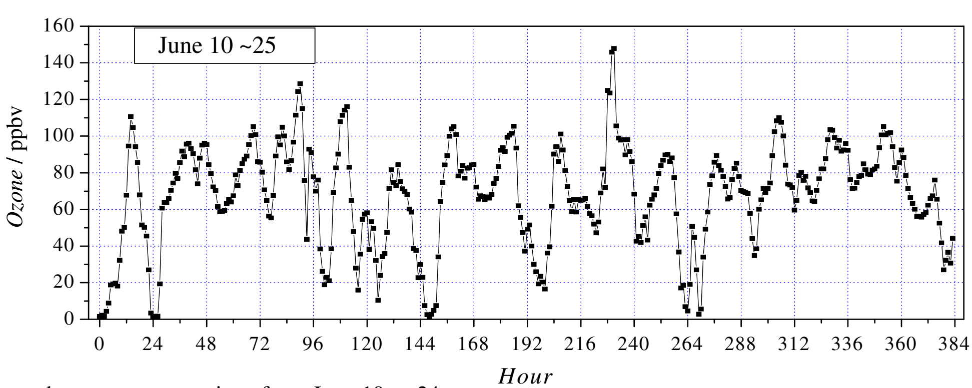

Fig. 6 Hourly averaged ozone concentrations from June 10 to 24

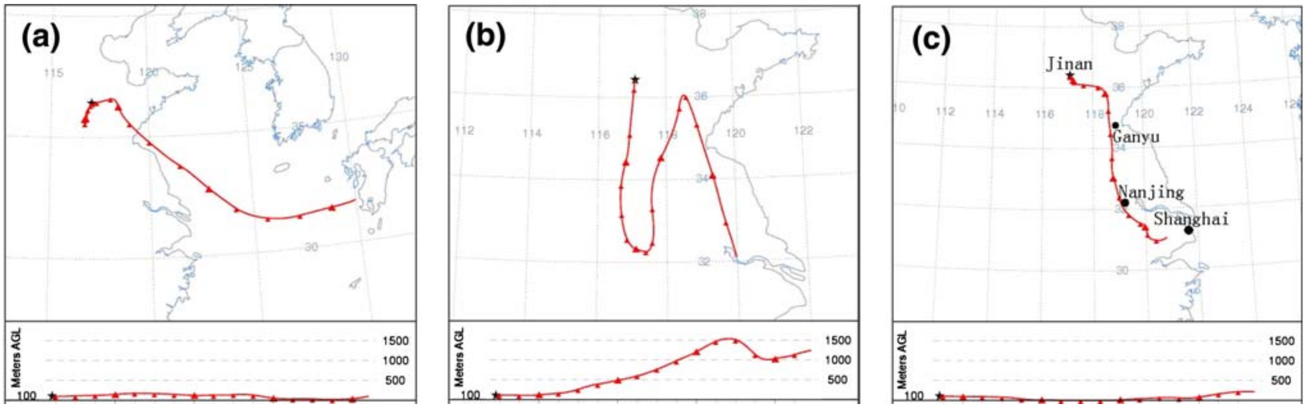

Fig. 7 The 96 h backward trajectories of air masses for 03:00 June 11 (**a**), 21:00 June 12 (**b**), and 15:00 June 19 (**c**)

of Nanjing in June 16 and Ganyu in June 17 before reaching Jinan slowly. Meteorological conditions for the cities along the trajectory were all in favor of photochemical reactions with warm weather and abundant sunshine duration (see Table 3). In addition, there was no rainfall during the transport processes of air masses. Therefore, there might be significant pollutants transported from the highly polluted southeastern region, especially from Yangtze Delta region. On the other hand, local photochemical production also might have contributed to this severe episode since there was a distinct afternoon ozone peak.

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