A Study on the Characteristics of Spatial and Temporal Evolution of Ozone Pollution in Chengdu (2014 - 2016)

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Abstract. This study conducted an in-depth research on the characteristics of spatial and temporal evolution of ozone pollution by analyzing the 2014-2016 observation data from the state-controlled monitoring sites of ambient air quality in Chengdu. The result shows 1) that the 90th Percentile Daily Maximum 8-Hour Average $O_3$ Concentrations of Chengdu in 2014, 2015 and 2016 are 147μg/m$^3$, 183μg/m$^3$ and 167μg/m$^3$, respectively; 2) that the trends of concentration change of $O_3$ at the seven state-controlled monitoring sites for assessment of the air quality of Chengdu are exactly matched, i.e. unimodal distribution, high during the daytime and low at night with hourly minimum concentration of $O_3$ that is 5~8 μg/m$^3$; 3) that there is a rather obvious negative correlation between NO$_2$ and $O_3$ and that the correlation coefficient ranges from -0.931 to -0.565; and 4) that the ozone pollution in the west of Chengdu is more serious than that in the east of Chengdu in general and that the more serious the pollution is, the bigger the area with high concentration of $O_3$ is.

1. Introduction

In recent years, the atmospheric ozone pollution of China is worsening. It has negatively impacted the improvement and standard management of urban air quality, just like PM$_{2.5}$. Near-ground ozone is the air pollutant formed after photochemical reaction, frequently occurring in summer. In case the ozone concentration in the near-ground troposphere is too high, it has negative effects on human health, i.e. the mucous membrane of eyes and respiratory system, etc. will be stimulated and damaged. In recent years, scholars from all over the world have carried out researches on the characteristics of ozone pollution and the cause and origin of ozone pollution, etc. in multiple cities and regions, such as Nairobi [1], Houston [2], Beijing [3], the East of the United States [4], North America [5] and Europe, [6] etc. The scholars often study the characteristics of ozone pollution with mathematical statistic methods such as Multiple Linear Regression [7] and Principal Component Analysis [8], etc., or with Multi-variable Additive Model [9], Lagrangian Model [10], Eulerian Model [11], the Global Chemistry-climate Model EMAC [12] and multiple technological means [13]. The study of Cheng Nianliang et al.[14] that pointed out the daily variation of over-standard day of ozone is unimodal from May to September; and a certain correlation exists between ozone concentration and air pressure, humidity, visibility, wind velocity and temperature. Qi Bing et. al. [15] pointed out that ultraviolet radiation, temperature, relative humidity, wind direction and wind velocity have a certain influence on the concentration of $O_3$. What is clear from the above is that the atmospheric ozone concentration is influenced by many factors including unfavorable meteorological conditions, long-distance diffusion and pollutant emission, etc. Thus, studying the characteristics of spatial and temporal evolution and
weekend effect of near-ground ozone pollution is of significance to the formulation of strategies on photochemical pollution control that are scientific and effective.

2. General Characteristics
From the systematic analysis on the 2014-2016 observation data from the state-controlled monitoring sites of ambient air quality in Chengdu, it can be found that since the Chinese government implemented the Ten Measures on Prevention and Control of Atmospheric Pollution, the overall air quality of Chengdu has been improved, however, the situation of heavy air pollution has not yet been completely resolved. Nowadays, the concentration of PM$_{2.5}$ in the ambient air of Chengdu is still high, exceeding the corresponding standard to a great extent. Meantime, O$_3$ Pollution increases prominent. The atmospheric pollution is more complicated than before.

In accordance with the grading standard specified in Technical Regulation on Ambient Air Quality Index (AQI) (HJ 633-2012) of Ministry of Environmental Protection of the People’s Republic of China, when AQI is more than 100, i.e. when Maximum 8-Hour Average O$_3$ Concentration is more than 160μg/m$^3$, the ozone concentration exceeds the corresponding standard that day[16]. Pursuant to the assessment rules of the said standard, the 90th Percentile Daily Maximum 8-Hour Average O$_3$ Concentrations of Chengdu in 2014, 2015 and 2016 are 147μg/m$^3$, 183μg/m$^3$ and 167μg/m$^3$, respectively. From the data above, it is shown that the ozone pollution in 2015 is the most serious. Although in 2016, the situation of ozone pollution got better, the annual average O$_3$-8h concentration still increased by 13.5% compared with that in 2014.

From the 2014-2016 statistical data, it can be found that the ozone pollution in 2015 is worse than that in 2016 and that the ozone pollution in 2016 is worse than that in 2014, which is shown in Table 1.

### Table 1. Statistical Chart on Severity of 2014-2016 Ozone Pollution of Chengdu

| Year | Number of Days When Concentration of Pollutants Exceeding the Corresponding Standard Only Due to Ozone Pollution | The 90th Percentile of O$_3$-8h$_{max}$ (μg/m$^3$) |
|------|-------------------------------------------------------------------------------------------------|---------------------------------|
| 2014 | 21                                                                                           | 147                             |
| 2015 | 61                                                                                           | 183                             |
| 2016 | 46                                                                                           | 167                             |

According to the assessment rules of reference [16], from 2015, ozone pollution has been included in the air quality assessment for some cities of China including Chengdu, and from 2017, the said standard has become applicable to all the cities of China. From the statistical data above, it can be seen that in 2015, the annual average O$_3$-8h of Chengdu was around 191μg/m$^3$, exceeding the corresponding standard by 19.4%; and that in 2016, there were 46 days when O$_3$-8h exceeded the corresponding standard, including 37 days with Grade III Mild Pollution, 7 days with Grade IV Moderate Pollution and 2 days with Grade V Heavy Pollution based on the AQI of O$_3$-8h. In general, the O$_3$ pollution of Chengdu is worsening.

3. Characteristics of Time Series
From the monthly average concentration distribution of O$_3$, it can be seen that in Chengdu, the high concentration of O$_3$ mainly occurs from May to August, which is shown in Figure 1. The concentration of ozone in 2015 and 2016 is obviously higher than that in 2014. From 2014 to 2016, the monthly maximum average concentration of O$_3$ occurred in August 2016, i.e. 220μg/m$^3$; and the monthly minimum average concentration of O$_3$ occurred in January 2014, i.e. 50μg/m$^3$. From May 2016 to August 2016, the monthly average concentration of O$_3$ is 192.5μg/m$^3$, compared with the same period in 2014, it increased by 12%. 

Figure 1. Bar Graph on 2014-2016 Monthly Average Concentration of O₃ in Chengdu

Affected by meteorological factors including solar radiation, temperature and sunlight [17], in summer, the photochemical reaction rate is faster, accordingly, the concentration of O₃ formed after the photochemical reaction is higher. In winter, the average temperature is low, the visibility is poor, the ultraviolet intensity is not so high and the photochemical reaction is weak; moreover, under a certain circumstance, high concentration of particles increases the aerosol optical depth and reduces the rate of ozone formation. For the aforementioned reasons, the concentration of O₃ in winter is at the lowest level of the whole year.

As for the process of ozone pollution, a typical example is the process of ozone pollution occurring from August 10, 2016 to August 15, 2016. During that period, the concentration of O₃ in Chengdu exceeded the corresponding standard for three consecutive days, and the concentration of O₃ at the seven state-controlled monitoring sites for assessment of the air quality exceeded the corresponding standard for 29 hours in average. The ozone concentration during that period is shown in Figure 2.

Figure 2. Line Graph on Daily Change of O₃ Concentration at the State-controlled Monitoring Sites of Chengdu from August 10, 2016 to August 15, 2016
Figure 2 shows that except for the reference site for clean air located at Lingyan Temple that characterizes the regional background concentration, the trends of concentration change of O$_3$ at the seven state-controlled monitoring sites for assessment of the air quality of Chengdu were exactly matched. The concentration of O$_3$ began to increase at 9 and the daily maximum occurred at around 16. As night fell, due to the formation-and-depletion effect of NO and ozone [18-20], the concentration of O$_3$ gradually reduced and maintained at an extremely low level in the small hours. The minimum concentration of O$_3$ could even reach 5–8 µg/m$^3$.

In Figure 2, the background site is the Lingyan Temple monitoring site, located at the highest peak of a mountain in the west of Chengdu, surrounded by dense plants and far away from industry and traffic. The site is a reference site for air quality assessment. Thus, it is not included in the air quality assessment of Chengdu City. It is worth mentioning that the characteristics of daily change of O$_3$ concentration at the background site is totally different from that at the seven state-controlled monitoring sites for assessment of the air quality of Chengdu. During the process of ozone pollution from August 10 to August 15, influenced by atmospheric photochemical reaction, the O$_3$ concentration of the reference site for clean air located at Lingyan Temple also gradually increased from sunrise, but the extent of increase is much smaller than that at the urban sites for assessment. What is similar to the urban sites for assessment is that the daily maximum O$_3$ concentration at the reference site for clean air occurred at around 16, i.e. about 180 µg/m$^3$ (not exceeding the corresponding standard) that is much lower than the daily maximum O$_3$ concentration at the urban sites for assessment. As the sun set, the ultraviolet intensity gradually became weak, O$_3$ reacted with NO and produced O$_2$ and NO$_2$, and the O$_3$ concentration gradually reduced to 100µg/m$^3$. In the mountainous area, there is no emission source of NO like vehicle exhaust and the NO in the atmosphere of the reference site for clean air located at Lingyan Temple mainly comes from regional background. After the limited atmospheric NO was consumed, the ozone depletion reaction at the site could not continue. Therefore, the ozone concentration could only maintain around 100µg/m$^3$ till the sun rose the next day when the whole process was repeated. The result is consistent with the findings of research conducted by Monteiro A on the mountainous area [21].

From the time-series change of the concentration of NO$_2$, the precursor of ozone, it can be seen that there is a rather obvious negative correlation between NO$_2$ and O$_3$, which is shown in Figure 3.
Figure 3 shows that during the process of ozone pollution from August 10, 2016 to August 15, 2016, the trend of concentration change of NO₂ was generally contrary to that of O₃; during the daytime, the concentration of NO₂ was relatively low and at night, the concentration of NO₂ was relatively high; and the concentration of NO₂ reached its daily minimum when the maximum O₃ concentration occurred. With regard to the correlation coefficient, it ranged from -0.931 to -0.565 of NO₂ and O₃ during the pollution process, showing a significant negative correlation.

4. Characteristics of Spatial Evolution

From the spatial distribution of ozone pollution, it can be seen that there is a consistent formation-and-depletion rule of ozone in Chengdu. From 10 to 18 on August 13, the O₃ pollution moved from the northwest to the southeast, which is shown in Figure 4.

Figure 4 is drawn according to the hour-by-hour data of the 38 air quality monitoring subsites located in the 22 counties, districts and cities of Chengdu based on Kriging Interpolation [22-23]. By 10, the O₃ concentration in all the areas of Chengdu was at a relatively low level; at 11, the hourly O₃ concentration of the areas located in the northwest of Chengdu including Xindu, Pixian and Pengzhou exceeded the corresponding standard first; after that, the O₃ concentrations of the other areas of Chengdu rose at the same time; at 16, the O₃ concentrations in almost all the counties, districts and cities of Chengdu reached their daily maximum; and then, the degree of O₃ pollution gradually decreased. From the characteristics of spatial evolution of ozone pollution shown in Figure 4, it can be seen that the ozone pollution in the west of Chengdu is more serious than that in the east of Chengdu in
general; that the more serious the pollution is, the bigger the area with high concentration of O$_3$ is; that the areas with high concentration of ozone include the central urban area and the areas located in the northwest of Chengdu, such as Xindu and Pixian; and that in the areas along the mountain, especially in the areas of the east of Chengdu such as Longquanyi District and Jianyang, the concentration of ozone is relatively low.

5. Conclusion
This paper studied the characteristics of spatial and temporal evolution of Chengdu ozone pollution based on the statistical data of Chengdu air quality in recent years. From the systematic analysis on the 2014-2016 observation data from the state-controlled monitoring sites of ambient air quality in Chengdu, it is found that the concentration of PM$_{2.5}$ in the ambient air of Chengdu is still at a relatively high level, exceeding the corresponding standard to a great extent. O$_3$ pollution is increasingly prominent while still exists unresolved PM$_{2.5}$ pollution. The atmospheric pollution is more complicated than before. The conclusion of the study is set forth as follows:

1) The 90th Percentile Daily Maximum 8-Hour Average O$_3$ Concentrations of Chengdu in 2014, 2015 and 2016 are 147μg/m$^3$, 183μg/m$^3$ and 167μg/m$^3$, respectively. From the data, it can be seen that the ozone pollution in 2015 is the worst, and that although in 2016, the situation of ozone pollution got better, the annual average O$_3$-8h concentration still increased by 13.5% compared with that in 2014.

2) The trends of concentration change of O$_3$ at the seven state-controlled monitoring sites for assessment of the air quality of Chengdu were exactly matched, i.e. unimodal distribution, high during the daytime and low at night. The concentration of O$_3$ began to increase at 9 and the daily maximum occurred at around 16. As night fell, due to the depletion effect of NO, the concentration of O$_3$ gradually reduced and maintained at an extremely low level in the small hours. The minimum concentration of O$_3$ could even reach 5–8 μg/m$^3$.

3) With regard to time series of NO$_2$ concentration of precursors of ozone, the correlation coefficient ranged from -0.931 to -0.565 of NO$_2$ and O$_3$ during the pollution process, showing a significant negative correlation.

4) From the characteristics of spatial evolution of ozone pollution, it can be seen that the ozone pollution in the west of Chengdu is more serious than that in the east of Chengdu in general; that the more serious the pollution is, the bigger the area with high concentration of O$_3$ is; that the areas with high concentration of ozone include the central urban area and the areas located in the northwest of Chengdu, such as Xindu and Pixian; and that in the areas along the mountain, especially in the areas of the east of Chengdu such as Longquanyi District and Jianyang, the concentration of ozone is relatively low.

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