Forecast Method of Ozone Concentration in Yulin City Based on Meteorological Conditions

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Abstract Based on the monitoring data of ozone (O_3) concentration, conventional meteorological data and reanalysis products in Yulin City from 2018 to 2019, the weather situation of O_3 pollution was classified through case analysis and mathematical statistics. At 500 hPa, the weather situation was divided into continental high pressure type, subtropical high type and mixed type. At 850 hPa, it was divided into southwest air flow type, east air flow type and south air flow type. The correlation between meteorological element and O_3 concentration were analyzed, and factors with good correlation such as temperature, air pressure and wind speed were selected to establish regression equations. The fitting effect was good, and O_3 concentration could be objectively predicted.

Key words Ozone; Weather situation; Meteorological factor; Statistical forecast
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In terms of near-formation ozone (O_3) pollution, many scholars have analyzed the relationship between meteorological conditions and O_3 concentration, and concluded that that O_3 pollution mostly occurs in sunny days with high temperature, low wind speed and few clouds, and there is a close correlation between O_3 concentration and meteorological elements such as air temperature, humidity, precipitation, air pressure, wind speed, and sunshine hours. On the basis of these achievements, meteorologists around the world continue to study the prediction methods of O_3 concentration. For instance, Han Yu *et al.* [1] used meteorological impact factors to forecast the 8-h sliding average daily maximum of ozone in Chongqing by using stepstep regression, support vector machine and neural network methods. The results show that the three prediction models all had strong forecasting ability, but the forecast values were slightly smaller than the actual values. Jiang Lulu *et al.* [2] analyzed the common weather patterns when ozone concentration exceeded the standard in Ningbo City, and found that ozone pollution easily happened in several types of weather such as transformed cold high pressure, uniform pressure field, upper ridge, subtropical high and peripheral tropical cyclone. An Junlin *et al.* [3] used principal component and regression analysis to forecast O_3 concentration in Beijing City. Song Rongrong *et al.* [4] carried out air quality forecast in Xiamen. Liu Minghua[5] used multivariate nonlinear models to forecast O_3 concentration in Shanghai City. The prediction of O_3 concentration mentioned above was mainly concentrated in the east and south of China. The formation mechanism of O_3 concentration in Shaanxi is the same as that in other parts of China, but its seasonal characteristics and the relationship between O_3 concentration and meteorological conditions are different in various regions. In this paper, by using the analysis idea of weather classification and multiple regression, the pollution cases in 2018 were summarized and analyzed, and the atmospheric circulation configuration of O_3 pollution was studied. Sensitive meteorological factors were selected to establish multiple regression equations. The maximum of ozone concentration in 8 consecutive hours (O_{3-8}) could be calculated by using conventional meteorological elements given by numerical forecasting products. When exceeding the threshold, it can be used for the prediction of O_3 pollution.

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1 Weather situation of O_3 pollution

Ten typical cases of O_3 pollution from April to August in 2018 were selected, and the weather situation in the average layer 500 hPa and boundary layer 850 hPa was analyzed by using nc reanalysis products. At 500 hPa, the weather situation was divided into continental high pressure type, subtropical high type and mixed type. At 850 hPa, it was divided into southwest air flow type, east air flow type and south air flow type.

1.1 Continental high pressure type There were five cases of such weather. From mid-April to mid-June, the cold air weakened, while the warm advadvation increased, and the continental high pressure was in the developing stage. On the 500 hPa weather chart, Shaanxi was in the high pressure control area, and the 576 dagpm line was located in Yulin; the temperature ridge lagged behind the height ridge, and the temperature in the warm center reached –9 ℃; at 850 hPa, there was southerly or easterly wind in Shaanxi, with the wind speed of 2 – 4 m/s; there was weak convergence and warm center, and the central temperature was up to 25 ℃ or higher. O_3 pollution occurred in the stage of high pressure development and maturation. The upstream cold trough moved eastward, and northern Shaanxi was behind the ridge; there was northerly wind in lower layers, and O_3 pollution ended. In late August, the subtropical high retreated to the east, and Shaanxi was controlled by the continental high pressure, so that O_3 pollution would also happen.

Typical weather situation is shown in Fig. 1. From April 16 to 19, 2018, there was continental warm high pressure at 500 hPa over Shaanxi, southerly wind (4 m/s) at 850 hPa, and warm convergence in northern Shaanxi.

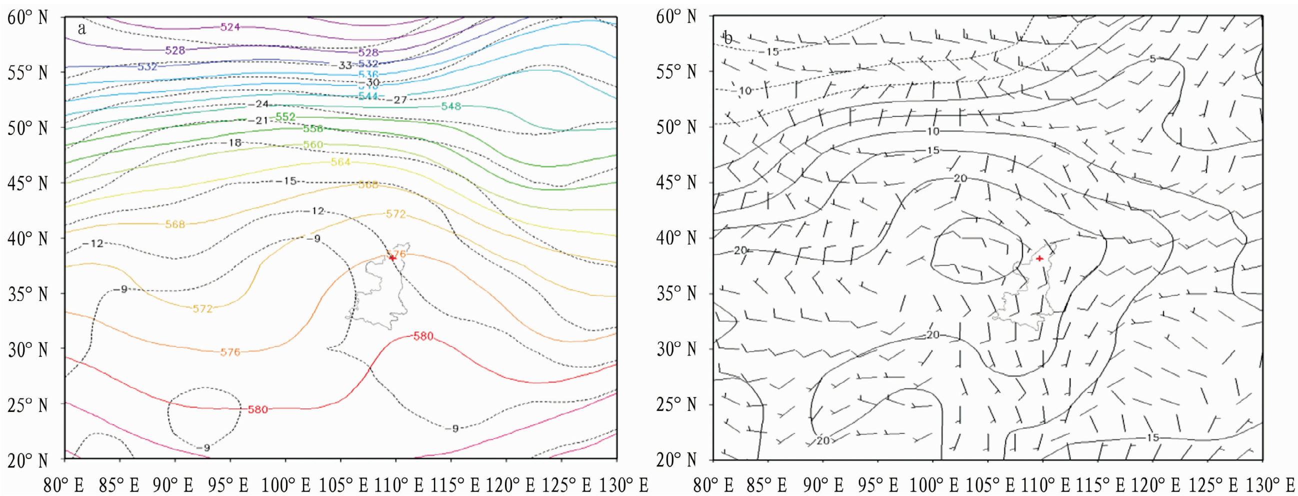


Fig. 1 Circulation situation at 500 (a) and 850 hPa (b) at 20:00 on April 18, 2018

1.2 Mixed type There were two cases of such weather. From late June to early July, the continental high was strong, while the subtropical high raised northward and extended westward, and the continental high pressure and the subtropical high alternately controlled Shaanxi. The 580 dagpm line was located in northern Shaanxi, and there was a southerly flow at 850 hPa, with the wind speed of 2 – 4 m/s. O_3 pollution lasted for 7 – 10 d.

Typical weather is shown in Fig. 2. From June 20 to 28, 2018, the continental high pressure and the subtropical high alternately controlled Shaanxi at 500 hPa, and there was southwesterly wind at 850 hPa, with the wind speed of 2 m/s. Weak shear in northern Shaanxi was conducive to the accumulation of pollutants, and high pressure control was long, so O_3 pollution lasted for 9 d.

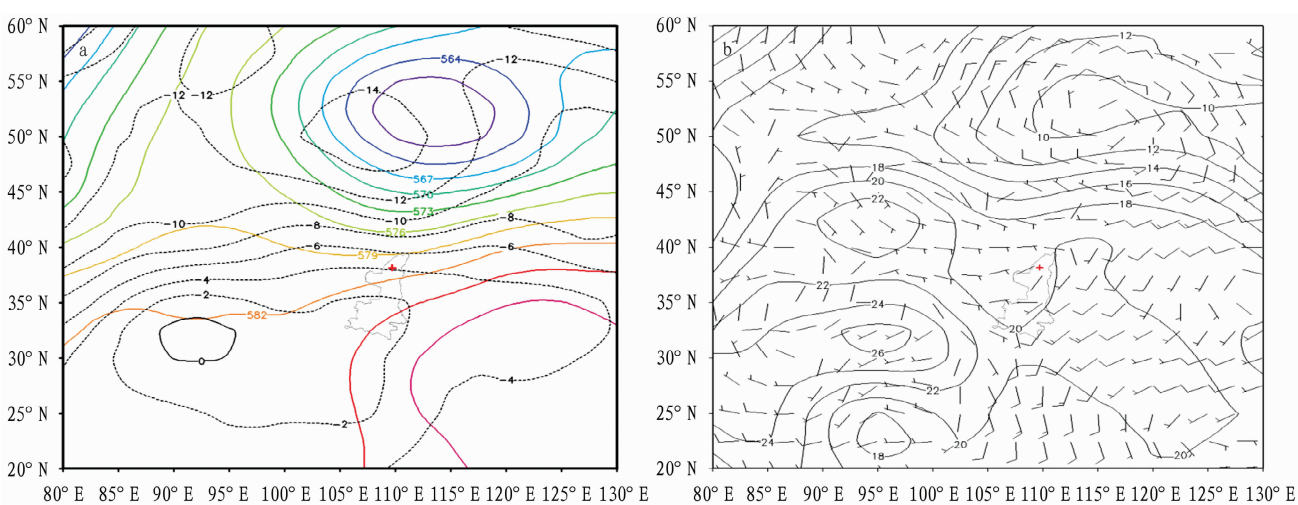


Fig. 2 Circulation situation at 500 (a) and 850 hPa (b) at 08:00 on June 25, 2018

1.3 Subtropical high type There were three cases of such weather. From late July to early August, the subtropical high raised northward to North China. During the period of westward extension of the subtropical high, Shaanxi was located within the 588 dagpm line of the subtropical high, and sometimes it was connected with the continental high. There was easterly wind in middle and low layers, with the wind speed of only 2 m/s. O_3 pollution occurred in Shaanxi due to continuous hot and sunny weather.

Typical weather was shown in Fig. 3. From July 25 to 30, 2018, the subtropical high extended westwards and raised northwards; the northern boundary of 590 dagmp was at 45° N, and the western boundary was at 105° E. Shaanxi was completely surrounded by the subtropical high, and the weather was continuously sunny and hot. At 850 hPa, there was easterly wind, with the transport of precursors. As a result, O_{3-8} concentration rose to 216 μg/m^3, and air pollution was moderate.

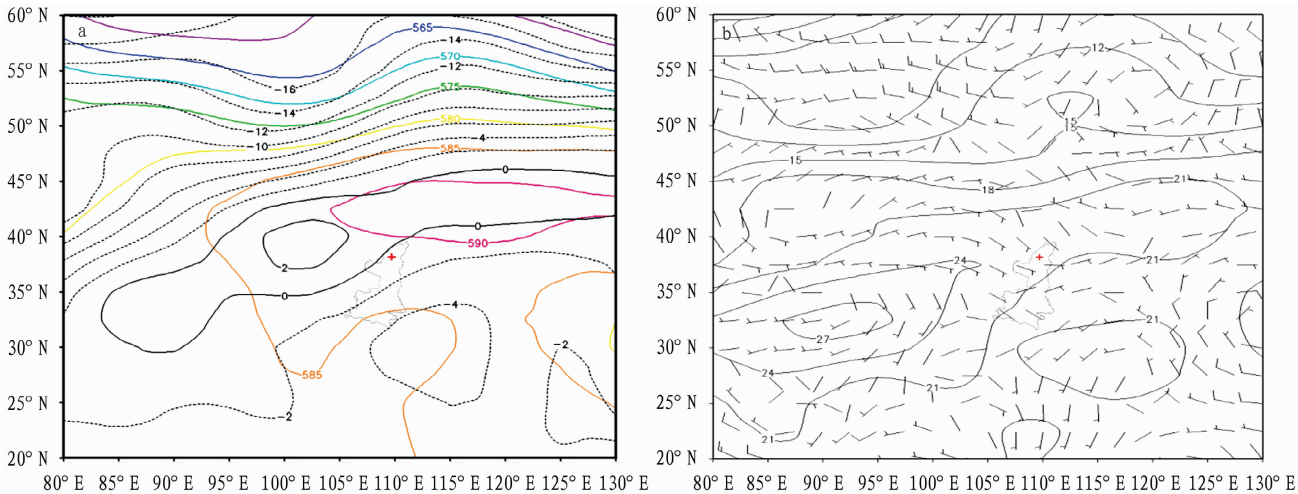


Fig. 3 Circulation situation at 500 (a) and 850 hPa (b) at 08:00 on July 30, 2018

2 Multiple linear regression analysis

2.1 Establishment of multiple linear regression equation A total of 8 267 samples were obtained by using hourly data of O_3 and meteorological elements from December 2018 to November 2019. The correlation analysis method was used to obtain the correlation coefficient between O_3 and each meteorological element. As shown in Table 1, the correlation of O_3 concentration and three meteorological elements (air pressure, temperature and wind speed) was significantly stronger than that of relative humidity and precipitation. The correlation of O_3 concentration and air pressure was negative, while O_3 concentration was positively correlated with temperature and wind speed, and temperature had the strongest correlation. The correlation coefficient of air pressure, temperature and wind speed was > 0.3, so the three meteorological elements were chosen as independent variables. After mathematical modeling was conducted by using the above factors, the R and R^2 value of model 1 reached 0.753 and 0.568, respectively, so the correlation was good (Table 2). The regression coefficient of the independent variable factors was calculated using model 1, and passed the residual test (Table 3).

According to the above calculation results, the equation of O_3 concentration can be obtained as follows:

$$O_3 = 0.364P + 2.745T + 11.46WS - 318.105$$

In the formula, O_3 stands for ozone concentration (μg/m^3); P is air pressure (hPa); T is the temperature at a height of 1.5 m (℃); WS is the wind speed at a height of 10 m (m/s).

Table 1 Correlation coefficient of O_3 concentration and meteorological elements

Meteorological element	Pearson correlation coefficient
O_3 concentration	1.000
Air pressure	-0.475**
Temperature	0.683**
Relative humidity	-0.195**
Precipitation in the last hour	0.062**
10-min average wind speed	0.428**

Note: ** means the correlation was significant at 0.01 level (double tail).

Table 2 Correlation after mathematical modeling

Correlation coefficient	Value
R	0.753[a]
R^2	0.568
Adjusted R^2	0.568
Errors estimated	32.130
Durbin - Watson	0.232

Note: a. Predictive variables: (constant), 10-minute average wind speed, air pressure, and temperature; b. Dependent variable: hourly average O_3 concentration.

Table 3 Regression coefficient and residual calculation

Variable	Unnormalized coefficient		Standardization coefficient β	t	Error significance < 0.001	Collinearity statistics	
	B (coefficient)	Standard error				Allowance	VIF (autocorrelation < 5)
(Constant)	-318.105	65.999	-	-4.820	0	-	-
Air pressure	0.364	0.074	0.052	4.904	0	0.470	2.126
Temperature	2.745	0.044	0.666	62.764	0	0.465	2.151
10-minute average wind speed	11.460	0.261	0.322	43.872	0	0.971	1.030

2.2 Calculation results The regression equation was used to calculate the hourly O_3 concentration from May 23 to June 3, 2018, and was compared with the real situation (Fig. 4). Although the simulation reflected the daily change of O_3, there was no fitting effect of O_3 pollution process. It shows that the prediction ability of the equation for O_3 hourly concentration was insufficient.

In actual work, O_3 pollution is mostly assessed by the average of maximum O_3 concentration in 8 consecutive hours (O_{3-8}).

Therefore, this equation was used to calculate O_3 concentration in three typical months in 2019. That is, O_3 concentration began to increase in April, was high in June, and decreased in August. The daily average temperature, air pressure and 2-min wind speed were selected as independent variables to calculate O_{3-8} concentration, and it is found that the fitting effect was good, but the regression values were generally lower than the measured values, and there was systematic error. Therefore, the error was calculated in each month to obtain the average and correct parameters, and the calculation effect was optimized. As shown in Fig. 5, in April, the simulated values were very close to the measured values, and the O_3 pollution process during April 18 – 19 was accurately simulated. In June, the trend simulation was better; the fitting effect of continuous O_3 pollution during June 9 – 11 and 17 – 25 was better, and the peak was slightly less than the measured value. In August, one of the three O_3 pollution cases had a good fitting effect.

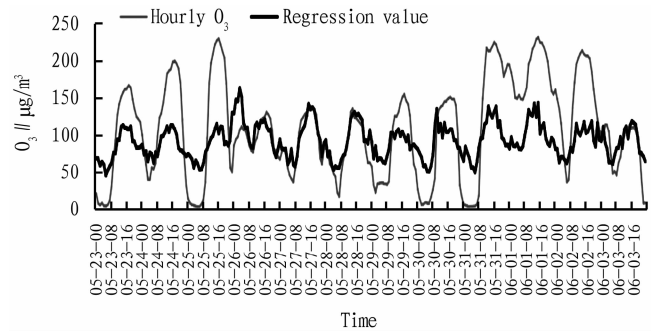
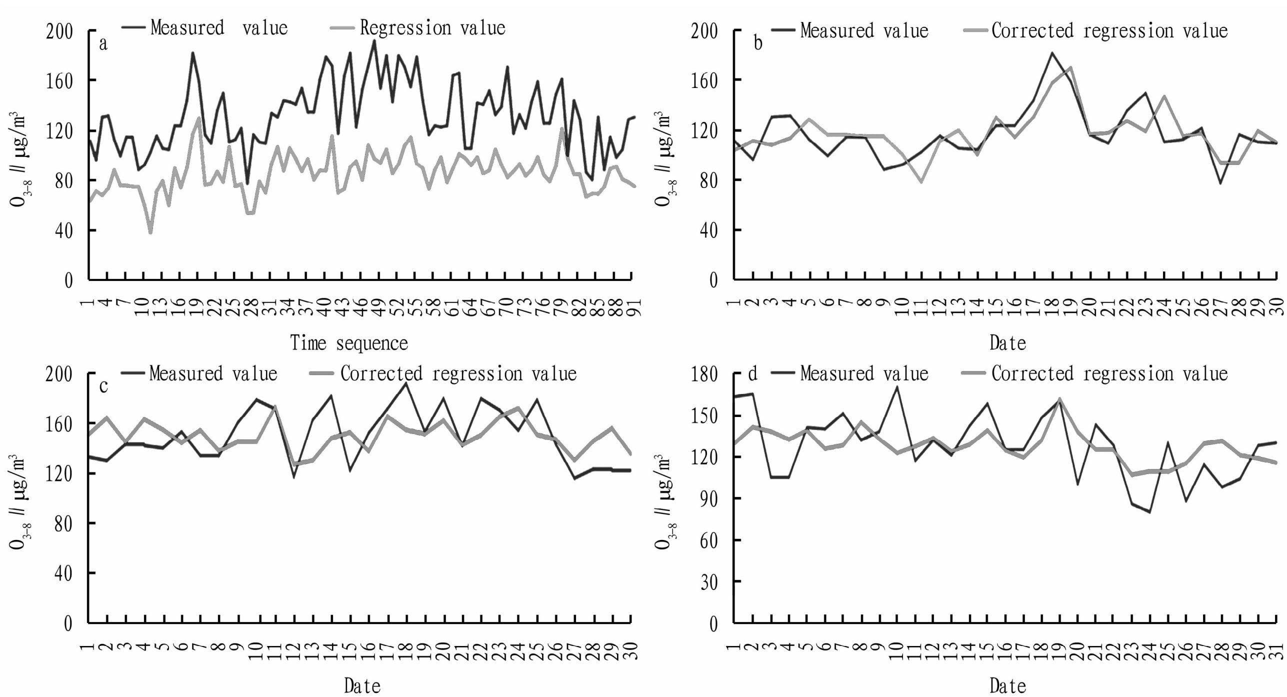


Fig. 4 Regression fitting and measured values of O_3 concentration from May 23 to June 3, 2018

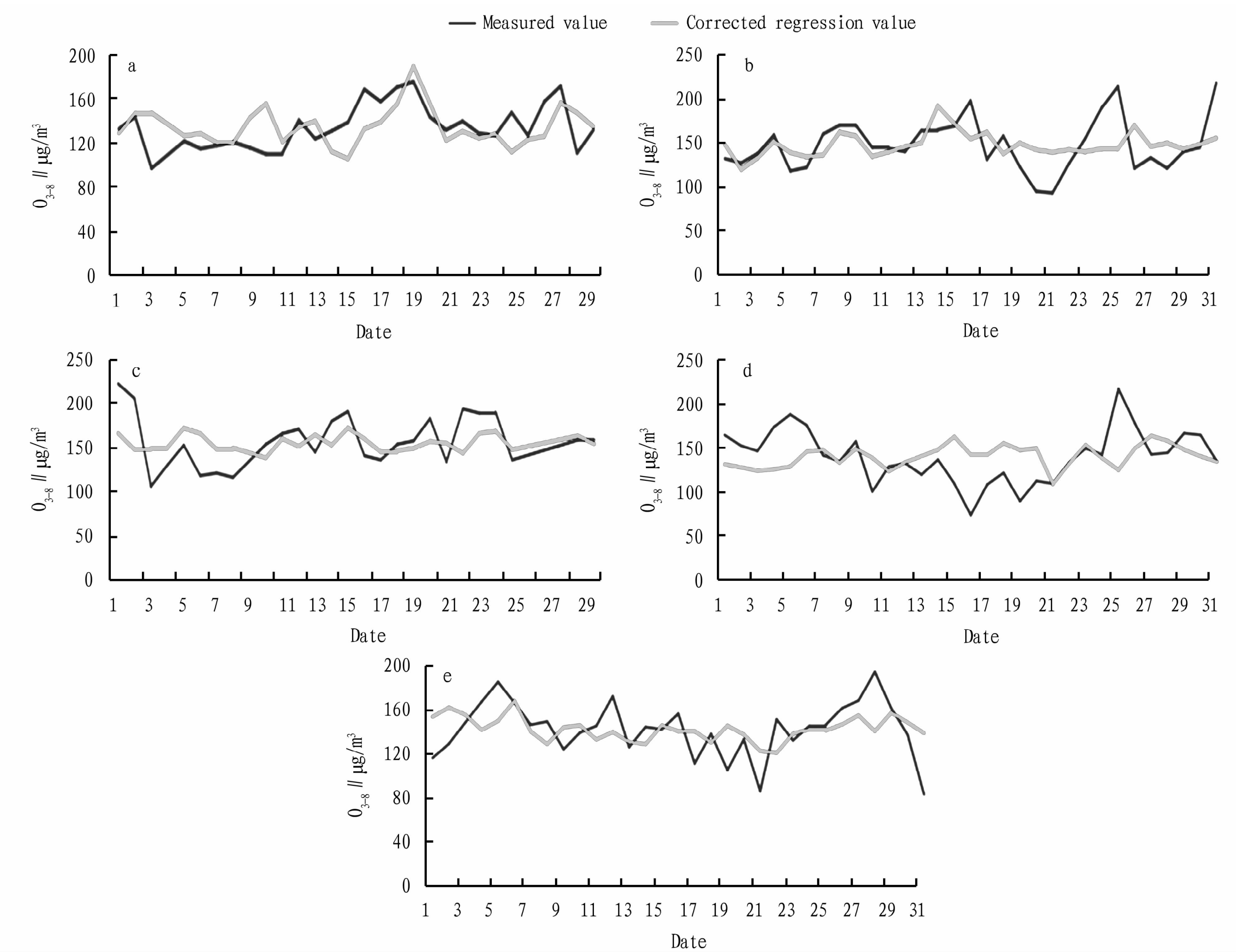


Note: b. April; c. June; d. August.

Fig. 5 Comparison between the fitting and measured values of O_{3-8} concentration in April, June and August, 2019 before and after parameter correction

The regression equation and parameter correction method were applied to fit O_{3-8} concentration from April to August in 2018, and the fitting effect on a polluted day was mainly studied (Fig. 6). It is found that among the 12 days with O_3 pollution in 2018, the simulated value of O_{3-8} concentration on 9 days exceeded the pollution threshold 160 μg/m^3, and the maximum reached 192 μg/m^3, smaller than the measured value. It did not reach the threshold on 3 days, and there was 1 empty report. Missed and empty reports appeared mostly on a single polluted day, and the simulation results of continuous pollution weather were better. From the distribution in each month, the simulation effect was better during April – June, and the fitting value was close to the peak during April – May. The simulation effect was poor during July – August, and the missing report also appeared in July.

Less precipitation and good continuity of meteorological elements during April – June were important factors for good O_3 regression effect. From July to August, there were more convective weather. Cloud cover, precipitation, convective gale and lightning had effects on O_3, and were non-continuous factors, so the simulation accuracy of the regression equation decreased. The simulation results show that the multiple regression method was suitable for the prediction of O_{3-8}, and the fitting effect was better especially for the continuous O_3 pollution process. This equation has accumulated basic experience for the late forecast of O_3 in Yulin.



Note: a. April; b. May; c. June; d. July; e. August.

Fig. 6 Comparison between the corrected regression and measured values of O_{3-8} concentration during April – August, 2019 after parameter correction

3 Forecasting process

Firstly, the circulation configuration favorable to O_3 pollution was obtained by analyzing the weather situation, and then O_{3-8} concentration was calculated by the multiple regression equation. Afterwards, it was corrected by different parameters in various months, and the calculated results were used as forecast values. If the pollution threshold was reached, relevant forecast products can be released.

The above scheme may have empty or missed reports. In addition to the objective errors of regression equations and parameters, the accuracy of numerical forecasting products is also an important factor affecting the prediction of O_3 concentration.

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