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Optical Remote-sensing Monitoring and Forecasting of Atmospheric Pollution in Huaibei Area, China

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Huaibei is an energy city. Coal as the primary energy consumption brings a large number of regional pollution in Huaibei area. Differential optical absorption spectroscopy (DOAS) as optical remote sensing technology has been applied to monitor regional average concentrations and inventory of nitrogen dioxide, sulfur dioxide and ozone. DOAS system was set up and applied to monitor the main air pollutants in Huaibei area. Monitoring data were obtained from 7 to 28 August, 2011. Monitoring results show measurements in controlling pollution are effective, and emissions of pollutants are up to the national standard in Huaibei area. Prediction model was also created to track changing trend of pollutions. These will provide raw data support for effective evaluation of environmental quality in Huaibei area.

Key words: Optical remote sensing, Atmospheric pollution, Huaibei area, Monitoring, Forecasting

I. INTRODUCTION

With the rapid economic and social development, environmental pollution has become more and more severe than ever. Human existence and development have been threatened by bad weather phenomena such as global greenhouse effect, destruction of the ozone layer and acid rain [1−3]. Huaibei is an energy area, which is dominated by coal and electricity. The rapid economic development based on energy consumption of coal is leading to environmental deterioration. Monitoring of main atmospheric pollution is one of most important topics for Huaibei municipal authorities in order to make up appropriate controlling measures.

Regional distribution and total flux of pollution emissions need to be measured and controlled effectively in order to know regional atmospheric environment and levels of main pollution concentration in Huaibei area. All these put forward higher requirements to the existing monitoring technology. Gaseous pollutants such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3) have wide distributions. The distributed or multi-point networks measurements are generally used in traditional air pollution monitoring. Limited and isolated point concentrations are obtained, which cannot give real-time, continuous and accurate total distribution of the atmospheric pollution gases.

Differential optical absorption spectroscopy (DOAS) is a regional atmospheric pollution monitoring technology [4−6]. Due to its real-time, online, non-contact and non-change, DOAS is more commonly used in the determination of a variety of trace gases (such as O_3, SO_2, NO_x, HCHO, HONO, and NO_3) in visible and ultraviolet regions [7−9]. Optical remote sensing DOAS system was used to monitor the main atmospheric pollutants such as SO_2, NO_2, and O_3 from 7 to 28 August, 2011 in Huaibei area, China.

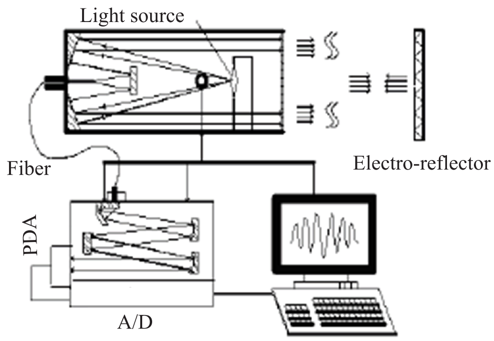

FIG. 1 Structure sketch of DOAS system.

II. EXPERIMENTS

A. Principle of DOAS

DOAS system is integrated with optics, mechanics and electrics. Concentrations of trace gases can be measured continuously and automatically. The structure sketch of DOAS system are shown in Fig.1. DOAS

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setup includes light source, the transmitting and receiving telescopes, spectrometer, retro-reflectors array, fiber, PDA detector, A/D converter, and computer.

Light, with intensity $I_0(\lambda)$, is emitted by a suitable source passing through the open atmosphere. The light undergoes extinction due to absorption processes of different trace gases and scattering of air molecules and aerosol particles. The intensity $I(\lambda)$ at the end of the optical path is given in Eq.(1) with Lambert-Beer's law [10, 11]:

$$I(\lambda) = I_0(\lambda)\exp\left\{\sum_{i=1}^{n}\big[-\sigma_i(\lambda)-\sigma_i'(\lambda)-\varepsilon_{\rm R}(\lambda)-\varepsilon_{\rm M}(\lambda)\big]N_iL\right\}+B(\lambda) \tag{1}$$

here, λ denotes the wavelength, L is optical path, n is the trace gas species. The differential cross section $\sigma_i(\lambda)$ represents narrow spectral structures. $\sigma_i'(\lambda)$ is the broad spectral features. N_i denotes the concentration of atmospheric trace gases. $\varepsilon_{\rm R}(\lambda)$ and $\varepsilon_{\rm M}(\lambda)$ are Rayleigh extinction coefficient and Mie extinction coefficient, respectively. $B(\lambda)$ denotes the noise intensity. $\sigma_i'(\lambda)$, $\varepsilon_{\rm R}(\lambda)$, and $\varepsilon_{\rm M}(\lambda)$ are slow change parts, which can be removed through appropriately designed filter. Then logarithm of $I_0(\lambda)/I(\lambda)$ is called optical density:

$$\ln\left[\frac{I_0(\lambda)}{I(\lambda)}\right]=\sum_{i=1}^{n}\sigma_i(\lambda)N_iL+B'(\lambda) \tag{2}$$

Least squares fitting are done between Eq.(2) and standard differential absorption cross-sections of trace gases. Then total concentrations of trace pollutants along the road are retrieved. Regional average concentration is obtained by dividing optical path L.

Optical paths are usually from hundreds of meters to thousands of kilometers. Due to optical remote sensing, monitoring results are inevitably affected by meteorological conditions. The returned light intensity sometimes becomes weak when bad weather is coming. These will bring abnormal monitoring results, and monitoring accuracy of DOAS system will be affected, even can not normally monitor. Therefore the monitoring data need real-time tracking and forecasting.

B. Measurement site

Optical remote sensing monitoring DOAS system was set up on physical experimental building at Huaibei Normal University (33°95′N, 116°80′E), which is in the east of Huaibei city. The light path was folded by retro-reflectors which were mounted at a distance about 232 m on the top of library building with a height of about 20 m. The wavelength coverage of 240.2−363.9 nm allows monitoring SO_2, NO_2 and O_3 from 7 to 28 August, 2011. The time resolution of the measurements varied between 5 and 10 min, depending on visibility.

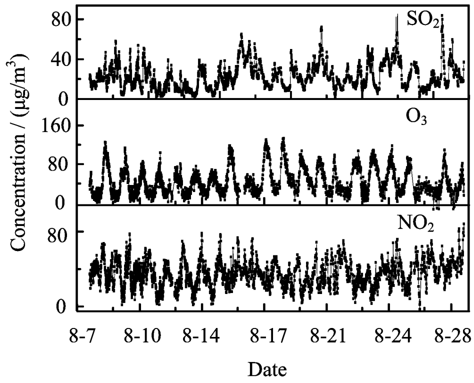

FIG. 2 Time series of NO_2, SO_2, and O_3 in 2011.

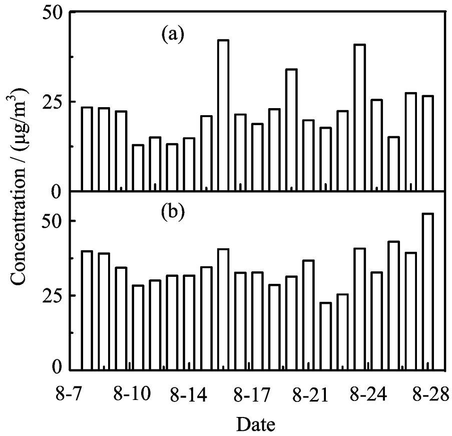

FIG. 3 Diurnal mean series of (a) SO_2 and (b) NO_2 in 2011.

III. RESULTS AND DISCUSSION

DOAS system was used to monitor SO_2, NO_2, and O_3 from 7 to 28 August, 2011 in Huaibei area. The time series of NO_2, SO_2 and O_3 concentrations are shown in Fig.2. Figure 3 is time series of daily mean value of NO_2 and SO_2. Figure 4 is hourly mean time series of O_3 concentrations. The time series of meteorological parameters are shown in Fig.5 during this campaign.

From Fig.2, we can see that the concentrations of NO_2 showed a typical diurnal variation with maximum of 88.7 μg/m^3 and an average of 33.41 μg/m^3 at monitoring site. The detection limit of NO_2 was about 1.56 μg/m^3. Low concentration of NO_2 was observed for photolysis in the daytime while concentration reached high concentrations at night during this campaign. Wind speed was 6.6 m/s on 23 August, which made minimum value of NO_2 concentration during monitoring period. Since then, low wind speed, the static and stable weather conditions appeared during

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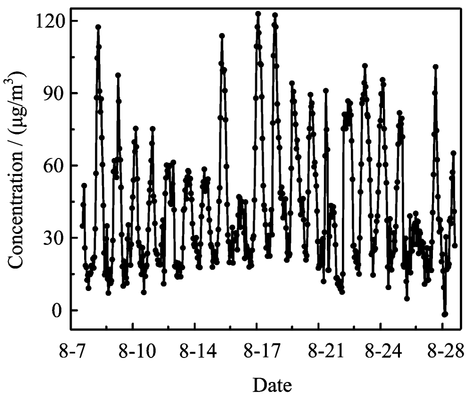

FIG. 4 Hourly mean series of O_3 in 2011.

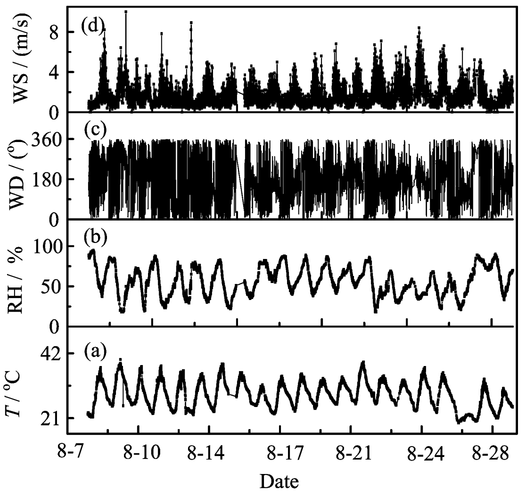

FIG. 5 Time series of (a) temperature, (b) relative humidity, (c) wind direction, and (d) wind speed in 2011.

monitoring period, resulting that concentrations of NO_2 accumulated, and peaks were observed on 28 August during the period of measurement. The diurnal trend of SO_2 was unobvious at monitoring site with maximum daily mean value of 88.7 $\mu g/m^3$ and average daily concentration of 22.6 $\mu g/m^3$. The detection limit of SO_2 is about 0.85 $\mu g/m^3$. Huaibei is a coal-dependent area. Even in summer, concentrations of SO_2 and NO_2 remain higher than that in other cities. Concentrations of O_3 showed a strong diurnal variation in typical urban areas with low concentration at nighttime and in the morning, peaks during the afternoon. The detection limit of O_3 was about 3.9 $\mu g/m^3$. Maximum value of 133.43 $\mu g/m^3$ was observed at about 14:29 on 18 August.

IV. FORECASTING SYSTEM

The regularity of the trace gases concentrations was found during long-term observation. The time series and distribution of the O_3 concentrations are shown

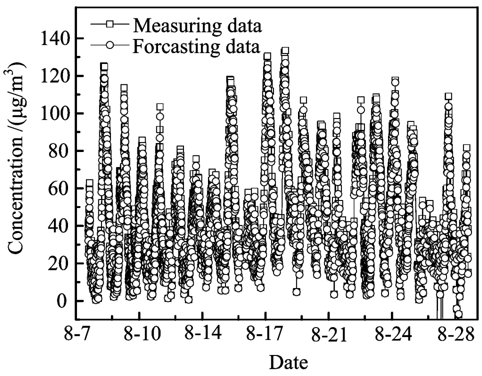

FIG. 6 Forecasting data and measuring data in 2011.

from 7 to 28 August in Fig.2. We can see that the trend change of trace gases concentrations is similar in every day, and concentrations were continuous (DOAS time resolution was several minutes, and pollution sources were relative fixed). So the real time forecasting for DOAS monitoring data was possible.

The change of trace gases concentrations is also affected by meteorological data such as temperature, relative humidity, wind direction, wind speed, and air pressure. And there is relationship among current, previous and other time concentrations. The temperature varied from time to time, but it is regular every day. Maybe there is relationship between concentration and temperature. Relative humidity reflects current weather. Humidity is larger in rainy day than in sunny day. Atmospheric trace gases may be easily wet sink or loss on aerosol surfaces when the humidity is higher. Therefore, relative humidity is an influencing factor for the trace gases concentrations in the environment. Air pressure is the function of sea level, which is almost constant in one area. Maybe there is no relationship between air pressure and pollution concentrations. This needs to be further gone into. Wind direction and wind speed play an important role in concentration change of pollutants. Pollution concentrations in leeward are heavier than those in windward. When wind speed is high, air pollution rapidly disappears and concentrations are lower than those when wind speed is lower. For example, when there is pollutant in northward of monitoring area and wind direction is north wind, concentrations of monitoring will become high in windward.

Forecasting factors were chosen based on step-wise regression [12]. The six obvious forecasting factors, *i.e.* the previous concentration before current time, yesterday concentration this time (Fig.2), temperature, relative humidity, wind speed and wind direction (seen in Fig.5), were chosen. These factors were chosen as input vector of Elman predicting network. After training, the Elman network was applied to trace the monitored data by differential optical absorption spectroscopy. Forecasting values and actual measuring values of O_3 are shown in Fig.6. Relative errors were below 5% between

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measuring data and forecasting data. So the trend of pollutants can be track during field campaign, and forecasting network can meet with the DOAS system's forecasting demand.

V. CONCLUSION

Optical remote sensing DOAS system was set up to real-timely monitor atmospheric pollution in Huaibei area. The prediction model was developed to estimate and track O_3 concentrations. During the whole measurement period, daily average concentration of NO_2 was 33.41 μg/m^3, and SO_2 was 22.6 μg/m^3 using DOAS system, which was up to the national standard. But the concentration of O_3 seriously exceeded the national second grade standards. These will provide raw data support for effective evaluation of environmental quality and implemented controlling measures for environmental pollution in Huaibei area in the future.

VI. ACKNOWLEDGMENTS

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