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The Study of Near-surface wind and pollution characteristics in Yuxi Center District

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Abstract. The pilot balloon observation system with dual theodolite was used to investigate the effect of near-surface wind characteristics on pollutant diffusion in Yuxi NO.1 middle school, and by using the meteorological observation data analysis of the different weather characteristic and the impact on the pollutant concentration distribution. The experimental results showed that the predominant wind direction was not so apparent due to the affection of channels to the wind and the valley of the wind. During the observation, the regional atmospheric stability is more unstable and neutral stability, and longer duration of neutral stability would not be good at contamination diffusion. Winds profile observed four types of irregular, reverse, extreme value, normal. Under neutral stability conditions, the degree of fitting of wind profile exponent P in normal-type wind velocity is good, and its value is 0.608. The mountain-valley wind relates to daily range of temperature and the greater this difference in temperature is, the more frequency of mountain-valley wind blowing. In the morning and evening is the transition of mountain-valley wind, the period of time due to wind direction changes, causing the circulate accumulation of the pollutants in the air over the city.

1. Introduction

With the rapid development and prosperity of human society, the acceleration of urbanization, the continuous optimization and adjustment of urban functional areas and industrial structure layout, the constant consumption of energy, a large number of exhaust gas, dust and other substances are discharged into the atmosphere, Ambient air pollution is becoming more complex. Now more and more people pay attention to the problem of urban air quality. The transport and diffusion of air pollutants in cities has become a hot topic in recent years. The near-surface wind field and topographic features have an important effect on the dilution and diffusion of urban pollutants. Combined with the data of environmental pollutants, WANG F J et al [1] found that pollution is easy to be formed in the stable stage of atmosphere and local pollutant diffusion is easy in the stage of strong convection instability. Su Sheng et al [2] have found that the average wind speed in most parts of North China obviously decreases in winter, which affects the dilution and diffusion of atmospheric pollutants and easily accumulates and results in high concentration of pollution. Li Fei et al [3] has found that the diurnal variation and seasonal variation of SO_2 distribution are closely related to solar radiation and sunshine length. Wei Peng et al [4] used AQI and NCEP reanalysis data as well as surface and small ball sounding data to analyze the meteorological causes and formation process of heavily polluted weather in autumn. It was also found that the main weather background field to reduce AQI is when the wind speed reaching 6m/s.

Yuxi is a typical mountainous city in southwest China, and its meteorological characteristics of air pollution have its particularity. Therefore, the analysis and study of the characteristics of near-surface flow field in Yuxi central city is helpful to more scientific and accurate analysis of pollutant concentration change. At present, the wind field data at different altitudes are retrieved by meteorological radar in most regions. [5-6], many scholars have used wind profile radar data to study the upper air wind field, boundary layer structure and disastrous weather. [7-10], Most of the radar data come from the meteorological observation data of the weather stations or airports in the suburbs or far suburbs, which is not representative of the urban areas, and there is little research on obtaining the regional near-surface wind field data through direct observation in the urban areas. On the other hand, because of the principle [11-12] of radar wind measurement itself, there exists a blind area of wind measurement, the height of which is about 0 to 300m, and the flow field of this height has the most direct effect on the pollution diffusion. This study obtained the meteorological characteristics and wind speed profile of Yuxi central urban area by using double theodolite, and discussed the effects of atmospheric stability, valley wind and other meteorological conditions on the concentration of SO_2,NO_2,O_3; The wind profile index under the condition of neutral stability is analysed, which provides a scientific and effective theoretical basis for simulating the distribution of atmospheric flow field and obtaining the distribution law of pollutant dilution and diffusion through the environmental wind tunnel experiment.

2. Experimental materials and methods

2.1. Instruments and materials

Theodolite, Meteorological balloon, walkie-talkie, stopwatch, helium

2.2. Experimental content

Yuxi (24°22´20"N, 102°32´13"E) is located in the middle of Yunnan Province, facing mountains from east to west, and belongs to the central Yunnan basin. It is a typical mountain city on the plateau. The site of the experiment is located at the intersection of Taiji Road and Longma Road in Yuxi Middle School.

This experiment uses double theodolite to measure wind, A and B theodolite are located at the top of two buildings in Yuxi No. 1 middle school. The balloon release point C is located in the staff apartment. The A and B observation points (baseline) are perpendicular to the prevailing wind direction in Yuxi. A, B and C forms an obtuse triangle. The observation time is from January 1 to 31, 2015, 10 times a day. In considering if there was thick fog every morning during the observation period. So the observation time is set as follows: 10: 00,11: 00,12: 00,13: 00,14: 00,15: 00,16: 00,17: 00,18: 00,19: 00. The elevation and azimuth angles of the two theodolites of A and B are read at 10s every time. In order to ensure that the A and B theodolite read data synchronously on time, each observation point is equipped with a walkie talkie, and the special person directing the ball and reading the data.

2.3. Data processing method

The experimental data are processed by vector method, as shown in Figure 1. Due to the presence of instrumental errors and visual errors, line of sight$\underset{AD}{\rightarrow}and\underset{BC}{\rightarrow}$ disjoint at the same time, the largest space position of the balloon may fall on$\underset{DC}{\rightarrow}$.On the base of

$$\underset{AD}{\rightarrow} + \underset{DC}{\rightarrow} = \underset{AB}{\rightarrow} + \underset{BC}{\rightarrow}$$
$$\underset{AD}{\rightarrow} \times \underset{DC}{\rightarrow} = \underset{BC}{\rightarrow} \times \underset{DC}{\rightarrow} = 0$$

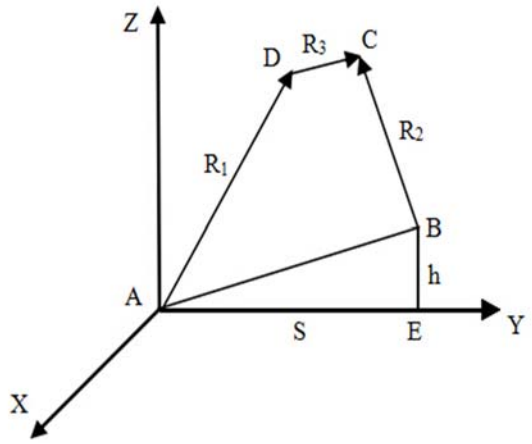


Figure 1. Vector diagram of pilot balloon observation system with dual theodolite

We can calculated the spatial coordinates of the wind balloon. To ensure the accuracy of observation data, only the data of $\overrightarrow{DC}$length less than or equal to 2m is retained. Finally, according to the balloon trajectory coordinates, we could calculate the wind speed values at different altitudes.

3. Results and Analysis

3.1. The Meteorological characteristics of Yuxi City

3.1.1. Wind rose map. According to the meteorological data provided by Yuxi meteorological station from August 2014 to July 2015, an annual wind direction rose chart for the region is obtained by analysis (figure 2). As figure 2 shows, the wind speeds of the south-southwest, south and southwest winds are respectively2.49m/s, 1.61m/s, 3.04m/s, the dominant wind direction is not obvious. Owing to its narrow distribution, surrounded by mountains (figure 3), and it is affected by both the systematic wind and the valley wind.

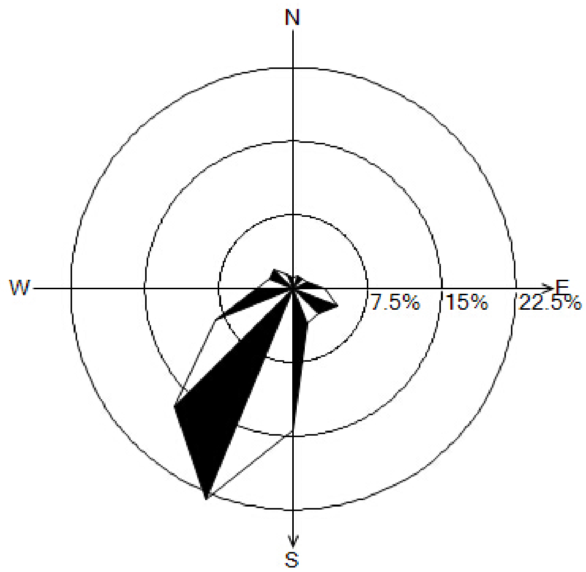
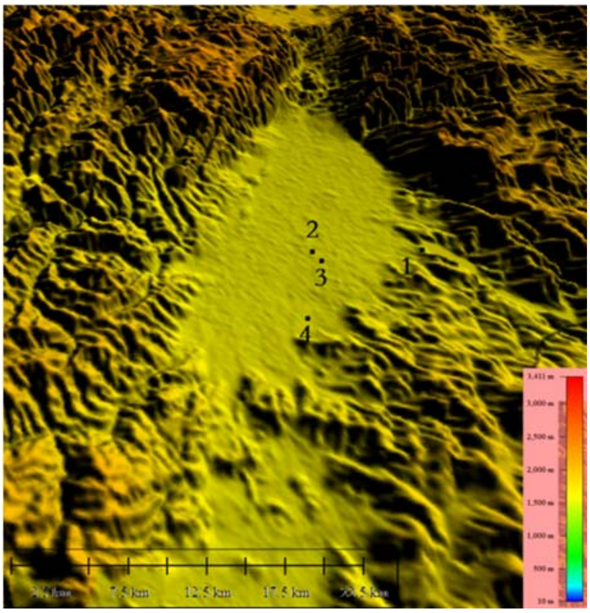


Figure 2. Wind rose (the whole year, Static wind frequency=5.42%)



1 Dongfeng reservoir 2 Yuxi No. 1 Middle School 3 Municipal monitoring station 4 industrial park

Figure 3. Topographic map of Yuxi

3.1.2. Stability. The stability of the atmosphere is closely related to the diffusion of pollutants in the atmosphere, which in turn will affect the concentration distribution of pollutants. Based on the observation results, the Pasquill classification method [13] (PS) is used to judge the atmospheric stability during the experiment. The results are shown in figure4.

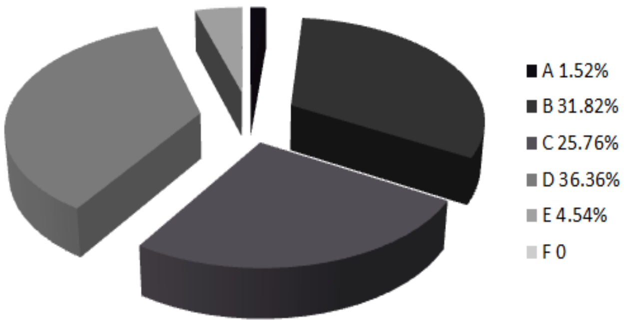


Figure 4. Distribution of stability frequencies

As figure4 shows, The frequency of stability during the observation period is as follows:A:1.52%,B:31.82%,C:25.76%,D:36.36%,E:4.54%,F:0.This is due to the fact that the F occurs at night and the observed time is clear day, and the frequency of neutral stability is the highest in cloudy days, morning and evening.

During sunny days, the earth surface temperature rises under sunlight, and the solar radiation from the surface during the day is transmitted upward in the form of sensible heat and latent heat, heating the air above and the air is gradually heated up from the bottom, the temperature gradient is decreasing. The atmosphere is in an unstable state; at night, the net radiation of the ground turns into a negative value, the underlying surface is cooled, the ground radiates heat to lose heat, the ground temperature decreases, the air first cools down from below, and gradually develops into a stable atmospheric boundary layer of the inversion layer, and the atmosphere is in a stable state; Before and after the sunrise and sunset, it is in the transition period and is close to the neutral layer. This observation time is daytime, so the most common unstable types are observed. In addition to the observation of neutral stratification in the morning and evening, wind speeds were also observed. Because high winds cause the air to mix evenly in all directions, the air block temperature is equal to the ambient air temperature, and the atmosphere is neutral. The probability of instability observed is higher than the probability of stability, which is contrary to the more stable state [14] in winter. This is mainly because the urban areas of Yuxi are not obvious during the four seasons. During the observation period, the amount of cloudiness is small and the solar radiation is weak. A breeze with a certain frequency increases the frequency of declining temperatures, leading to unstable atmosphere.

3.1.3. Basic characteristics of valley wind in Yuxi. As shown in Fig.3, Yuxi city is mainly affected by systematic wind and valley wind. The hourly measured wind speed in the surface meteorological data provided by Yuxi meteorological station is the vector sum of system wind and valley wind. The system wind is the vector sum of the mean value of the wind u, v component measured every day, and the valley wind is the vector sum of the measured wind u, v component, subtracting the system wind u, v component, respectively. [15]. If the valley wind occurs at least 4 times during the day and the mountain wind at least 4 times at night, then the valley wind is considered to be blowing on that day. The central district of Yuxi is affected by the topography. The mountain in the north has the highest elevation. During the day, we define the south wind, the south-southwest wind, the southwest wind as the valley wind, while at night we define the north wind, the northeast north wind, the northeast wind as the mountain wind.

In this paper, we separate the hourly wind data from august 2014 to july 2015 with the above method. The results are shown in figure 5. The diurnal variation of temperature by quarter is shown in figure 6. From the results of figure 5 and figure 6, we find that during the day, the frequency change of the millet wind is positively correlated with the temperature, and the frequency of the valley wind is the highest when the temperature is the highest; while in the evening, the frequency change of the mountain wind is negatively correlated with the temperature, and the frequency of the mountain wind is the highest when the temperature is low. From 8: 00 a.m. to 10:00, the sun came out and the temperature rose slowly, It is a period of mountain wind turns to valley wind; and from 19 p.m. to 21:00,the setting of the sun caused the temperature to slow down, It is a period of valley wind turns to mountain wind. In spring and winter, the difference of the temperature between day and night is high, the frequency of mountain wind and valley wind is higher than that in summer and autumn. And it was found that valley winds had 44 days in spring, 26 days in autumn and 28 days in winter, and only 8 days in summer. When the valley wind can be observed obvious, the wind value of the system is usually small, but when the system wind is strong, the local circulation will be masked, and the valley wind will not be observed. From the number of valley wind days in each quarter, it can be seen that the system wind dominates, therefore, the southwest winds of Yuxi city center have the highest wind frequency.

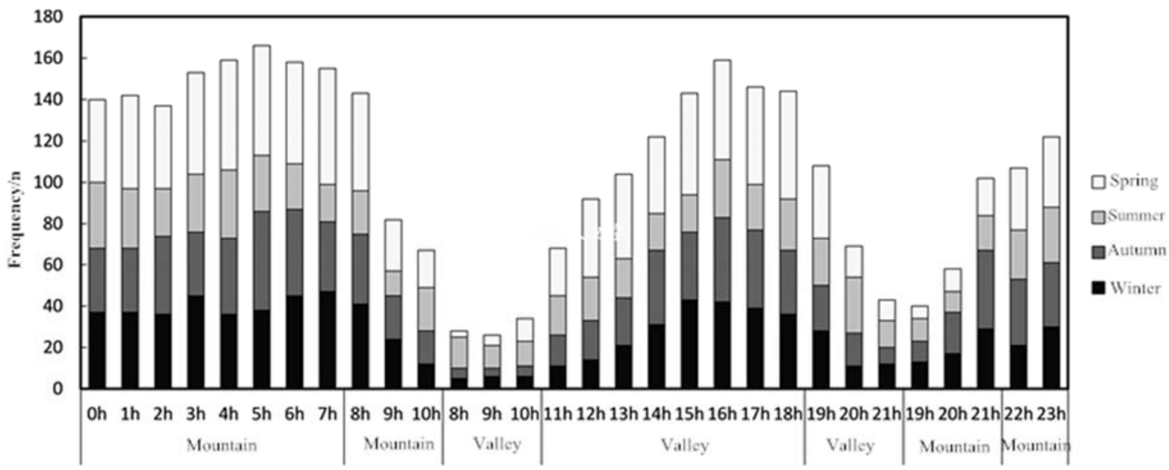


Figure 5. Diurnal variation of mountain-valley wind in different seasons

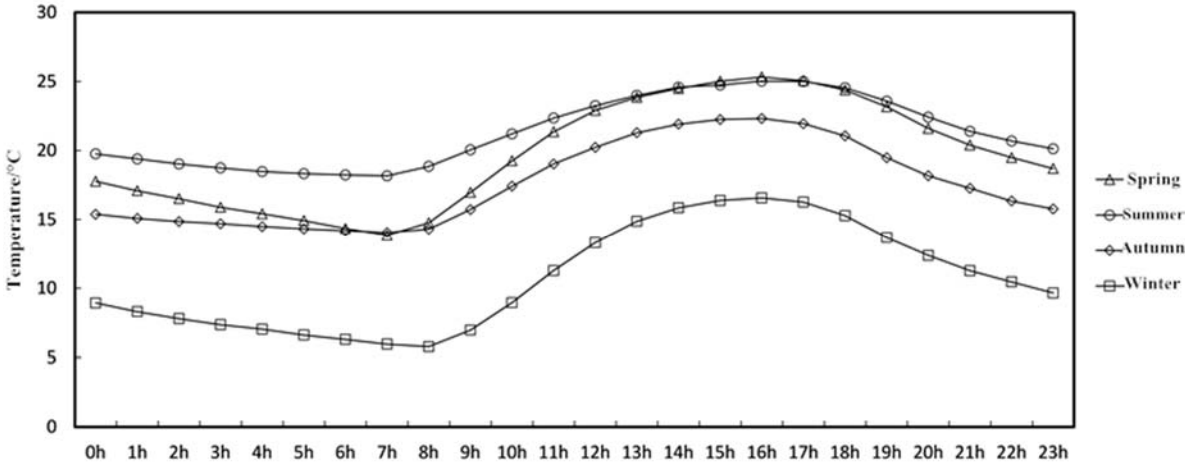


Figure 6. Diurnal variation of temperature in different seasons

3.2. Wind speed profile

The vertical structure of wind field in mountainous area is more complicated than that in plain area. The observed data show that there is an obvious change in height about wind direction and wind speed. From figure 3 we can see that Yuxi city is located in a wide and shallow valley, which is affected by both the systematic wind and the valley wind. The vertical structure of the wind field is complex, especially during the period of mountain wind and valley wind conversion, the wind direction and wind speed at each height is unstable. Therefore, the wind field near the surface of the mountain area cannot be easily calculated to obtain the wind speed of each height layer.

The experimental data of wind measurement with the double theodolite ball were processed by vector method. Wind profiles are divided into 5 types (Fig. 7): normal type, extreme type, equivalent type, reverse type, irregular type. Yuxi is a mountainous city on the plateau which the east and west are adjacent to the mountain and the underlying surface is quite complex. During the observation period, the weather changes greatly and the wind changes too often, the results show that the proportion of irregular type is 45.45, while the normal type is 30.91.And the proportion of extreme value type, reverse type and equivalent type are 16.37,5.45 and 1.82 respectively. The irregular type often occurs at 10, 17, 18 and 19 o'clock, the period is dominated by that of mountain and valley wind alternating, and the wind at different heights changes chaotic, so the wind profiles are mostly irregular. For the extreme wind profile, the extreme points mostly appear at about 300 meters. This is mainly because the central area of Yuxi is surrounded by mountains. The height of the air outlet at the height of 300 meters has become broad, making the wind speed drop rapidly, figure7 (c).

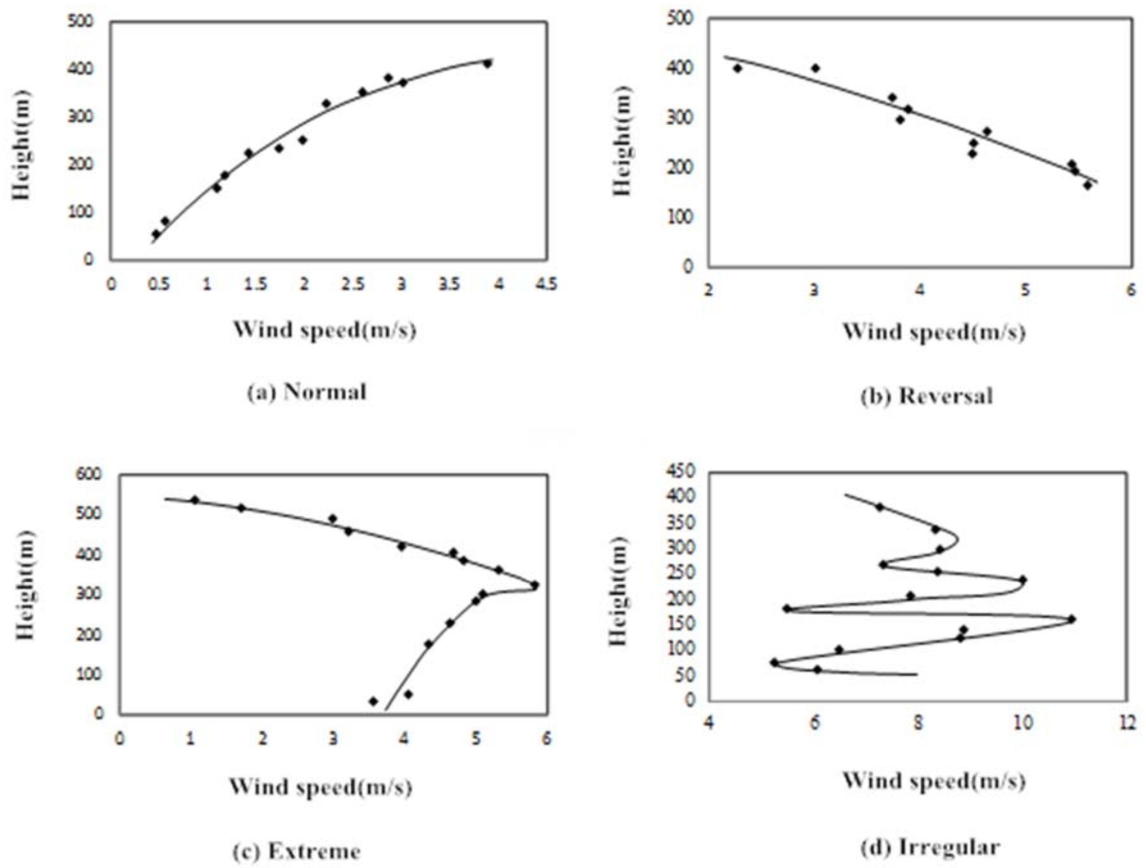


Figure 7. Wind variation with height

3.3. Normal wind profile index with different stability

During the observation period, the normal wind speed is observed under the condition of B and D stability. When the location of the observation point is south-west wind direction, the exponential rate and logarithmic law were used to analyze the variation of normal wind speed with height. It is found that the fitting degree of the data is high by using exponential rate analysis. This is mainly due to the fact that the effect of the formation temperature layer on the air movement only becomes significant above a certain height away from the underlying surface.

From the analysis result of index rate (Table 1), it can be seen that the wind profile index in the unstable state is quite different in numerical value, which is 0.469, 0. 527. The wind profile exponents measured under neutral stability are close to each other at different time. The wind profile index p is 0.608 when the correlation coefficient is the highest. The observed results are greater than the urban wind profile index recommended in the *Environmental impact assessment technical guidelines - Atmospheric Environmet.*[16] the p value given by Irwin(Irwin,1979) [14], Wind measurement results of conventional small balls in Nanjing and other places [17-18] , the measured fitting values of 325m meteorological tower of the institute of atmospheric physics of the Chinese academy of environmental sciences in Beijing.[19] However, this result is close to the observed p value of 0.59 under the condition of neutral stability in Gejiu city [20] Yuxi and Gejiu city all belong to plateau mountain city, it's topography and landform are similar, and the city is in a long and narrow distribution. the system wind is the dominant wind direction. Therefore, the p values of the two regions are similar under both unstable conditions and neutral stability conditions. Under the condition of neutral stability, the turbulent motion of the atmosphere depends entirely on the action of the dynamic factors, and the turbulence motion near the ground is very similar to the turbulence motion simulated manually in the wind tunnel. Therefore, the p value obtained in the experiment under the condition of neutral stability is suitable for simulating the turbulence problem in wind tunnel. Below 500m, the wind speed is greatly affected by ground friction. The greater the ground friction is, the more obvious the wind speed increases with the increase of height, and the greater the wind profile index p is. [21] Yuxi is a mountainous city with high altitude and low air pressure. The underlying surface is more complicated than that of plain area, the density of buildings in the observation area is large and the height is uneven. Therefore, the observed p value in the central urban area of Yuxi City is larger than that in the plain area and the p value recommended by the guidelines. In addition, observation points are also an important factor affecting wind profile index. The experimental test points are located in the center of the city, with dense buildings and uneven height, while the meteorological stations are usually located in the suburbs or the suburbs of the city, so the wind profile index obtained by the test stations will be small.

Table 1. The wind profile

Atmospheric stability	Wind profile index p	$u/m \cdot s^{-1}$	R^2
Neutral stability	0.596	1.31	0.8918
	0.608	1.05	0.9357
	0.639	0.389	0.8013
	0.592	0.94	0.9127
Unstable	0.469	0.77	0.9161
	0.527	1.45	0.9315
	0.515	1.23	0.9240
	0.498	0.84	0.9305

3.4. Concentration variation of pollutants during observation period

During the wind measurement with the ball, based on the hourly monitoring data of pollutants from Municipal monitoring station and Dongfeng reservoir (Figure 8), The monitoring value of Dongfeng reservoir is much smaller than that of municipal monitoring station., Combined with the geographical location of the two sites we can know that :The city monitoring station is located in the bustling area of the city center, while the Dongfeng Reservoir is located in the east of the central city of Yuxi City. The surrounding vegetation is lush, so the local contribution of pollutants from the city monitoring station plays a leading role. The change trend of monitoring concentration of SO_2 and NO_2 is consistent, and the total amount of pollutant emission increases during the morning and evening peak period of urban traffic. In combination with figure 5, it can be seen that the alternation of urban valley wind causes the rapid circulation and accumulation of pollutants over the city, exacerbating the pollution near the surface of the city, and the concentration of pollutants reaches the maximum value at the end of the alternate period of valley wind, and quickly be diluted and diffused. Based on the analysis of the previous stability observation results, the observed results during the day of January 20 are all neutral stable conditions. In this case, the pollutants spread slowly, after 17 o'clock, although the atmosphere is still in a neutral stable condition, the change in the direction of the wind causes the pollutants in the distant areas to migrate back and increase pollution. In the daytime, the atmospheric instability and neutral stability were observed during the day from 21 to 26, and the unstable situation was observed and the duration was long .the atmospheric turbulence contributes to the diffusion of pollutants and in addition to the valley wind effect, the accumulation and diffusion of pollutants are evident in figure 8.However, the trend of O3 is slightly different from SO_2 and NO_2. With the urban traffic moring and evening peak, also the valley wind alternate ,there will be basically two peak stages of the NO_2 value, but the O_3has only one peak stage and the time of occurrence is 15:00.The main source of O_3 in the lower atmosphere is the photochemical reaction between nitrogen oxides and organic compounds. And the solar radiation intensity is the main meteorological condition that affect O_3.

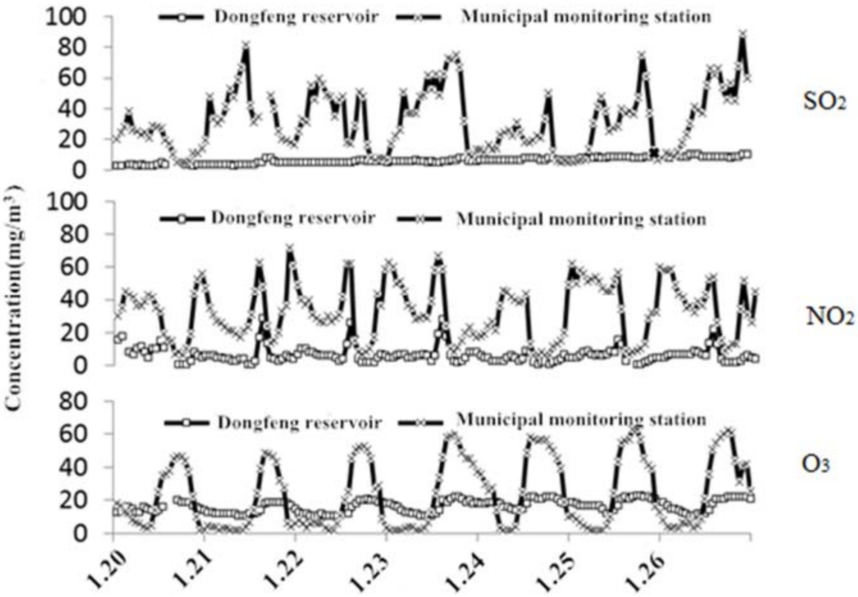


Figure 8. Diurnal concentration variation of several kinds of air pollutants

4. Conclusion

(1) The thermal turbulence is mainly related to the temperature stratification, and the atmospheric stability is the most intuitionistic reflection of the temperature stratification, which shows the intensity of the vertical movement of the atmosphere. The most frequent occurrence during the observation period was neutral stability, with a frequency of 36.36. When the wind is neutral, the mechanical turbulence is stronger, but the thermal turbulence is restricted, which is not conducive to the diffusion of pollutants. The frequency of occurrence of Classes B and C was 31.82% and 25.76%, respectively. The turbulence activity is strong, which is beneficial to diffusion dilution.

(2) The diffusion of pollutants can not only be explained by the degree of atmospheric stability, but also by the effect of the dynamic factors, and the wind and roughness of the ground also should be considered near the ground. The observed results show that the wind profile indices fitted under the condition of instability and neutral stability are 0.527 and 0.608, respectively. The p value is larger than the recommended value of the guideline and other urban radar inversion wind profile index, in addition to the complexity of the terrain, it is also related to the observation site. The meteorological radar is usually located in the suburb or the outer suburb of the city, but the experimental point is located in the city center, the ground buildings are dense and uneven, which is another factor leading to the higher wind profile index.

(3) For Yuxi, the dynamic effect of urban underlying surface also includes valley wind effect. The observed results show that the variation of mountain wind and valley wind presents diurnal and seasonal variations, and the greater the temperature difference, the easier it is to form valley wind; From 8: 00 to 10:00, 19: 00 to 21:00, It is the alternate period of mountain wind and valley wind, which results in the periodic variation of pollutant concentration. At the same time, solar radiation is the main reason for the day-night difference in O_3.

(4)The mountainous terrain may also form static wind, small wind area, airflow subsidence area and so on. It will take longer time to obtain this kind of meteorological data. The basic meteorological characteristics, wind speed profile and pollutant concentration distribution of Yuxi which is obtained by this observation are important for the establishment of flow fields similar to the actual ones in environmental wind tunnels and to study the diffusion distribution of pollutants.

Acknowledgments
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