Analysis of the Change Characteristics of PM2.5 and PM10 Concentrations in Tianjin

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Abstract. This paper studied the time series of daily average concentration of PM2.5 and PM10 in Tianjin. The time series of daily average concentration were studied to analyze their annual change rules and mutation characteristics, and the annual change rules of PM2.5 concentration and PM10 concentration time series were compared. It is concluded that PM2.5 and PM10 have similar change rules, corresponding policies should be formulated to reduce pollution emission, reduce the pollution emission of heavy industry in winter.

1. Introduction
With the acceleration of urbanization, economic development has been significantly improved, the energy consumption is increasing, the automobile exhaust emissions are increasing, and the air quality in cities is deteriorating day by day. Among the air pollution indicators, mainly including PM2.5 and PM10 in the air of Tianjin. PM2.5 and PM10 affect human health. Studies have shown that if the concentration of PM10 in the atmosphere increases by 10 kg /m$^3$, the daily death toll increases by 0.53%. If the concentration of PM2.5 in the atmosphere increases by 10 grams per m$^3$, the daily a multi-resolution dynamic analysis method for signal processing. The wavelet function can decay rapidly to zero. The death toll increases by 0.85%. For PM2.5 concentration time series and PM10 concentration time series, it contains two important information, the change rule and the mutation characteristic, the change rule reflects the overall trend, the mutation part represents the serious pollution.

Wavelet analysis can reflect the local variation characteristics of time series and is widely used in signal analysis, image processing, medical imaging and diagnosis, fault diagnosis of large machinery, atmospheric science and hydrology. Christian et al. [1] used Morlet wavelet to study the multi-time scale problem of meteorological parameter time series. Xavier Querol et al. [2] examined the distribution of PM2.5 and PM10 in Barcelona was tested using Daubechies wavelet. Soni et al. [3] recorded NO$_2$, SO$_2$ and suspended particles from three sites and analyzed them with Daubechies wavelet. Ye B et al. [4] studied the evolution characteristics of the time series of PM2.5 concentration in Shanghai using Morlet wavelet. Diapouli E et al. [5] analyzed the time series of PM10 and PM2.5 concentration in Greece in 2010 by using Daubechies wavelet. Z.-M. Li et al. [6] studied the changes of air pollution index in Beijing city from 2010 to 2015 based on Morlet wavelet. These studies show that wavelet analysis of atmospheric index time series is an effective and feasible method. However, most of the above studies are focused on PM10 concentration time series, and there are few studies on PM2.5 concentration time series.
This article uses Daubechies wavelet transform method, to Tianjin between April 2018 and March 2019 nearly a year of PM2.5 concentrations of time series and PM10 concentration time series were studied, analysis the change rule to reveal their change rule, in order to make a strategic decision for environmental monitoring and protection of the atmosphere of Tianjin.

2. Wavelet analysis principle

In the wavelet transform, the variable scale factor and translation factor are introduced to make the signal analysis have adjustable time-frequency window, so as to provide a multi-resolution dynamic analysis method for signal processing. The wavelet function has the characteristic of oscillation and can decay to zero rapidly. The definition is as follows:

\[
\int_{-\infty}^{\infty} \psi(t) dt = 0
\]  

(1)

\( \psi(t) \) also known as fundamental wavelets or mother wavelets. Based on the translation and scaling of the wavelet, a cluster function system is obtained

\[
\psi_{\alpha,\tau}(t) = |\alpha|^{-1/2} \psi \left( \frac{t-\tau}{\alpha} \right), \alpha > 0, \tau \in \mathbb{R}
\]  

(2)

In the type (2), \( \psi_{\alpha,\tau}(t) \) is called the child wavelet; \( \alpha \) is the scale factor, which reflects the period length of the wavelet. \( \tau \) as the time factor, reflected in the translation of time.

The function \( f(t) \in L^2(\mathbb{R}) \); its wavelet \( \psi_{\alpha,\tau}(t) \) of the continuous wavelet transform is:

\[
w_f(\alpha, \tau) = \int_{-\infty}^{\infty} f(t) \psi_{\alpha,\tau}(t) dt
\]  

(3)

In the type (3), \( w_f(\alpha, \tau) \) called wavelet coefficients.

The reconstruction formula of continuous wavelet transform is as follows:

\[
f(t) = C_\psi^{-1} \int_{0}^{\infty} \alpha^2 \left( \int_{-\infty}^{\infty} w_f(\alpha, \tau) \psi_{\alpha,\tau}(t) d\tau \right) d\alpha
\]  

(4)

In the type (4), \( C_\psi = \int_{-\infty}^{\infty} \frac{|\psi(\omega)|}{|\omega|} d\omega, \psi(\omega) \) is the base of wavelet bits of Fourier transform \( \psi(t) \).

The basic idea of wavelet transform is to decompose the signal into combinations of components at different scales. The global characteristics of the signal can be observed at a coarser scale, while the local characteristics or mutation points of the signal can be analyzed at a finer scale. The choice of wavelet cardinality determines the result [7]. The wavelet is selected according to its self-similarity, orthogonality and compact support, which are determined according to practical problems. Daubechies wavelet is a compactly-supported regular orthogonal wavelet basis with good time-frequency analysis performance, so it has been widely used in practice [8].

3. Time series analysis of PM2.5 concentration

3.1. Data sources

The air pollution data on 14th April, 2018 (solstice, 15th March, 2019) of Tianjin were selected and simply processed. In the data set, PM2.5 and PM10 concentrations are measured in hours. Due to the large amount of data, their daily average concentration values are measured in days.

3.2. Annual change

Wavelet transform is used to decompose PM2.5 concentration time series into low frequency part and high frequency part. As the number of decomposition layers increases, the high-frequency information
contained in the low-frequency part will gradually decrease, and the rest is the variation rule of PM2.5 concentration time series, that is, the low-frequency coefficient of the wavelet transform corresponding to the maximum scale [8]. Therefore, the higher-level low-frequency coefficients obtained after wavelet decomposition are reconstructed, and the obtained sequences can be used to judge the annual change rule of PM2.5 concentration time series.

In this paper, Db6 wavelet is used to decompose the PM2.5 concentration time series in four layers of multi-resolution, and then according to the sequence obtained by reconstruction of the low-frequency coefficient of the fourth layer, the change of PM2.5 concentration in a year can be judged time series. The scatter diagram of PM2.5 concentration time series on 14th April, 2018, solstice, 15th March, 2019 and the reconstructed sequence diagram of the low-frequency coefficient of the fourth layer. In the Figure, the horizontal axis is the days, and the vertical axis is the concentration. From Figure 2, it can be seen that the PM2.5 concentration is small and the change range is small from May to September. From October to March, PM2.5 concentration was relatively high, with a large change range. In late March it fell rapidly; From May to September, the change was relatively stable; From November to March, the change was quite drastic, in which there were three times of rise and fall. It starts to rise in early November, peaks in late November, then starts to decline, and drops to a trough in late December; It recovered quickly, peaked in mid-January and bottomed in mid-February. It went up, peaked in early February, and then went down.

The reason for the drastic change from November to March is that PM2.5 concentration is significantly affected by climate change. From November to March, Tianjin basically falls into the winter and spring stages [10]. On the one hand, during this period, the climate was relatively cold and dry with little rain. Under the influence of the dry and cold air mass from Siberia, a large number of particles were brought to Tianjin along with the airflow. Because Tianjin is relatively dry in winter, less rainfall leads to the pollutant in the air is not conducive to the discharge and diffusion and leads to the
accumulation of pollutants. With heating in the north, Tianjin and surrounding areas are burning more coal, increasing carbon emissions and pollution. The situation eased in April.

3.3. Mutation characteristics
The abrupt part of the PM2.5 concentration time series is often the status point of severe air pollution. Mutation is mainly characterized by local changes in time and space. For PM2.5 concentration time series, if the improper wavelet technique and decomposition layer number are selected, the wavelet change cannot produce good local analysis function.

Using db1 wavelet, the time series of PM2.5 concentration in Tianjin on 14th April, 2018, solstice, 15th March, 2019, was decomposed for 3 times. The reconstructed sequence curves of the first and second layers of high-frequency coefficients obtained are shown in Figure 3 and Figure 4. In the Figure, the number of horizontal axis, vertical axis is PM2.5 concentration.

![Recomposition of high-frequency signals in the first layer of wavelet decomposition](image1)

**Figure 3.** Recomposition of high-frequency signals in the first layer of wavelet decomposition

![Recomposition of high-frequency signals in the second layer of wavelet decomposition](image2)

**Figure 4.** Recomposition of high-frequency signals in the second layer of wavelet decomposition

From Figure 3 and Figure 4 we can find the mutation point location. From Figure 3 and Figure 4, there are three obvious mutation points, which are located on day 227, 247 and 315, respectively, corresponding to specific dates, namely November 26, 2018, December 16, 2018 and February 2, 2019. The concentration of PM2.5 on November 26, 2018 was 255, 242 on December 16, 2018, and 237 on February 2, 2019. These days are serious pollution.

4. Time series analysis of PM10 concentration

4.1. Annual change law
Similar to the analysis of PM2.5 concentration time series, db6 wavelet was used to decompose PM10 concentration time series into 4 layers of multi-resolution. Reconstruction of the fourth low frequency
sequence. Then the reconstructed sequence was used to judge the annual variation of PM10 concentration time series. On 14th April, 2018, solstice, 15th March, 2019, the scatter diagram of PM10 concentration time series and the reconstructed sequence diagram of the low-frequency coefficient of the fourth layer are shown in Figure 5 and Figure 6.

![Figure 5. Scatter plot of PM10 concentration time series](image1)

![Figure 6. Annual variation of PM10 concentration time series](image2)

As can be seen from Figure 5, PM10 concentration from June to September is small, and the change range is small. From October to May, PM10 concentration was large, and the variation range was large. In mid-to-late April, it declines rapidly, reaches the bottom in early April, and then rises to the peak in mid-May and reaches the trough in early June. From June to September, the change was relatively stable; From October to March, the change was quite drastic, which was similar to the change of PM2.5 concentration, in which there were three rises and falls. It starts to rise in early November, peaks in late November, then starts to decline, and drops to a trough in late December; It recovered quickly, peaked in mid-January and bottomed in mid-February. It went up, peaked in early February, and then went down.

4.2. Comparison of annual variation patterns of PM2.5 concentration and PM10 concentration

It can be observed from Figure 2 and Figure 5 that PM2.5 and PM10 have the same change pattern. Except in May, the change of PM2.5 concentration is relatively stable, while the change of PM10 concentration is quite drastic. This is because Tianjin belongs to the northern climate, and the dust is heavy in spring, so the PM10 concentration is high.

The ratio of PM2.5 concentration to PM10 concentration can reflect the degree of air pollution and pollutant particle composition. The monthly concentrations of PM2.5 and PM10 from April 2018 to March 2019 are shown in Table 1.
Table 1. Ratio of monthly PM2.5 concentration to PM10 concentration (%)

| Month | 4  | 5  | 6  | 7  | 8  | 9  |
|-------|----|----|----|----|----|----|
| Ratio | 42 | 51 | 58 | 73 | 57 | 55 |
| Month | 10 | 11 | 12 | 1  | 2  | 3  |
| Ratio | 62 | 81 | 58 | 72 | 75 | 76 |

The ratio of PM2.5 monthly concentration to PM10 monthly concentration in this year was greater than 50% except for April, indicating that nearly half of the PM10 monthly concentration in this year came from fine particles with diameter less than or equal to 2.5 μm. In a year, the ratio of monthly PM2.5 concentration to PM10 concentration is the smallest, at 42%, in April, and greater than or equal to 50% in all other months. On the one hand, it shows that PM2.5 concentration and PM10 concentration are closely related, which explains why the annual change of PM2.5 and PM10 concentration time series is basically similar. On the other hand, it also reflects the reason why the time series of PM2.5 and PM10 concentrations varied in May.

4.3. Mutation characteristics
Db1 wavelet is used to decompose the PM10 concentration time series into 3 layers of multi-resolution, and then the first and second layers of high frequency coefficients are reconstructed. The obtained sequences can be used to determine the mutation position of the PM10 concentration time series. The reconstructed sequence curves of the first and second layers of the PM10 concentration time series in Tianjin on 14th April, 2018 and 15th March, 2019 are shown in Figure 7 and Figure 8.

Figure 7. Recomposition of high-frequency signals in the first layer of wavelet decomposition

Figure 8. Recomposition of high-frequency signals in the second layer of wavelet decomposition
As can be seen from FIGURE. 7 and FIGURE. 8, there are five mutations and three of them are obvious (the specific locations can be determined by zooming in on the detailed Figure), which are respectively on day 221, 277 and 308, corresponding to the specific dates of November 20, 2018, January 15, 2019 and February 15, 2019. On November 20, 2018, PM10 concentration was 360 μg /m$^3$, on January 15, 2019, it was 375 μg /m$^3$, and on February 15, 2019, it was 308 μg /m$^3$. These days are serious pollution.

5. Conclusion
Based on the Matlab wavelet analysis toolbox, this paper analyzed the time series of PM2.5 and PM10 concentrations of 14th April, 2018, solstice, 15th March, 2019, and analyzed their annual change rules and mutation characteristics, and made a simple comparison of the annual change rules of PM2.5 concentration and PM10 concentration time series. In terms of annual variation, the time series of PM2.5 concentration and PM10 concentration are basically similar. From June to September, the concentration of the two was small and the variation range was small. From October to April, the concentration was larger and the variation range was larger. In May, the change patterns of the two are slightly different, with the PM2.5 concentration changing slightly and relatively stable, while the PM10 concentration changing greatly and dramatically. They have similar mutation points in terms of mutation, and the date is basically the same.

In this paper, it can be concluded that Tianjin is a highly polluted city in winter. In view of this phenomenon, corresponding policies should be formulated to reduce pollution emission, reduce the pollution emission of heavy industry in winter, and close down the high-polluting enterprises, so as to reduce the PM2.5 and PM10 values and improve the air quality of the city.

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