Spatial and Seasonal Distribution Study and Correlation Analysis of Aerosol and PM2.5 in Beijing City Based on MODIS Data

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Abstract. The inversion of aerosol optical depth (AOD) of Beijing in each four seasons of 2014 year was carried out in this paper. The results show that, in seasonal distribution, the AOD of Beijing city was lower in winter and spring, stable in summer and autumn. In spatial distribution, the AOD is large in the centre area and the southwest area of Beijing city and small in the suburbs of Beijing city, because there's less air pollution. Further exploration of correlation between AOD and PM2.5, R^2, the squared value of the correlation coefficient of them (R) is 0.03 in spring, 0.74 in summer, 0.45 in fall, 0.44 in winter. It can be seen that the correlation of PM2.5 and AOD was higher in summer, lower in spring, and the correlation in fall was similar with it in winter.

1 Introduction

Atmospheric aerosols are defined as suspended particles in the atmosphere in liquid or solid phase. Their dynamic diameter is about 0.001 um - 100 um. The particulates with dynamic diameter less than 10um (PM_{10}) and the particulates with dynamic diameter less than 2.5um (PM2.5, able to go directly to the alveoli) have great harm to human health. The increasing of aerosol particles in recent years is supposed to be one of the important reasons of the haze weather of the city and suburbs.

Beijing, as the capital of China, its air quality is obviously affected by human factors, such as urban traffic pollution, municipal construction, industrial gas emissions from surrounding areas and destruction of natural ecological environment. The air is seriously polluted. In order to reduce the influence of pollution sources, the monitoring of urban atmospheric environment quality is particularly important. Aerosol particles has widely been paid attention and studied because of its important role in atmospheric monitoring [1].

Optical Depth is one of the most important parameters of aerosol. As an important physical quantity of atmospheric turbidity, it is a key factor to determine the climate effect of aerosol. At present, there are two methods to obtain the aerosol optical depth (AOD). One is foundation exploration, and the other is satellite remote sensing [2]. Foundation exploration can more accurately measure the information of aerosol, but it requires to deploy a large number of ground stations. Besides, this method gets just the data on the spatial point. It is unable to correctly reflect the space-time distribution over large area. On the contrary, the satellite remote sensing method has the characteristics of fast, non-contact, wide coverage. Relative to the foundation exploration method, the satellite remote sensing method can more efficiently get the information of atmospheric aerosol [3].

At present, the aerosol optical depth (AOD) is mainly inversion by the high resolution satellite remote sensing data of the moderate resolution imaging spectroradiometer (MODIS) sensor of Terra/Aqua satellite. MODIS image has 36 channels of data from visible light, near infrared and far infrared band, and has the ability of monitoring of the clouds and aerosols in the aspect of atmospheric monitoring [4-6]. Its channel 1 (0.620 ~ 0.670 μ m, the red channel) and channel 3 (0.459 ~ 0.479 μ m, the blue channel) are mainly used for remote sensing observation of aerosol, because their narrow bandwidth is good for the correction of the influence of atmospheric gas absorption uncertainty on the remote sensing of aerosol. The forest is distinguished as dark target by NDVI or the reflectivity of near infared channel (2.1 μ m) , making the advantage of the characteristics of low reflectivity of most of the land surface. Then the surface reflectivity of the research area in red channel and blue channel can be calculated by relevant formula. The dense dark vegetation (DDV) method to determine the surface reflectivity has become the most widely used algorithm in the applications of aresols remote sensing [7-9].

Since the U.S. government announced the distribution map of PM2.5, the concertration of PM2.5 in Beijing and other cities is especially paid attention to. At present, the PM2.5 monitoring method of the cities, including Beijing, is foundation exploration method, depending on those detection equipments set at fixed sites. As in AOD, the method can not correctly reflect the space-time distribution of PM2.5. Therefore, it is necessary to study on the correlation between PM2.5 and aerosols.

The inversion of AOD from four season in Beijing was carried out based on the MODIS data of 2014 year in the article. Beijing's spatial distribution and seasonal characteristics of aerosol were given through comparative analysis. The correlation between AOD and PM2.5 was analyzed with 2014 full-year measeured data from monitoring sites in Beijing in the article. The correlation coeffients of AOD and PM2.5 in different seasons were given. These results laid the foundation for the subsequent research about the PM2.5 monitoring with remote sensing.

2 Study area

Beijing, the capital of the People's Republic of China, The center is located in north latitude 39°54'20", longitude 116°25'29", and the geographical scope is in

115.7°~117.4° east longitude, latitude 39.4 °~41.6 °, with a total area of 16410.54 square kilometers.

There is odd arteries of the Taihang Mountains in the west and JunDou Mountain of the Yanshan Mountains in the north. The both mountains intersect in nankouguan ditch, forming a curved, southeast of semicircle mountain known as "Beijing corner", it is around a small plain is the Beijing plain. The average elevation of Beijing is 43.5 meters. The elevation is about 20 ~ 60 meters in plain region, and generally 1000 ~ 1500 meters in mountainous region. The geography graph of Beijing city is shown in Figure1.

Figure 1. The geography graph of Beijing city

3 The inversion of aerosol optical depth (AOD)

3.1 The basic principle

The remote sensing analys is about the Characteristics of aerosols is based on the theory of the relationship between the radiant intensity of the atmosphere and the surface reflectance properties. Assume that the surface observed by the satellite is uniform lambert surface, without considering gas absorption the top-of-atmosphere (TOA) reflectance observed by satellite can be expressed as:

$$\rho^*(\mu, \emptyset, \mu_0, \emptyset_0) = \rho_a(\mu, \emptyset, \mu_0, \emptyset_0) + \frac{T(\mu_0)T(\mu)\rho}{1-\rho s} \quad (1)$$

where: $\rho^*$is surface reflectance from satellite observations，ρ_a is atmospheric reflectivity for the whole, $\mu_0, \mu, \emptyset_0, \emptyset$ are solar zenith angle,satellite zenith angle (observation), solar azimuth,and satellite azimuth, $T(\mu_0), T(\mu)$ are the total atmospheric transmittances, containing both direct and diffuse transmissions for sun illumination and satellite viewing geometry, s is spherical surface albedo of atmosphere, ρ is the surface reflectance.

In fact, ρ^* is also a function of aerosol optical thickness. For uniform lambert surface, changing evenly in the vertical direction of atmosphere, TOA can be expressed as[9]:

$$\rho^* = \frac{\pi L（\tau_o，\mu_v，\emptyset_v；\mu_s，\emptyset_s）}{\mu_s E_s} \quad (2)$$

Where: L is sensor measurement radiance, E_s is solar radiant flux of the sensor receivers, τ_o is atmospheric optical depth of the whole layer, (μ_s， $\emptyset_s$) is the direction of the incident light of the sun, (μ_v， $\emptyset_v$) is sensor concept, μ_v， $\emptyset_v$； μ_s， $\emptyset_s$ are the observation direction and the direction of the incident solar zenith angle and azimuth angle cosine.

Combining (1) and (2), if the surface reflectance is known, and according to the characteristics of different regions, the types of atmospheric aerosols are determined, the aerosol optical depth can be obtained by the formula; On the other hand, if the aerosol optical depth and the corresponding atmospheric parameters are known, the surface reflectance can be retrieved by the formula.

3.2 The inversion model

At present, the most commonly used aerosol inversion method is DDV algrithm. DDV is mainly based on vegetation index or near infrared band reflectance performance to distinguish，so this method is suitable for the dense vegetation area, and Holben is used to distinguish DDV from the mid infrared band (3.8 μm).And Kaufman et al. Considering the diversity of the surface coverage, the relationship between the three different regions of the band and the relationship between the surface, these three bands are blue band (0.47 μm), red band (0.66 μm) and mid infrared band (2.1 μm). According to the experimental results of Kaufman[10], the relationship between the surface reflectance of the red blue channel and the surface reflectance of 2.1 μm can be expressed as:

$$\rho_R = \rho^*_{2.1}/2 \qquad (3)$$

$$\rho_B = \rho^*_{2.1}/4 \qquad (4)$$

Where: ρ_B is the surface reflectance under blue channel (0.47 mm), ρ_R is the surface reflectance under red channel (0.0.66 μm).

In 2007, Levy et al. To improve the relationship between the DDV and the influence of the vegetation index and the scattering angle on the surface reflectance, the new ratio relation is given.

$$\rho_R = \rho_{2.1} \times (\varepsilon + 0.002\delta - 0.27) + 0.00025\delta + 0.033 \quad (5)$$

$$\rho_B = \rho_R \times 0.49 + 0.005 \quad (6)$$

Where ε is can be obtained by MODIS's 1.24 μm and 2.1 μm channel, δ is scattering angle, can be expressed as the solar zenith angle, satellite zenith angle and relative azimuth angle function, the method can be expressed as:

$$\delta = \arccos(-\cos\mu_0 \cos\mu + \sin\mu_0 \sin\mu \cos\emptyset) \quad (7)$$

3.3 Data and method for inversion

Remote sensing data: MODIS L1B 1KM data in January 30, 15th April, 16th July and 20th October of 2014 year.

Method: Referring to the method of Fan Jiao, Guo Baofeng, He Hongchang, et al [12]. Firstly determining the type of aerosol, then establishing the LUT, and then use the IDL programming in ENVI5.0 to inversion according to the following process:

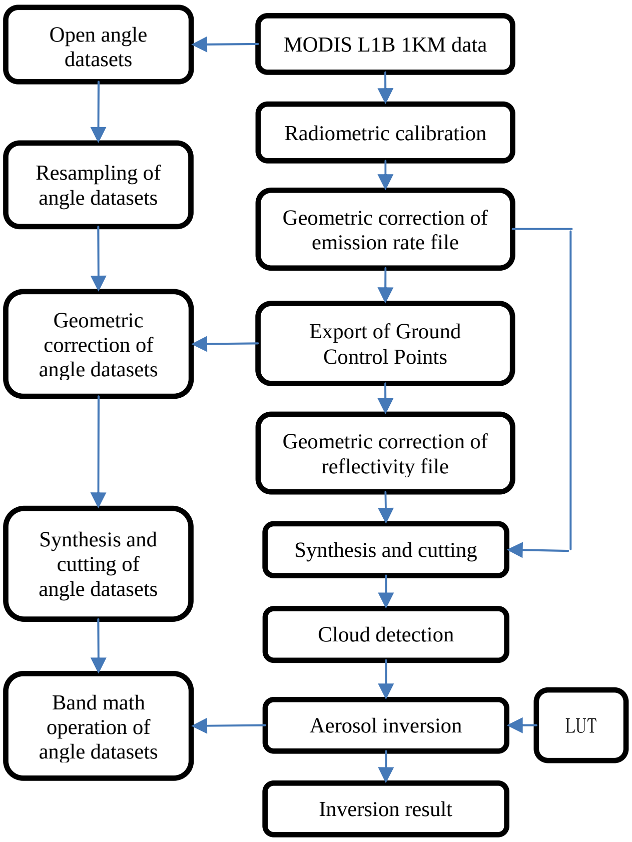

Figure 2. Schematic diagram for aerosol retrieval in the study.

3.4 The results of inversion

The results of aerosol inversion of four seasons in Beijing are shown in Figure 3.

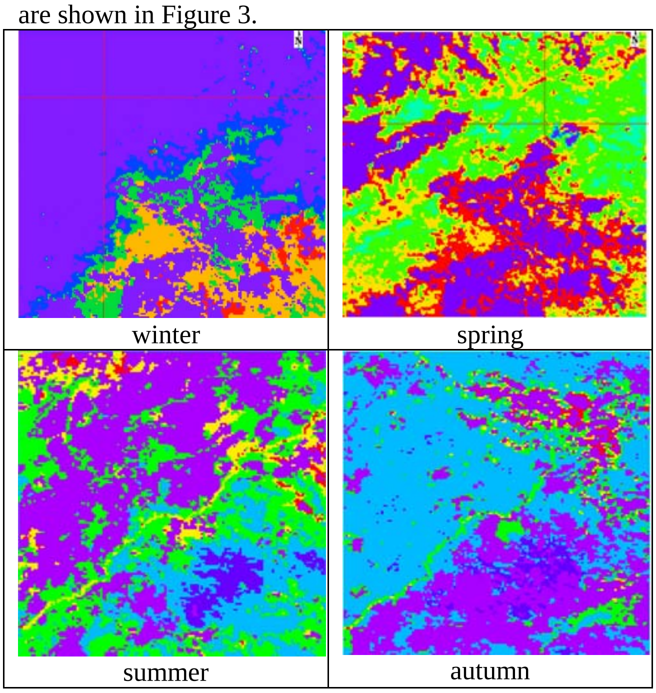

Figure 3. The aerosol distribution map of four seasons of 2014 year in Beijing

The results of aerosol retrieval in four seasons in Beijing city can be seen that from the time-series analysis, the pollution of air in winter and spring is more serious than that in summer and autumn, and the concentration of aerosol is relatively large and the air quality is poor.

From the spatial analysis, the central area of Beijing and the southwest region are densely populated, the traffic developed area, and the aerosol optical depth (AOD) is larger, while the other suburban area is relatively small.

4 The analysis of pm2.5 data of Beijing

4.1 The source of PM2.5 of Beijing

According to relevant research, the regional transport contribution of PM2.5 in Beijing city in recent years accounted for about 28-36%, the contribution of local pollution emissions accounted for 64-72%. In the local pollution, motor vehicles, coal, industrial production, dust as the main source, respectively, 31.1%, 22.4%, 18.1% and 14.3%, catering, car repair, livestock breeding, construction and other emissions of about PM2.5 14.1%, as shown in Figure 4and Figure 5.

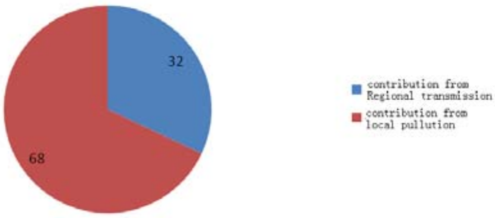

Figure 4. The source contribution chart of PM2.5 of Beijing

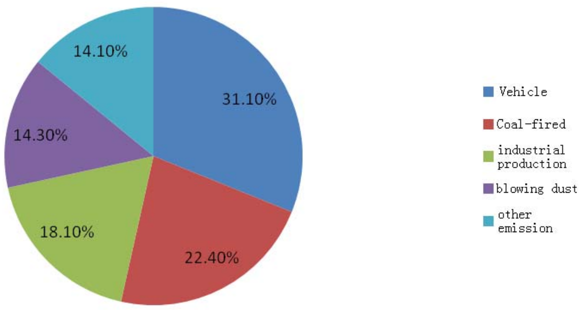

Figure 5. The source classification chart of PM2.5 of Beijing

4.2 Data processing of PM2.5 from environmental monitoring sites in Beijing

4.2.1 Data source

Beijing PM2.5 data from the Beijing City Environmental Protection Testing Center website, data for the full 2014 year, the data include PM2.5, PM10, and AQI data. Beijing city existing 35 ambient air test site (site distribution, see Figure 6), part of the site is every 1 hours to detect a data.

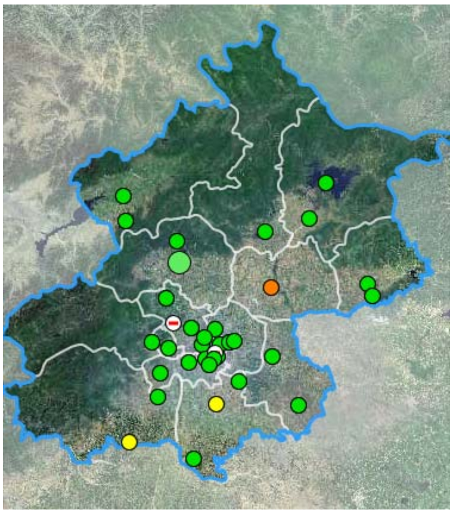

Figure 6. The location map of environment air monitoring sites in Beijing

4.2.2 Data Processing

According to January, November, December for the winter, February, March, April for the spring, May, June, July for the summer, August September, October for the fall, the data will be divided into four seasons in 2014 12 months. The average PM2.5 concentration of each month was calculated by the daily data, and then the average concentration of PM2.5 in each season was calculated according to the seasonal average. The final calculation of the various sites of the PM2.5 average concentration of the four seasons is shown in Table 1.

Table 1 Average concentrations of PM2.5 in each season Unit: microgram per cubic meter

season / site	Sping	Summer	autumn	winter
Dongsi	210.1845	49.4389	42.7181	83.5653
Temple of Heaven	190.3472	50.3798	41.6431	88.8271
Guanyuan	189.7659	50.5986	34.0833	82.9667
Wan Nishinomiya	210.8651	49.7111	43.1347	102.7346
Olympic Sports Center	198.2044	56.2153	44.9931	91.0208
Agricultural Exhibition Hall	208.3472	52.0528	48.1275	111.4797
Wanliu	207.6746	52.9764	39.5708	94.4944
Northern New Area	201.8948	49.7250	30.6181	113.1659
Botanical Garden	182.4147	46.8986	25.5874	76.7840
Fengtai garden	234.6806	51.8269	47.1125	121.8931
Yungang	188.4524	52.6097	35.2903	110.3014
Gucheng	150.9583	56.5125	39.7958	91.9861
Fangshan	200.3016	57.0653	43.0014	136.2085
Daxing	217.2321	59.4083	59.3208	142.6750
Yizhuang	204.6488	65.0020	58.9847	145.2458
Tongzhou	224.8155	72.0443	59.8319	170.7847
Shunyi	200.4067	53.3750	40.3833	85.6958
Changping	177.8294	38.1528	25.9653	89.8146
Men Tougou	191.9484	45.7958	24.8889	76.6461
Pinggu	191.5303	42.3694	38.8292	82.5042
Huairou	179.3175	35.8897	25.3606	55.7753
Miyun	182.8849	32.2722	31.5911	64.4417
Yanqing	180.8492	36.9444	25.8569	80.5694
Dingling	201.3472	33.5042	21.8069	67.5989
Ba Daling	149.5218	43.5722	23.8417	40.8486
Miyun Reservoir	152.1329	28.6417	42.4876	32.7285
Dong Gaocun	165.2679	47.8528	42.9306	86.1798
Yong Ledian	220.3472	75.3240	53.7583	198.7722
Yufa	197.4588	62.5889	52.0653	161.2983
Liuli river	212.0833	63.1458	54.4806	206.5340
Qianmen	209.1071	73.0051	55.6444	107.6569
Yongding door	200.6667	55.6222	59.8597	108.4572
Xizhimen North	190.5635	54.8972	68.5167	94.1025
Nan Sanhuan	222.0972	59.7597	56.8028	115.7528
Dong Sihuan	201.2063	57.8236	69.8470	118.8264

4.2.3 Data analysis

According to the data from table 1, we can draw a histogram to display intuitive changes every season PM2.5, as Figure 7 and Figure 8 shows.

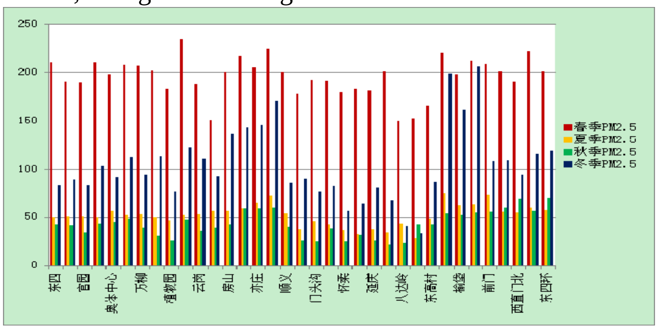

Figure 7 Average concentrations of PM2.5 on each site in each season

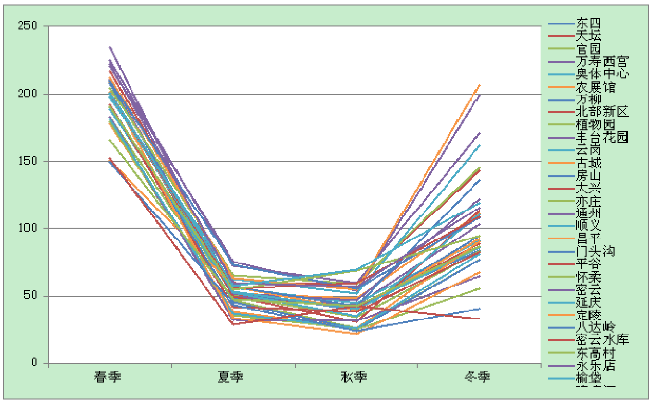

Figure 8 Seasonal PM2.5 concentrations change on each site

By the two pictures above, we can see that Beijing overall PM2.5 feature in the time series show obvious seasonal characteristics, namely in the winter and spring of PM2.5 higher, in the summer and autumn of PM2.5 relatively low. Showing a growth and decline trend.

5 The AOD and the relativity analysis of pm2.5 of Beijing

5.1 AOD and PM2.5 data preprocessing

Based on chapter 3 as a result, the performance of aerosol due to the data of aerosol optical thickness value is limited, we will be the thickness of the aerosol value according to seasonal is divided into the corresponding data and the matching correlation analysis. Similarly, PM2.5 measurement sites is not completely in the work state, some sites for various reasons in one day to work of data collection, so we in the data on the control of the also can't get a complete site control data table, draw a part of the site after data validity screening of PM2.5 and AOD data reference table are shown in table 2.

Table 2. The comparison table of PM2.5 and AOD data in each season.

season / site	Spring		Summer		autumn		winter	
Data type	PM2.5	AOD	PM2.5	AOD	PM2.5	AOD	PM2.5	AOD
Dongsi	210.1845	0.6716	49.4389	1.3232	42.7181	1.5193	83.5653	0.9498
Temple of Heaven	190.3472	0.0246	50.3798	1.1558	41.6431	1.6711	88.8271	0.1339
Olympic Sports Center	198.2044	0.0777	56.2153	1.4172	44.9931	1.1144	91.0208	0.7230
Agricultural Exhibition Hall	208.3472	0.0427	52.0528	1.4880	48.1275	1.5557	111.4797	0.1952
Botanical Garden	182.4147	0.1658	46.8986	1.7753	25.5874	1.9568	76.7840	1.0567
Fengtai garden	234.6806	0.0236	51.8269	1.4898	47.1125	1.7372	121.8931	0.4287
Fangshan	200.3016	0.4745	57.0653	1.3966	43.0014	1.4689	136.2085	0.9881
Daxing	217.2321	0.1461	59.4083	1.5490	59.3208	1.5645	142.6750	0.8730
Shunyi	200.4067	0.1846	53.3750	1.4271	40.3833	1.6935	85.6958	0.0647
Changping	177.8294	0.2474	38.1528	1.7332	25.9653	1.9601	89.8146	0.1376
Huairou	179.3175	0.2209	35.8897	1.7735	25.3606	1.9684	55.7753	1.4196
Miyun	182.8849	0.1574	32.2722	1.8832	31.5911	1.8500	64.4417	1.2653
Ba Daling	149.5218	0.1169	43.5722	1.6367	23.8417	1.9879	40.8486	1.6200
Miyun Reservoir	152.1329	0.0470	28.6417	1.9024	42.4876	1.6560	32.7285	1.8297
Yufa	197.4588	0.0980	62.5889	1.2829	52.0653	1.4856	161.2983	0.1586
Liuli river	212.0833	0.0378	63.1458	1.2888	54.4806	1.4260	206.5340	0.0365
Qianmen	209.1071	0.0743	73.0051	1.1292	55.6444	1.4288	107.6569	0.4962
Nan Sanhuan	222.0972	0.1460	59.7597	1.3486	56.8028	1.4127	115.7528	0.5215
Dong Sihuan	201.2063	0.1352	57.8236	1.3831	69.8470	1.6912	118.8264	0.2448

5.2 AOD and PM2.5 correlation analysis

Section. Based on the screening effectiveness of PM2.5 in Beijing site with AOD data table (table 2), respectively, the four seasons of AOD and PM2.5 data correlation analysis, get the square of the four seasons correlation coefficient R of the two values, the results are shown in figure 9, 10, 11, 12.

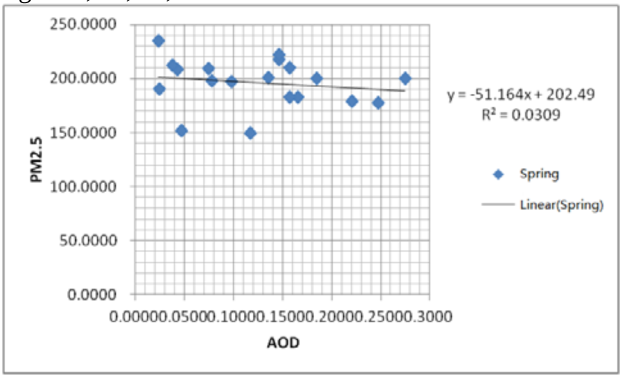

Figure 9 The correlation analysis figure of PM2.5 and AOD of Beijing in Spring

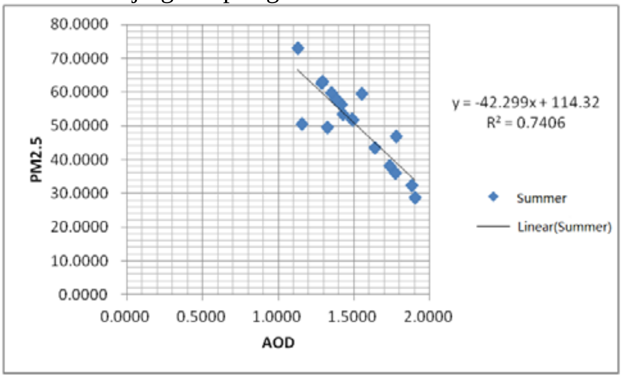

Figure 10 The correlation analysis figure of PM2.5 and AOD of Beijing in summer

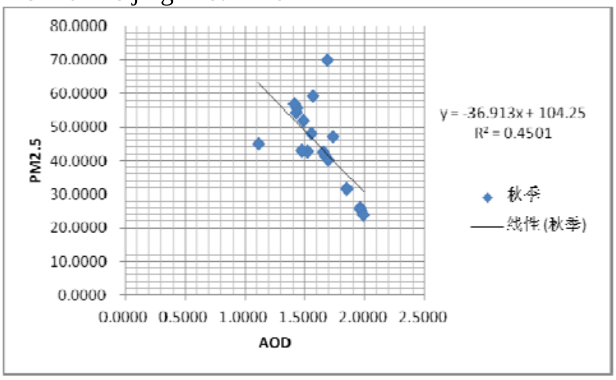

Figure 11. The correlation analysis figure of PM2.5 and AOD of Beijing in autumn

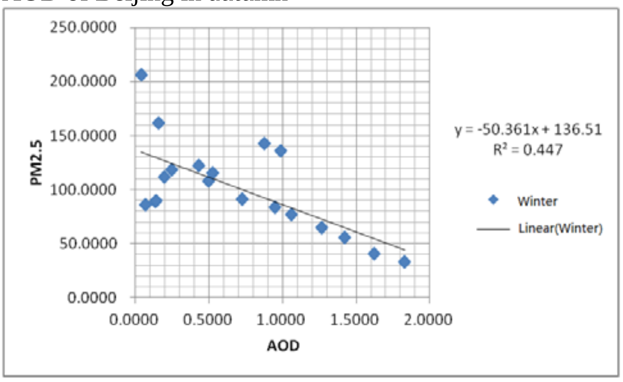

Figure 12. The correlation analysis figure of PM2.5 and AOD of Beijing in winter

Can be seen by the above figure, most images present a negative correlation is the case, it shows that a large area in PM2.5 concentrations of AOD value relatively small, the theoretical basis of the above mentioned AOD is consistent, namely in the area of PM2.5 is larger, the air pollution is larger, the transparency of air is relatively low, AOD data is small, light is not entirely through go to, and in PM2.5 smaller area, the air pollution is low, so the corresponding AOD is larger, the stronger the light through the air capacity.

6 Conclusion and prospect

In this paper, the aerosol optical depth of the four seasons in Beijing area is retrieved by MODIS data, and the spatial distribution and seasonal variation of the aerosol optical depth (AOD) in Beijing are analyzed, the spatial distribution and seasonal variation of PM2.5 in Beijing city were analyzed by the data of PM2.5 monitoring station in Beijing, and the correlation analysis between AOD and PM2.5 was carried out. The following conclusions are drawn from this study:

(1) Through the aerosol inversion results, it can be concluded that there are some differences in the space, in the suburbs of Beijing, the air is better, and the AOD is smaller. While in urban areas, the air transparency is poor, and the corresponding AOD is relatively large. In the timing, the Beijing winter and spring in the AOD than in the summer and autumn, it is the air transparency is poor.

(2) Through the analysis of the PM2.5 data, the change characteristics of PM2.5 in the time series of Beijing city were highest in the spring, after a continuous decline in the summer and fall to the bottom of the trough, to the beginning of the winter to rise to the peak.

(3) By the correlation analysis between AOD and PM2.5, the AOD and PM2.5 data are consistent with the spatial distribution, and the high value areas are located in the downtown area of Beijing and southwest of the region, other regions are relatively low value.

(4) Correlation analysis results also show that PM2.5 and AOD are negative correlation, PM2.5 concentration is larger, and the corresponding AOD data is small, and vice versa. The square value of PM2.5 and AOD correlation coefficient R was 0.03 in spring, 0.74 in summer, 0.45 in autumn and 0.44 in winter. The correlation between the two in the summer, the worst in the spring, autumn and winter, the basic agreement. While the correlation between the two is also obvious seasonal variation trend, the spring of R^2 to a significant increase in the summer, while the autumn and winter were significantly reduced, the basic stability of the two seasons. Analysis of its causes, mainly in the spring windy weather, air transport in the city of rapid change in the city, the time of the day AOD is relatively poor, resulting in urban and suburban PM2.5 and AOD relative to other seasons is poor.

Through this study, it is found that the MODIS data retrieval aerosol optical depth can be set up by the PM2.5 observation and prediction system, but some problems need to be further improved:

(1) DDV algorithm, also called dense vegetation, with better operability, the inversion effect is relatively good, but in the time range of September to March, so the air quality of Beijing city in winter and spring, the method of inversion results is poor; In the area, there are some limitations in the area of the area of vegetation cover, the inversion effect is also poor.

(2) The correlation analysis results between PM2.5 and AOD show that the linear relationship between the two is different in different seasons, that is to say that the linear coefficients of the corresponding linear coefficients will fluctuate within a certain range, then the R^2 will tend to a stable range. This study has not carried out the research.

Acknowledgements

The research work was supported by Fundamental Research Support Project “**Research on Carbon Sinks near the Coast in Tianjin Port (TKS140214)**” and Fundamental Research Support Project “**The Research of VOCs Emissions of Crude Oil Inventory and Reuse Technology in Loading and Unloading Process in Water Transport Engineering (TKS140218)**”.

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