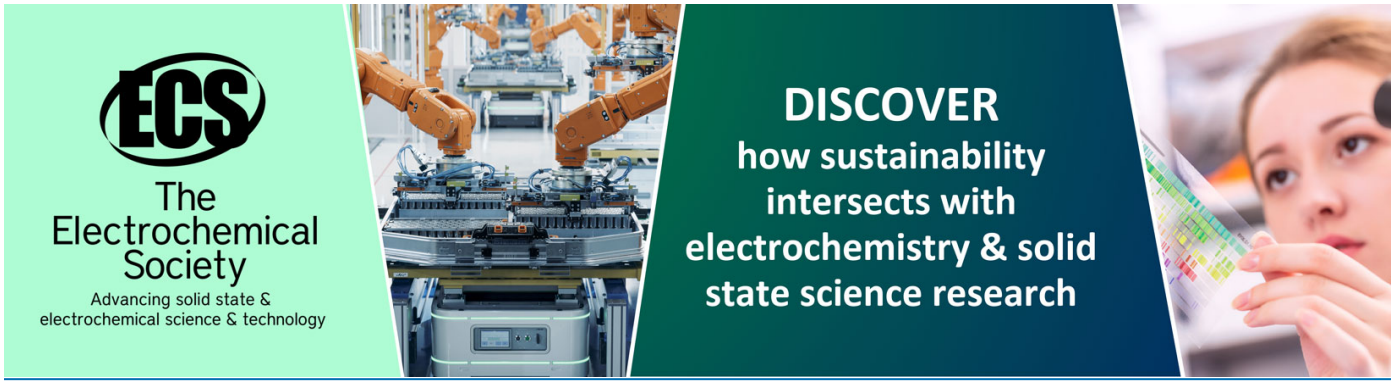
The spatial-temporal evolution of aerosol optical depth and the analysis of influence factors in Bohai Rim



The spatial-temporal evolution of aerosol optical depth and the analysis of influence factors in Bohai Rim

Chunliang Hou[1, 2], Hong Jiang[1, 3*], Xiaoyan Wang[2], Huan Pei[2]

[1]International Institute for Earth System Science, Nanjing University, Nanjing, China
[2]College of Information Science and Engineering, Yanshan University, Qinhuangdao, Hebei Province, China
[3]Laboratory of Carbon Cyling in Forest Ecosystems and Carbon Sequestration, Zhejiang Agriculture and Forestry University, Hangzhou, China

E-mail: houchunliang78@126.com

Abstract. Aerosol Optical Depth (AOD) is an important parameter of aerosol optical properties and it is an important physical parameter quantity to understanding the atmospheric environment. Bohai Rim is one of the three major urban agglomeration regions with rapidly developing economy in China. The study of AOD over this region is important to understand the environment and climate in Bohai Rim. Firstly, aerosol product data from 2000 to 2010, published by NASA, were used to analyze the temporal-spatial evolution of AOD in Bohai Rim with precision evaluation. The results showed that the spatial distribution of AOD had an obvious regional characteristic. The spatial distribution characterized that a much high value existed at urban areas and plain areas. On the contrary, the low value data existed in some mountainous regions which had higher percentages of forest coverage. The AOD values fluctuated somewhat each year in the region, from the minimum annual mean in 2003 to the maximum in 2009. Generally, the highest AOD value was in summer, followed by spring, autumn and winter. In terms of monthly variation, the value of AOD reached its peak in June and the lowest value was in December. This study analyzed the relation between AOD and some influence factors such as land use types, elevation, and distribution of urban agglomeration and so on. These results provide an important basic dataset for climate and environmental research.

1. Introduction

Atmospheric aerosols are a system consists of atmosphere and the solid and liquid particles suspended in air [1]. The diameter of aerosols ranges from 0.001 to 100 micrometers. Aerosols have been shown to play an important role in local, regional, and global climate change [2]. The research results showed that atmospheric aerosols also have a significant impact on geophysical and geochemical processes, significantly affect the lithosphere and biosphere [3]. As atmospheric aerosols affect the climate and environment in a significant manner, it is important to study the effects of aerosols on the climatic effect and the environment change and their influence on the changes they undergo; this issue is currently a hot topic in the atmospheric sciences and related fields. AOD is an important parameter for evaluating the atmospheric environment and evaluating the influence of atmospheric aerosols on

* Corresponding author: jianghong_china@hotmail.com

radiative effects. AOD, which is the main factor that describes the light attenuation effect of aerosols, is defined as the integrated extinction coefficient in the vertical direction [4]. AOD is the most used and accurate data in obtaining information on aerosols. It is also used for calculating the aerosol composition, evaluating the extent of atmosphere pollution, and collecting data on aerosol-induced climatic effects. This paper focuses on the spatial-temporal evolution of AOD and the analysis of influence factors in Bohai Rim.

AOD data can be obtained using remote sensing in two ways: ground remote sensing and satellite remote sensing. Ground remote sensing has higher precision, but only for obtaining data for small region. It is typically only used for proving AOD obtained by satellite remote sensing. Satellite remote sensing has relatively low precision, but it can rapidly obtain AOD for a wide area and even the whole global. In this paper, Moderate Resolution Imaging Spectrometer (MODIS) data collected by satellite remote sensing are used for obtaining AOD for Bohai Rim region, and it is used to analyze the spatial-temporal evolution of AOD and its influence factors.

2. Materials

2.1 Study Area

Bohai Rim is the coastal region rounding the whole Bohai and part of Huanghai, China. It is located in the northern region of the west coast of the Pacific Ocean. The regional longitude and latitude range is $34^0$22'N – $43^0$26'N, $113^0$04'E – $125^0$46'E. Including the Liaoning, Hebei, Shandong Provinces, and Tianjin and Beijing cities, Bohai Rim has a 515,000 square kilometres land area and a population of 244 million, in 2010. It is one of the three major urban agglomeration regions with a rapidly developing economy, following the Yangtze River Delta and the Pearl River Delta. In recent years, the impact of human activities on the surface environment has become increasingly apparent, and emissions of aerosols into the environment have increased rapidly. Therefore, analyzing the space-time variation of AOD of Bohai Rim and the factors of aerosols will contribute to increasing the reliability of environment and climate change. Studying AOD may also supply scientific input for reasonable countermeasures to environment and climate change.

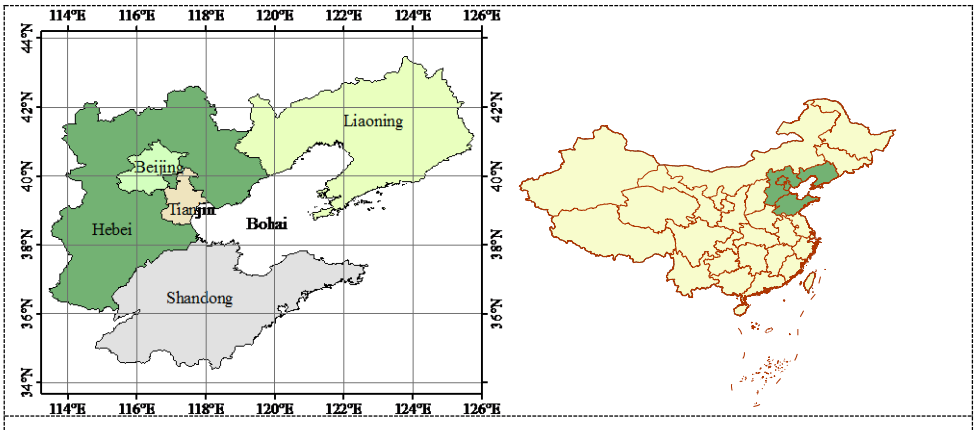


Figure 1. The geographical regions and the location of Bohai Rim in the study. In the figure to the right, the green parts indicate the Bohai Rim in China.

2.2 Data

In order to realize long-term observations and research of the atmosphere and environmental change, NASA launched the Terra and Aqua satellites with MODIS sensors, in 1999 and 2002. A MODIS sensor has 36 bands and provides an abundance of data that could be used in characterizing the land and sea atmospheres. Using AOD, measured through sun photometer of AERONET, we validated the MODIS aerosol products issued by NASA. The result of correlation coefficients is up to 0.8, and this

proves that MODIS aerosol products have certain precision [5]. Several scholars, Li Chengcai [6] and Zhou Chun Yan [7] validated MODIS aerosol products for different underlying surfaces and different regions. On this basis, the distribution and changing characteristics of aerosols in some parts of China using MODIS have already been analyzed. MODIS aerosol products have met the requirements for studying the distribution, changing characteristics, and the factors that affect AOD in Bohai Rim.

In this paper, the terra-MODIS aerosol products L2 data was obtained from the LADSWEB NASA data center. The web site can be accessed at: http://ladsweb.nascom.nasa.gov/data/search.html. The MODIS aerosol products have been carried out radiometric and geometric correction. The spatial resolution is 10 kilometers by 10 kilometers, and the duration of the study was from February 2000 to June 2010.

3. Methods

3.1 Obtaining AOD and processing the data

For the MODIS aerosol data, the spectral information of product data was extracted, projected, the region was trimmed, the data format transformed and the grid calculated using Matlab and ArcGIS. The result of AOD in the 550 nm wavelength, from February 2000 to June 2010, was determined.

3.2 Analysis of the spatial-temporal variation of AOD and its relationship with its influences

Based on this work, we analyzed the spatial distribution of annual AOD, seasonal AOD, and monthly AOD. For Bohai Rim, data were obtained by the averaging of an entire day's aerosols that were evaluated as MODIS aerosol products. In order to analyze seasonal changes, we divided the entire year into four parts according to the weather patterns as, spring from March to May, summer from June to August, autumn from September to November and winter from December to the following February. The space and time distribution and change of year, season and month in this region from February 2000 to June 2010 were studied. Based on these data, we were able to analyze the relationship between AOD and Land-Use and Land-Cover Change (LUCC), elevation, and the distribution of urban agglomeration.

4. Results and Discussion

4.1. Spatial-temporal variation analysis

4.1.1 Mean annual AOD distribution characteristics and variation trend. Figure 2 shows the yearly mean AOD distributions map of areas around Bohai Rim from 2000 to 2010. It is clear from the distributions map that the mean AOD value increased from 2000 to 2003. The variation of mean AOD values for areas around Bohai Rim were 0.32, 0.40, 0.45, 0.55, 0.40, 0.42, 0.50, 0.52, 0.49, 0.41, and 0.50, from February 2000 to June 2010, determined by using ArcGIS statistical results. Analyses of annual variation, presents a fluctuating trend, increasing at first, the decreasing, then increasing, and then decreased.

Viewed from space, this area appeared obvious local characteristics from 2000 to 2010 and 40°N was its apparent south-north boundary. The areas to the north of 40°N had lower AOD values with a mean value of 0.3, except for the middle flat-bottomed lands of Liaoning Province. Areas to the south of 40°N all had relatively higher AOD, except to the west of the Hebei Tai-hang Mountains, the middle hilly areas of Shandong and the coastal regions of Shandong Peninsula.

4.1.2 Seasonal mean AOD distribution characteristics and variation trend. Figure 3 shows the mean AOD distribution for areas around Bohai Rim during spring, summer, autumn, and winter from 2000 to 2010. Analyzed per each season, the AOD spatial distribution of this area shows an apparent regional variation. The AOD reached a maximum in summer with a mean value of 0.67, followed by spring with a value of 0.45, autumn with a value of 0.41, and winter with a value of 0.26. The AOD

values indicate an increasing trend from spring to summer and a decreasing trend towards a minimum in winter.

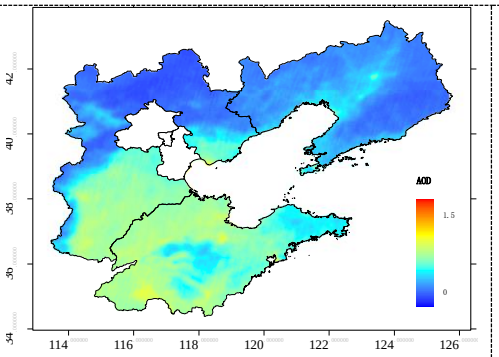


Figure 2. Annual mean AOD for MODIS aerosol products, level 2 data at 550 nm wavelength in Bohai Rim from February 2000 to June 2010.

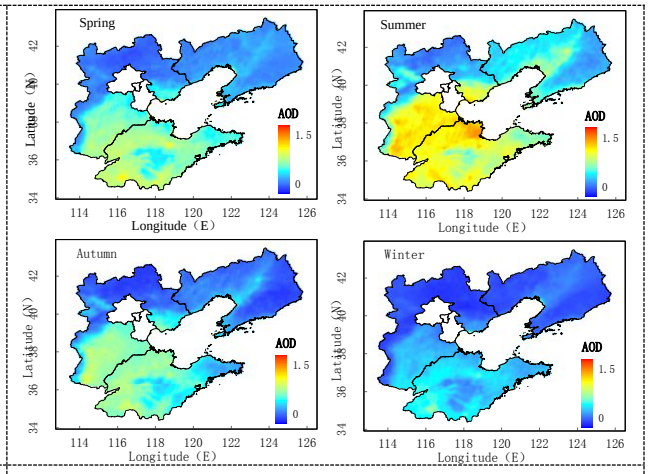


Figure 3. Seasonal mean AOD for MODIS aerosol products, level 2 data at 550 nm wavelength in Bohai Rim from February 2000 to June 2010.

4.1.3 Monthly mean AOD distribution characteristics and variation trend. The monthly variation of AOD in Bohai Rim over a period of 11 years, from 2000 to 2010, is presented in Fig. 4. From this, it can be seen that areas around Bohai Rim also presented with evident monthly variation. The AOD spatial distribution of this area also shows specific variation from month to month.

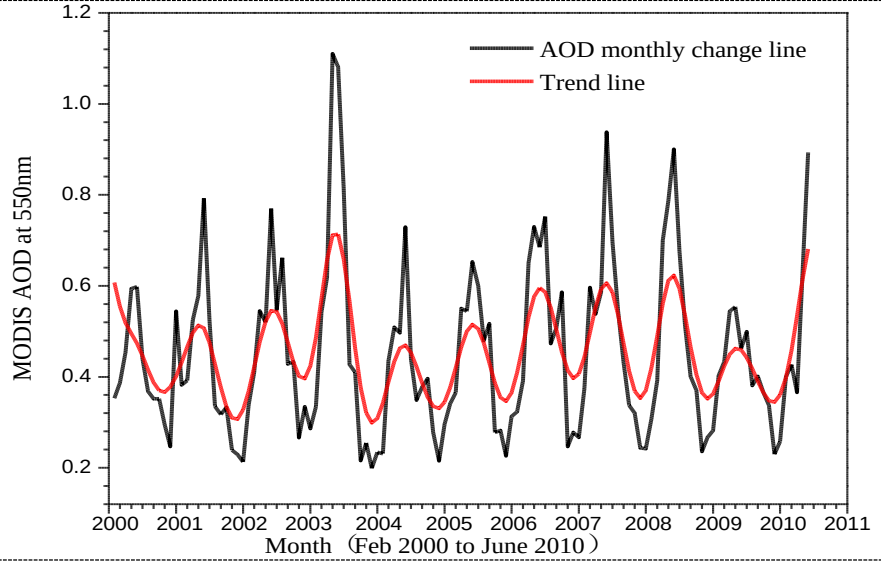


Figure 4. Time series of monthly mean AOD at 550 nm over Bohai Rim, from February 2000 to June 2010.

Fig. 4 shows the monthly mean AOD variation at 550 nm obtained from Terra-MODIS, level 2 for areas around Bohai Rim. From Fig. 3, we can see that monthly mean AOD variation increasing gradually from January with an annual peak in June, and decreasing from June to a minimum in December. January and December were the months with the lowest AOD values, averaging at 0.22

and 0.25. AOD values increase rapidly from February, with an AOD of 0.41 to a maximum in June. The maximum regional AOD was typically 1.2, occurring in cities with large area and other small towns with denser populations. The AOD were approximate 0.6 in the grasslands, farmlands and rural places. AOD decreased by degrees from July. The original maximum value regions of vast areas in May and June gradually broke as sporadically distributed small regions which were big cities-centered. Compared with June, the area of maximum value region greatly reduced and AOD decreased step by step. By November, there were only certain maximum value regions relative to the north areas of the Bohai Rim existing in low latitude area of the whole areas around the Bohai Rim.

4.2. Important influencing factors analysis

4.2.1 The effects of land types on AOD. The LUCC data used in this paper was interpreted from a remote sensing image obtained in 2005 by the medium resolution imaging spectrometer (MERIS).In this paper, we classified land-use types for areas around the Bohai Rim into twenty types: Post-flooding or irrigated croplands, rain fed croplands, mosaic croplands, mosaic vegetation, broadleaved evergreens, broadleaved deciduous forest, broadleaved deciduous forest/woodlands, needleleaved evergreen forest, needleleaved deciduous or evergreen forest, mixed broadleaved and needleleaved forest, forest or shrubland, closed to open (>15%) shrubland, herbaceous vegetation, sparse vegetation, fresh or brackish water, saline or brackish water, brackish or saline water, urban, bare areas, water bodies, permanent snow and ice, and regions with no data.

Compared with Fig. 2 and Fig. 5, reveals that the AOD shows a close relationship with land type. Forest land and grassland were the low value regions of AOD, and constitute the regions less affected by human activity. Farmlands, urban land, and sections of water bodies were the higher value regions of AOD. These areas have relatively dense populations, and also frequent human and industrial activities, showing that in areas around the Bohai Rim, the distribution of AOD is clearly affected by population density, urban and industrial activities, and other factors, and it also had close relationship with human activities.

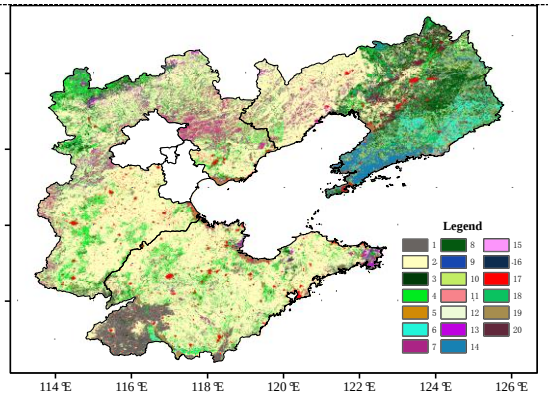


Figure 5. The land type map over Bohai Rim. In this map and legend, there are twenty land types. A detailed legend explanation refers to the corresponding parts of the text.

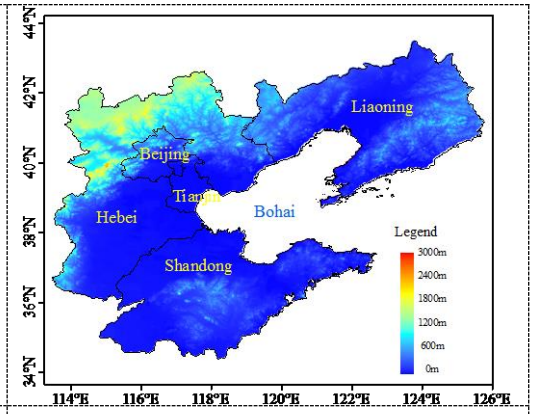


Figure 6. Digital Elevation Model (DEM) map over Bohai Rim.

4.2.2 The effect of terrain on AOD. Fig. 6 shows a DEM map of areas around the Bohai Rim. Compared with Fig. 2 and Fig. 5, it can be clearly seen that landforms have a significant effect on aerosol distribution. The DEM map shows a negative correlation between landform type and AOD. The inverse relationship between terrain and the AOD is also shown by the fact that the AOD of flat areas is higher. Lower value regions of AOD are mainly spread over the eastern and western mountainlands and hilly areas of Liaoning Province, the Tai-hang, and Yanshan Mountains of Hebei Province, the mid-southern mountainlands and hilly areas of the Shandong Province, the northeastern

mountainlands of Beijing, and low mountains and hilly areas at the southern foot of Yanshan Mountain in the north of Tianjin. These low AOD areas occur where the terrain elevation is higher, forest coverage is high, grassland distribution is wide, and the population density is low. These areas have fewer industrial activities, pollutant discharges, and higher wind power, benefitting from a low concentration of pollutants. Maximum value AOD regions are the central flatland of the Liaoning Province, the central plains, and southeast part of the Hebei Province, the western and northern Yellow River alluvial plain of the Shandong Province, and the flatlands located in Beijing and Tianjin with the exception of the downtown of each city, especially in summer when AOD decreases to 1.2. The high AOD areas have high population density, frequent human activity, and developed industry and agriculture, increased production of pollutants, low terrain elevations, and poor air circulation (inhibiting pollutant dispersal).

5. Conclusions

This paper analyzed the temporal AOD variation and spatial distribution of areas around the Bohai Rim, and the factors which influence this variation. Analyzed per year, the AOD of the Bohai Rim has increased from 2000 to 2006, remained almost unchanged for two years, and then gradually increased up until 2010. Viewed per season, AOD variation exhibited an increasing trend from spring to a maximum in summer, after which the AOD began to decrease until it reached a minimum in winter. The month-to-month variation of AOD showed the areas around the Bohai Rim to reach a maximum in July, with a minimum in December. The monthly AOD trend increases gradually from January to July and decreases from July to December. Analyzed by terrain type and elevation, the large plains, especially in urban areas with dense populations, were those with the highest AOD. The low value terrains are mainly distributed around hilly and mountainous areas with higher elevation. Lastly, AOD of these areas show a close relationship with the population density, urban, industrial, and agricultural activities, and local humidity and climate conditions.

Acknowledgement

Funding support partially from NSF of China (41101315 & 41171324), and The State Key Fundamental Science Funds of China (2011CB302705, 2010CB950702 and 2010CB428503), The Funds for Ph.D. Education (20110091110028), The Project Funded by Qinhuangdao science and technology support program(201001A058) and science and technology support program of Hebei(12277637).

References

[1] Ramachandran S 2007 Aerosol optical depth and fine mode fraction variations deduced from Moderate Resolution Imaging Spectroradiometer (MODIS) over four urban areas in India *J Geophys Res* **112** 16207

[2] Haywood J, Boucher O 2000 Estimates of the direct and indirect radiative forcing due to tropospheric aerosols: A review *Reviews of Geophysics* **38** 523-531

[3] Chu D A, Kaufman Y J, Zibordi G 2003 Global monitoring of air pollution over land from the Earth Observing System-Terra Moderate Resolution Imaging Spectroradiometer(MODIS) *J Geophys Res* **108** 4661

[4] Remer L A, Kaufman Y J, Tanre D 2005 The MODIS aerosol algorithm, products, and validation J *Atmospheric Science* **62** 947- 973

[5] Li C C, Mao J T, Liu Q H, Liu X Y, Liu G Q, Zhu A H Resarch on the air pollution with MODIS in Beijing and Its surroundings AOD products *China Journal of Atmospheric Sciences* **27** 872

[6] Wang L L, Xin J Y, Wang Y S, Li Z Q, Wang P C, Liu G R and Wen T X Validation of MODIS aerosol products by CSHNET over China *Chinese Science Bulletin* **52** 1711-1718

[7] Zhou C Y, Liu Q H, Tang Y, Wang K, Sun L and He Y X 2009 Comparison between MODIS aerosol product C004 and C005 and evaluation of their applicability in the north of China *Journal of Remote Sensing* **13** 866-870