Analysing PM2.5 concentrations using MODIS and monitoring measurements for Shanghai area

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Abstract. Analyzing PM2.5 concentrations from remote sensing images and surface measurements using the model of aerosol optical depth (AOD) is a popular method to evaluate the exposure to PM2.5 in some geographic regions. For analyzing the ground-level PM2.5 density on a daily basis using satellite-derived AOD in Shanghai area, we use Aqua MODIS (Moderate Resolution Imaging Spectroradiometer) to obtain the AOD values at 3-km resolution by dark pixel. However, AOD values are missing in many regions caused by processing method and imaging process. Interpolating the AOD values to extend the coverage area of MODIS and integrating the surface measurements, we filter the AOD values and PM2.5 measurements. The analysis results indicate that the correlation coefficient is 0.54 in Shanghai area. Satellite derived mean PM2.5 for Shanghai was 42.69 ug/m³ during the study period (Jan 2016 to Dec. 2018), whereas mean PM2.5 is highest in winter period (61.68 ug/m³), and lowest in autumn period (31.4 ug/m³) over study period in study area.

1. Introduction

PM2.5 refers to atmospheric particulate matter (PM) with an aerodynamic diameter ≤2.5μm, which is identified as a risk factor to threaten human health, the fourth prevailing peril factor for death in China [1]. Currently, PM2.5 pollution is a serious environmental problem in China, and has attracted researcher’s attention, such as geographers, environmental scientists, epidemiologists. Many studies research the associations between PM2.5 pollution and related diseases, including human respiratory system, cardiovascular disease and infectious disease [2-4]. The hazy weather is due to fine particles. When annual mean concentration of PM2.5 reached 35 ug/m³, the long-term mortality risk is 15% higher than an annual mean PM2.5 concentration of 10 ug/m³ [5]. As the PM2.5 concentration increases, the incidence of respiratory diseases and cardiovascular diseases also increase synchronously. Therefore, many scientists paid their attention to research PM2.5 concentration spatio-temporal variations using various geographically weighted regression (GWR) models to calculate daily PM2.5 density. For example, through satellite-derived aerosol optical depth (AOD) we can get many ground-level PM2.5 estimations or predictions by spatial statistical models, or machine learning methods for different geographical areas [6-9].

In this paper, the missing AOD values are interpolated by DWI (Inverse Distance Weighted) method based on the preprocessing MODIS images. The rest content of the article is organized as follows. Section 2 presents study area and experimental data. Section 3 presents the method obtained.
from MODIS images and analyzes the relationship between the AOD and PM$_{2.5}$ in study area. Section 4 concludes the results and discuss that.

2. Study area and experimental data

2.1. Study area

The study area (Figure 1) includes 16 regions, of which seven areas are situated in the Shanghai center, and nine suburban areas are located around downtown Shanghai with an overall population of 24.2 million [10]. Ten monitoring sites are located in study area. Most of them distributed in Baoshan District, Pudong District and urban area.

2.2. Experimental data

Accessing The Level-1 and Atmosphere Archive & Distribution System (LAADS) Distributed Active Archive Center (DAAC) (https://ladsweb.modaps.eosdis.nasa.gov), we can get 3-km resolution MODIS (Moderate Resolution Imaging Spectroradiometer) images.

Daily PM$_{2.5}$ density (ug/m$^3$) were measured at 10 monitoring stations in study area (Figure 2) from the China National Environmental Monitoring Centre (http://webinterface.cnemc.cn/) during January 1, 2016 and December 31, 2018.

Figure 1. Distribution of 10 PM$_{2.5}$ monitoring stations in Shanghai

Figure 2. Mean PM2.5 density at each site averaged during the study period
3. Methods and analysis

3.1. MODIS AOD

The daily AOD values can be calculated from MODIS images by dark pixel method. However, some AOD values are missing in many regions caused by processing method and imaging process. In our method, the AOD values were interpolated to extend the coverage area of MODIS (Figure 3).

![Distribution of the averaged AOD values of 3 km resolution MODIS during the study period, the black line showing the boundaries of 16 districts, Shanghai.](image)

Figure 3. Distribution of the averaged AOD values of 3 km resolution MODIS during the study period, the black line showing the boundaries of 16 districts, Shanghai.

Average AOD shows that urban districts such as Zhabei and Yangpu have lower values, some suburban districts such as Qingpu, Jiading and Nanhui have higher values.

3.2. PM2.5 observations

For eliminating the wrong observations caused by instruments, the PM$_{2.5}$ concentrations are filtered out according to the following rules in this research:

- The PM2.5 concentration remains the same in more than 12 consecutive hours.
- Hour concentration values deviate from more than 3 times standard deviation of the mean value of day 24-hour concentration.

Figure 4 represents the illustrative statistical monitored PM$_{2.5}$ density at the 10 sites and site-related MODIS AOD during the study.
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Figure 4. During the study (Jan. 1st 2016 to Dec. 31st 2018), PM2.5 observations were made from 10 ground sites and site-positioned AODs of 3 km MODIS products.

3.3. AOD-PM2.5 Relationship

The AOD values and PM2.5 concentrations in 2017 are selected to validate the correlation. The AOD-PM2.5 correlation, obtained by simple the model of linear regression: $y=23.1x+25.2$ ($y$ denotes PM$_{2.5}$ concentration value; $x$ denotes related AOD value). With the model, the $R^2$ values is 0.47 (Figure 5). Daily series of the site-average PM$_{2.5}$ density and MODIS AOD (Figure 6) indicates an overall good correlation ($r = 0.54$).

![Figure 5. The model of the linear regression of AOD-PM2.5 relationship](image)

| Averaging Period | $N$ | Mean | SD | min | max | median |
|------------------|-----|------|----|-----|-----|--------|
| All              | 10901 | 37.78 | 26.44 | 0.5 | 218.04 | 32.54 |
| Winter period    | 2538  | 52.37 | 34.03 | 2.25 | 218.04 | 42.68 |
| Spring period    | 2668  | 44.58 | 22.34 | 0.5 | 160.75 | 40.18 |
| Summer period    | 2658  | 29.98 | 18.4 | 1.12 | 116.21 | 25.67 |
| Autumn period    | 2568  | 29.73 | 21.29 | 2.22 | 132.33 | 23.2 |

| Averaging Period | $N$ | Mean | SD | min | max | median |
|------------------|-----|------|----|-----|-----|--------|
| All              | 6496 | 0.81 | 0.42 | 0.21 | 3.96 | 505.8 |
| Winter period    | 1370 | 0.78 | 0.37 | 0.21 | 2.81 | 0.71 |
| Spring period    | 1664 | 0.94 | 0.43 | 0.32 | 3.96 | 0.84 |
| Summer period    | 2889 | 0.82 | 0.44 | 0.22 | 3.64 | 0.72 |
| Autumn period    | 2377 | 0.76 | 0.42 | 0.25 | 1.95 | 0.67 |

| PM$_{2.5}$ (AOD) during Periods when Both Data are Available | $N$ | Mean | SD | min | max | median |
|-------------------------------------------------------------|-----|------|----|-----|-----|--------|
| All              | 6231 | 42.69(0.78) | 27.64(0.41) | 1.12(0.23) | 218.04(3.96) | 36.37(0.71) |
| Winter period    | 1311 | 61.68(0.76) | 35.64(0.37) | 5.91(0.13) | 218.04(3.96) | 53.15(0.85) |
| Spring period    | 1553 | 47.43(0.93) | 22.56(0.43) | 8.26(0.15) | 160.75(2.81) | 43.58(0.71) |
| Summer period    | 1973 | 35.49(0.81) | 29.54(0.46) | 1.12(0.18) | 109.58(3.96) | 26.02(0.61) |
| Autumn period    | 1394 | 31.40(0.64) | 22.76(0.29) | 2.21(0.10) | 132.33(1.93) | 28.56(0.70) |

* $N$ denotes the number of valid observations. 
* SD Represents the standard deviation of the data.
* Numbers in parentheses are for the MODIS AOD.

Figure 5. The model of the linear regression of AOD-PM2.5 relationship.
Figure 6. Daily series of the average PM2.5 density of the 10 monitoring stations, average site-collocated AOD. (correlation coefficient r between the different parts of the four seasons in 2017)

4. Conclusion Results and discussion

Figure 4 shows that the average PM$_{2.5}$ density from surface monitoring stations is 37.78 ug/m³ in the study period. Standard deviation (SD) is 26.44 ug/m³. The mean AOD value is 0.81 and SD value is 0.42. The highest site-average daily average PM$_{2.5}$ value is 218.04 ug/m³. The maximum of AOD values in each season are higher than 2.0. In study period, the data are further divided into four sub-periods (four seasons): spring, summer, autumn and winter. In these four seasons, the average AOD value is not much distinct, but the PM2.5 density in autumn is much lower than that in winter.

In 2017, we can see an overall correlation ($r=0.54$) from the site-mean PM$_{2.5}$ density and the MODIS AOD (Figure 3). In spring and summer (warm season), the correlation coefficient ($r=0.68$) is higher than cold season (autumn and winter) ($r=0.48$). Besides the impact of rainy characteristics in cold seasons as well as other complex meteorological conditions in Shanghai, AOD retrievals missed much more than spring and summer. Moreover, it indicates that the lower mean and SD in the cold season.

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