

COMPARISON OF THREE TYPES OF AEROSOL PRODUCTS DURING 2015-2017 IN CHINA

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ABSTRACT:

In this study, we use sunphotometer (AERONET) data as reference to evaluate MODIS, Himawari-08, and MERRA-2 aerosol products over China. AERONET data from Beijing, Xianghe, Xuzhou, Taihu and Hong Kong are used. The results indicate that aerosol optical depths (AODs) obtained from MODIS, Himawari-08, and MERRA-2 from 2015-2017 over China are consistent with the AERONET observations. The accuracy of these AOD products shows a spatial and temporal variation. MODIS aerosol products tend to overestimate the AODs at Beijing, Xianghe and Xuzhou, with stronger overestimation in winter. For Taihu and Hong Kong, MODIS only overestimates the AODs in winter. Himawari-08 and MERRA-2 underestimate the AODs in autumn over almost all stations except Taihu.

1. INTRODUCTION

Atmospheric aerosols participate directly or indirectly in radiative forcing processes and cloud-forming processes, and have an extremely important impact on global climate change. By directly scattering or absorbing sunlight, aerosols can alter surface albedo and influence radiative budget. Therefore, increasing attentions have been paid to accurately determine the aerosol radiative effects in recent years [1-5]. In the study of atmospheric aerosols, people often have to obtain aerosol data all over the world. But, due to the limitation of the number of ground-based observation sites, it is not conducive to derive global aerosol properties for researches worldwide. Satellite remote sensing measurements can fill in these huge data voids and achieve global coverage easily. However, influenced by surface characteristics and weather conditions easily, the accuracy of satellite inversion data is lower than that of ground-based observations. So it is necessary that the accuracy of the aerosol products should be verified before they can be put into use [6].

With the development of measurement techniques and radiative transfer calculations, various of satellite aerosol data products are available. Nowadays MODIS, Himawari-08 and MERRA-2 aerosol products are widely used as they provide aerosol optical properties with high spatial and temporal resolution on a global scale. Since the 1990s, the inversion algorithm of MODIS aerosol products has been developed for more than 20 years and the accuracy of data is constantly improving [7-8]. Munchak et al. developed a new algorithm (MxD04 3K) for the inversion of aerosol optical properties from MODIS observations [9]. Wang et al. conducted an accuracy test of MODIS data over China [10]. Zhang et al. validated the MODIS C6 AOD product based on a station in the Beijing–Tianjin–Hebei areas [11].

Different from MODIS aerosol products, Himawari-08 aerosol products have the advantages of higher spatial and temporal resolutions and more detection channels including the band 3 (0.64 μm), band 4 (0.86 μm), and band 6 (2.3 μm) [12-13]. As the Japanese geostationary meteorological satellite Himawari-08 is located at 140.7°E, which was launched in October 2014, its

aerosol products provide important information of aerosol distribution over East Asia. Lots of efforts have been done to improve the algorithm of Himawari-08 aerosol products. Fukuda et al. proposed an improved Kaufman algorithm for the inversion of aerosol optical properties from Himawari-08 observations [14]. Zhang et al. proposed an improved algorithm for monitoring and forecasting air quality from Himawari-8/AHI over East Asia [15]. However, there is less work on the accuracy of Himawari-08 aerosol products.

The Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2) from the NASA Global Modeling and Assimilation Office is the new modern satellite era [16]. To our knowledge, MERRA-2 assimilates numerous data sets, like the assimilation of bias-corrected AOD from the Advanced Very High Resolution Radiometer (AVHRR) instruments and analyzed aerosol fields that are radiatively coupled to the atmosphere [17]. Because of using a larger number of new observations than MERRA, MERRA-2 has made a huge improvement in many aspects. Like MODIS and Himawari-08 aerosol products, the accuracy of its distribution characteristics also has to be evaluated. In addition, the validation of MERRA-2 aerosol product is also necessary.

In previous studies, validation is mainly focused on MODIS aerosol products [7-11], and the result shows that the accuracy of MODIS aerosol products is constantly improving. However, there are not much work about the evaluation of Himawari-08 and MERRA-2 aerosol products. Based on this starting point, this paper evaluates the accuracy and applicability of three satellite aerosol products, MODIS, Himawari-08 and MERRA-2, choosing Beijing, Xianghe, Xuzhou, Taihu and Hong Kong as representative stations, and analyzes regional and seasonal differences.

2. DATA AND METHODS

2.1 MODIS, Himawari-08, MERRA-2 and AERONET AODs

The MODIS data set used in our analysis is Terra and Aqua MODIS AOD products (MOD04_L2) at 550nm, covering the

time period from January 2015 to December 2017 with the spatial resolution of 10km×10km^[1]. The Himawari-08 data set used in our analysis covers the time period from July 2015 to December 2017 with the spatial resolution of 5km×5km^[2]. The MERRA-2 data set used in our analysis covers the time period from January 2015 to December 2017 with the spatial resolution of 0.5° latitude×0.625° longitude^[3].

The sunphotometer (AERONET) data is used as the benchmark result. In our study, the AERONET stations in Beijing, Xianghe, Xuzhou, Taihu and Hong Kong are chosen as representative stations (see Table 1). The effects of the complicated underlying surface condition are considered in the analysis of the aerosol characteristics^[10].

Table 1. Observation time and level of AERONET AODs in the representative stations

Area	Station	longitude and latitude	Level	Time Period
North China	Beijing	(116.381 E, 39.977 N)	2.0	2015.01-2017.05
	Xianhe	(116.962 E, 39.754 N)	2.0	2015.01-2017.05
East China	Xuzhou	(117.142 E, 34.217 N)	1.5	2015.01-2017.12
	Taihu	(120.215 E, 31.421 N)	2.0	2015.10-2016.08
South China	Hong Kong	(114.180 E, 22.303 N)	2.0	2015.01-2017.03

2.2 Methodology

Due to the lack of AERONET AOD data at 550nm, we use an interpolation method to interpolate AERONET AOD at 440nm and 675nm to obtain the AOD data at 550nm^[18]. The interpolation method is

$$AOT_{\lambda_3} = AOT_{\lambda_1} \left(\frac{\lambda_1}{\lambda_3} \right)^{\alpha_{\lambda_1-\lambda_2}} \quad (1)$$

$$\alpha_{\lambda_1-\lambda_2} = - \frac{\ln \left(\frac{AOT_{\lambda_1}}{AOT_{\lambda_2}} \right)}{\ln \left(\frac{\lambda_1}{\lambda_2} \right)} \quad (2)$$

Where $\lambda_1, \lambda_2, \lambda_3$ respectively indicate different wavelengths, and $AOT_{\lambda_i} (i=1,2,3)$ are AERONET AODs at 440nm 675nm and 550nm, respectively.

For the purposes of comparison, AODs products of MODIS, Himawari-08, MERRA-2 and AERONET AODs in these five stations must be corresponded in space and time. The space-time matching scheme is that MODIS, Himawari-08 and MERRA-2 AODs are averaged over a circular field with a radius of 50 km, and AERONET AOD is averaged within half an hour before and after the satellite overpass.

3. RESULTS AND DISCUSSIONS

Figure 1 shows the scatter plots of MODIS AODs versus AERONET AODs in Beijing during different seasons. From Fig.1, it is obvious that MODIS AODs show good correlation with AERONET AODs in Beijing. The squared correlation coefficients for the linear regression fits R^2 are 0.261, 0.849, 0.291 and 0.61 in the four seasons, respectively. The root mean square errors between MODIS and AERONET AODs are very close to zero (0.153 for spring, 0.038 for summer, 0.093 for

autumn and 0.046 for winter). Moreover, the slopes of regression line are slightly higher than unity in summer and winter (0.437 for spring, 1.143 for summer, 0.574 for autumn and 1.167 for winter), indicating that MODIS AODs in Beijing tend to overestimate the AODs in summer and winter.

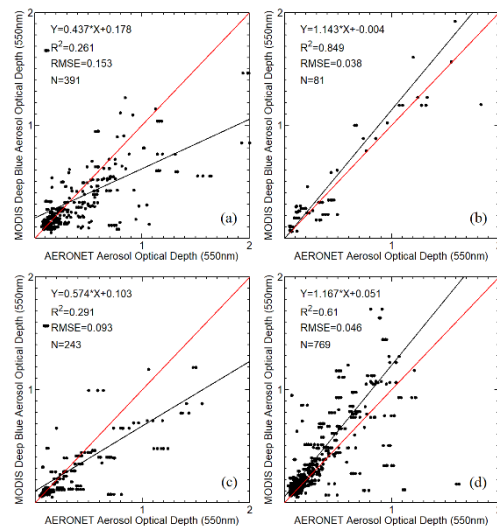


Figure 1. Scatter plots of MODIS AODs versus AERONET AODs in Beijing

(a) spring (b) summer (c) autumn (d) winter.

The black and red lines represent the slopes of linear regression and the 1:1 lines of scatter plots.

Figure 2 shows the scatter plots of Himawari-08 versus AERONET AODs in Beijing during the four seasons. From Fig.2, It is obvious that Himawari-08 AODs show good correlation with AERONET AODs in Beijing. The R^2 are 0.463, 0.766, 0.625 and 0.398 in the four seasons, respectively. The root mean square errors between Himawari-08 and AERONET AODs are very close to zero (0.077 for spring, 0.069 for summer, 0.082 for autumn and 0.075 for winter). Besides, the slopes of regression line are lower than unity (0.565 for spring, 0.497 for summer, 0.334 for autumn and 0.388 for winter). To put it differently, Himawari-08 AODs in Beijing tend to underestimate the AODs in every season.

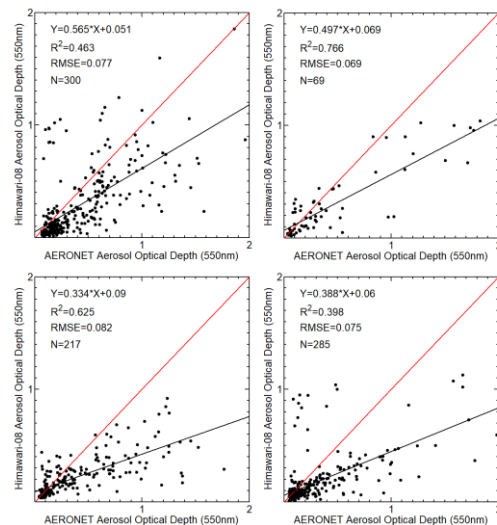


Figure 2. Scatter plots of Himawari-08 AODs versus AERONET AODs in Beijing

(a) spring (b) summer (c) autumn (d) winter.

The black and red lines represent the slopes of linear regression
and the 1:1 lines of scatter plots.

Table 2. The squared correlation coefficients (R^2), the root mean square errors (RMSE) and the slopes (K) of regression lines of MODIS, Himawari-08, MERRA-2 comparing with AERONET AODs

Area	Station	Season	MODIS			Himawari-08			MERRA-2		
			R^2	RMSE	K	R^2	RMSE	K	R^2	RMSE	K
North China	Beijing	spring	0.261	0.153	0.437	0.463	0.077	0.565	0.418	0.099	0.399
		summer	0.849	0.038	1.143	0.766	0.069	0.497	0.746	0.128	0.573
		autumn	0.291	0.093	0.574	0.625	0.082	0.344	0.349	0.198	0.324
		winter	0.610	0.046	1.167	0.398	0.075	0.388	0.526	0.059	0.465
	Xianhe	spring	0.541	0.103	0.620	0.599	0.088	0.595	0.458	0.159	0.400
		summer	0.788	0.086	1.173	0.772	0.103	0.566	0.571	0.235	0.610
		autumn	0.526	0.122	1.047	0.763	0.045	0.546	0.452	0.169	0.490
	Xuzhou	spring	0.411	0.058	0.760	0.413	0.072	0.548	0.219	0.153	0.280
		summer	0.925	0.037	1.028	0.553	0.118	0.602	0.408	0.192	0.411
		autumn	0.156	0.081	0.684	0.571	0.060	0.525	0.609	0.062	0.843
winter		0.819	0.019	1.332	0.566	0.044	0.601	0.225	0.077	0.377	
East China	Taihu	spring	0.452	0.032	0.428	0.408	0.050	0.804	0.308	0.057	0.667
		summer	0.059	0.025	0.208	0.412	0.049	0.720	0.370	0.052	0.527
	autumn	0.337	0.017	0.701	0.658	0.016	1.010	0.655	0.016	1.343	
	winter	0.872	0.009	1.081	0.154	0.050	0.403	0.481	0.030	0.663	
South China	Hong Kong	spring	/	/	/	/	/	/	0.364	0.054	0.772
		summer	/	/	/	0.542	0.031	0.630	0.567	0.037	0.592
		autumn	/	/	/	0.446	0.020	0.740	0.430	0.020	0.705
		winter	0.465	0.024	2.196	0.715	0.007	0.810	0.465	0.031	0.614

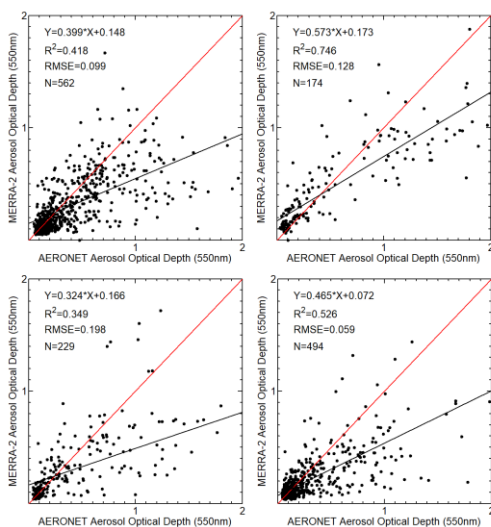


Figure 3. Scatter plots of MERRA-2 AODs versus AERONET AODs in Beijing

(a) spring (b) autumn (c) autumn (d) winter.

The black and red lines represent the slopes of linear regression and the 1:1 lines of scatter plots.

Figure 3 shows the scatter plots of MERRA-2 AODs versus AERONET AODs in Beijing in different seasons. Like Himawari-08 aerosol products, MERRA-2 AODs also show good correlation with AERONET AODs in Beijing. The R^2 are 0.418, 0.746, 0.349 and 0.526 in the four seasons, respectively. The root mean square errors between Himawari-08 and AERONET AODs are very close to zero (0.099 for spring, 0.128 for summer, 0.198 for autumn and 0.059 for winter). Besides, the slopes of regression line are lower than unity (0.399 for spring, 0.573 for summer, 0.324 for autumn and 0.465 for winter). Like Himawari-08 AOD, MERRA-2 AODs in Beijing tends to underestimate the AODs in all seasons.

From Fig.1-3, it can be inferred that three kinds of aerosol products (MODIS, Himawari-08, MERRA-2) show good correlations with AERONET AODs in Beijing. Furthermore, MODIS aerosol products in Beijing tend to overestimate the AODs in summer and winter and underestimate AODs in spring and autumn, while the Himawari-08 and MERRA-2 aerosol products always underestimated the AODs in all seasons.

Table 2 shows the squared correlation coefficients, the root mean square errors and the regressed slopes of MODIS, Himawari-08 and MERRA-2 comparing with AERONET AODs. It can be concluded from Table 2 that MODIS,

Himawari-08 and MERRA-2 products have good correlations with AERONET AODs in the other representative stations (i.e. Xianghe, Xuzhou, Taihu and Hong Kong), like Beijing station. For instance, the R^2 of Himawari-08 comparing with AERONET AODs in Xianghe are 0.599, 0.772, 0.763 and 0.429 in the four seasons, which are proved by significant testing. The root mean square errors between Himawari-08 and AERONET AODs in Xianghe are very close to zero (0.088 for spring, 0.103 for summer, 0.045 for autumn and 0.074 for winter). Besides, based on the squared correlation coefficients and the root mean square errors of MODIS, Himawari-08 and MERRA-2 comparing with AERONET AODs, it is easily seen that MODIS, Himawari-08 and MERRA-2 AODs have the best applicability for the summer in North China. In addition, Himawari-08 and MERRA-2 AODs have the best applicability for the autumn in East China. The R^2 of Himawari-08 comparing with AERONET AODs in Xuzhou are 0.413, 0.553, 0.571, 0.566 and in Taihu, are 0.408, 0.412, 0.658 and 0.154 in the four seasons. The R^2 of Himawari-08 comparing with AERONET AODs for the autumn in East China are higher than other three seasons. According to the regressed slopes, we can easily know situations when the AODs are overestimated by the three types of aerosol products. When the regressed slope is higher than unity, the aerosol products tend to overestimate the AODs. It can be clearly seen from Table 2 that AODs are overvalued by MODIS at Beijing, Xianghe and Xuzhou during summer and winter, with the strongest overestimation occurring in winter. As for Taihu and Hong Kong, overestimation only appears in winter for MODIS AOD products. Meanwhile, except for Taihu station in autumn, the Himawari-08 and MERRA-2 aerosol products always underestimate the AODs.

4. SUMMARY

This paper compares the AODs of the three types of aerosol products with AERONET AODs at Beijing, Xianghe, Xuzhou, Taihu and Hong Kong respectively. The results indicate that the aerosol optical depths (AODs) obtained by MODIS, Himawari-08, and MERRA-2 in China are basically consistent with the results from AERONET. In general, the accuracy of these AOD products varies with regions and seasons. MODIS aerosol products tend to overestimate the AODs in summer and winter at Beijing, Xianghe and Xuzhou, and the strongest overestimation are found in winter. As for Taihu and Hong Kong, overestimation only appears in winter for MODIS AOD products. Himawari-08 and MERRA-2 underestimate the AODs in autumn over almost all stations except Taihu.

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