remote sensing

Supplementary Information

Himawari-8/AHI and MODIS Aerosol Optical Depths in China: Evaluation and Comparison

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Abstract: The geostationary earth orbit satellite—Himawari-8 loaded with the Advanced Himawari Imager (AHI) has greatly enhanced our capacity of dynamic monitoring in Asia–Pacific area. The Himawari-8/AHI hourly aerosol product is a promising complementary source to the MODerate resolution Imaging Spectroradiometer (MODIS) daily aerosol product for near real-time air pollution observations. However, a comprehensive evaluation of AHI aerosol optical depth (AOD) is still limited, and the difference in performances of AHI and MODIS remains uncertain. In this study, we evaluated the Himawari-8/AHI Level 3 Version 3.0 and MODIS Collection 6.1 Deep Blue AOD products over China against AOD measurements from AErosol RObotic NETwork (AERONET) sites in a spatiotemporal comparison of the products from February 2018 to January 2019. Results showed that AHI AOD achieved a moderate agreement with AERONET with a correlation coefficient of 0.75 and a root-mean-square-error of 0.26, which was slightly inferior to MODIS. The retrieval accuracy was spatially and temporally varied in AHI AOD, with higher accuracies for XiangHe and Lulin sites as well as in the morning and during the summer. The dependency analysis further revealed that the bias in AHI AOD was strongly dependent on aerosol loading and influenced by the Ångström Exponent and NDVI while those for MODIS appeared to be independent of all variables. Fortunately, the biases in AHI AOD could be rectified using a random forest model that contained the appropriate variables to produce sufficiently accurate results with cross-validation R of 0.92 and RMSE of 0.15. With these adjustments, AHI AOD will continue to have great potential in characterizing precise dynamic aerosol variations and air quality at a fine temporal resolution.

Keywords: aerosol optical depth (AOD); Himawari-8; MODIS; validation; China

1. Information of AERONET sites

AERONET Level 1.5 and 2.0 AOD measurements from 23 sites located in China from February 2018 to January 2019 were collected from http://aeronet.gsfc.nasa.gov/ to evaluate satellite-based AOD retrievals from AHI and MODIS, and details of AERONET sites were listed in Table S1.

Table S1. The information of AERONET sites.

Name	Latitude	Longitude	Elevation	Name	Latitude	Longitude	Elevation
AOE Baotou	40.85	109.63	1314	EPA-NCU	24.97	121.19	144
Dongsha Island	20.70	116.73	5	Kaohsiung	22.68	120.29	15
Hong Kong PolyU	22.30	114.18	30	Lulin	23.47	120.87	2868
Hong Kong Sheung	22.48	114.12	40	QOMS CAS	28.37	86.95	4276
NAM CO	30.77	90.96	4746	Tai Ping	10.38	114.36	4
Taihu	31.42	120.22	20	Xitun	24.16	120.62	91
Taipei CWB	25.01	121.54	26	XuZhou-CUMT	34.22	117.14	59.7
XiangHe	39.75	116.96	36	Chen-Kung Univ	22.99	120.20	50
Beijing-CAMS	39.93	116.32	106	Chiayi	23.50	120.50	62
Beijing	39.98	116.38	92	Douliu	23.71	120.54	60
Beijing PKU	39.99	116.31	53	NCU Taiwan	24.97	121.19	171
Beijing RADI	40.00	116.38	59				

2. Performance of AHI Version 1.0 and MODIS AOD products from July 2015 to June 2017

Comparison of AHI Level 3 Version 1.0 and MODIS AOD products with AERONET AOD values at 500 nm from July 2015 to June 2017 in China is presented in Figure S1. Results show that AHI AOD achieves a relatively high agreement with AERONET measurements indicated by the correlation coefficient of 0.84 and RMSE of 0.24 (Figure S1a). However, the Mann Whitney Wilcoxon (MWW) test reveals that there is a significant difference between AHI AOD and AERONET measurements (Table S2). In terms of other quantitative statistics (Table S2), the mean bias with -0.11 reveals that compared with AERONET measurements, AHI retrievals tend to have negative biases. Also, the mean relative bias of -3.80% shows there are considerable percentage of underestimations in AHI AOD retrievals. Specifically, there are 46.0%, 12.9%, and 41.1% of retrievals falling within, above, and below EE envelope, respectively. The underestimations of AHI AOD retrievals are especially obvious during the heavy aerosol loading periods, for example as shown in Figure S1a, and a large percentage of AHI AOD retrievals with high values are below 1-to-1 line.

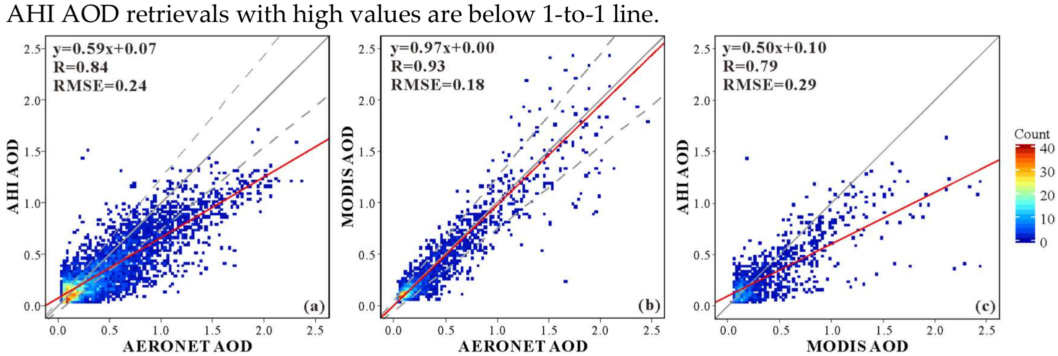

Figure S1. Evaluation of AHI Version 1.0 (a) and MODIS AOD with QA=2, 3 (b) AOD values at 500 nm against AERONET AOD as well as AHI against MODIS (c) in China from July 2015 to June 2017.

Table S2. Statistics of comparison of AHI Version 1.0, MODIS and AERONET AOD values at 500 nm in China from July 2015 to June 2017.

Comparison	N	R	Below EE (%)	Above EE (%)	Within EE (%)	RMSE	MB	MAE	MRB(%)	p*
AHI-AERONET	5119	0.84	41.1	12.9	46.0	0.24	−0.11	0.17	−3.80	≪0.01
MODIS-AERONET	1783	0.93	16.8	14.3	69.0	0.18	−0.01	0.10	14.62	0.55
AHI-MODIS	1099	0.79	/	/	/	0.29	−0.10	0.16	−3.30	≪0.01

* p value is the result of Mann Whitney Wilcoxon (MWW) test.

Figure S2 shows the result of AHI Version 1.0/MODIS-AERONET difference dependency on AERONET AOD, Ångström Exponent between 440-675 nm and NDVI. The linear fits of standard deviations of AHI-AERONET AOD are not in good agreement with EE envelop, shown in Figure S2a. There is a distinctive trend of positive-negative shift on AHI-AERONET difference. At a low AOD (τ < 0.15), AHI exhibits slightly positive biases, but AHI turns to show larger negative biases with the increase of AERONET AOD values. It is concluded that the accuracy of AHI is strongly dependent on the level of AERONET AOD. The linear fits of standard deviations of MODIS-AERONET difference in Figure S2b are close to EE envelope and the average biases for each bin are almost negligible, implying that MODIS retrieval accuracy is independent on AERONET AOD.

Figure S2c-d shows the satellite-AERONET AOD differences as a function of Ångström Exponent (AE) at 440-675 nm wavelengths from AERONET. Negative AHI-AERONET AOD differences first increase and then shrink with a larger AE. In general, AHI AOD is underestimated for situations with moderate aerosol size (0.7 < AE < 1.6), whereas for fine-dominated (AE > 1.6) and coarse-dominated (AE < 0.7) aerosol, AHI AOD retrievals are more accurate. As for MODIS, there is a negligible variability of average MODIS-AERONET AOD differences, suggesting MODIS has a robust performance in retrieving AOD with various aerosol sizes. The satellite-AERONET AOD differences as a function of NDVI presented in Figure 10e-f show that the satellite-AERONET AOD differences are mostly independent on NDVI except for NDVI around 0.2, implying that AHI and MODIS aerosol retrieval algorithm are successful over land areas with various NDVI.

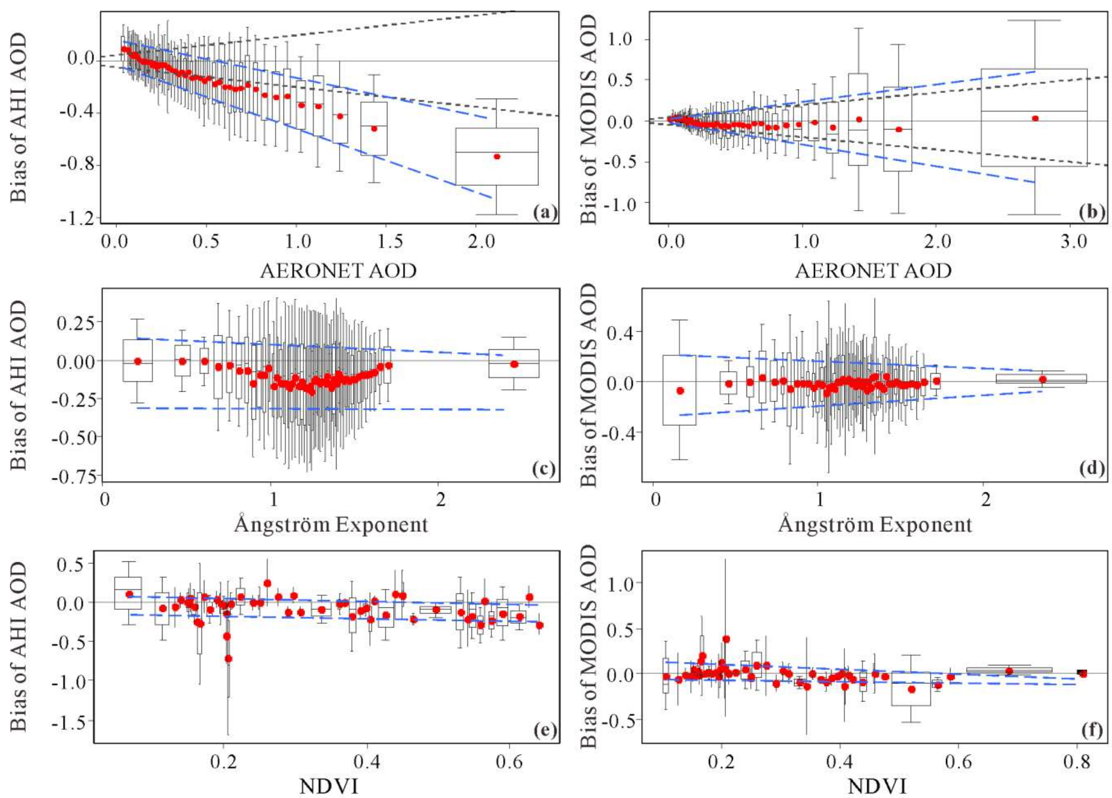

Figure S2. Biases in AHI version 1.0 and MODIS AOD as functions of AERONET AOD values at 500 nm (**a**,**b**), Ångström Exponent between 440–675 nm (**c**,**d**) and NDVI (**e**,**f**).

3. Performance of AHI Version 3.0 and MODIS AOD products from February 2018 to January 2019

Details on comparison of AHI Version 3.0, MODIS against AERONET from February 2018 to January 2019 are described in Table S3.

Table S3. Statistics of site comparison of AHI, MODIS against AERONET AOD and comparison of AHI and MODIS from February 2018 to January 2019.

Sensor	Site	N	R	Below EE (%)	Upper EE (%)	Within EE (%)	RMSE	MB	MAE	MRB (%)
AHI	Beijing-CAMS	726	0.79	17.1	41.9	41.1	0.30	0.11	0.21	82.11
	Kaohsiung	661	0.73	31.6	13.0	55.4	0.21	−0.08	0.14	−4.50

	Beijing	491	0.78	21.2	36.9	42.0	0.30	0.08	0.20	62.09
	XuZhou-CUMT	444	0.84	55.0	10.1	34.9	0.22	−0.11	0.18	−24.67
	XiangHe	443	0.85	28.2	23.3	48.5	0.25	0.01	0.17	7.77
	Taihu	294	0.71	19.1	49.7	31.3	0.28	0.09	0.22	71.72
	Xitun	150	0.60	24.0	30.0	46.0	0.21	0.01	0.16	25.51
	EPA-NCU	127	0.82	51.2	3.2	45.7	0.22	−0.14	0.16	−27.49
	Chiayi	88	0.75	86.4	0.0	13.6	0.33	−0.29	0.30	−48.31
	Lulin	15	0.90	0.0	6.7	93.3	0.04	0.00	0.03	1.18
MODIS	Beijing-CAMS	301	0.91	13.0	21.6	65.5	0.18	0.03	0.11	13.71
	Kaohsiung	4	0.99	0.0	0.0	100.0	0.05	0.04	0.04	19.96
	Beijing	204	0.90	14.2	29.9	55.9	0.23	0.05	0.14	17.93
	XuZhou-CUMT	173	0.81	27.2	17.3	55.5	0.19	−0.02	0.15	−7.89
	XiangHe	193	0.90	6.7	38.9	54.4	0.24	0.09	0.15	29.67
	Taihu	33	0.87	36.4	6.1	57.6	0.14	−0.08	0.11	−31.95
	Xitun	17	0.80	0.0	41.2	58.8	0.18	0.11	0.13	41.17
	EPA-NCU	14	0.95	7.1	14.3	78.6	0.08	0.02	0.06	12.05
	Chiayi	29	0.74	17.2	27.6	55.2	0.19	0.02	0.15	7.16
	Lulin	39	0.76	5.1	25.6	69.2	0.07	0.03	0.05	91.71
AHI	Beijing-CAMS	178	0.69				0.34	0.11	0.25	85.17
-MODIS	Kaohsiung	4	0.89				0.18	−0.16	0.16	−39.42
	Beijing	114	0.68				0.39	0.05	0.25	56.38
	XuZhou-CUMT	114	0.74				0.24	−0.11	0.19	−13.06
	XiangHe	98	0.73				0.37	−0.16	0.27	−19.73
	Taihu	27	0.55				0.28	0.22	0.24	>>100
	Xitun	9	−0.50				0.30	−0.06	0.25	6.19
	EPA-NCU	4	0.91				0.19	−0.13	0.14	−21.97
	Chiayi	18	0.73				0.34	−0.29	0.30	−47.23
	Lulin	2	−1.00				0.09	0.05	0.07	50.28