VALIDATION AND COMPARISON OF FINE-MODE AEROSOL OPTICAL DEPTH PRODUCTS BETWEEN MODIS AND POLDER

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ABSTRACT:

Fine-mode aerosol usually comes from anthropogenic emissions. The fine-mode aerosol optical depth (AOD_f) is an important parameter for estimating the particulate matter with an aerodynamic diameter little than 2.5 μm ($PM_{2.5}$). Compared to the ground-based observations, AOD_f products from satellite remote sensing have an advantage of high spatial coverage, which is suitable for monitoring the air quality at a regional or global scale. Up to now, AOD_f products have been released by several sensors, such as the single-angle multi-spectral intensity sensor MODIS and multi-angle multi-spectral polarization sensor POLDER, then what're the different performances of AOD_f products from them? In this study, the different spatial resolution AOD_f products respectively from MODIS latest Collection 6.1(C6.1, 3 and 10 km) and POLDER latest level 2 version 1.01 (L2, 18 km) were firstly compared with each other in Beijing-Tianjin-Hebei (BTH) domains. Then those products were validated against the ground-based AERosol RObotic NETwork (AERONET) measurements, where has been suffering the severe air pollution since decades ago. The comparison of yearly averaged AOD_f products between MODIS and POLDER shows a good consistency on the spatial distribution, the higher spatial resolution products of MODIS show more details, both low values of AOD_f appeared in the northwest area with small population and industry, high values appeared in the southeast area with lots of cities, industries, and large population. However, the whole yearly AOD_f average values of MODIS are higher than that of POLDER. The results of validation against AERONET show that the accuracy of AOD_f products at 865 nm from POLDER (R=0.94, RMSE=0.05) is high than that at 550 nm of MODIS (3km: R=0.69, RMSE=0.32; 10 km: R=0.76, RMSE=0.3). In this study, the performance of different spatial resolutions AOD_f products retrieved from the intensity (MODIS 3 and 10 km) and polarized sensors (POLDER 18 km) were evaluated. Those results not only have a great significance to provide users a more appropriate choice of the AOD_f products in the BTH region but also display that the accuracy and spatial resolution of MODIS and POLDER AOD_f products need to be improved.

1. INTRODUCTION

Aerosol at the atmosphere can be retrieved utilizing ground-based and satellite remote sensing observations. Aerosol from ground-based measurements has the advantage of high accuracy but less spatial coverage (Giles et al., 2019; Xie et al., 2015). On the contrary, aerosol from satellite remote sensing observations has superiority in wide spatial coverage, however, how to decouple atmospheric and surface contributions from reflectance at the top of atmosphere is still challenging. To solve this problem, there are many algorithms have been proposed (Ge et al., 2019; Hou et al., 2018; 2017; 2016; Li et al., 2018; 2015; Qie et al., 2015; Wang et al., 2014a; Wang et al., 2014b; Wang et al., 2014c; Wang et al., 2014d; Waquet et al., 2014; Yang et al., 2014; Zhang et al., 2017; 2016).

Fine-mode aerosol, the effective radius range from 0.1 to 0.25 μm, often generated from man-made sources, which plays an important role in climate (Kaufman et al., 2002; 2001; Kleidman et al., 2005). Fine-mode aerosol optical depth (AOD_f) is a significant optical parameter of fine-mode aerosol and has been used in many fields (Anderson et al., 2005). Besides, AOD_f has been found that has a higher correlation with the particulate matter with an aerodynamic diameter little than 2.5 μm ($PM_{2.5}$) than AOD (Yan et al., 2017; Zhang and Li, 2013). What's more, Zhang and Li (2015) developed a $PM_{2.5}$ remote sensing (PMRS) mode and used the AOD_f products from MODIS to estimate ground-level $PM_{2.5}$.

AOD_f is the key parameter of the PMRS model (Li et al., 2016; Yan et al., 2017). However, compared to AOD, it seems that there are fewer satellite remote sensing sensors providing AOD_f products, such as Moderate Resolution Imaging Spectroradiometer (MODIS) and POLarization and Directionality of the Earth's Reflectances (POLDER) (Deuzé et al., 2001; Levy et al., 2013; 2015; 2010; 2007a; 2007b; Tanré et al., 2011). The AOD_f products from MODIS were mainly validated over the ocean (Jones and Christopher, 2007; Kleidman et al., 2005). Bréon et al. (2011) compared and validated the AOD_f products between MODIS (10 km) and POLDER (18 km) on a global scale. However, the validation results may not suitable for some special areas (Zhang et al., 2018). Thus, in this paper, we compared and validated the AOD_f products retrieved from the MODIS (intensity) and POLDER (polarization) in the Beijing-Tianjin-Hebei (BTH) region. To reveal their performances at different spatial (3, 10 and18 km) and temporal variations. The results will be helpful for users to choose more appropriate AOD_f products to monitor local or urban air pollution in the BTH region.

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2. STUDY AREA AND DATA

2.1 Study Area

BTH area is located in the North China Plain (Figure 1a). The elevation of BTH is shown in Figure 1b. It can be seen that mountains are located in the northwest part with a small population, while plains are located in the southeast part with a population of more than 100 million. In the past few decades, with the rapid urbanization, industrialization, and unprecedentedly high aerosol emissions, the BTH region has become one of the most heavily polluted areas in the world (Huang et al., 2014).

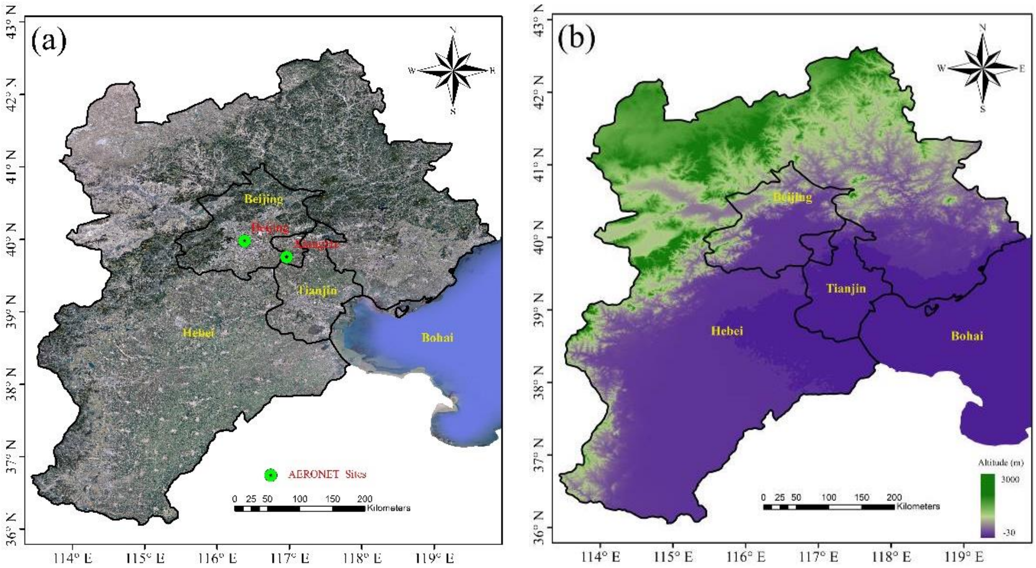

Figure 1. Geophysical information of studying area. (a)The RGB of BTH from Google map and locations of AERONET sites, (b) is the elevation map of BTH.

2.2 AERONET Data

Aerosol products from ground-based AERONET are measured by sun photometer, the uncertainty of AOD is 0.01(Giles et al., 2019). In this study, the AERONET latest version 3 AOD-SOLAR and inversion products were used for validating the AOD_f products. Two typical AERONET sites over different underlying surface types were selected, the distribution of them is shown in Figure.1. Bejing site (116.381° E, 39.977° N) is located in the Urban area, and XiangHe site (116.962° E, 39.754° N) is located in the Cropland area.

2.3 MODIS AOD_f Products

MODIS is a single-angle multi-spectral intensity sensor, which is equipped on Terra and Aqua satellites since 1999 and 2002. Terra is on a descending orbit and Aqua is on an ascending orbit, they are over the equator about 10:30 and 13:30 local sun time, respectively (Levy et al., 2013). In this study, MODIS Collection 6.1 (C6.1) 3 and 10 km AOD and fine-mode fraction (FMF) products (MYD04, Aqua) were used for comparison and validation. Due to without the AOD_f products, AOD_f were calculated by AOD*FMF. However, it should be noticed that the FMF products of MODIS only reported by Dark Target (DT) algorithm and AOD large than 0.2 (Levy et al., 2007b). Products of MODIS can be obtained from LAADS DAAC (https://ladsweb.modaps.eosdis. nasa.gov).

2.4 POLDER AOD_f Products

POLDER is a multi-angle and multi-spectral sensor, which is onboard the Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar (PARASOL) satellite. Polarized measurement is sensitive to small particles at the scattering angles range from 80°to 120°, which is very useful to retrieve fine-mode aerosol (Deuzé et al., 2001). POLDER level 2 (L2) aerosol products over land only include parameters about fine-mode aerosol, such as AOD_f at 865 nm, Ångström exponent (AE) and effective radius. The spatial resolution is about 18.5×18.5 km (Bréon et al., 2011). Products of POLDER can be obtained from http://www.icare.univ-lille1.fr/parasol/mission.

2.5 Method of Validation

In this study, the fine-mode aerosol particle radius is assumed ≤ 0.3 μm in the BTH region (Fan et al., 2008). The strategy of validation mainly according to Su et al. (2010). AOD_f products from MODIS and POLDER will be averaged over 0.5° × 0.5° box centred on the AERONET site. Due to the POLDER L2 only provide the AOD_f products at 865 nm, so the AE will be used to derive the AOD_f products at 550nm according to the Eq. (1). Meanwhile, the Pearson correlation coefficient (R) and Root Mean Square Error (RMSE) are used to evaluate the AOD_f products from MODIS and POLDER.

$$AOD_f^{\lambda_1} = (\frac{\lambda_1}{\lambda_2})^{-AE} * AOD_f^{\lambda_2} \quad (1)$$

where λ_1 and λ_2 are the wavelength.

3. RESULTS AND ANALYSIS

3.1 Comparison of Yearly Averaged AOD_f Products

Figure 2 (a) and (d) show the yearly averaged AOD products (at 550 nm) of MODIS 3 and 10 km. Figure 2 (b) and (e) show the yearly averaged AOD_f products (at 550 nm) of MODIS when FMF >0 at 3 and 10 km. Figure 2 (c) and (f) show the yearly averaged AOD_f products (at 550 nm) of MODIS when FMF ≥0 at 3 and 10 km respectively. Figure 3 shows the yearly averaged AOD_f (at 550 nm) products at 18 km of POLDER. From those results, it can be seen that MODIS and POLDER results show a good coincidence in aerosol spatial distribution features. The clean air zone with lower AOD_f values is located in the western area of BTH. The polluted zone with the corresponding high AOD_f values is located in the southeast area. Besides, the higher spatial resolution of AOD_f products from MODIS can reveal more details.

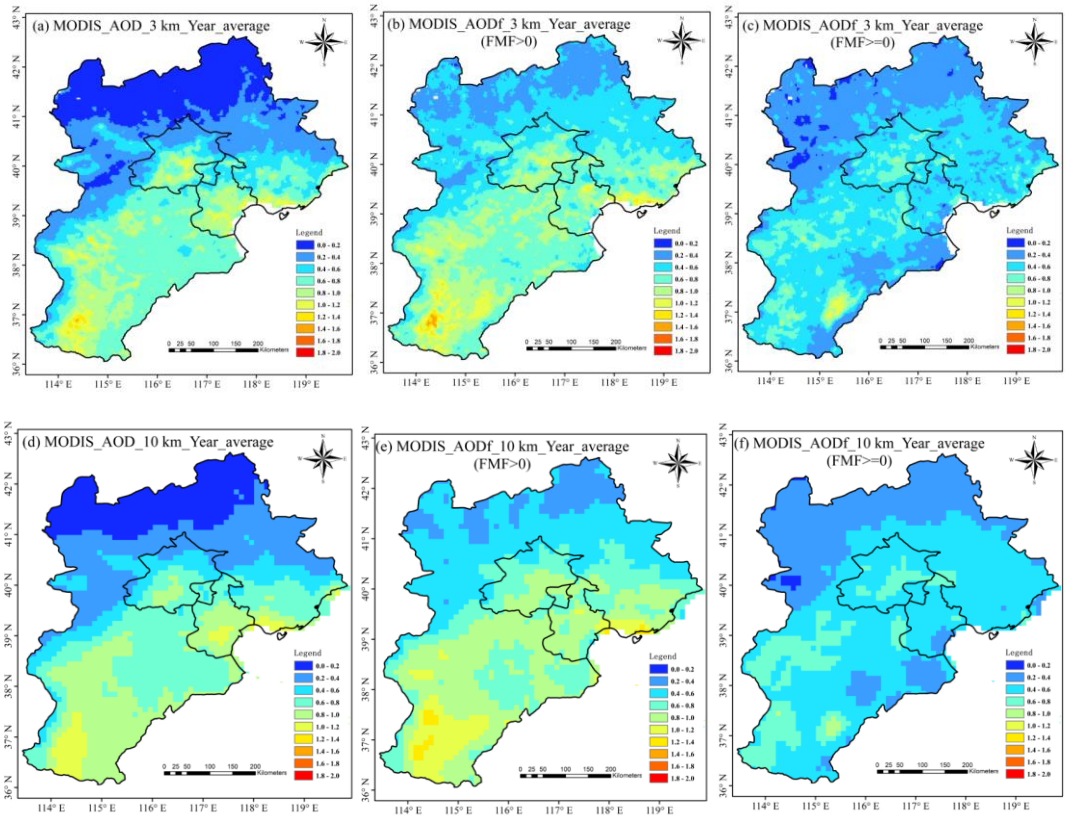

Figure 2. The yearly averaged aerosol products of MODIS for 3 and 10 km, (a) and (d) are the AOD at 550 nm, (b) and (e) are the AOD_f at 550 nm when FMF >0, (c) and (f) are the AOD_f at 550 nm when FMF ≥0.

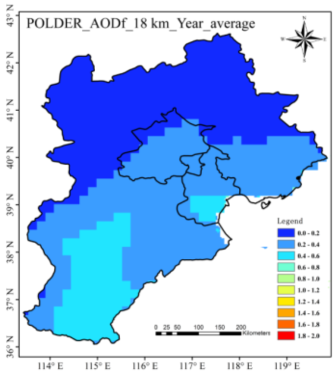

Figure 3. The yearly averaged AOD_f products at 550 nm of POLDER for 18 km.

3.2 Validation Against with AOD_f Products

Figure 4 shows the validation of MODIS and POLDER AOD_f products against two typical AERONET sites (Beijing and XiangHe) measurements for the year of 2011. Table 1 shows the statistical summary for validation results. Figure 4 (a) and (b) show the MODIS validation results when FMF ≥ 0 and FMF >0 at 10 and 3 km, respectively. The results of MODIS AOD_f at 10 km are R=0.76, RMSE = 0.3 when FMF≥0, and R=0.82, RMSE= 0.26 when FMF>0. The results of MODIS at 3 km are R=0.69, RMSE = 0.32 when FMF ≥ 0 and R=0.74, RMSE=0.38 when FMF>0. Those results of MODIS are lower than that of the POLDER with R=0.94, RMSE = 0.11 (550 nm) and R=0.94, RMSE=0.05 (865 nm) as shown in Figure 5 (a) and (b).

4. CONCLUSION

In this study, three version AOD_f products with different spatial resolution from MODIS (3 and 10 km) and POLDER (18 km) were firstly compared and validated against two typical AERONET sites (Beijing and XiangHe) in the BTH region. The comparison results show that the high spatial resolution of AOD_f products at 550 nm of MODIS can show more details than POLDER. The results of validation against two AERONET sites data show that the accuracy of MODIS AOD_f at 10 km (RMSE is 0.3 when FMF≥0; RMSE is 0.26 when FMF>0), MODIS 3 km (RMSE is 0.32 when FMF≥0; RMSE is 0.38 when FMF>0), which are lower than that of the POLDER (RMSE is 0.11 for 550 nm; RMSE is 0.05 for 865 nm). From the validation results, we can conclude that the accuracy of MODIS AOD_f products at 550 nm (FMF>0) are higher than that when FMF≥0. AOD_f products of POLDER have higher accuracy than that of MODIS, and the AOD_f products at 865 nm are higher than that at 550 nm, the reasons may be that the AE can bring some errors. On the whole, it can be found that AOD_f products at 550 nm of MODIS are overestimated, and the AOD_f products at 550 and 865 nm of POLDER have higher accuracy, the reasons may be that the multi angle and polarized signal can provide more information of fine-mode aerosol than single-angle intensity signal. However, both AOD_f products of them are still underestimated. Those results have a great significance to provide users a more appropriate choice of the AOD_f products from different sensors in the BTH region. In addition, it is still necessary to improve the accuracy and spatial resolution of MODIS and POLDER AOD_f products.

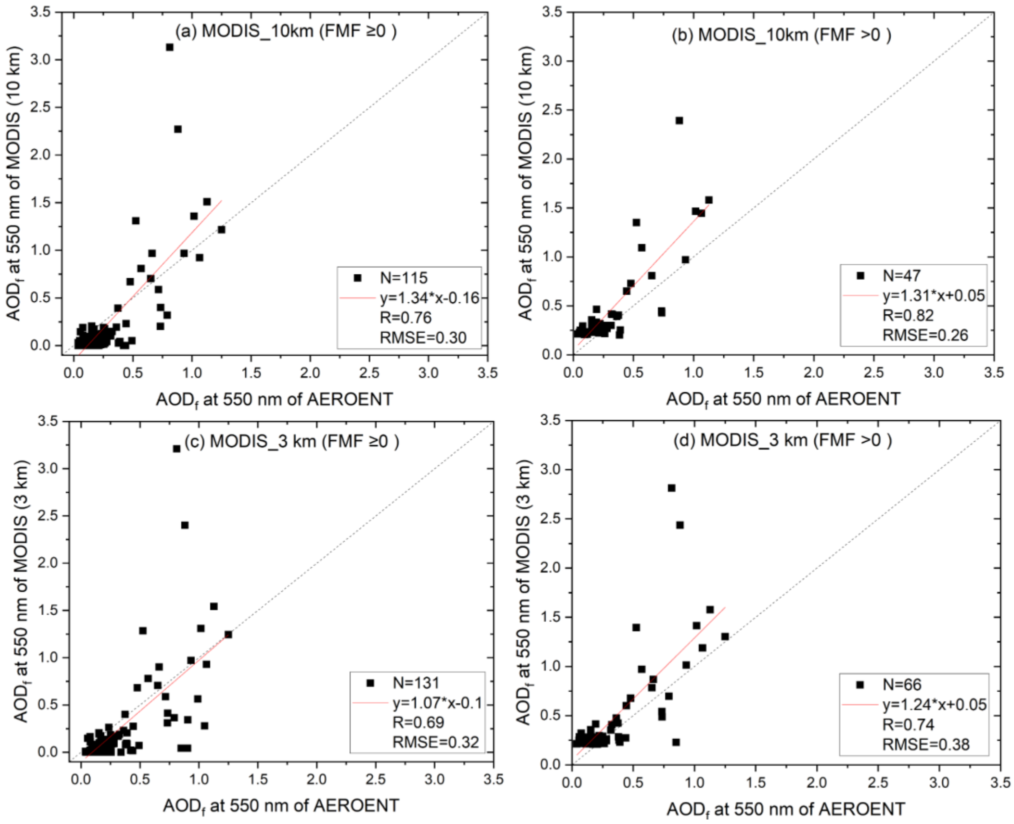

Figure 4. Validation of MODIS AOD_f products at 550 nm against two typical sites AERONET measurements for a year. (a) and (c) are the AOD_f at 550 nm when FMF ≥0, (b) and (d) are the AOD_f when FMF >0.

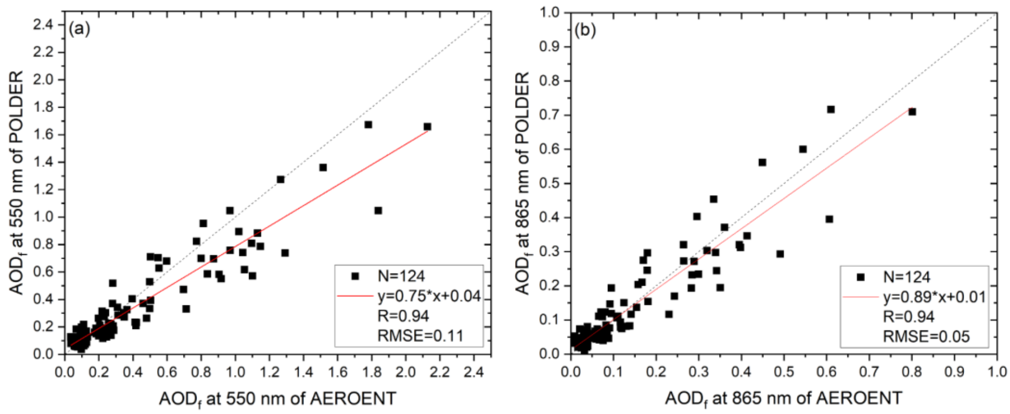

Figure 5. Validation of POLDER AOD_f products against two typical sites AERONET measurements for a year, (a) is the AOD_f at 550 nm, (b) is the AOD_f at 865 nm.

Parameters \ AOD_f	MODIS 3 km (FMF ≥ 0)	MODIS 3 km (FMF >0)	MODIS 10 km (FMF ≥ 0)	MODIS 10km (FMF >0)	POLDER 18km (550 nm)	POLDER 18km (865 nm)
N	131	66	115	47	124	124
R	0.69	0.74	0.76	0.82	**0.94**	**0.94**
RMSE	0.32	0.38	0.30	0.26	0.11	**0.05**

Table 1. Statistical summary for validation of MODIS and POLDER AOD_f products. The best statistics have italic bold characters.

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REFERENCES

Anderson, T.L., Charlson, R.J., Bellouin, N., Boucher, O., Chin, M., Christopher, S.A., Haywood, J., Kaufman, Y.J., Kinne, S., Ogren, J.A., Remer, L.A., Takemura, T., Tanré, D., Torres, O., Trepte, C.R., Wielicki, B.A., Winker, D.M.,Yu, H., 2005. An “A-Train” strategy for quantifying direct climate forcing by anthropogenic aerosols. *Bull. Amer. Meteorol. Soc,* 86, 1795-1810.

Bréon, F.-M., Vermeulen, A.,Descloitres, J., 2011. An evaluation of satellite aerosol products against sunphotometer measurements. *Remote Sens Environ,* 115, 3102-3111.

Deuzé, J.L., Bréon, F.M., Devaux, C., Goloub, P., Herman, M., Lafrance, B., Maignan, F., Marchand, A., Nadal, F.,Perry, G., 2001. Remote sensing of aerosols over land surfaces from POLDER‐ADEOS‐1 polarized measurements. *J. Geophys. Res. Atmos,* 106, 4913-4926.

Fan, X., Goloub, P., Deuzé, J.-L., Chen, H., Zhang, W., Tanré, D.,Li, Z., 2008. Evaluation of PARASOL aerosol retrieval over North East Asia. *Remote Sens Environ,* 112, 697-707.

Ge, B.o.t.A.M.S., Li, Z., Liu, L., Yang, L., Chen, X., Hou, W., Zhang, Y., Li, D., Li, L.,Qie, L., 2019. A Dark Target Method for Himawari-8/AHI Aerosol Retrieval: Application and Validation. *IEEE Trans. Geosci. Remote Sens,* 57, 381-394.

Giles, D.M., Sinyuk, A., Sorokin, M.G., Schafer, J.S., Smirnov, A., Slutsker, I., Eck, T.F., Holben, B.N., Lewis, J.R., Campbell, J.R., Welton, E.J., Korkin, S.V.,Lyapustin, A.I., 2019. Advancements in the Aerosol Robotic Network (AERONET) Version 3 database – automated near-real-time quality control algorithm with improved cloud screening for Sun photometer aerosol optical depth (AOD) measurements. *Atmos. Meas. Tech,* 12, 169-209.

Hou, W., Li, Z., Wang, J., Xu, X., Goloub, P.,Qie, L., 2018. Improving Remote Sensing of Aerosol Microphysical Properties by Near‐Infrared Polarimetric Measurements Over Vegetated Land: Information Content Analysis. *J. Geophys. Res. Atmos,* 123, 2215-2243.

Hou, W., Wang, J., Xu, X.,Reid, J.S., 2017. An algorithm for hyperspectral remote sensing of aerosols: 2. Information content analysis for aerosol parameters and principal components of surface spectra. *J. Quant. Spectrosc. Radiat. Transfer,* 192, 14-29.

Hou, W., Wang, J., Xu, X., Reid, J.S.,Han, D., 2016. An algorithm for hyperspectral remote sensing of aerosols: 1. Development of theoretical framework. *J. Quant. Spectrosc. Radiat. Transfer,* 178, 400-415.

Huang, R.-J., Zhang, Y., Bozzetti, C., Ho, K.-F., Cao, J.-J., Han, Y., Daellenbach, K.R., Slowik, J.G., Platt, S.M., Canonaco, F., Zotter, P., Wolf, R., Pieber, S.M., Bruns, E.A., Crippa, M., Ciarelli, G., Piazzalunga, A., Schwikowski, M., Abbaszade, G., Schnelle-Kreis, J., Zimmermann, R., An, Z., Szidat, S., Baltensperger, U., Haddad, I.E.,Prévôt, A.S.H., 2014. High secondary aerosol contribution to particulate pollution during haze events in China. *Nature,* 514, 218-222.

Jones, T.A.,Christopher, S.A., 2007. MODIS derived fine mode fraction characteristics of marine, dust, and anthropogenic aerosols over the ocean, constrained by GOCART, MOPITT, and TOMS. *J. Geophys. Res. Atmos,* 112, D22204.

Kaufman, Y.J., Didier, T.,Olivier, B., 2002. A satellite view of aerosols in the climate system. *Nature,* 419, 215-223.

Kaufman, Y.J., Smirnov, A., Holben, B.N.,Dubovik, O., 2001. Baseline maritime aerosol: Methodology to Derive the optical thickness and scattering properties. *Geophys Res Lett,* 28, 3251–3254.

Kleidman, R.G., O''Neill, N.T., Remer, L.A., Kaufman, Y.J., Eck, T.F., Tanré, D., Dubovik, O.,Holben, B.N., 2005. Comparison of Moderate Resolution Imaging Spectroradiometer (MODIS) and Aerosol Robotic Network (AERONET) remote-sensing retrievals of aerosol fine mode fraction over ocean. *J. Geophys. Res. Atmos,* 110, D22205.

Levy, R., Mattoo, S., Munchak, L., Remer, L., Sayer, A., Patadia, F.,Hsu, N., 2013. The Collection 6 MODIS aerosol products over land and ocean. *Atmos. Meas. Tech,* 6, 2989-3034.

Levy, R., Munchak, L., Mattoo, S., Patadia, F., Remer, L.,Holz, R., 2015. Towards a long-term global aerosol optical depth record: applying a consistent aerosol retrieval algorithm to MODIS and VIIRS-observed reflectance. *Atmos. Meas. Tech,* 8, 4083-4110.

Levy, R., Remer, L., Kleidman, R., Mattoo, S., Ichoku, C., Kahn, R.,Eck, T., 2010. Global evaluation of the Collection 5 MODIS dark-target aerosol products over land. *Atmos. Chem. Phys,* 10, 10399-10420.

Levy, R.C., Remer, L.A.,Dubovik, O., 2007a. Global aerosol optical properties and application to Moderate Resolution Imaging Spectroradiometer aerosol retrieval over land. *J. Geophys. Res. Atmos,* 112, D13210.

Levy, R.C., Remer, L.A., Mattoo, S., Vermote, E.F.,Kaufman, Y.J., 2007b. Second - generation operational algorithm: Retrieval of aerosol properties over land from inversion of Moderate Resolution Imaging Spectroradiometer spectral reflectance. *J. Geophys. Res. Atmos,* 112, D13211.

Li, Z., Hou, W., Hong, J., Zheng, F., Luo, D., Wang, J., Gu, X.,Qiao, Y., 2018. Directional Polarimetric Camera (DPC): Monitoring aerosol spectral optical properties over land from satellite observation. *J. Quant. Spectrosc. Radiat. Transfer,* 218, 21-37.

Li, Z., Li, D., Li, K., Xu, H., Chen, X., Chen, C., Xie, Y., Li, L., Li, L.,Li, W., 2015. Sun-sky radiometer observation network with the extension of multi-wavelength polarization measurements. *J. Remote Sens,* 19, 495-519.

Li, Z., Zhang, Y., Shao, J., Li, B., Hong, J., Liu, D., Li, D., Wei, P., Li, W.,Li, L., 2016. Remote sensing of atmospheric particulate mass of dry PM2. 5 near the ground: Method validation using ground-based measurements. *Remote Sens Environ,* 173, 59-68.

Qie, L., Li, Z., Sun, X., Sun, B., Li, D., Liu, Z., Huang, W., Wang, H., Chen, X.,Hou, W., 2015. Improving remote sensing of aerosol optical depth over land by polarimetric measurements at 1640 nm: Airborne test in north china. *Remote Sens,* 7, 6240-6256.

Su, X., Goloub, P., Chiapello, I., Chen, H., Ducos, F.,Li, Z., 2010. Aerosol variability over East Asia as seen by POLDER space - borne sensors. *J. Geophys. Res. Atmos,* 115, D24215.

Tanré, D., Bréon, F., Deuzé, J., Dubovik, O., Ducos, F., François, P., Goloub, P., Herman, M., Lifermann, A.,Waquet, F., 2011. Remote sensing of aerosols by using polarized, directional and spectral measurements within the A-Train: the PARASOL mission. *Atmos. Meas. Tech,* 4, 1383-1395.

Wang, H., Sun, X., Sun, B., Liang, T., Li, C.,Hong, J., 2014a. Retrieval of aerosol optical properties over a vegetation surface using multi-angular, multi-spectral, and polarized data. *Adv Atmos Sci,* 31, 879-887.

Wang, J., Xu, X., Ding, S., Zeng, J., Spurr, R., Liu, X., Chance, K.,Mishchenko, M., 2014b. A numerical testbed for remote sensing of aerosols, and its demonstration for evaluating retrieval synergy from a geostationary satellite constellation of GEO-CAPE and GOES-R. *J. Quant. Spectrosc. Radiat. Transfer,* 146, 510-528.

Wang, Y., Zhang, J., Wang, L., Hu, B., Tang, G., Liu, Z., Sun, Y.,Ji, D., 2014c. Researching Significance,Status and Expectation of Haze in Beijing-Tianjin-Hebei Region. *Advances in Earth Science,* 29, 388-396.

Wang, Y., Zhang, R.,Saravanan, R., 2014d. Asian pollution climatically modulates mid-latitude cyclones following hierarchical modelling and observational analysis. *Nature Communications,* 5, 3098.

Waquet, F., Peers, F., Goloub, P., Ducos, F., Thieuleux, F., Derimian, Y., Riedi, J., Chami, M.,Tanré, D., 2014. Retrieval of the Eyjafjallajökull volcanic aerosol optical and microphysical properties from POLDER/PARASOL measurements. *Atmos. Chem. Phys,* 14, 1755-1768.

Xie, Y., Li, Z., Li, D., Xu, H.,Li, K., 2015. Aerosol Optical and Microphysical Properties of Four Typical Sites of SONET in China Based on Remote Sensing Measurements. *Remote Sens,* 7, 9928-9953.

Yan, X., Shi, W., Li, Z., Li, Z., Luo, N., Zhao, W., Wang, H.,Yu, X., 2017. Satellite-based PM2.5 estimation using fine-mode aerosol optical thickness over China. *Atmos Environ,* 170, 290-302.

Yang, L., Xue, Y., Jie, G.,Kazemian, H., 2014. Improved Aerosol Optical Depth and Ångstrom Exponent Retrieval Over Land From MODIS Based on the Non-Lambertian Forward Model. *IEEE Geosci. Remote Sens. Lett,* 11, 1629-1633.

Zhang, Y.,Li, Z., 2013. Estimation of PM2. 5 from fine-mode aerosol optical depth. *J. Remote Sens,* 17, 929-943.

Zhang, Y.,Li, Z., 2015. Remote sensing of atmospheric fine particulate matter (PM2. 5) mass concentration near the ground from satellite observation. *Remote Sens Environ,* 160, 252-262.

Zhang, Y., Li, Z., Liu, Z., Zhang, J., Qie, L., Xie, Y., Hou, W., Wang, Y.,Ye, Z., 2018. Retrieval of the Fine-Mode Aerosol Optical Depth over East China Using a Grouped Residual Error Sorting (GRES) Method from Multi-Angle and Polarized Satellite Data. *Remote Sens,* 10, 1838.

Zhang, Y., Li, Z., Qie, L., Hou, W., Liu, Z., Zhang, Y., Xie, Y., Chen, X.,Xu, H., 2017. Retrieval of Aerosol Optical Depth Using the Empirical Orthogonal Functions (EOFs) Based on PARASOL Multi-Angle Intensity Data. *Remote Sens,* 2017, 578.

Zhang, Y., Li, Z., Qie, L., Zhang, Y., Liu, Z., Chen, X., Hou, W., Li, K., Li, D.,Xu, H., 2016. Retrieval of aerosol fine-mode fraction from intensity and polarization measurements by PARASOL over East Asia. *Remote Sens,* 8, 417.

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