

# VALIDATION OF MODIS AEROSOL OPTICAL THICKNESS PRODUCT DISTRIBUTED BY NSMC OVER SEAS AROUND CHINA AND ITS ADJACENT AREA

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## ABSTRACT:

MODIS (Terra) aerosol optical thickness product distributed by NSMC were validated over seas around China and its adjacent area using AERONET data from Jan. 2005 to May 2007. Two spatio-temporal matching up schemes were adopted and the results were not quite the same. Using 25km radius and  $\pm 0.5h$  as the sampling window, there were 32 match-ups. The linear fitting results between MODIS and AERONET were  $y=0.672075x+0.132479$  ( $R^2=0.68$ ),  $y=0.707179x+0.112427$  ( $R^2=0.65$ ) and  $y=0.650986x+0.089910$  ( $R^2=0.56$ ) for MODIS 550, 658 and 860nm channels respectively. The RMSE was 0.15, 0.13 and 0.10 respectively. The percentages of retrievals within the expected uncertainties were 62.5%, 46.9% and 46.9% respectively. Using data in spring (Mar. to May, 22 match-ups), the linear fitting results were  $y=0.804612x+0.050988$  ( $R^2=0.77$ ),  $y=0.862697x+0.034432$  ( $R^2=0.75$ ) and  $y=0.851294x+0.012003$  ( $R^2=0.71$ ) respectively. Using 45km radius and  $\pm 1.0h$  as the sampling window, there were 120 match-ups. The validation results were relatively poor with large data dispersion and  $R^2$  of 3 channels were all less than 0.3 while exceeding 0.6 without data from “Taichung” in the linear fitting. The RMSE was 0.23, 0.20 and 0.17 for 550, 658 and 860nm respectively with the best result 0.11, 0.09 and 0.07 at Hong Kong PolyU. The percentages of retrievals within the expected uncertainties were all less than 50% with the best result 61.5% at “NCU Taiwan”. Generally speaking, for the research area, the sampling window of 25km radius and  $\pm 0.5h$  was more suitable than 45km radius and  $\pm 1.0h$ . Although the MODIS AOT products over ocean produced at NSMC can assure certain precision, the validation results are not quite satisfying. Besides the influences of turbid water reflectance near shore, cloud contamination, aerosol model suitability and representative ability of aerosols over ocean by nearby land-based observation, we conclude that calibration of LIB data may be the important error source.

## 1. INTRODUCTION

With intensive investigations for many years, the National Satellite Meteorological Center (NSMC) has constructed the MODIS products processing software based on the operational framework of acquisition, collection, preprocessing and distribution of MODIS data. It can operate in real-time or batch processing mode and aerosol product is one of its products.

The MODIS aerosol retrieval algorithm over ocean adopted by NSMC is a multi-wavelength optimization algorithm based on look-up tables, coming from the IMAPP software package developed by CIMSS Institute of Wisconsin University. The product includes aerosol optical thicknesses (AOT) of 7 channels over ocean ( $0.47\sim 2.13\mu m$ ), Ångström exponent, aerosol particle effective radius and ratio of small mode optical thickness with a resolution of 10km.

From the AOT distribution over China averaged for each season from 2005 to 2007 shown in figure 1, it is clear that AOT over ocean is maximum in spring, smaller in autumn and winter, and minimum in summer over southern waters, but influenced by high turbid water, AOT in coastal regions around China is overestimated, especially at Subei and Hangzhou Bay in winter and spring.

In this paper, the operational MODIS (Terra) AOT product over ocean distributed by NSMC is validated with ground-based measurements.

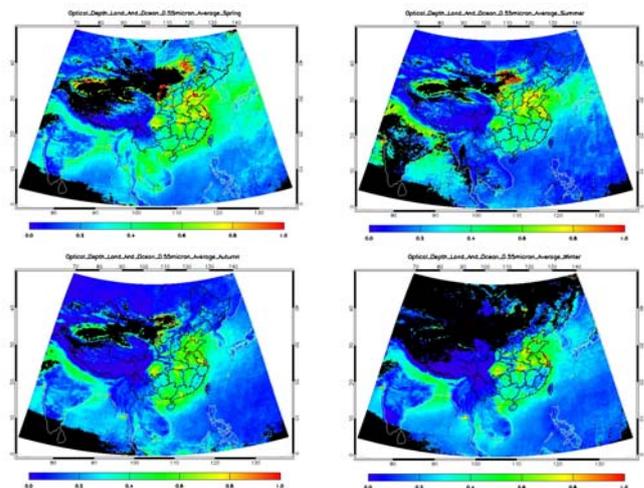


Figure 1. AOT over China averaged for each season from 2005 to 2007

## 2. VALIDATION METHOD

### 2.1 Data Description

The level 2 sunphotometer product from AERONET (Aerosol Robotic Network) with cloud clearing and quality insurance was adopted as the true value for validation.

The AERONET ground-based sunphotometer makes one measurement every 15 minutes. AOT of 7 channels (0.34, 0.38, 0.44, 0.50, 0.67, 0.87 and 1.02 $\mu$ m) can be derived from the direct solar radiation measurements (with only part channels at some sites) with the precision of 0.01~0.02 (Eck et al, 1999).

The ground-based and satellite products used covered the period from Jan. 2005 to May 2007.

### 2.2 Spatio-temporal Matching Up Method

The spatio-temporal sampling properties of satellite and ground-based data are different. Thus, proper sampling window should be determined according to the measurement interval of ground-based data, space resolution of satellite product and aerosol variation and uniformity over time and space. The averages of effective aerosol pixels in the space window and effective ground-based measurements in the time window make one match-up to be involved into the validation dataset.

Based on former studies (Choku et al, 2002; Remer et al, 2002, 2005; Chen & Yang, 2005), ground-based data were averaged within  $\pm 0.5$ h (or  $\pm 1.0$ h) centered at the satellite observation time, and those with measurements not less than 2 (or 4) were included into the validation dataset.

Satellite data were averaged within a radius of 25km (or 45km) centered at the AERONET site location, and those with effective pixels not less than 5 (or 9) after data elimination for land, turbid water, and cloud contamination were included into the validation dataset.

### 2.3 Validation Channel Selection

Although MODIS and AERONET provide AOT for several channels, only channels centered at 658nm (675nm for AERONET) and 860nm (870nm for AERONET) are most nearest for direct comparison.

Former research indicated that the natural logarithm of AOT can be well fitted as the quadratic polynomial of natural logarithm of wavelength, with the fitting error of about 0.01~0.02 (Eck et al, 1999). Thus, the 550nm AOT at AERONET site was estimated with equation (1) to validate the MODIS AOT at 550nm. Wavelengths of 440, 675, 870 and 1020nm were selected for fitting.

$$\ln \tau_a(\lambda) = a_0 + a_1 \ln \lambda + a_2 (\ln \lambda)^2 \quad (1)$$

where  $\tau_a(\lambda)$  = AOT at wavelength  $\lambda$   
 $a_0, a_1, a_2$  = polynomial coefficients

## 3. RESULTS AND DISCUSSION

Using 25km radius and  $\pm 0.5$ h as the sampling window, there were 162 match-ups. Excluding those with ground-based measurements less than 2 and satellite pixels less than 5, 32 matched data were left, in which ground-based data were from sites of "Gosan SNU" (29 match-ups) and "Shirahama" (3 match-ups) with the averaged AOT at 550nm of 0.35. Figure 2 displays scatter diagrams of the match-ups, in which dashed lines represent the upper and lower limits of expected uncertainties of MODIS AOT product (over ocean,  $\Delta\tau = \pm 0.05 \pm 0.05\tau$  for 550nm (Tanre et al, 1997) and  $\Delta\tau = \pm 0.03 \pm 0.05\tau$  (Remer et al, 2002) for 660 and 860nm), and

the red is the linear fitting line. Table 1 lists the corresponding error statistics.

The  $R^2$  of linear fitting between MODIS and AERONET was 0.68, 0.65 and 0.56 for MODIS 550, 658 and 860nm channels respectively. There was relatively large dispersion at low AOT, and the  $R^2$  of these 3 channels was increased to 0.77, 0.74 and 0.67 when data with AOT less than 0.05 were discarded.

The RMSE was 0.15, 0.13 and 0.10 for MODIS 550, 658 and 860nm channels respectively. The mean relative errors all exceeded 70%, but were reduced to 37.8%, 30.8% and 30.0% without AOT less than 0.05.

The percentages of retrievals within the expected uncertainties were 62.5% for 550nm channel (only 46.9% for  $\Delta\tau = \pm 0.03 \pm 0.05\tau$ ) and 46.9% for channels of 658 and 860nm. There were relatively large disparities compared with the results of Remer et al.(2005) using MODIS aerosol products from Aug. 2000 to Aug. 2002 and AERONET data from 132 sites globally distributed ( level 1.5 product, 2052 match-ups with averaged AERONET 550nm AOT of 0.18): 62%, 66% and 70% respectively for 550, 660 and 870nm\*. But, in that research, the percentages were only 56%, 53% and 60% over Asia-Pacific waters (57 match-ups with averaged AERONET 550nm AOT of 0.21). It indicates that the retrieval performance is relatively poor in this region compared with that of global. When data with AOT less than 0.05 were discarded, the percentages were increased to 66.7% for 550nm (50.0% for  $\Delta\tau = \pm 0.03 \pm 0.05\tau$ ) and 51.7% for 658 and 860nm channels. If the uncertainties were  $\Delta\tau = \pm 0.05 \pm 0.05\tau$  for 658 and 860nm channels, the percentages were increased to 59.4% and 65.6% separately.

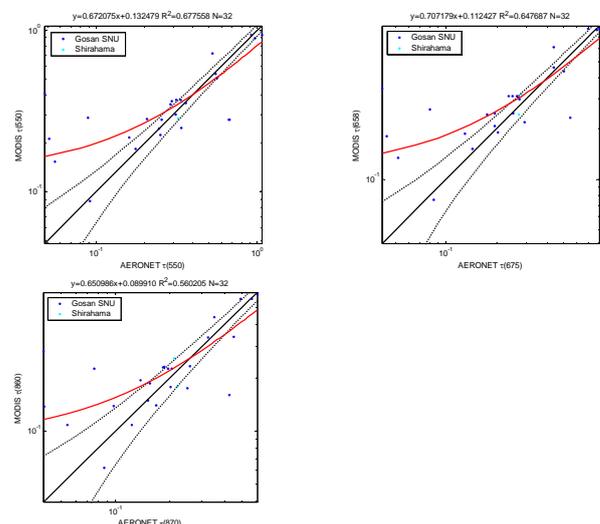


Figure 2. AOT match-up scatter diagrams at 550nm, 658nm and 860nm for 25km radius and  $\pm 0.5$ h

The result of "Shirahama" was better with RMSE of 0.03, 0.04 and 0.04, and mean relative error of 8.0%, 13.2% and 20.9% respectively for 550, 658 and 860nm channels compared with others. But, it lacked statistical meaning because of the little data amount. For spring (Mar. to May, 22 match-ups), the linear

\*  $\Delta\tau = \pm 0.03 \pm 0.05\tau$ , sampling window was 5 $\times$ 5 pixels and  $\pm 0.5$ h, same data elimination method as in this paper.

fitting results were  $y=0.804612x+0.050988(R^2=0.77)$ ,  $y=0.862697x+0.034432(R^2=0.75)$  and  $y=0.851294x+0.012003(R^2=0.71)$ , and the mean relative errors were decreased to 16.4%, 18.2% and 19.3% respectively for 550, 658 and 860nm channels.

Indexes		550nm	658nm	860nm
RMSE	Gosan SNU	0.159	0.134	0.108
	Shirahama	0.028	0.037	0.045
	All Sites	0.151	0.128	0.103
Mean $\left(\frac{\tau_M - \tau_A}{\tau_A}\right)$	Gosan SNU	89.4%	90.2%	78.0%
	Shirahama	8.0%	13.2%	20.9%
	All Sites	81.8%	83.0%	72.6%
Percentage of retrievals within expected uncertainties	Gosan SNU	58.6%	41.4%	48.3%
	Shirahama	100%	100%	33.3%
	All Sites	62.5%	46.9%	46.9%

Table 1. AOT match-up error statistics for 25km radius and  $\pm 0.5h$

Using 45km radius and  $\pm 1.0h$  as the sampling window, there were 616 match-up. Excluding those with ground-based measurements less than 4 and satellite pixels less than 9, 120 matched data were left, in which ground-based data were from sites of "Gosan SNU" (74 match-ups), "Hong Kong PolyU" (12 match-ups), "NCU Taiwan" (13 match-ups), "Shirahama" (9 match-ups) and "Taichung" (8 match-ups) with the averaged AOT at 550nm of 0.35. Figure 3 displays the scatter diagrams of match-ups. Table 2 lists the corresponding error statistics.

From the AOT linear analysis results, the validation was not satisfying with large data dispersion and  $R^2$  all less than 0.3. When data from "Taichuang" were discarded, results were better with  $R^2$  all exceeding 0.6.

The RMSE was 0.23, 0.20 and 0.17 respectively for 550, 658 and 860nm channels. The result of "Hong Kong PolyU" was best with RMSE of 0.11, 0.09 and 0.07 respectively, and the result of "NCU Taiwan" was the worst. From the mean value distribution of match-ups shown in figure 4, except for "Gosan SNU", the MODIS retrievals were lower than AERONET measurements, especially at "NCU Taiwan". It indicates to some extent that the retrieval is not largely influenced by cloud, and calibration may have the main impact. The large errors and AERONET AOT at "NCU Taiwan" indicate that this site may reflect the aerosol condition over land more than over ocean.

The mean relative errors of 3 channels all exceeded 55%. The result of "Hong Kong PolyU" was best with errors of 23.8%, 24.0% and 25.7% respectively for 550, 658 and 860nm channels. The result of "Gosan SNU" was the worst with lowest ground-based measurements.

The percentages of retrievals within the expected uncertainties were all less than 50%. If the uncertainties were  $\Delta\tau = \pm 0.05 \pm 0.05\tau$  for 658 and 860nm channels, the percentages were only increased to 47.5% and 50.8% separately. The result of "NCU Taiwan" was the best with 61.5% for 3 channels, and the result of "Taichung" was the worst. When data from "Taichuang" were discarded, the percentages of 550, 658 and 860nm were 49.1%, 37.0% and 40.7%.

Chen & Yang (2005) validated the NASA MODIS (Terra/Aqua) aerosol product from 2000 to 2004 using ground-based data

from AERONET (2 sites) and SKYNET (4 sites) around Taiwan straits and adjacent area. With 34 match-ups mainly from "NCU Taiwan" and "Chen Kung Univ" of AERONET, the percentages of retrievals within the expected uncertainties were 58.8% and 64.7% for 550 and 660nm separately\*, with the ground-based averaged AOT at 550nm of 0.6. It was close to our result of 61.5% at "NCU Taiwan" (13 match-ups) with AERONET averaged 550nm AOT of 0.50. Because the RMSE and averaged relative error at "NCU Taiwan" were relatively high (0.44 and 35.6% for 550nm) and the AOT linear relationship between AERONET and MODIS was not good, it was considered that the validation at this site was still not satisfying.

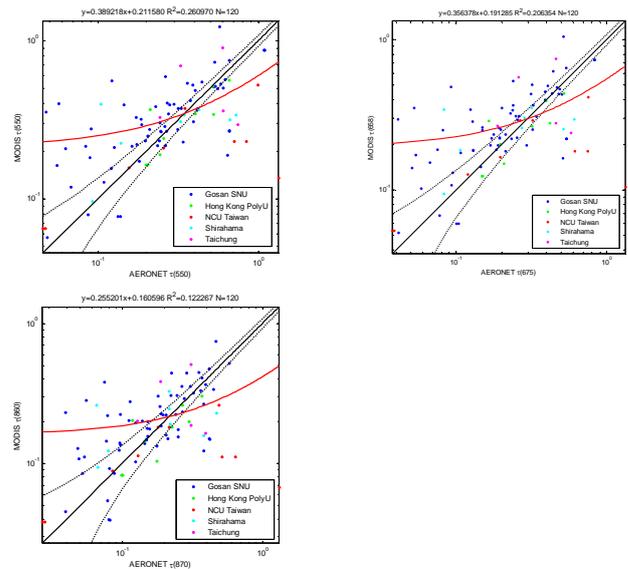


Figure 3. AOT match-up scatter diagrams at 550nm, 658nm and 860nm for 45km radius and  $\pm 1.0h$

Indexes		550nm	658nm	860nm
RMSE	Gosan SNU	0.180	0.152	0.113
	Hong Kong PolyU	0.109	0.086	0.066
	NCU Taiwan	0.437	0.414	0.401
	Shirahama	0.201	0.163	0.135
	Taichung	0.327	0.266	0.181
Mean $\left(\frac{\tau_M - \tau_A}{\tau_A}\right)$	All Sites	0.231	0.202	0.172
	Gosan SNU	81.3%	82.0%	68.8%
	Hong Kong PolyU	23.8%	24.0%	25.7%
	NCU Taiwan	35.6%	36.3%	36.8%
	Shirahama	53.0%	59.6%	66.7%
Percentage of retrievals within expected uncertainties	Taichung	56.4%	60.4%	61.3%
	All Sites	64.8%	66.1%	58.9%
	Gosan SNU	44.6%	31.1%	37.8%
	Hong Kong PolyU	58.3%	33.3%	33.3%
	NCU Taiwan	61.5%	61.5%	61.5%
Percentage of retrievals within expected uncertainties	Shirahama	55.6%	55.6%	44.4%
	Taichung	0.0%	0.0%	0.0%
	All Sites	45.0%	34.2%	37.5%

Table 2. AOT match-up error statistics for 45km radius and  $\pm 1.0h$

\* The sampling window was 9x9 pixels and  $\pm 1.0h$ , same data elimination method as in this paper.

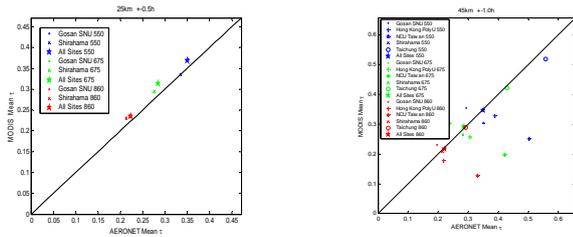


Figure 4. Scatter diagrams of mean AOT for match-ups

#### 4. CONCLUSIONS

Most AERONET sites lie with certain distances to the sea, influenced by the local aerosol (In this paper, only “Gosan SNU” and “Shirahama” are near the sea with little factitious contamination), which makes it difficult to validate aerosol product over ocean. Restricted by the distance to sea and wind direction, suitable sampling window may be different for different sites and seasons. Two spatio-temporal sampling approaches were adopted and the results were not quite the same. For the research area, the sampling window of 25km radius and  $\pm 0.5h$  was better than 45km radius and  $\pm 1.0h$ . However, using the small window, there were small amount of matched data, which was easily affected by data distribution. It still needs more data to get reliable validation result.

Using 25km radius and  $\pm 0.5h$  as the sampling window, there were 32 match-ups. The linear fitting results were  $y=0.672075x+0.132479(R^2=0.68)$ ,  $y=0.707179x+0.112427(R^2=0.65)$  and  $y=0.650986x+0.089910(R^2=0.56)$ , and without AOT less than 0.05, the  $R^2$  was increased to 0.77, 0.74 and 0.67 respectively for MODIS 550, 658 and 860nm channels. The RMSE was 0.15, 0.13 and 0.10 respectively. Without AOT less than 0.05, the mean relative errors were 37.8%, 30.8% and 30.0% respectively. The percentages of retrievals within the expected uncertainties were 62.5%, 46.9% and 46.9% respectively, and increased to 51.7% for 658 and 860nm without AOT less than 0.05. For spring (Mar. to May, 22 match-ups), the linear fitting results were  $y=0.804612x+0.050988(R^2=0.77)$ ,  $y=0.862697x+0.034432(R^2=0.75)$  and  $y=0.851294x+0.012003(R^2=0.71)$  respectively, and the mean relative errors were reduced to 16.4%, 18.2% and 19.3%.

Using 45km radius and  $\pm 1.0h$  as the sampling window, there were 120 match-ups and the validation results were relatively poor with large data dispersion, and  $R^2$  of 3 channels were all less than 0.3 while exceeding 0.6 without data from “Taichung” in the linear fitting. The RMSE was 0.23, 0.20 and 0.17 respectively for 550, 658 and 860nm with the best result 0.11, 0.09 and 0.07 at “Hong Kong PolyU” and worst result at “NCU Taiwan”. The mean relative errors all exceeded 55% with the best result 23.8%, 24.0% and 25.7% at “Hong Kong PolyU”. The percentages of retrievals within the expected uncertainties were all less than 50% with the best result of 61.5% at “NCU Taiwan”.

According to former researches, the retrieval performance is relatively poor in Asia-Pacific region compared with that of global region. Although our validation result is not as good as that of former similar region, it should be considered that there are differences of sites and time span used in these studies.

Generally speaking, the MODIS AOT product over ocean distributed by NSMC can assure certain precision, but the validation is not quite satisfying.

There appeared relatively large errors, dispersion and intercepts in linear fitting in the validation. Considering that the aerosol algorithm used in NSMC is almost the same as that of NASA, we conclude that calibration of LIB data may be the important error source besides the influence of turbid water reflectance near shore, cloud contamination, aerosol model suitability, and the representative ability of aerosols over ocean by nearby land-based observation.

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