

PRIMARY VALIDATION OF THE SYNTEM AEROSOL RETRIEVAL MODEL OVER BEIJING AREA USING AERONET DATA

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ABSTRACT:

Atmospheric aerosol, as particulate matter suspended in the air, exists in a variety of forms such as dust, fume and mist. It deeply affects climate and land surface environment in both regional and global scales, and furthermore, lead to be hugely much influence on human health. For the sake of effectively monitoring it, satellite remote sensing data are used to inverse aerosol optical depth and become the one of the most available and effective approach. With the launches of sensors several aerosol retrieval models were developed. By exploiting the synergy of MODIS data from two successive orbit of lesser interval for the same area, nonlinear equations can be solved by means of numerical methods to retrieve simultaneously the ground surface reflectance, Angstrom exponent, and aerosol optical thickness of two overpasses. The model showed promising potential to address the aerosol retrieval over higher reflective surface over land, and need to be validated and analysed. In this paper, a regional validation package for satellite aerosol optical thickness retrieval using the Aerosol Robotic Network (AERONET) observations as ground truth is described. To standardize the validation procedure, the optimum time-space match-up window, the ensemble statistical analysis method, the best selection of AERONET channels, and the numerical scheme used to interpolate/extrapolate these observations to satellite channels have been identified through sensitivity studies. More than 30 groups of MODIS data, during December 1st to 31st of 2007, were used to validate the model. All of this data are about Beijing and area around Beijing. The MODIS/AERONET τ regression has an equation of: $y = 1.0937x - 0.0373$.

1. INTRODUCE

Atmosphere aerosols exert an important influence on climate and environment in both regional and global scales, and are considered one of the largest uncertainties in today's climate modelling. Aerosol particles affect climate by changing the flow of radiant energy from the sun to the Earth's surfaces and within the atmosphere. They do this both directly, by scattering and absorbing solar radiation (Twohy et al., 1995), and indirectly, by changing cloud properties, rain, snow, and atmospheric mixing (Rosenfeld, 2000; Toon, 2000). Furthermore, the resent research has show that aerosol in troposphere have many adverse influences on human health. Ambient aerosol particles originating from the emissions o fossil-fuel-burning power plants may be transported to the respiratory system of the human organism. This particulate matter may contain harmful toxic elements and may cause adverse health effects (Alföldy et al., 2003).

For the sake of effectively monitoring it, many atmospheric aerosol observation networks are set up and provide associated informational services in the wide world, as well-known Aerosol robotic network (AERONET), Canadian Sunphotometer Network (AeroCan) and so forth. However, the aerosol optical depth show large spatial and temporal variations because of the variety of production (e.g., car exhaust, power plants, forest fires, evaporation from petroleum products,

agriculture, natural living plants, dust storms, breaking ocean waves, volcanoes), transport and removal processes and the prevailing meteorological conditions. This applies to the concentration, the size distribution, and the chemical composition, and therefore also to the aerosol optical properties. Only satellite remote sensing can provide the spatial and temporal resolution to measure the inhomogeneous aerosol fields.

Many methods have been proposed to retrieval aerosol optical depth. By exploiting the synergy of MODIS data from two successive orbit of lesser interval for the same area, nonlinear equations can be solved by means of numerical methods to retrieve simultaneously the ground surface reflectance, Angstrom exponent, and aerosol optical thickness of two overpasses. The model showed promising potential to address the aerosol retrieval over higher reflective surface over land. In order to justify the use of its aerosol products for any application, the uncertainty of the retrieval must be quantified.

Whereas MODIS achieves an almost complete global coverage one or twice a day, sun-photometer retrievals occur several times a day, but only over individual instrumented locations. The aerosol products are raster data sets with a pixel size of $1 \times 1 \text{Km}$. AERONET AOT data are acquired at 15-minute intervals on the average. It would be incongruous to compare

single MODIS pixel values directly to AERONET point measurements for many reasons.

In this paper, a regional validation package for satellite aerosol optical thickness retrieval using the Aerosol Robotic Network (AERONET) observations as ground truth is described. To standardize the validation procedure, the optimum time-space match-up window, the ensemble statistical analysis method, the best selection of AERONET channels, and the numerical scheme used to interpolate/extrapolate these observations to satellite channels have been identified through sensitivity studies. More than 30 groups of MODIS data, during December 1st to 31st of 2007, were used to validate the model. All of this data are about Beijing and area around Beijing.

2. THE VALIDATION MODEL

Xue and Cracknell (1995) have developed an operational method which relies on multiple view angle observations or multiple solar zenith angle observations of the surface to retrieval atmospheric aerosol optical depth over land. This approach can be used with ERS-2 ATSR and NOAA AVHRR data. With the launches of the MODIS sensors on the Terra and Aqua spacecrafts, new data sets of the Earth surface are obtained, and a aerosol retrieval model by exploiting the synergy of Terra and Aqua MODIS data was promoted (Tang, 2005).

Due to the different spatial and temporal resolution between MODIS aerosol optical products and the values from AERONET sites, it would be incongruous to compare single MODIS pixel values directly to AERONET point measurements for several reasons. First of all, the parameter value in an image pixel represents a spatial average over the

pixel surface (an area of 1×1Km for MODIS aerosol), and cannot be justifiably equated with a point value measured with a sun-photometer. Another important reason is that, even if the pixel is small enough to represent a sun-photometer point data, it is unlikely that it would represent the same conditions as a sun-photometer point data, since their observation axes are different and the atmosphere is constantly in motion. So the values from MODIS aerosol optical products can't compare with the observations from AERONET sites directly. To solve this problem (Ichoku et al., 2002) proposed a spatio-temporal approach for validation MODIS aerosol products (derived with the second-generation NASA/MODIS operational aerosol retrieval algorithm).

The basis for the validation model is to identify within each MODIS aerosol image each pixel falling over a validation point by its longitude and latitude. Then an N×N Km subset centred on that pixel is extracted and its mean is computed. Compare this mean with corresponding statistics of AERONET site observations. Ichoku et al. (2002) also found that the window-size dependence is generally small and has no specific trend. The average travel speed of an aerosol front is of the order of 50 km/h. This was visually estimated from animated daily sequences of TOMS aerosol index images (<http://jwocky.gsfc.nasa.gov/aerosols/aermovie.html>) for July to September 1988, where aerosol fronts are seen crossing the Atlantic from the west coast of Africa to the East coast of America (approximately 6000 Km) in about five or six days. In this paper, subsets of MODIS aerosol products were extracted and the size are 13×13 Km (13×13 pixel), and matched with about a 15 minutes sun-photometer data segment (shown in the following figure).

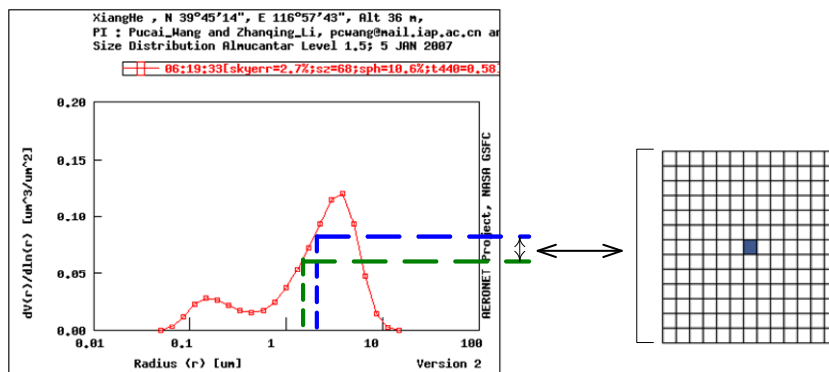


Figure 1. Subsets of MODIS aerosol products match with about a 15 minutes sun-photometer data segment

3. DATA AND PROCESSING

3.1 Data

The test area chosen is Beijing in China (about 39°-41°N, 116°-118°E). Beijing, the capital of the People's Republic of China, is the political, economic, scientific and cultural centre of the country. The 29th Beijing Olympic Games 2008 will hold in Beijing in august. However, as it gears up to host the 2008 Olympic Games Beijing has been awarded an unwelcome new accolade: the air pollution capital of the world. To monitoring air pollution well over Beijing, the authors

validated the model using a series of MODIS data of TERRA and AQUA passed over Beijing during December 1st and 31st, 2007.

In this paper AERONET observations were download form the official net and taken as ground truth. The AERONET (Aerosol Robotic NETWORK) program is a federation of ground-based remote sensing aerosol networks established by NASA and LOA-PHOTONS (CNRS) and is greatly expanded by collaborators from national agencies, institutes, universities, individual scientists, and partners. The program provides a long-term, continuous and readily accessible public domain database of aerosol optical, microphysical and radiative

properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases.

AERONET collaboration provides globally distributed observations of spectral aerosol optical depth (AOD) at 0.34, 0.38, 0.44, 0.50, 0.67, 0.87, and 1.02µm wavelengths, inversion products, and precipitable water in diverse aerosol regimes. Aerosol optical depth data are computed for three data quality levels: Level 1.0 (unscreened), Level 1.5 (cloud-screened), and Level 2.0 (cloud-screened and quality-assured). There are more than 500 observe site all the world. We use the aerosol optical depth from XiangHe observation site (39N, 116E) as the validation site. Because there isn't level 2.0 AOD Product of the validation site during the research time. So the level 1.5 product were downloaded. The aerosol optical depth according AERONET during December 2007 are showing in the following figure (Figure 2).

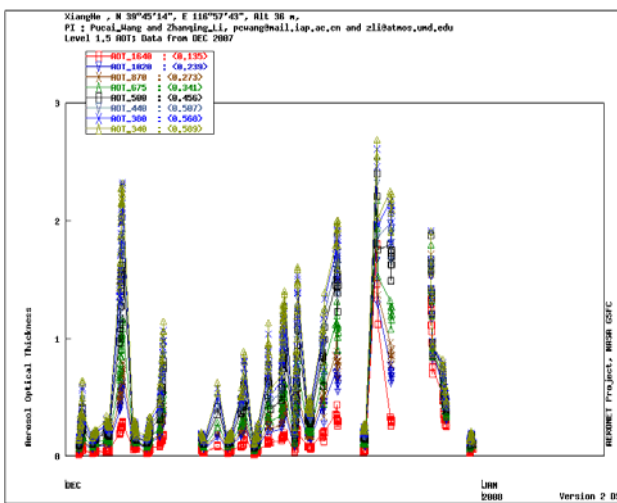


Figure 2. Aerosol optical depth level 1.5 during December 2007 from AERONET XiangHe site

3.2 Processing

To validate the model, we downloaded the MODIS data, calculated the aerosol optical depth over Beijing area using this model, extracted subsets, calculated the mean, and in the same time downloaded the relevant AERONET data, and then compared the mean with corresponding aerosol optical depth derived from XiangHe AERONET site. The whole work flow is shown in figure 3.

Before the MODIS data were used for aerosol retrieval, they should be pre-processed. The pre-processing are mainly as follow: the first process is image radiation, and then geometric correction and study area mask, and the last but most important step is cloud and water detection and mask. Because we focus on discussing the feasibility of our model, the detailed algorithm of pre-processing of data is not described in this paper.

To make the aerosol optical depth derived from AERONET observations with the MODIS aerosol optical depth products, they should well match in not only in spatial and time, but also wavelength. As what has been mentioned above, the wavelengths of former spectral aerosol optical depth are at 0.34, 0.38, 0.44, 0.50, 0.67, 0.87, and 1.02µm. However the

wavelengths of MODIS products are at 0.659, 0.55 and 0.47µm. We use the approximate expression

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

to estimate the aerosol optical depth at 0.55 and 0.47µm. In this function, λ is the wavelength, and $\ln \tau_a(\lambda)$ is the aerosol optical depth at λ , a_0, a_1, a_2 are constant. This function was proposed by ECK et al. (1999) and used widely in AERONET data interpolation/extrapolation (Zhao et al. 2002; Xia et al. 2004). Construct a group of linear functions by using the spectral aerosol optical depth are at 0.50, 0.67, 0.87µm replace $\ln \tau_a(\lambda)$. After a_0, a_1, a_2 were worked out, the aerosol optical depth at 0.55 and 0.47µm could be calculated.

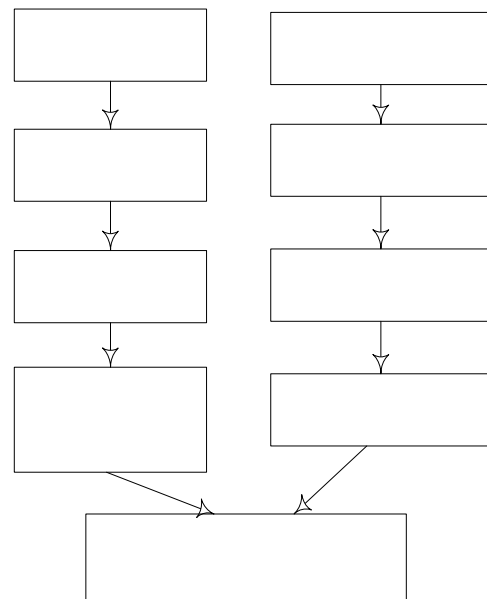


Figure 3. Work flow of validation

4. RESULT AND DISCUSSION

Using the approach mentioned above, we deal with the MODIS and XiangHe AERONET site data, work out the aerosol optical depth, and compare them with each other. Some of the retrieval results are shown in the appendix. The MODIS/AERONET τ (at 0.659, 0.55 and 0.47µm, both Terra and Aqua) regression has an equation of: $y = 1.0937x - 0.0373$, $R^2=0.95$, as shown in Figure 4. The MODIS/AERONET τ (at 0.659, 0.55 and 0.47µm, Terra) regression has an equation of: $y=1.0154x-0.0163$, $R^2=0.9245$, as shown in Figure 5. The MODIS/AERONET τ (at 0.659, 0.55 and 0.47µm, Aqua) regression has an equation of: $Y=1.1471x-0.0512$, $R^2=0.9712$, as shown in Figure 6.

Most of these validation studies have shown that although MODIS generally derived τ to within the expected error, MODIS tended to underestimate τ for small aerosol optical depth and over-estimate for high aerosol optical depth. One of the most important factors may be that the MODIS data did not corrected for water vapour, ozone, and carbon dioxide before proceeding. The MODIS products derived using MODIS aboard on Terra data are more reliable than the products derived using MODIS aboard on Aqua.

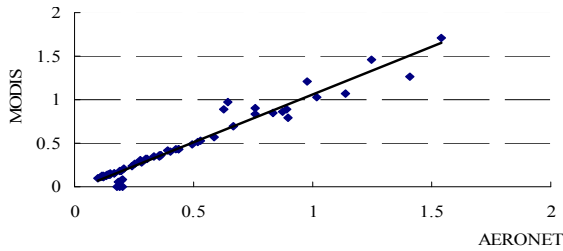


Figure 4. The correlation of AODs derived using MODIS and XiangHe AERONET site observation

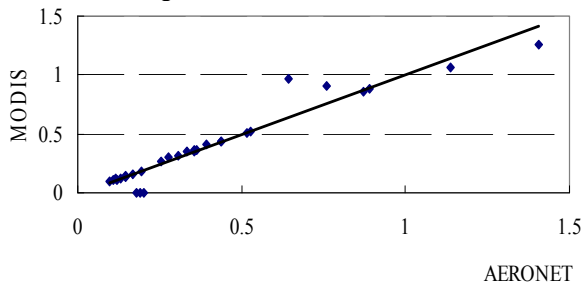


Figure 5. The correlation of AODs derived using MODIS/Terra and XiangHe AERONET site observation

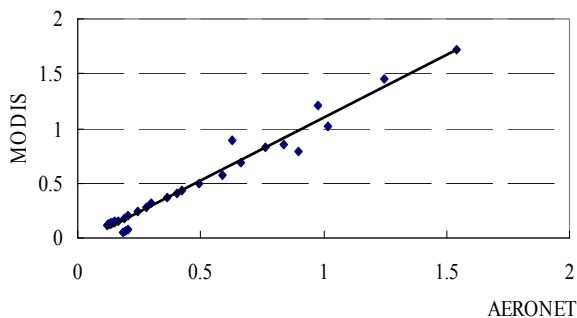


Figure 6. The correlation of AODs derived using MODIS/Aqua and XiangHe AERONET site observation

5. CONCLUSIONS

A spatio-temporal approach was used to validate the model. Using the Aerosol Robotic Network (AERONET) observations as ground truth, the retrieval values are extracted and compared with the former. The results show that, the synergy model is reliable, and the result derived using MODIS/Terra is better than using MODIS/Aqua. The reason account for have not been found, and it must be put forward in the near future.

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APPENDIX A. SOME OF THE RETRIEVAL RESULTS DERIVED USING MODIS/TERRA

| Date | Satellite | Wavelength (nm) | AERONET | MODIS | Absolute Error | Relative Error |
|------------|-----------|-----------------|-------------|-------------|----------------|----------------|
| 2007.12.3 | Terra | 660 | 0.118265505 | 0.11371489 | -0.004550615 | 0.038477957 |
| | | 550 | 0.131980377 | 0.12689603 | -0.005084347 | 0.038523507 |
| | | 470 | 0.145074519 | 0.13948455 | -0.005589969 | 0.038531708 |
| 2007.12.4 | Terra | 660 | 0.14462235 | 0.13471934 | -0.00990301 | 0.068474963 |
| | | 550 | 0.169296512 | 0.15760514 | -0.011691372 | 0.069058552 |
| | | 470 | 0.193922778 | 0.18043552 | -0.013487258 | 0.069549633 |
| 2007.12.5 | Terra | 660 | 0.888508434 | 0.88710879 | -0.001399644 | 0.001575274 |
| | | 550 | 1.137687563 | 1.0678329 | -0.069854663 | 0.061400568 |
| | | 470 | 1.407936131 | 1.2599261 | -0.148010031 | 0.105125529 |
| 2007.12.6 | Terra | 660 | 0.179270768 | 0.002545643 | -0.176725125 | 0.985800011 |
| | | 470 | 0.203657151 | 0.003615751 | -0.2000414 | 0.982245892 |
| | | 550 | 0.191979574 | 0.00307352 | -0.188906054 | 0.98399038 |
| 2007.12.8 | Terra | 660 | 0.362228973 | 0.36364001 | 0.001411037 | 0.003895428 |
| | | 470 | 0.515502692 | 0.51064003 | -0.004862662 | 0.009432855 |
| | | 550 | 0.437804314 | 0.43636 | -0.001444314 | 0.003298994 |
| 2007.12.13 | Terra | 660 | 0.098086562 | 0.099710003 | 0.001623441 | 0.016551105 |
| | | 470 | 0.117277051 | 0.11937 | 0.002092949 | 0.017846194 |
| | | 550 | 0.107965258 | 0.10982 | 0.001854742 | 0.017179063 |
| 2007.12.14 | Terra | 660 | 0.277049448 | 0.29954001 | 0.022490562 | 0.081178873 |
| | | 470 | 0.392081892 | 0.41040999 | 0.018328098 | 0.046745587 |
| | | 550 | 0.333849033 | 0.34961 | 0.015760967 | 0.047209863 |
| 2007.12.18 | Terra | 660 | 0.356516662 | 0.35282459 | -0.003692072 | 0.010355959 |
| | | 470 | 0.526186094 | 0.52120591 | -0.004980184 | 0.009464682 |
| | | 550 | 0.43940794 | 0.4350671 | -0.00434084 | 0.009878838 |
| 2007.12.19 | Terra | 660 | 0.254866755 | 0.26580705 | 0.010940295 | 0.042925548 |
| | | 470 | 0.356009915 | 0.36213122 | 0.006121305 | 0.017194198 |
| | | 550 | 0.304972592 | 0.31375133 | 0.008778738 | 0.028785334 |
| 2007.12.20 | Terra | 660 | 0.645254215 | 0.96689734 | 0.321643125 | 0.498475047 |
| | | 470 | 0.873342816 | 0.86279965 | -0.010543166 | 0.012072196 |
| | | 550 | 0.759143722 | 0.90880864 | 0.149664918 | 0.197149649 |

APPENDIX B. SOME OF THE RETRIEVAL RESULTS DERIVED USING MODIS/AQUA

| Date | Satellite | Wavelength (nm) | AERONET | MODIS | Absolute Error | Relative Error |
|------------|-----------|-----------------|-------------|-------------|----------------|----------------|
| 2007.12.3 | Aqua | 660 | 0.122136345 | 0.11407584 | -0.008060505 | 0.065995957 |
| | | 550 | 0.135009065 | 0.12730151 | -0.007707555 | 0.057089167 |
| | | 470 | 0.147191009 | 0.1399254 | -0.007265609 | 0.049361772 |
| 2007.12.4 | Aqua | 660 | 0.142596701 | 0.13563248 | -0.006964221 | 0.048838584 |
| | | 550 | 0.166621202 | 0.1586713 | -0.007949902 | 0.047712427 |
| | | 470 | 0.190558546 | 0.18165562 | -0.008902926 | 0.046720161 |
| 2007.12.5 | Aqua | 660 | 0.976029931 | 1.2084761 | 0.232446169 | 0.238154755 |
| | | 550 | 1.246727788 | 1.4536193 | 0.206891512 | 0.165947622 |
| | | 470 | 1.53965635 | 1.7141208 | 0.17446445 | 0.11331389 |
| 2007.12.6 | Aqua | 660 | 0.182773841 | 0.055978737 | -0.126795104 | 0.693726757 |
| | | 470 | 0.202152164 | 0.079067942 | -0.123084222 | 0.608869178 |
| | | 550 | 0.192937346 | 0.067368625 | -0.125568721 | 0.650826414 |
| 2007.12.8 | Aqua | 660 | 0.405157266 | 0.40909001 | 0.003932744 | 0.00970671 |
| | | 470 | 0.586904201 | 0.57446998 | -0.012434221 | 0.021186117 |
| | | 550 | 0.494371342 | 0.49090999 | -0.003461352 | 0.007001522 |
| 2007.12.13 | Aqua | 660 | 0.123400831 | 0.12464 | 0.001239169 | 0.010041821 |
| | | 470 | 0.147691739 | 0.14921001 | 0.001518271 | 0.010279999 |
| | | 550 | 0.135902043 | 0.13728 | 0.001377957 | 0.01013934 |
| 2007.12.14 | Aqua | 660 | 0.301253864 | 0.31529999 | 0.014046126 | 0.046625546 |
| | | 470 | 0.425077084 | 0.43200999 | 0.006932906 | 0.016309762 |
| | | 550 | 0.362439646 | 0.36801001 | 0.005570364 | 0.01536908 |
| 2007.12.18 | Aqua | 660 | 0.665647319 | 0.69118771 | 0.025540391 | 0.038369254 |
| | | 470 | 1.016322764 | 1.0210431 | 0.004720336 | 0.004644525 |
| | | 550 | 0.835490324 | 0.8523032 | 0.016812876 | 0.020123364 |
| 2007.12.19 | Aqua | 660 | 0.204131998 | 0.2058528 | 0.001720802 | 0.008429849 |
| | | 470 | 0.280095264 | 0.28048644 | 0.000391176 | 0.001396582 |
| | | 550 | 0.241932686 | 0.24299891 | 0.001066224 | 0.00440711 |
| 2007.12.20 | Aqua | 660 | 0.627675369 | 0.88750385 | 0.259828481 | 0.413953604 |
| | | 470 | 0.89812379 | 0.79106973 | -0.10705406 | 0.119197444 |
| | | 550 | 0.760844204 | 0.83369314 | 0.072848936 | 0.095747507 |