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# Applications of Satellite Data for Aerosol Optical Depth (AOD) Retrievals and Validation with AERONET Data

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## Abstract

An understanding of the amount and type of aerosols present in the atmosphere is required for the atmospheric correction of satellite imagery. A sensitivity analysis of the atmospheric inputs to the MOD09 software has shown that uncertainty in the estimation of Aerosol Optical Depth (AOD) has the greatest impact on the accuracy of atmospheric correction of MODIS data. The MOD09 software used for the generation of surface reflectance products estimates the AOD of the atmosphere at the time of image acquisition. AOD measurements retrieved from MODIS were compared with near-simultaneous AErosol RObotic NETwork (AERONET) data over three sites in Australia, using time-series of MODIS surface reflectance products. The results of the study provide an important independent validation of ACRES MODIS Surface Reflectance Products. This procedure may be applied to long time series MODIS data for estimating the accuracy of MOD09 retrieved AOD.

**Keywords:** Aerosol Optical Depth, MODIS Data, Urban Area

## 1. Introduction

Aerosols are one of those important geophysical parameters that determine the earth's energy balance and hydrological cycle. These suspended airborne particles scatter solar radiation back, absorb solar radiation in the atmosphere, and shade the earth's surface. Light can be scattered to the sensor through single backscattering by an aerosol particle or by a series of forward and/or backward scattering events in the atmosphere. Absorption by aerosol particles is generally spectrally and angularly dependent (King et. al, 1999). Furthermore airborne particles act as cloud condensation nuclei entering into cloud processes and thereby change cloud reflectivity and the hydrological cycle. Aerosols also affect human health and reduce visibility**.** Some aerosol types are natural, such as wind-blown desert dust or sea salt caused by breaking waves. Other aerosol types are created from human activities such as urban/industrial pollution and biomass burning. Unlike $CO_2$, another atmospheric pollutant input into the atmosphere from human activity, aerosols are not well mixed in the atmosphere and, because of their spatial and temporal variability, the uncertainty of estimating human-induced aerosol forcing on climate and the hydrological cycle is on the order of 2 W $m^2$, which is equal to the estimated forcing of all the greenhouse gases combined. Therefore, characterizing global AOD presents one of our major challenges today (Kaufman et. al, 2002). Several international agencies such as the Australian Centre for Remote Sensing (ACRES) are conducting research on reducing atmospheric attenuations from the image and on improving the MODIS surface reflectance products. Aerosols are one of the greatest sources of uncertainty in climate modeling. Aerosols vary spatially and temporally leading to variations in cloud microphysics, that could impact cloud radiative properties and climate. One of the key objectives of this study is to understand the spatio-temporal dynamics of aerosols over 3 stations in Australia for the year 2005 by comparing MODIS retrieved AODs and AERONET collocated aerosol data.

**Objectives**

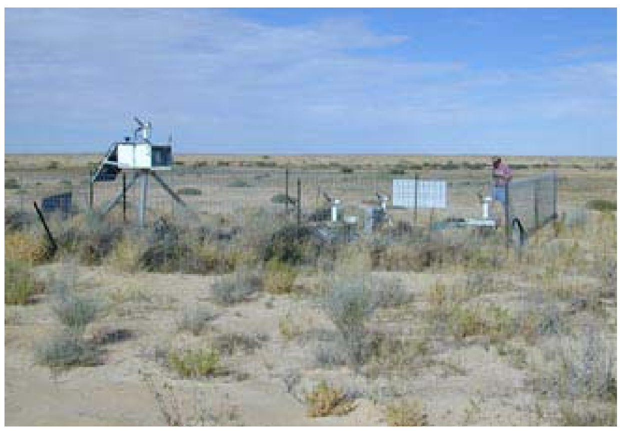
The main objective of this study was to compare the MODIS retrieved spectral AODs at 3 wavelengths onboard Terra and temporally coincident measurements of ground truth data obtained from AERONET (Aerosol Robotic Network) solar direct radiance measurements. The purpose of validation is to detect biases, if any, originating from the processes involved in deriving the products and to establish the accuracy levels of the products, based on comparison with independent observations of known accuracy (ground truth).The datasets were collocated from 3 operational AERONET sites in Australia Canberra –35˚16′15″, 149˚06′39″, Birdsville –23˚53′56″, 139˚20′49″ and Tinga Tingana –28˚58′33″, 139˚59′27″and compared with AODs retrieved from MODIS bi-products. The sun photometers from ground sites provide unprecedented spectral coverage from visible (VIS) to the solar near-infrared (NIR) and infrared (IR) wavelengths.

## 2. AERONET

The AERONET (**AE**rosol **RO**botic **NET**work) is a global consortium of ground based sun-sky radiometers where data is centrally archived and disseminated by Internet to all users. A sunphotometer is an instrument which measures the intensity of the Sun's light, when pointed directly at the Sun. Any aerosols and gases (haze) between the Sun and the photometer tend to decrease the Sun's intensity. A hazy sky would read a lower intensity of sunlight and give a lower voltage reading on the photometer. A clear blue sky would result in a greater intensity and a higher voltage reading **(*URL http: // www. nasa.gov/vision/earth/everydaylife/aeronet.html,* 2-9-2011).** The AERONET was originally established by AERONET and PHOTONS and greatly expanded by AEROCAN and other agency, institute, and university partners. The goal of this site is to assess aerosol optical properties and validate satellite retrievals of aerosol optical properties. The network imposes standardization of instruments, calibration, and processing. Data from this collaboration provides globally distributed observations of spectral AODs, inversion products, and precipitable water in geographically diverse aerosol regimes. AERONET data is available in 340 nm, 380 nm, 440 nm, 500 nm, 670 nm, 870 nm and 1020 nm. Three levels of data are available from this website: Level 1.0 (unscreened), Level 1.5 (cloud-screened), and Level 2.0 (Cloud -screened and quality-assured) (reference from Aeronet website). Since the AOD is generally less than unity, a good calibration of the radiometer is essential for the successful retrieval of aerosol optical density from space (Griggs, 1975). Only Level 1.5 cloud screened data were used since calibrated Level 2.0 data were not available for the study sites at the time of analysis.

(a)

(b)



(c)

(d)

(e)

**Figure 1. (a) A view of the instrument and site in Canberra; (b) A view of the sun photometer and the sun taken during a January 2003 firestorm, Site: Canberra; (c) Sun photometer in a weather station enclosure at a local airport, Site: Birdsville; (d) A view of the instrument site and surrounding terrain, Site: Birdsville; (e) A close-up view of the instrument platform and sun photometer, Site: Inga Tingana (with a hawk on top).**

## 3. Study Sites

Canberra (–35˚16′15″, 149˚06′39″; Elevation –600 mts) is located in the Australian Capital Territory, Birdsville and Tinga Tingana sites in Australia were selected for the study. The site began collecting data from the 15th January, 2003 and the operational time is 1038 Days [2.844 years]. The sun photometer is mounted on the roof of the two-storey CSIRO lab in Australia's capital city, Canberra.

Data was collected at the Birdsville (23˚53′56″, 139˚ 20′49″; Elevation –46.5 mts) site on the 13th August, 2005. The site has been in operational mode for 269 Days. Birdsville is located near the maximum of dust storm frequency on the continent. It lies just east of the Simpson desert, and to the north of the Strzelecki desert (where TT is located) so receives dust from the prevailing southerly and westerly winds. The third site selected for this study in Australia is Tinga Tingana (28˚58′33″, 139˚59′27″; Elevation –38.0 mts). Data has been collected from this site since the 3rd January, 1993 and the site has been in operation for 1727 Days. The Tinga Tingana site is enclosed within a fence in a desert region in Tinga Tingana, Australia. The CSIRO is responsible for the instruments and all AERONET sites in Australia are managed by a PI from CSIRO, Canberra.

## 4. Methodology

A spatial-temporal approach demonstrated by Ichoku et. al. (2002a) was employed for this study. Twenty two (22) raw Full Swath L1B MODIS packet data sets (pds) were acquired from the ACRES digital catalogue for the time period between January, 2005 to December, 2005 over the three (3) selected study sites in Australia. The MODIS scenes were acquired by using series of near coincident Landsat ETM scenes from the ACRES digital catalogue software. The pds MODIS scenes were processed by using a modified version of MOD09 atmospheric processing algorithm (originally from NASA).The product is an estimate of the surface spectral reflectance for each band as it would have been measured at ground level if there were no atmospheric scattering or absorption. It includes corrections for the effect of atmospheric gases, aerosol, and thin cirrus clouds and provides inputs to NDVI, EVI and BRDF. MOD09 permits rigorous temporal comparison and cross calibration with other sensors including AVHRR, Landsat and ASTER which leads to better exploitation of ACRES archive. The MODIS surface reflectance product (MOD09), is a seven-band product computed from the MODIS Level 1B land bands 1, 2, 3, 4, 5, 6, and 7. **Table 1** and **Table 2** show the number of bands used by MOD09 in the retrieval process, and the total number of MODIS passes used in the study respectively. The entire MOD09 work flow process is shown on **Figure 2**.

The AODs were retrieved at 3 wavelengths (Band1: 620 - 670 nm; Band3: 450 - 479 nm and Band8: 405 - 420 nm) respectively from the MOD09 atmospheric correction algorithm. At ACRES, AOD products are generated

**Table 1. MOD09 Bands**

| • Band1 648 nm | • Band2 858 nm |
|---|---|
| • Band3 470 nm | • Band4 555 nm |
| • Band5 1240 nm | • Band6 1640 nm |
| • Band7 2130 nm | |

**Table 2. Time series of MODIS scenes and information.**

| SNo | Acquisition date | Orbit No | Ancillary data used | Aeronet site names | Solar Zenith Angle (sza) Canberra and Birdsville |
|---|---|---|---|---|---|
| 1 | 04-03-2005 | 27707 | TOVS | Canberra | 0.62° |
| 2 | 08-06-2005 | 29105 | Not Available | Canberra | 1.96° |
| 3 | 15-01-2005 | 27008 | TOVS | Canberra | Geolocation error |
| 4 | 16-02-2005 | 27474 | TOVS | Canberra | Geolocation error |
| 5 | 17-12-2005 | 31901 | TOAST | Canberra | 3.11° |
| 6 | 20-03-2005 | 27940 | TOVS | Canberra | 0.78° |
| 7 | 23-5-2005 | 28872 | TOVS | Canberra | 3.65° |
| 8 | 02-07-2005 | 29455 | TOAST | Birdsville/Tinga | 6.67° |
| 9 | 03-08-2005 | 29921 | TOAST | Birdsville/Tinga | 3.44° |
| 10 | 04-09-2005 | 30387 | TOAST | Birdsville/Tinga | 3.33° |
| 11 | 07-11-2005 | 31319 | TOAST | Birdsville/Tinga | 2.17° |
| 12 | 12-03-2005 | 27824 | TOVS | Birdsville/Tinga | 9.02° |
| 13 | 13-04-2005 | 28290 | TOVS | Birdsville/Tinga | 4.05° |
| 14 | 15-05-2005 | 28756 | TOVS | Birdsville/Tinga | 6.94° |
| 15 | 16-06-2005 | 29222 | TOAST | Birdsville/Tinga | 5.85° |
| 16 | 18-07-2006 | 29688 | TOAST | Birdsville/Tinga | 3.54° |
| 17 | 19-08-2005 | 30154 | TOAST | Birdsville/Tinga | 7.39° |
| 18 | 20-09-2005 | 30620 | TOAST | Birdsville/Tinga | 3.96° |
| 19 | 22-10-2005 | 31086 | TOAST | Birdsville/Tinga | 3.88° |
| 20 | 28-03-2005 | 28057 | TOVS | Birdsville/Tinga | 5.85° |
| 21 | 29-04-2005 | 28523 | TOVS | Birdsville/Tinga | 4.23° |
| 22 | 31-05-2005 | 28989 | TOVS | Birdsville/Tinga | 4.51° |

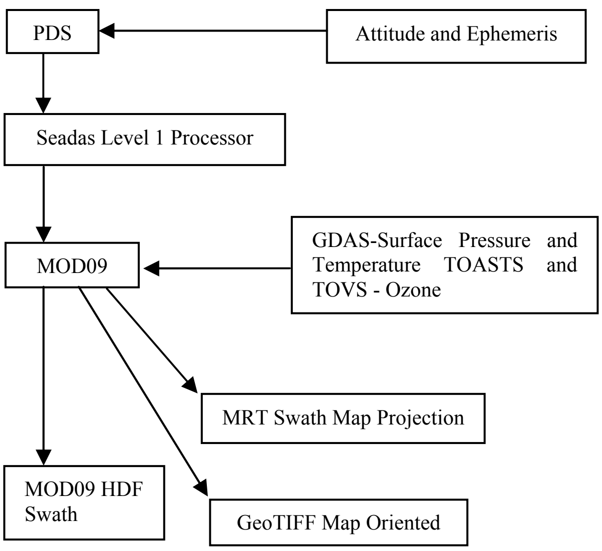



**Figure 2. MOD09 Atmospheric correction process work flow to generate a full single swath at ACRES, Australia.**

in 3 different formats - ER Mapper he differences in their data structures. MODIS covers an extensive area across a given AERONET instrument site almost in an instant, whereas the AERONET sun photometer takes point measurements several times during the daytime. MODIS expresses spatial variability, AERONET expresses temporal variability (Ichoku et.al, 2004). The AOD values for all the 3 sites were collocated and extracted over all 3 sites at a coarse and fine spatial resolution by using both spatial windows of 50 km by 50 km and 10 km by 10 km (Kaufman et.al, 2000). The MODIS retrieved AODs were then compared by plotting them against the AODs retrieved from AERONET for all 3 sites for the year 2005.

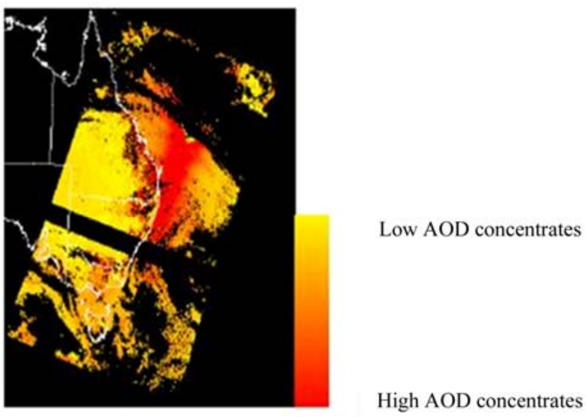
## 5. Aerosol Comparison - Results and Discussions:

Spatial and temporal distribution of MODIS and Aeronet AODs over Canberra, Birdsville and Tinga Tingana for the year 2005

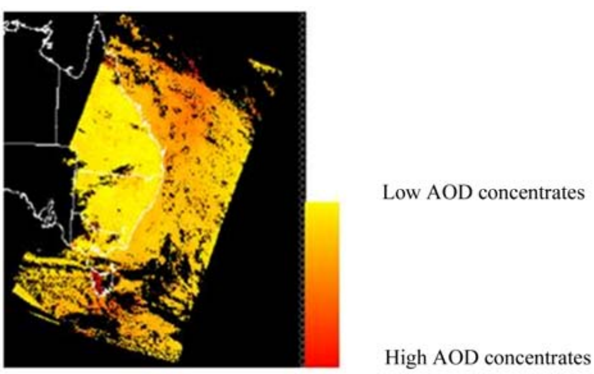
A spatial-temporal approach based on Ichoku (2002a) was employed to validate MODIS AOD retrievals in this study. MODIS retrieved AODs for 3 wavelengths (405 - 420 nm, 450 - 479 nm and 620 - 670 nm) were plotted against temporally coincident AERONET retrieved AODs. **Figures** 3 **(a)-(d)** below shows the graphs for the 3 sites for the year 2005. Spatial and temporal trends of aerosol retrievals from MODIS and AERONET for Canberra, Birdsville and Tinga Tingana sites in Australia for year 2005 are described in the following paragraphs. A generally observation is that MODIS retrievals overestimates for low aerosols and underestimates for higher AOD. AODs were extracted for variable spatial windows of 50 km by 50 km and 10 km by 10 km from the MODIS scenes. The solar zenith angle (sza) of each scenes were recorded to provide a qualitative estimate of the angular variations of AOD retrievals. The statistics (mean, median, standard deviation) were generated for each scenes and were plotted against the 3 wavelengths of AERONET (380 nm, 440 nm and 675 nm) and MODIS spectral bands (center wavelengths). The distribution of AODs (MODIS retrievals) were also mapped for all scenes to display the concentrations of high and low aerosol depths over the 3 study sites.

### 5.1. Spatio-temporal Distribution of AOD in Canberra – 2005

Yearly trend in spectral AODs retrieved by both MODIS and Aeronet over Canberra shows that AOD is low in the beginning of year and peaks during mid year period (May-June, 2005). High concentrations of AERONET AODs (0.40 and 0.10) are found in the months of May and June which reduces towards the end of the year. For these two months AERONET sun photometer estimates are significantly higher compared to MODIS retrieved AODs. This may be attributed to the increase in mid year bush fires which engulfed Canberra in 2005. The MODIS retrievals generally are overestimated for all the months compared to the AODs retrieved by the sun photometer instrument in Canberra. Overall estimates for both MODIS and AERONET are generally low for




(a)

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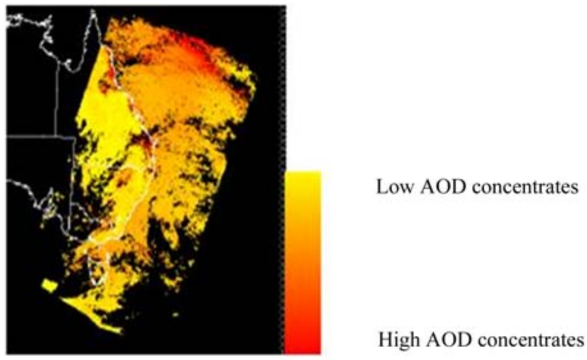


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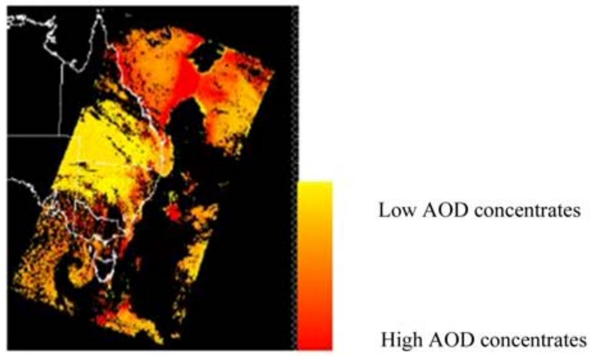


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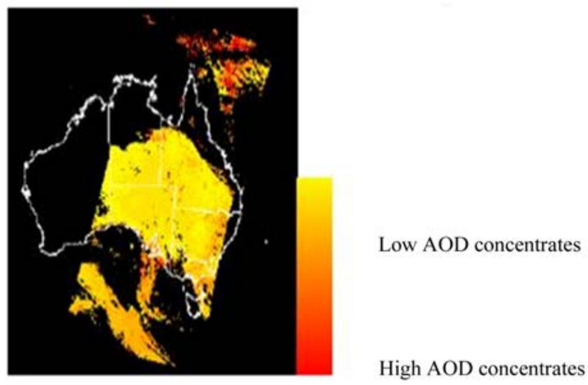


(e)

**Figure 3. (a) Spatial distribution of AOD retrievals from MODIS: Band 1 over Canberra – 4 March, 2005. (b) Spatial distribution of AOD retrievals from MODIS: Band 1 over Canberra – 23rd March, 2005. (c) Spatial distribution of AOD retrievals from MODIS: Band 1 over Canberra – 8th June, 2005. (d) Spatial distribution of AOD retrievals from MODIS: Band 1 over Birdsville – 12th March, 2005.(e) Spatial distribution of AOD retrievals from MODIS: Band 1 over Birdsville – 12th March, 2005.**

Canberra expect for May, 2005 where the MODIS and Aeronet AODs reach a peak of 0.60 and 0.40 respectively.

 

### 5.2. Spatio-temporal Distribution of AOD in Birdsville, 2005

For Birsdville in general MODIS retrievals overestimate AODs. For instance for 12th March, 2005 MODIS more than Aeronet retrievals by 0.02 except at 440 nm - 470 nm where MODIS retrievals are underestimated to the Aeronet AODs. 28thMarch, 2005: MODIS retrievals overestimate AOD at 470 nm but run close to Aeronet retrievals for the other wavelengths. 13thApril, 2006 MODIS retrievals overestimate AODs at 412 nm and 470 nm but underestimate at 659 nm. 29th April: MODIS retrievals underestimate AODs at 412 nm and 659 nm, but overestimate at 470 nm.15thMay, 2005: MODIS retrievals underestimate AODs at 412 nm and 659 nm but overestimate at 470 nm 31stMay, 2005: MODIS retrievals underestimate AOD at 412 nm and 659 nm but overestimate at 470 nm MODIS retrievals underestimate at all wavelengths. 2ndJuly,2005: MODIS underestimates at 412 nm and 470 nm but overestimates at 675 nm marginally. 18th July,2005: MODIS retrievals underestimate AODs at 412 nm and 659 nm but overestimate at 470 nm. For the months of August, September, and October MODIS retrievals underestimate Aeronet retrievals at all the wavelengths.

### 5.3. Spatio-temporal Distribution of AOD in Tinga Tingana – 2005

MODIS retrievals overestimate Aeronet retrievals for all wavelengths but for certain months the opposite trend is observed particularly for in the months of October and November, 2005 where the MODIS retrievals are underestimated by Aeronet estimates. Some months the MODIS and Aeronet estimates underestimate at some wavelengths but overestimate at others. For instance on 12th March, 2005 the MODIS retrievals match Aeronet at 380 - 412 nm (**Figure 3 (e)**) but overestimates at 440 - 470 nm and underestimates at 659 - 675 nm wavelength. On 28th March, 2005 the MODIS retrievals overestimate the Aeronet retrievals at all wavelengths. On the 13th April, 2005 the MODIS retrievals underestimate the Aeronet estimates at 380 - 412 nm and 659 - 675 nm wavelengths, but between 440 – 470 nm wavelengths the MODIS retrievals match the Aeronet retrievals. On 15th May,2005 the MODIS retrievals overestimate the Aeronet retrievals at all wavelengths and on the 2ndJuly, 2005 the MODIS retrievals underestimate at 380 - 412 wavelength, but overestimate the Aeronet retrievals at the 440 - 470 nm and 659 - 675 nm wavelengths. On the 18thJuly, 2005 the MODIS retrievals underestimate AODs at 412 nm and 659 nm but overestimate at 470 nm. On 3rdAugust, 2005 the MODIS retrievals overestimate Aeronet retrievals for all the wavelengths.

On the 4thSeptember, 2005 the MODIS retrievals underestimate the Aeronet retrievals for all wavelengths. On 22ndOctober and 7thNovember, 2005 the MODIS retrievals underestimate the Aeronet retrievals for all wavelengths.

## 6. Conclusions

Yearly data sets were compared in this study over three sites in Australia using level 1.5 cloud free data. The MODIS retrieved AOD overestimates compared with the Aeronet retrievals. The results also may be affected by the numerous problems posed to aerosol retrieval by the surface background over land and the potential sampling mismatch in comparing averages from MODIS spatially variable data space and AERONET temporally variable data space. There were some limitations that may have contributed to the accuracy of validation. AOD is generally less than unity, a good calibration of the radiometer is essential for the successful retrieval of aerosol optical density from space. Calibrated Aeronet data (Level 2.0) was not available over the 3 study sites which further reduced the accuracy of the study. It is important to understand the proportion of trace gases like water vapour, carbon dioxide which absorb solar radiation in the 1600, 2100 nm wavelengths. Estimating AODs is a challenging research investigation due to the highly variable spatial and temporal dimensions of AODs. Some changes in the internal instrument temperature are also some cause of false signals in sun photometers. Calibration of sites is a complex process and efforts are underway in Australia to provide calibrated AOD data which we hope this will further enhance the accuracy of results presented in this study.

Despite these limitations in the assessment a general conclusion is that MODIS AODs tend to overestimate the AODs particularly over land.

## 7. Acknowledgements

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