VALIDATION OF AEROSOL OPTICAL DEPTH RETRIEVALS BY REMOTE SENSING OVER BRAZIL AND SOUTH AMERICA USING MODIS

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RESUMO: Um sistema para a obtenção de produtos de aerossol a partir de dados do sensor MODIS/Terra e MODIS/Aqua foi estabelecido na DSA-CPTEC/INPE baseado em algoritmos da NASA/GSFC, conforme detalhado em outro trabalho. Esse sistema permite a obtenção do mapeamento da profundidade óptica de aerossóis (AOD) sobre o Brasil e partes da América do Sul. Este trabalho apresenta os primeiros resultados de comparações entre a profundidade óptica de aerossóis obtidas pelo sistema e medidas de atenuação óptica com radiômetros da rede AERONET em vários locais na América do Sul. A maior parte das observações disponíveis atualmente refere-se ao período úmido sobre a região amazônica, quando a emissão de aerossóis atinge os menores valores anuais. Os resultados preliminares obtidos a partir de 380 observações permitiram ajustar um modelo linear da forma [AOD DSA-CPTEC/INPE] = (-0,089±0,066) + (1,25±0,27) [AOD AERONET], com índice de correlação de cerca de 0,92 estatisticamente significativo ao nível de 95%. O modelo linear concorda com estimativas de incertezas pré-lançamento MODIS e também com resultados prévios de outros autores. Os resultados apresentados neste trabalho ajudam a corroborar a validade das estimativas de profundidade óptica de aerossóis do sistema DSA-CPTEC/INPE.

ABSTRACT: A system to derive timely aerosol products after each MODIS/Terra and MODIS/Aqua satellite overpass was put together at DSA-CPTEC/INPE based on NASA/GSFC computer algorithms, as discussed in a companion work. This system allows for the prompt retrieval of maps of Aerosol Optical Depth (AOD) covering large areas in Brazil and parts of South America. This work presents the first results of comparisons between AOD estimates obtained by the system and experimental optical attenuation measurements performed with AERONET sun/sky radiometers at several sites in South America. The major part of observations now available occurred under the wet season period in Amazon Basin, when aerosol emissions due to biomass burning is minimal during the year. The preliminary results of 380 observations allowed fitting the linear model [DSA-CPTEC/INPE AOD] = (-0.089±0.066) + (1.25±0.27) [AERONET AOD], with a correlation index of 0.92, statistically significant to the 95% level. The linear model agrees with MODIS pre-launch estimates for the uncertainty in AOD retrievals, and with previous results by other authors. The results presented here help corroborate the validity of AOD estimates obtained by the DSA-CPTEC/INPE system.

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INTRODUCTION

The climatic relevance of atmospheric aerosol particles has been discussed for several years. These particles can influence the climate from regional to global scales, by directly interacting with sunlight through scattering or absorption processes, or indirectly by acting upon cloud formation and cloud lifetime. The daily atmospheric loading of aerosols can be assessed by MODIS (Moderate Resolution Imaging Spectroradiometer), a multi-channel sensor installed on Terra (King *et al.*, 2003) and Aqua (Parkinson, 2003) satellites controlled by NASA/GSFC (National Aeronautics and Space Administration/Goddard Space Flight Center). A system based on NASA/GSFC MODIS aerosol retrieval algorithms modified to some extent was deployed at the DSA-CPTEC/INPE (Satellite and Environmental Systems Division – Center for Weather Forecast and Climatic Studies/National Institute for Space Research, Brazil), as discussed in a companion work (Correia, 2006). The system is being used for deriving timely aerosol products after Terra and Aqua overpasses and also for reprocessing archived overpasses since 1999. This work discusses the first results on the validation of aerosol optical depths (AOD) retrieved by the DSA-CPTEC/INPE system by comparison with ground radiometers measurements in several places in South America.

VALIDATION OF MODIS AEROSOL RETRIEVALS

The validation of any satellite product, like MODIS aerosol retrievals, is a complex task involving the comparison with calibrated "ground truth" instruments accepted by the scientific community. Ideally the comparisons should be performed under the most extensive set of conditions such as different seasons, geographic locations, altitudes, biomes, etc., in order to assess how these variations impact over the satellite retrievals. In practice data availability limitations usually preclude a definitive assessment, and the validation process is performed continuously or in several steps. An important issue is how to convert experimental ground measurements into corresponding satellite-equivalent results for direct comparison with the retrieved values. Ground measurements and satellite retrievals usually have different characteristics such as spatial and

temporal resolution, measurement geometries, validity range and instrumental reliability. In order to allow comparisons between these different systems, a number of hypotheses need to be assumed.

The aerosol optical depth retrieved by MODIS is validated by comparison with AERONET (Aerosol Robotic Network) results, a network of automated sun/sky radiometers conceived and maintained by NASA/GSFC (Holben *et al.*, 1998). These radiometers measure, among other parameters, the attenuation of direct sunlight in up to eight wavelengths (1640, 1020, 870, 675, 500, 440, 380 and 340 nm) to derive the corresponding aerosol optical depths from Beer-Bouguert-Labert's Law, as well as the Angström exponent between a number of wavelength pairs (440-870, 380-500, 440-675, 500-870 and 340-440 nm). AERONET measurements are site-specific since the instruments are fixed in a location, with measurement intervals of up to 15 minutes during all daylight period. AERONET products are available in different processing levels: level 1.0 (raw data), level 1.5 (automated cloud-screened data), and level 2.0 (quality-assured data). Level 2.0 data is only available several months after the measurements (Smirnov *et al.*, 2000), so this work uses level 1.5 data, but introducing a more restrictive cloud-screening logic (Pires *et al.*, 2006) due to a few anomalous episodes in AERONET level 1.5 data over Brazil.

The MODIS aerosol product has a nominal spatial resolution per pixel of 10 km and the time coverage is at most twice a day over Brazil. In order to compare MODIS and AERONET retrievals, Ichoku *et al.* (2002) consider a 50 x 50 km box of MODIS pixels around an AERONET site location and the average AOD value in this box is compared to 1 hour average of AERONET measurements centered on the overpass time. In this work a similar methodology is used, but employing four box sizes and two time intervals to determine the best combination between AERONET time averages and MODIS spatial averages.

METHOD

The MODIS overpasses used in this work correspond to the months of August-September 2002 and from April to August 2006, amounting to a total number of 1085 5-minute slabs of data (granules). For each data granule the MODIS AOD values were assessed over selected locations in South America corresponding to the AERONET sites listed in Table 1, extending from the Amazon Basin to high latitude sites, from nearly sea level up to about 3400 m above sea level (asl) sites.

Table 1. Geographic coordinates and elevation of AERONET sites used in this work.

Site name	*Latitude*	*Longitude*	*Elevation (m asl)*
Alta Floresta	-09.92	-56.02	175
Rio Branco	-09.96	-67.87	212
Ji Paraná SE	-10.93	-62.85	218
Cuiabá Miranda	-15.73	-56.02	210
La Paz	-16.54	-68.07	3439
Campo Grande Sonda	-20.44	-54.54	677
São Paulo	-23.56	-46.73	865
Cordoba CETT	-31.52	-64.46	730
CEILAP-BA	-34.57	-58.50	10
Trelew	-43.25	-65.31	15

For the sites shown in Table 1, the retrieved MODIS AOD value on the site pixel was stored, as well as the mean AOD and its standard deviation in grids of 30 km, 50 km and 150 km centered around the site. Figure 1 shows an example of RGB composition for a Terra/MODIS overpass over the Amazon Basin, the retrieved map of AOD in 550 nm, and a schematic drawing showing the relative sizes of averaging boxes used in this study from 30 to 150 km, centered on the retrieved AOD pixel with 10 km spatial resolution.

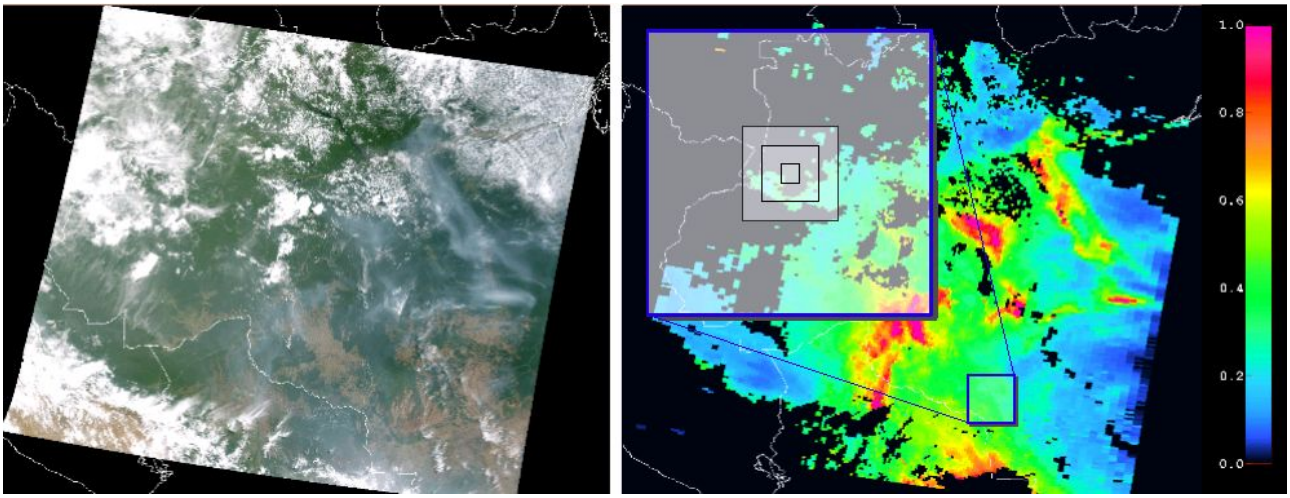

Figure 1. Example of RGB composition (left) of Terra/MODIS overpass over Amazon Basin on 16 August 2006 14:35 UTC, and corresponding AOD map (right) retrieved at 550 nm showing the relative sizes of averaging boxes of 30, 50 and 150 km around the 10 km AOD pixel.

Since AERONET retrievals are done for 500 nm and MODIS AOD is retrieved on 550 nm, the AERONET Angström exponent between wavelengths 440 and 675 nm was used to derive AERONET AOD at 550 nm, using the equation:

$$\tau_2 = \tau_1 / \exp [-\alpha \ln (\lambda_1/\lambda_2)]$$

where τ_2 is the AOD in 550 nm, τ_1 is the AOD in 500 nm, α is the Angström exponent between 440 and 675 nm, λ_1 is 500 nm, and λ_2 is 550 nm.

The AERONET AOD results in 550 nm for each site on Table 1 were used to derive AOD averages of 1 hour and 24 hours centered on the MODIS overpass time above each location to allow comparison with MODIS box averages. As a result of this methodology, the final dataset was composed of 387 coincident pairs of AERONET time AOD averages of 1h and 24h, and MODIS spatial AOD averages of 10, 30, 50 and 150 km.

RESULTS AND DISCUSSIONS

Comparing AERONET time averages and MODIS spatial averages for the dataset used in this study, for 7 cases in 387 the AERONET AOD value was exceptionally too high comparing with the MODIS AOD value. This turned out to be due to an anomalous behavior of AERONET level 1.5 data at just one site, in a way that passed the automated cloud-screening algorithm. For this reason a more rigorous cloud-screening logic was employed, following Pires *et al.* (2006).

After applying the new cloud-screening logic, the best correlation was obtained comparing AERONET 1 hour averages and MODIS 50 km spatial averages. In this way 380 individual observations of AERONET and MODIS retrievals were fitted to a linear model in the form of [DSA-CPTEC/INPE MODIS AOD] = (-0.089±0.066) + (1.25±0.27) [AERONET AOD], with a correlation index of 0.92 statistically significant to the 95% level. In order to allow the comparison of results with Remer *et al.* (2005), the individual observations were sorted according to increasing AERONET AOD values, then averaged in bins of 20 or 5 observations, storing also the respective standard deviation. Figure 2 shows the result of the comparison between MODIS and AERONET.

In Figure 2, most of the data concentrates in the region of lower AOD values because most of the MODIS data now available corresponds to the wet season in Amazon Basin, while the greatest source of aerosol particles in South America comes from biomass burning during the dry season. The error bars (*i.e.* standard deviation) for the lowest AOD bins are smaller than for higher AOD bins, reflecting the increasing scatter of values for retrievals with high AOD. Most of the data fall within the expected uncertainty bands based on pre-launch estimates for MODIS.

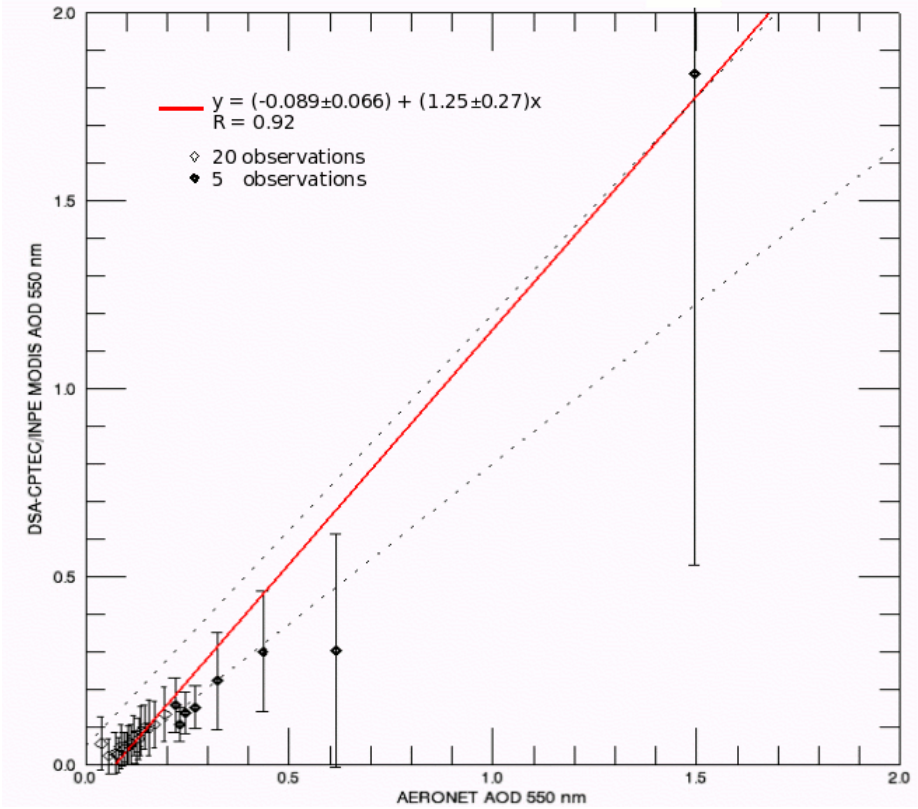

Figure 2. Comparison between AERONET AOD and DSA-CPTEC/INPE MODIS AOD in 550 nm. A total number of 380 cases was used for the fit shown in red, with a correlation coefficient R=0.92. After the fitting, individual data points were averaged in bins of 20 or 5 observations, as indicated. The error bars correspond to the standard deviation for each bin. The dotted lines represent pre-launch estimates of AOD uncertainty for MODIS. This graph was assembled in a manner similar to Remer *et al.* (2005), to allow for the comparison of results.

The results previously reported by Remer *et al.* (2005) show a similar data treatment and a resulting linear model of [MODIS AOD] = 0.068 + 0.78 [AERONET AOD], with a correlation index R = 0.80 for 5906 data points. No uncertainties for the linear or angular coefficients are reported by the authors. The results of the present work are in general agreement with Remer *et al.* (2005), with a slightly better correlation coefficient but with fewer data points. This shows that the AOD retrievals using the DSA-CPTEC/INPE system are compatible with "ground truth" retrievals by AERONET radiometers.

FINAL REMARKS

This work showed the preliminary results for the validation of AOD retrievals obtained by a system deployed at DSA-CPTEC/INPE based on modified NASA/GSFC algorithms. A total number of 380 observations allowed fitting the linear model [DSA-CPTEC/INPE AOD] =

(-0.089±0.066) + (1.25±0.27) [AERONET AOD], with a correlation index R = 0.92. The linear model agrees with MODIS pre-launch estimates for the uncertainty in AOD retrievals and with previous results by Remer *et al.* (2005). These results help corroborate the validity of AOD estimates obtained by the DSA-CPTEC/INPE system.

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