MONITORING AEROSOL OPTICAL DEPTH USING MODIS OVER BRAZIL AND SOUTH AMERICA

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RESUMO: Partículas de aerossol podem influenciar o clima diretamente devido à absorção ou espalhamento de luz solar, ou indiretamente devido à interações com nuvens. 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 computacionais da NASA/GSFC. Esse sistema permite a pronta obtenção do mapeamento da profundidade óptica de aerossóis em 550 nm sobre o Brasil e partes da América do Sul. Para estudos de longo prazo uma base de dados de estimativas de aerossol está sendo construída a partir das passagens de satélite arquivadas desde o lançamento do Terra (1999) e do Aqua (2003). Este trabalho apresenta os primeiros resultados obtidos a partir desse sistema, e sua validação é abordada em outro trabalho. Tipicamente sob condições limpas observaram-se profundidades ópticas de 0,038±0,067, e de 0,41±0,37 em situações poluídas, com um máximo de 2,480±0,005. Futuramente novos desenvolvimentos serão incorporados ao algoritmo de aerossóis, tais como modelos dinâmicos específicos para o Brasil e América do Sul, e/ou produtos com maior resolução espacial. Esses resultados poderão ser assimilados em modelos químicos de previsão do tempo e clima.

ABSTRACT: Atmospheric aerosol particles can influence the climate either by directly interacting with sunlight acting as scatterers or absorbers in the atmosphere, or indirectly by acting upon clouds and thus influencing hydrological cycles. 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. This allows for the prompt retrieval of maps of Aerosol Optical Depth (AOD) at 550 nm covering large areas in Brazil and parts of South America. For longer-term studies, a database is being built with aerosol retrievals from archived overpasses since the launch of Terra (1999) and Aqua (2003). This work presents the first results obtained by the system, whereas validation of this product is shown in a companion work. AOD under typical clean conditions was about 0.038±0.067, and 0.41±0.37 under polluted situations, reaching up to 2.480±0.005. In the future new developments will be incorporated into the aerosol algorithm, like specific dynamic aerosol models for Brazil and South America, and/or finer resolution aerosol products. These results can be assimilated into chemical weather forecast or climatic models.

Keywords: Atmospheric aerosols, remote sensing of the atmosphere, MODIS.

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INTRODUCTION

Atmospheric aerosols are solid or liquid particles suspended in the atmosphere, which can originate in natural or man-made processes. The particle matter composing the aerosol has an average residence time of a few days and, differently from gaseous pollutants, possess a high degree of spatial heterogeneity. Aerosol 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. Long range transport of aerosol particles can add complexity to this scenario, favoring chemical and physical interferences on atmospheric states not only locally but also potentially over regional to global scales (Freitas *et al.*, 2005).

MODIS (Moderate Resolution Imaging Spectroradiometer) is a multi-channel sensor installed on Terra (King *et al.*, 2003) and Aqua (Parkinson, 2003) satellites. Its design allows for global daily retrievals of aerosol loadings in the atmosphere and other aerosol parameters (Remer *et al.*, 2005). The basic NASA/GSFC (National Aeronautics and Space Administration/Goddard Space Flight Center) algorithm for deriving aerosol retrievals by MODIS employs the calibrated and geolocated radiances measured by the radiometer on Terra and Aqua spacecrafts, cloud mask information and ancillary NCEP (National Centers for Environmental Prediction) data. The algorithm uses look-up tables of pre-computed radiative transfer calculations in the atmosphere, under several observational and illumination conditions. Measured radiances at the top of the atmosphere, together with estimates of surface reflectance are compared to values in the look-up tables to find the best solution under least squares fits.

This work shows the first results of an aerosol retrieval system based on NASA/GSFC algorithms, modified to some extent and deployed at the DSA-CPTEC/INPE (Satellite and Environmental Systems Division – Center for Weather Forecast and Climatic Studies/National Institute for Space Research, Brazil). The system's use is twofold: it is being used for deriving timely aerosol loading information after each MODIS/Terra and MODIS/Aqua satellite overpass, allowing for the assimilation of aerosol maps into chemical weather models; the system is also being used for reprocessing overpasses archived since the launch of Terra (1999) and Aqua (2003) spacecrafts, in order to build a database of aerosol information that may be used on climate studies.

AEROSOL DETECTION SYSTEM USING MODIS

The main issue regarding aerosol detection using MODIS is the due accounting of gaseous and surface reflectance in the signal detected by the sensor. The aerosol layer in general scatters much less radiation in the direction of the detector than the underlying surface, so the MODIS strategy to detect aerosol loadings relays on the dark target approach (Fraser *et al.*, 1984; Kaufman *et al.*, 1997), by which the surface reflectance in the red and blue MODIS channels are estimated from measurements of dark pixels in the infrared 2.1 μm channel. A detailed discussion about the basics of aerosol retrieval by MODIS is given elsewhere (Remer *et al.*, 2005; Correia *et al.*, 2006).

The National Institute for Space Research (INPE) in Brazil receives MODIS/Terra and MODIS/Aqua data in a ground station strategically located in the city of Cuiabá (15.6°S, 66.1°W), allowing data coverage over most of Brazil and parts of South America. A system to derive aerosol products using MODIS was deployed at the DSA-CPTEC/INPE. The system uses the raw data acquired at Cuiabá and processes them up to aerosol products. This involves a complex processing chain, starting from the raw data, converting them to MODIS Level 0 data, then performing radiometric calibration and geolocation (Level 1B data), and then starting the product chain (Level 2 data) obtaining cloud mask, atmospheric profiles, and finally aerosol and water vapor products. The full processing time ranges between about 30-40 minutes, depending on computer load and the overpass length, *i.e.* the satellite zenith angle over the reception antenna. This allows obtaining timely aerosol retrievals after each satellite overpass, well suited for assimilation into chemical weather models. For these retrievals ancillary data are also used such as calculated attitude and ephemeris for each spacecraft and weather forecast fields from NCEP.

MODIS data collected at Cuiabá are stored in tapes for reprocessing a few days after the overpasses or after science upgrades in the algorithm code. The reprocessing after a few days employs "definitive" ancillary data, such as NCEP reanalysis fields and actual attitude and ephemeris data as recorded for Terra and Aqua spacecrafts. This reprocessing is being used to generate a database of aerosol retrievals over Brazil and South America since the launch of Terra (1999) and Aqua (2003) that may be used in climate studies or in applications over a determined area in South America (Corrêa *et al.*, 2006).

After implementation, the system operated generating data results with 10 km pixel resolution matching exactly the expected for the standard Collection 4 (*i.e.* the fourth version) NASA/GSFC computer algorithms. On April 2006 NASA/GSFC started processing a new set of improved algorithms named as Collection 5. A summary of the improvements in the aerosol retrieval algorithm is discussed by Remer *et al.* (2006). Following the recommendations by these researchers, some modifications were also implemented at the DSA-CPTEC/INPE system. The lower limit of valid range allowed for Aerosol Optical Depth (AOD) values was extended to -0.10 to reduce a positive bias in the long-term series of retrievals. Although negative optical depths lack physical meaning, small negative values are statistically consistent considering very clean scenes and the uncertainties attached to the estimation of any physical parameter. Along the same lines, small negative values are now allowed on the DSA-CPTEC/INPE system for the reflectance measured by MODIS in the 1.38 μm channel, which is very important to detect thin cirrus clouds. Under very clean conditions the reflectance in this channel is near zero, but due to statistical fluctuations it could return small positive or negative values. For example, in a specific clean scene extending the 1.38 μm reflectance lower range of validity to -0.005 was enough to boost the number of retrievals over Brazil by more than 300%, since the algorithm previously rejected a large number of good pixels due to their small negative reflectances. Another modification introduced on the DSA-CPTEC/INPE system was the improvement on the cloud mask logic, according to the discussion by Remer *et al.* (2006). In the future new developments will continue to be integrated into the DSA-CPTEC/INPE aerosol algorithm, such as dynamic aerosol models developed for Brazil and/or results in finer spatial resolution.

METHOD

A set of Terra and Aqua overpasses was used to assess statistics for the aerosol product, corresponding to the months of August-September 2002 and from April to August 2006. As the reprocessing of archived overpasses continues other sets of aerosol data become progressively available. Each pass is divided in two or three files corresponding to 5-minute slabs of data called “granules”, amounting to a total of 1085 granules for the time period under analysis. For the sake of statistical computation, a maximum threshold AOD value of 0.20 was used to classify pixels as "clean" or "polluted", according to experimental results by Artaxo *et al.* (2006). In order to study the statistical robustness and stability of the retrievals, AOD values returned by the algorithm were assessed over selected locations in South America corresponding to AERONET (Aerosol Robotic Network, Holben *et al.*, 1998) sites. Over these sites, the retrieved AOD value was stored, as well as the mean AOD and its standard deviation in grids of 30, 50 and 150 km centered around the sites.

RESULTS AND DISCUSSIONS

Initial aerosol results obtained by the DSA-CPTEC/INPE system are presented below. Figure 1 shows an example of RGB composition and the corresponding AOD granule retrieval for Terra/MODIS overpass on 16 August 2006 14:35 UTC.

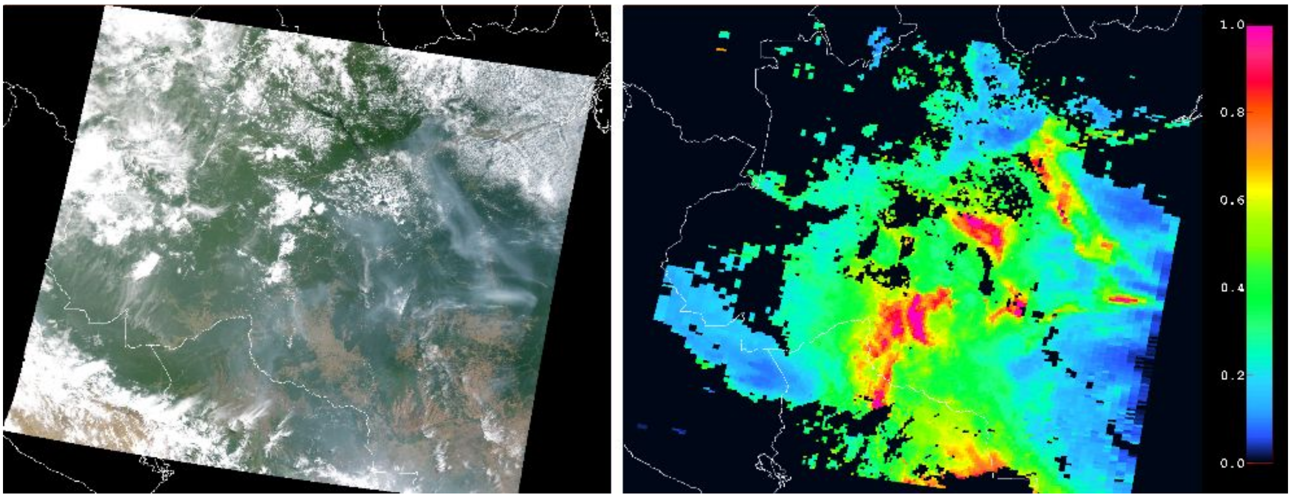

Figure 1. Example of RGB composition (left) of Terra/MODIS overpass over Amazon Basin on 16 August 2006 14:35 UTC, and corresponding AOD map (right) retrieved at 550 nm. Clouds and regions outside of sensor reach are masked as black areas.

In the RGB composition in Figure 1 one notices large areas covered by smoke from biomass burning that impact over the Amazon region every year. The corresponding aerosol map shows AOD values in excess of 1.0 for some regions, and cloud covered pixels are masked as black areas.

Table 1 summarizes the results of AOD statistics for clean and polluted scenes for the period discussed in the previous section, considering the AOD values for the pixels corresponding directly to the AERONET sites ("On site" 10 km pixel), and for grids centered on the sites, with sizes of 30, 50 and 150 km. In Table 1 one notices that the largest number of observations (N) occurred under clean conditions. This is due to the casual bias towards the wet season for the period under consideration. For the retrievals directly over the sites 475 cases were classified as "clean", with an average AOD and standard deviation of 0.038±0.067. For the 149 "polluted" cases the average AOD was about one order of magnitude higher, 0.413±0.369, with a maximum of 2.480±0.005. Comparisons of the AOD retrievals with AERONET experimental results are discussed in a companion work (Correia & Pires, 2006).

Table 1. AOD statistics over selected AERONET sites[a].

Grid	Condition	N	Average	Standard Deviation	Minimum	Maximum
On site	clean	475	0.038	0.067	-0.050	0.199
	polluted	149	0.413	0.369	0.200	2.480
	all	624	0.128	0.248	-0.050	2.480
30 km	clean	525	0.056	0.062	-0.045	0.199
	polluted	92	0.448	0.433	0.200	2.454
	all	617	0.114	0.225	-0.045	2.454
50 km	clean	650	0.061	0.057	-0.038	0.199
	polluted	109	0.470	0.530	0.200	3.809
	all	759	0.120	0.252	-0.038	3.809
150 km	clean	911	0.067	0.056	-0.036	0.200
	polluted	140	0.481	0.536	0.202	3.054
	all	1051	0.122	0.246	-0.036	3.054

a) Clean conditions: AOD < 0.20, polluted conditions: AOD >= 0.20; N is the number of observations. Uncertainty for minimum and maximum AOD retrievals is 0.005.

On Table1 the grid AOD averages for clean cases show values between 0.056 and 0.067, which is slightly above the 0.038 observed directly over the sites, especially considering the standard deviation of such averages. For the polluted scenes there is a small increase in the averages as the grids become larger. The on site polluted average is 0.413, while for the grids they are 0.448, 0.470 and 0.481. As observed for the on site averages, the grids results for polluted cases are in general about one order of magnitude higher than the clean cases.

The standard deviations under clean conditions are remarkably similar for all kinds of averages, ranging from 0.056 to 0.067, so the aerosol spatial distribution possess some scale invariance properties under low loading conditions. For polluted cases the standard deviations grew somewhat with grid size, varying between 0.369 up to 0.536 due to the heterogeneous spatial distribution of smoke plumes during the burning season. These findings may help improving aerosol-cloud discrimination algorithms based on spatial variability or image texture tests.

FINAL REMARKS

This work showed preliminary results of AOD retrievals obtained by a system deployed at DSA-CPTEC/INPE based on modified NASA/GSFC algorithms. Changes in AOD averages between clean and polluted conditions were about one order of magnitude from 0.038±0.067 to 0.413±0.369 for the time period under study. Spatial variability of AOD distribution shows scale invariance under clean conditions, with a mean value of 0.061. For polluted scenes the standard deviation of AOD spatial distribution depends on the chosen grid size due to the heterogeneity in smoke plume distribution during the burning season. The AOD retrievals obtained by the system can be assimilated on chemical weather and climatic models.

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