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OMI observations of the anomalous 2008 Southern Hemisphere biomass burning season

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Abstract

The 2008 season of biomass burning in the Southern Hemisphere was marked by a significant reduction in the number of fires in South America and, therefore, a large drop of the atmospheric load of carbonaceous aerosols over the subcontinent, relative to previous years, was registered by the Ozone Monitoring Instrument onboard the Aura satellite. In contrast, the 2008 copious aerosol production by fires in Central and Southern Africa generated an unusually large, synoptic scale aerosol layer that blanketed most of the tropical Southern Atlantic Ocean (0°–25° S) in August and September. Satellite observations on fire statistics and precipitation were analyzed to understand the anomalous Southern Hemisphere fire season. The fire reduction in South America was confined to Brazil that experienced a 62% reduction in fire activity in relation to 2007, and it was the result of factors other than meteorological reasons. The large spatial extent of the South Atlantic smoke layer seem to have been the result of unusually high free troposphere easterly winds that efficiently mobilized particulate matter thousands of kilometers away from the African source areas.

1 Introduction

Biomass burning is a widespread agricultural practice for land clearing used in most tropical farmlands in South America (SA) and Central and Southern Africa (CA). It is by far the main source of anthropogenic aerosols in the Southern Hemisphere (SH). In addition to the well known climate implications, biomass burning has a direct effect on air quality through the emission of large amounts of particulate matter and chemical byproducts such as CO_2, CO, N_2O, CH_4, NO, NO_2 and other substances some of which are tropospheric ozone precursors (Jacob et al., 1996).

The bulk of biomass burning activities in SA are carried out in a geographical region between 10° S and 30° S most of which is in Brazil, but also includes Eastern Bolivia, Norwest Paraguay and Northern Argentina. Although biomass burning also takes place in Equatorial Brazil during SH summer, most of the SA biomass burning occurs south of 10° S during the August–October period with peak activity in September. The CA burning season starts in June at about 10° S and slowly spreads south. Unlike in SA, peak biomass burning activity is reached generally in August but the season lasts longer until November. Convective activity associated with the intensive heating produced by the fires results in the vertical transport of smoke to altitudes between 2 and 6 km into the free troposphere forming a dense smoke cloud that covers most of the source regions and beyond as the smoke is efficiently transported by the prevailing winds thousands of kilometers away from the source regions into the South Atlantic Ocean as well as the South Indian Ocean forming the so-called rivers of smoke (Freitas et al., 2006).

The intensity and seasonality of the biomass burning activity have been documented by means of satellite observations of the effect on the ground (fire counts) as well as the atmospheric effects by means of the qualitative Aerosol Index (AI) from near-UV observations and estimates of the actual aerosol load in terms of optical depth from MODIS and OMI observations. SA biomass burning shows a great deal of inter-annual variability as shown by the long-term TOMS (Total Ozone Mapping Spectrometer) Aerosol Index record for the period 1979–1993 (Gleason et al., 1998). Koren et al. (2007) examined the inter-annual variability in the Amazon basin of the MODIS AOT data in the period 2000–2006. They reported a generally increasing trend up to about 2005 followed by a sudden drop in 2006.

In this paper we examine satellite data for the period 2005–2008 from different platforms and sensors to analyze the anomalous 2008 SH biomass burning season. The effect of the reduced 2008 fire activity in South America on tropospheric ozone production is analyzed by Ziemke et al. (2009).

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2 Observations

In this work we use observations over the period 2005–2008 from sensors on three different satellites. We analyzed the spatial and temporal variability of the SH smoke plume using OMI observations in terms of the UV Aerosol Index (UVAI) and the retrieved 388 nm Aerosol Absorption Optical Depth, AAOD (Torres et al., 2007). The fire-counts data set derived from Aqua-MODIS observations (Giglio et al., 2006) is used to monitor the actual fire activity in terms of number of fires per unit area. The third satellite data set used in this analysis is precipitation data as reported by the Tropical Rainfall Measuring Mission (TRMM) (Kummerow et al., 2000). In addition to the satellite data we also made use of NCEP reanalysis data (Kalnay et al., 1996) to examine the possible role of the variability of the wind fields on the observed transport patterns.

An analysis of OMI observations indicates that the 2008 SH biomass burning season was particularly different than in previous years. Figure 1 that shows the spread of SH smoke layer in terms of the OMI Aerosol Index for 7 September 2008 clearly illustrates two features that make the 2008 SH biomass burning season stand out. The figure shows the large horizontal extent of the aerosol plume over the Atlantic Ocean which results from the westward smoke transport all the way from Africa to the shores of Brazil and even reaching the sub-continent. Also shown are the NCEP wind fields at 700 hPa. Monthly UVAI average maps (not shown) indicate that the Southern Atlantic oceanic region covered by the smoke plume in 2008 is significantly larger than in any previous years indicating either a more intense than usual African biomass burning or a more efficient transport, or both. The other relevant feature is the spatial extent of the SA smoke layer that in 2008 is significantly smaller than what was observed in any of the three previous years of the OMI record. This is illustrated on the September average maps of OMI derived aerosol absorption optical depth in Fig. 2.

Figure 3 depicts the long term UVAI record averaged over the boxes in Fig. 1 for the South American (SA, 5° S–20° S, 65° W–30° W) and Central African (CA, 5° S–20° S,

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5° E–38° E) regions. Data shown includes observations from the Nimbus7 (1979–1992) and Earth Probe (1996–2001) TOMS sensors and the Aura-OMI instrument (2005–2008). No reliable AI data is available for the periods 1993–1995 and 2002–2004. The long term CA UVAI record shows a repeatable annual cycle with clearly defined maxima generally in August. The SA record on the other hand, exhibits a very large inter-annual variability. Although maxima UVAI values are regularly observed in September, on several years hardly any biomass burning seemed to have taken place. Years of minimum biomass burning activity according to the UVAI record are 1982, 1989, 2000, 2001, 2006 and 2008. The 2008 SA biomass burning season is the least active since the beginning of the OMI record in October 2004.

3 Data analysis

Monthly average values of OMI AAOD, fire counts, and precipitation amounts derived from satellite observations at a 1°×1° resolution were calculated over the SA and CA regions shown in Fig. 1. In this section a brief description of the observed 4-year record of these parameters is presented.

3.1 Fire statistics

Figure 4 shows the time series of parameters closely related to the intensity and frequency of biomass burning in South America and Central Africa. The top panel shows the number of fires per-pixel detected by the Aqua-MODIS sensor over the regions of the analysis. A significant inter-annual variability can be observed over South America (solid line). In 2005 the maximum number of fires per pixel was about 180, went down to about 130 in 2006 and peaked at 250 in 2007. The 2008 value did not reach 100 fires per pixel. Unlike the large inter-annual variability found in South America, the time series of the fire count data exhibits a very repetitive and steady annual cycle over the Central African region (dashed line).The peak number of fires remains remarkably constant at about 400 over the four-year period. The Middle panel of Fig. 2 shows the temporal evolution of the OMI derived Aerosol Absorption Optical Depth. The AAOD over the South American region exhibits identical inter-annual variability as the number of fires with a maximum value in 2007, and a minimum in 2008. Peak monthly values of 0.14, 0.08, 0.15 and 0.04 are observed in September in the four years of the analysis. In Central Africa peak monthly AAOD values of about 0.10 take place in August. The 2008 data shows a one-month lag in the month of peak AAOD in both regions with peaks in September and October for SA and CA respectively a month later than in the previous three years.

The 2007–2008 decrease in the number of fires was 62% whereas the AAOD value decreased by 73%. The consistency of the inter-annual variability of independently derived parameters confirms that the observed dramatic decrease is real and not the effect of possible instrumental degradations affecting the satellite derived quantities.

To gain an understanding of the influence of the regional meteorology on the fire activity we examined the regional annual cycle of precipitation over the regions of the study using TRMM data as shown on the bottom panel of Fig. 4. As expected the annual cycle for the two regions shows many similarities. The dry season in Central Africa is much longer than the one in South America. This explains why the duration of Central African burning season extends over a period twice as long than in South America. An anomalous increase in precipitation in the months previous to the onset of the burning season in SA could have produced a higher level of ground wetness and therefore a reduction in the overall fire activity could be expected. The observed precipitation regime over both areas, however, is very steady with no obvious anomaly during the actual burning season or during the preceding months that could be linked to the observed drop in fire activity in South America. The previous comparative analysis of the two areas indicates that different factors drive the biomass burning activity (or lack thereof) over the two areas with supposedly similar climate regimes.

A close analysis of the spatial distribution of the fire activity in South America during the month of September in 2007 and 2008 suggests the role of non-geophysical factors in the reduced fire activity observed in 2008. Figure 5 shows the difference of the total number of fires over South America between September 2008 and 2007 based on NOAA-15 observations. The number of NOAA-15 detected fires in Brazil decreased from 27 191 in 2007 to 10 309 in 2008, down by 62%. On the other hand, the total number of fires in the rest of South America (including the totality of Bolivia and Paraguay as well as Northern Argentina but excluding Brazil) went down only by 4% (from 6645 in 2007 to 6456 in 2008). Most of the observed reduction in fire activity took place in the Eastern part of the Brazilian states of Pará and Matto Grosso.

The absence of an obvious meteorological connection and the clear 2007–2008 fire reduction following political boundaries strongly suggests that the 2008 decrease in burning in South America is possibly related to actual changes in soil management practices and/or enforcement of existing regulations that resulted in a lesser number of fires started.

3.2 Transport

Satellite observations show that westward transport of carbonaceous aerosols from the sources in Central Africa and across the Atlantic Ocean was particularly efficient in September during the 2008 biomass burning season. Such efficient transport requires abundant particulate matter production at the source areas as well as free troposphere wind speeds high enough to achieve the mobilization of the carbonaceous aerosol layer across large distances over time scales shorter than those of gravitational settling and other removal mechanisms. The September monthly average horizontal extent of the smoke layer over the ocean has been quantified as the fractional area of Southern Atlantic Ocean in the box (see Fig. 1) where the September average UVAI is larger than unity. Table 1 lists the calculated September averages of oceanic extent of the smoke layer, the 700 hPa wind speeds from NCEP re-analysis, the regional average UVAI value in Central Africa over the source areas, and the monthly average 380 nm aerosol optical depth reported at the Mongu AERONET site (Eck et al., 2001) for the 2005–2008 period. The tabulated data show a clear correlative connection between the

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oceanic coverage of the aerosol layer, the wind speed and the aerosol production at the source areas. The connection is particularly robust and positive during the last three years. The increasing wind speed as a function of time given by the NCEP reanalysis is somewhat surprising but consistent with previously reported analysis (Pielke et al., 2001).

4 Discussion

The observed decrease in the OMI signal (on both Aerosol Index and Absorption Optical Depth) over South America is consistent with the reported fire count statistics that clearly indicate that there was an actual reduction in the number of fires started in South America during the 2008 burning season. The absence of a meteorological explanation to the observed anomaly in SA is confirmed by the analysis of the biomass burning season in the meteorologically similar region of Central and Southern Africa that shows a climatologically persistent 2008 annual cycle in both the aerosol load as well as fire counts. The partitioning by political boundaries of the actual number of satellite detected fires in SA clearly indicates that the large decrease in biomass burning in 2008 was largely confined to Brazil and that it was the result of factors other than meteorological reasons.

The combined TOMS-OMI long-term UVAI record of carbonaceous aerosol production in Central Africa and South America highlights the essentially different economical and political nature of the biomass burning activity in the two regions. In Central Africa biomass burning is a long-established agricultural practice for the disposal of agricultural residues and therefore its inter-annual variability is largely driven by natural meteorological factors. In South America, on the other hand, biomass burning is used for both the disposal of agricultural waste as well as a way of incorporating new land to economic activities. Thus the observed large inter-annual variability in South American biomass burning is very likely the result of the implementation of national and regional governmental regulations.

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The combined effect of large aerosol amounts generated during the African biomass burning season and high free troposphere wind speeds lead to the formation of a synoptic scale aerosol layer that blanketed the Southern Atlantic Ocean between 10° S and 25° S. A surprising finding out of this analysis is the apparent existence of a trend in free troposphere wind speeds in the region of this study. The NCEP data shown in Table 1 show a steady wind speed increase over the last four years. A more detailed analysis of this effect and its possible long-term effect on aerosol transport is certainly warranted but it is beyond the scope of this analysis.

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Table 1. September average ocean coverage, wind speed and aerosol source strength.

Year	Oceanic coverage (%)	700 hPa wind speed (m/s)	AI (CA)	Mongu AOD (380 nm)
2005	54	5.5	1.3	–
2006	33	5.5	1.2	0.82
2007	62	6.7	1.3	0.88
2008	81	7.0	1.7	0.96

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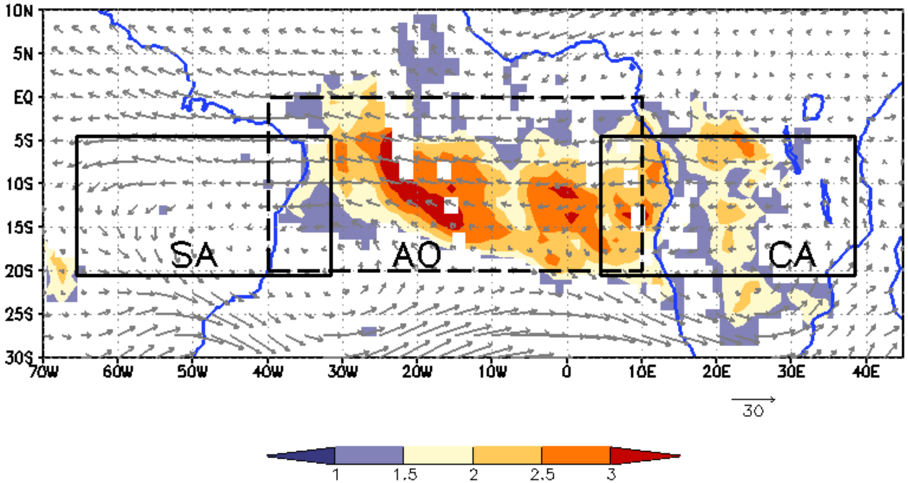

Fig. 1. Spatial distribution of the OMI Aerosol Index on 7 September 2008. Arrows indicate the prevailing NCEP 700 hPa wind field. Boxes indicate regions of analysis in South America (SA), Central Africa (CA), and Atlantic Ocean (AO).

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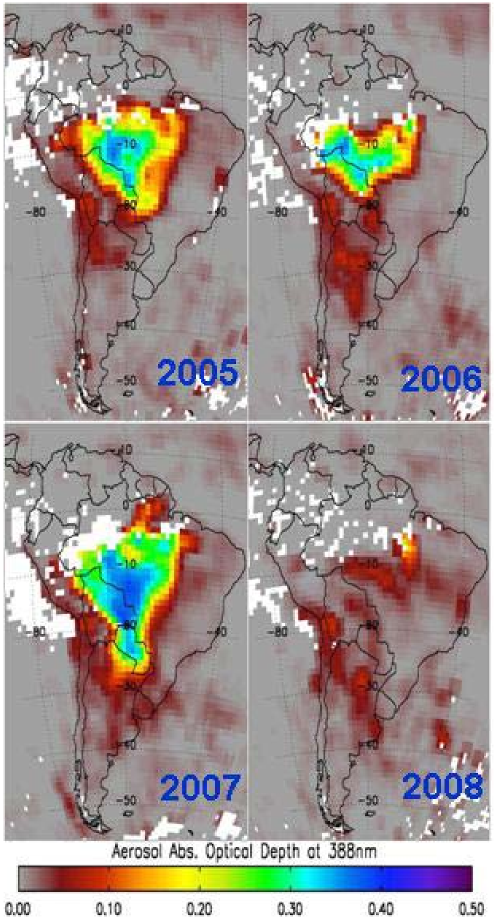

Fig. 2. September average spatial distribution of the South American smoke layer in terms of OMI aerosol absorption optical depth for the 2005–2008 period. White areas indicate regions of persistent cloudiness.

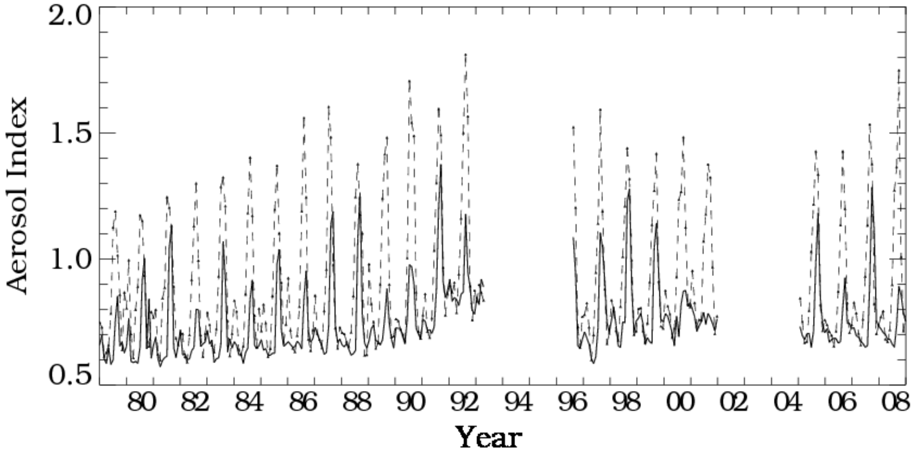

Fig. 3. Long term record of Aerosol Index over South America (solid line) and Central Africa (dashed line). See text for details.

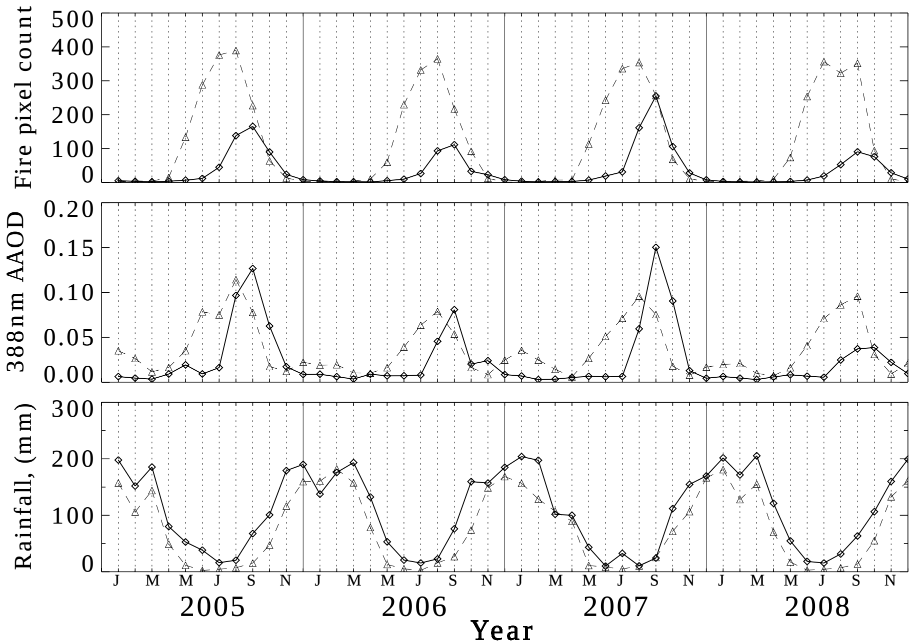

Fig. 4. Four year record of monthly average values of fire counts (top panel), 388 nm aerosol absorption optical depth (middle panel), and precipitation (bottom panel) for the SA (solid line) and CA (dashed line) regions.

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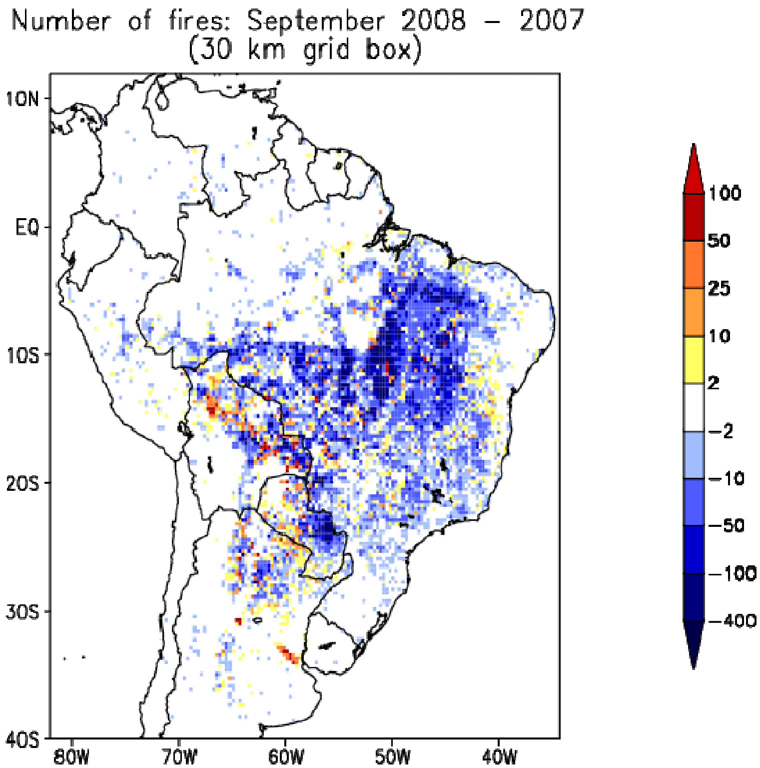

Fig. 5. Spatial distribution of the difference in the total number of fires between September 2008 and September 2007 as observed by the NOAA-15 AVHRR sensor. See text for details.