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Relationship between Amazon biomass burning aerosols and rainfall over La Plata Basin

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Reviewer #1

(1) Thank you, the article is being revised by a native English speaker.

(2) The reviewer is right, the relationship derived from observations is a combined effect of different mechanisms. In this article we examine the relationship between a low level jet carrying a load of aerosol to the La Plata Basin, and the rainfall features in that region. We ask the question of whether the flow of aerosol from the north, with origin in the Amazon Basin, has any potential effect on rainfall over La Plata Basin. At this point we are not separating microphysical and radiative effects. But we attempt to separate the possible dynamical forcing in the La Plata Basin, for which the results are consistent in our analysis.

(3) We have changed the introduction (also because of other reviewer suggestion) and have added the following paragraph:

"*Morales et al. (2010) characterized meteorological conditions associated with thunderstorms and non-thunderstorms days over the city of São Paulo and investigated the pollution influence on them. The thunderstorms were basically regulated by dynamical and thermodynamic characteristics while aerosols did not show any significant effect. On the other hand, Albrecht et al. (2011) observed that large-scale and local environmental thermodynamics processes favored the development of intense thunderstorms over the Amazon in the end of the dry season, with no apparent effect of aerosol loading. During the wet season, however, thunderstorms were preferably observed in periods of high CCN concentrations.*"

(4) Indeed, there are uncertainties in all type of data and attending your suggestion, we add this subject in the paper as follow below:

p.24000, l.16-22

"*The spatial and time variations of rainfall have been obtained from TRMM (Tropical Rainfall Measuring Mission) satellite, generated by the 3B42 algorithm version 7. These gridded rainfall estimates are available since 1998 with a 3-h temporal resolution and 0.25° × 0.25° spatial resolution covering global latitudes from 50° S to 50°N (http://trmm.gsfc.nasa.gov/3b42.html). According to Su et al. (2008), the precipitation estimates from TRMM-3b42 detect most of the daily precipitation events over the La Plata Basin although they tend to overestimate heavy precipitation. Rainfall rate in mm day*$^{-1}$ *and the percentage of rainy grid points over the blue rectangle (rainfall fraction) were computed. A rainy grid point is defined when rainfall rate* $>$ *0.2 mm hr*$^{-1}$. *Areal averages over all grid points in the blue box region (Fig. 3) are computed for rainfall rate; only cases with values above 1 mm day*$^{-1}$ *are considered as rain events. In the next sections the areal average of rainfall rate of the blue box are hereafter referred to as RR.*"

p.24000, l.24 - p.24001, l.5

"*We used AOD data provided by AERONET (Aerosol Robotic Network), described by Holben et al. (1998) and coordinated by NASA (National Aeronautic Spatial Agency). AERONET is a global network of sunphotometers that has monitored AOD and aerosol optical properties, under clear sky conditions during the day from directed sun measurements, since 1993. The level 2 product of daily AOD for the wavelength of 440 nm has been used for the sunphotometers at Alta Floresta, Ji Paraná, Rio Branco, Santa Cruz, Campo Grande, and Cuiabá. These locations are indicated in Fig. 2.*

AOD has been used as proxy for aerosol concentration following the work of Guyon et al. (2003). They showed that the Amazon Basin biomass burning causes the AOD increases with increases Ångström coefficient, indicating that in polluted conditions the fine mode of aerosols predominantly contribute to the aerosol concentration."

(5)

a) The description of analysis methods was rewritten as follows:

p.24001, l.7- p.24002, l.10.

"*The main assumption of this work is that aerosol from biomass burning is advected from Amazon and Central Brazil to the La Plata Basin under north wind conditions (Freitas et al., 2005). Figure 3 shows the average wind field for of all north wind cases from 1999 to 2012 in the transition from dry to wet season; the blue box represents the area under study in the La Plata Basin where rainfall and aerosol relationships are investigated. The red box is located between the blue box and biomass burning region. A north wind case is defined when the areal average of the meridional wind component over both red and blue rectangles is negative. The cases with wind direction between 30° and 90° over the blue rectangle are discarded to avoid sample contamination from other aerosol sources (e.g., from southeastern Brazil). A further condition to* *accept a north wind case is that minimum rainfall (< 3 mm as areal average over the red box) is observed between the source region and the study region, so that cases where aerosols would be removed by wet deposition before arriving at the blue rectangle are not considered.*

The aerosol travel time from the origin to the destination is taken into account by defining a time lag as the time period (in days) that aerosols take to travel form the origin station to the La Plata Basin. For each rain event, lagged correlations between RR and AOD retrieved from 1 up to 5 days before the rain event were computed.

The higher absolute value of lagged correlation for each station is used to define the lag as an indicator of the optimal time interval between aerosol sources and the blue rectangle region (i.e., there is a time lag for each AERONET station). The time lags were also calculated based on average wind at 850 hPa and the distance between the origin and destination. The results (not shown) were similar suggesting that the lags were adequate to relate AOD measurements from Amazon with rainfall in La Plata Basin."

b) We do not have lidar observations but we cited Andreae et al. (2004), Freitas et al. (2005). These authors show that the aerosol from biomass burning region can be transported by the low level flow downwind to La Plata Basin.

c) The rainfall fraction was used to identify the size of rainy systems (in terms of areal precipitation) and verify the possible aerosol effect.

d) Initially, the combined EOF was calculated with AOD, rainfall rate, mid-level relative humidity, omega, and wind shear. The wind shear component showed similar values for both first and second eigenvector. We calculated the EOF without the wind shear component and the EOF pattern did not change. Therefore, we chose to calculate the combined EOF without wind shear component.

(6) The figure captions have been changed. The new captions are:

"*Table 1: Variance explained by the first and second EOFs and the variance explained by these two EOFs for each AOD station for all selected cases (see Sect. 2.4) during the months of September-October-November-December of 1999-2012.*"

"*Fig. 3: Mean wind of north flow cases identified by the filtering method. Blue box represents the study area, red box is an auxiliary region for the filter and thick black contour delimits the La Plata Basin.*"

"*Fig. 4: Daily AOD during September 2007 from AERONET stations. There were not measurements from Santa Cruz station on this period.*"

"*Fig. 5: Enhanced infrared satellite images from GOES 11 for a MCS evolution on 12 September 2007 over La Plata Basin. Colors indicate infrared temperatures. (a) 0500 UTC, (b) 0645 UTC, (c) 1015 UTC, and (d) 14:45 UTC.*"

”*Fig. 6: Large-scale fields on 12 September 2007 at 0600 UTC: (a) wind and relative humidity at 850 hPa; (b) mean 700-500 hPa relative humidity (shaded) and omega at 500 hPa (contour); (c) wind and divergence at 200 hPa.*”

”*Fig. 7: Rainfall rate binned by AOD range of 0.1 for each AERONET station for all selected cases (see section 2.4) during the months of September-October-November-December of 1999-2012.*”

”*Fig. 8: Two-dimensional histogram of average rainfall rate for each AERONET station for all selected cases (see section 2.4) during the months of September-October-November-December of 1999-2012. Colors indicate average rainfall rate for each bin of rainfall fraction and AOD.*”

”*Fig. 9: Two-dimensional histogram of average rainfall rate for each AERONET station for all selected cases (see section 2.4) during the months of September-October-November-December of 1999-2012. Colors indicate average rainfall rate for each bin of ω and AOD.*”

Other comments:

p.23996, l.22-23 – corrected

p.23997, l.10 – corrected

p.23997, l.13-16 – this sentence was replaced by:

”*They verify an increase in amounts of rain associated to an increase of GCCN (Giant Cloud Condensation Nuclei) and IFN (Ice-Forming Nuclei) whereas an increase in CCN concentration causes a rainfall decrease.*”

p.23997, l.22 – corrected

p.23998, l.15 – deleted

p.23999, l.25 – corrected

p.24001, l.16-17 – corrected

p.24003, l.15 – corrected

p.24004, l.22-24 – corrected

p.24005, l.10 – The sentence was replaced by:

”*Differences of rainfall rates between rainfall fraction and AOD ranges are immediately apparent.*”

p.24005, l.16 – corrected

p.24006, l.5-8 – To make the results more easily transmitted to the readers, Table 2 has been replaced by a new Figure 10 and the paragraphs about the EOF were rewritten as follows:

”*Comgined EOFs were calculated in another attempt to observe the aerosol effect and reinforce the previous results. The combined EOF analyses are used to identify variability patterns from a group of variables. In other words, the eigenvectors detect linear relationships among AOD, RR, ω, and RH. Table 1 shows the variance explained by the first and second eigenvectors and the total explained by these two. The first EOF explains around 43 % of the variance of the dataset for all AOD stations and the second EOF 31 %, together this eigenvectors represent more than 70 % of the data variance explained. The other two EOFs are not shown since they explain a lower portion of the* *variance. Satellite images for the cases detected by the EOF time series were examined (not shown). It was observed that about 70 % of selected rain events are associated with MCS. The other 30 % are basically related to cold fronts and extratropical cyclones with embedded convective systems.*

EOFs and their respective components AOD, RR, ω, RH for each AOD stations (in colours) are shown in Fig. 10; values represent perturbations with respect to the average. Looking at e_1, it is possible to verify that this eigenvector detects a pattern with small AOD anomalies and large anomalies of RR, ω, and RH, reflecting a pattern basically independent of AOD. The physical interpretation of the first eigenvector is that stronger large-scale upward motion and moister mid-level atmosphere are associated with larger amounts of rainfall. For a moister mid-level environment, the entrainment into the cloud generates less evaporation thus potentially affecting the rainfall production.

The second EOF detects large positive anomalies of AOD associated with large negative anomalies in rainfall for small anomalies of ω and RH. For this pattern, the interpretation is that ω and RH are average while large AOD is associated with rainfall suppression.

The results from the EOF analysis agree with Fig. 7 and 9 in that the dynamic component appears as the main rainfall forcing and the aerosol loading as the second one. The first EOF is related to dynamic forcing whereas the second EOF seems to represent the aerosol forcing. Jones and Christopher (2010) also used EOF analysis to identify possible interactions between aerosols and precipitation in the Amazon Basin. Their results also detected two patterns, one related to atmospheric conditions favorable to rainfall and the other linked to the aerosol forcing, and associated with rainfall inhibition."

p.24007, l.4 – corrected

p.24007, l.20 – the word scale interaction was removed; the new sentence is:

"*In the particular case of the MCS over La Plata Basin, the system is apparently affected in its cloud microphysics with a steady flow of aerosol coming from biomass burning regions to the north.*"

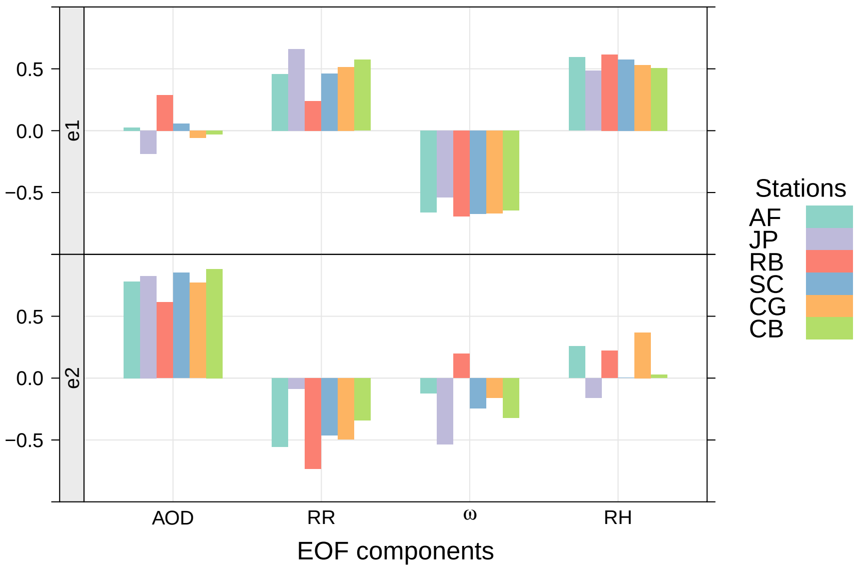

Fig. 10: EOFs and their components AOD, RR, ω, and RH for each AERONET station for all selected cases (see Sect. 2.4) during the months of September-October-November-December of 1999-2012. Colors indicate the stations of Alta Floresta (AF), Ji Paraná (JP), Rio Branco (RB), Santa Cruz (SC), Campo Grande (CG), and Cuiabá (CB).

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