Atmospheric Research 122 (2013) 298–309

Contents lists available at SciVerse ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

The relative role of Amazonian and non-Amazonian fires in building up the aerosol optical depth in South America: A five year study (2005–2009)

Fernando Castro Videla [a], Francesca Barnaba [b,*], Federico Angelini [b], Pablo Cremades [a], Gian Paolo Gobbi [b]

[a] *Universidad Tecnológica Nacional-Fac. Regional Mendoza, Mendoza, Argentina*
[b] *Istituto di Scienze dell'Atmosfera e del Clima-Consiglio Nazionale delle Ricerche (ISAC-CNR), Roma, Italy*

ARTICLE INFO

Article history:
Received 5 July 2012
Received in revised form 25 October 2012
Accepted 26 October 2012

Keywords:
Aerosol
Fires
Biomass burning
Long range transport
South America
MODIS

ABSTRACT

In South America (SA) biomass burning is the major source of atmospheric aerosols. Fires are mostly registered in the dry season (July–November) and are mainly concentrated in the Amazonia and Cerrado regions. Nonetheless, the growing systematic employment of fires for land clearing and pasture maintenance across the SA continent is introducing other, potentially significant, sources of BB aerosols. This study investigates the relative contributions of different SA biomass burning regions in building up the continental aerosol load. To this purpose, the SA continent is divided into four biomass burning source regions and their impact on the aerosol optical depth (AOD) is evaluated in eight different SA target domains. The dataset used includes multi-year (2005–2009) satellite observations of both aerosol and fires and model-based atmospheric trajectories. The methodology followed couples fire counts and atmospheric transport through the definition of a specific quantity, referred to as 'fire weighted residence time' (FWRT), which is used to assess the contribution of the four identified fire source regions to the continental aerosol load.

Results show that local fires play an important role in building up the regional aerosols load all over SA. Nevertheless, in some regions, contribution of BB aerosols transported from outside their boundaries is comparable to the local one. The major 'smoke exporter' regions are found to be the eastern Brazil and the Amazonia–Cerrado regions. In the dry season, due to the typical continental circulation pattern, the first is estimated to contribute to half of the AOD in Northern Amazonia, Southern Amazonia and Cerrado regions, while over 30% of the AOD in Paraguay and North Argentina derives from the Amazonia–Cerrado fires. Due to the presence of the inter-tropical convergence zone, which decouples wind circulation of the two hemispheres, regions north of the Equator (Venezuela, Guyana, Suriname) are found to receive almost no contribution to the local AOD from fires occurring in the nearby active regions of Amazonia and Caatinga. Similarly, Venezuela fires are shown not to impact the Northern Amazonia AOD. Finally, in excluding the continental fire driver of some AOD enhancements observed in the wet season, this study indirectly points to an important role of aerosol transoceanic transport from Africa.

1. Introduction

Biomass burning (BB) represents an important source of atmospheric aerosols and gases and is recognized to have an important role in regional and global climate changes (Forster et al., 2007). BB emissions reduce visibility and worsen air quality with enhanced risks for aviation transport and detrimental effects on human health (Martin et al., 2010). The South America (SA) continent is estimated to generate the world's highest biomass burning aerosol burden, about 50% of which is exported outside its boundaries, dominating much of the southern hemisphere (Koch et al., 2007). Wildfire emissions in

* Corresponding author at: ISAC-CNR, Via Fosso del Cavaliere 100, 00133, Roma, Italy.
E-mail address: f.barnaba@isac.cnr.it (F. Barnaba).

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http://dx.doi.org/10.1016/j.atmosres.2012.10.026

SA have been shown to markedly influence the regional and the global radiative balance both directly, by scattering and absorption processes (Artaxo et al., 2006; Procopio et al., 2004), and indirectly, by changing cloud microphysics and rainfall, and by suppressing cloud formation, with a significant influence on the overall water cycle (Andreae et al., 2004; Koren et al., 2004).

In South America, wildfires mainly occur during the dry season (July–November) and are mostly concentrated in the Amazon Forest and Cerrado regions (e.g., Martin et al., 2010; Schafer et al., 2008). A recent shift from forest to savanna/agricultural burning was documented for the Amazon basin, with a particularly intense fire activity at the edge of the forest frontier, where most of the land clearing activities occur (Ten Hoeve et al., 2012). In general, the growing systematic employment of fires for land clearing and pasture maintenance across the SA continent is introducing other, potentially significant sources of BB aerosols.

This study aims at quantifying the relative contribution of different SA biomass burning regions to the continental aerosol load in the recent years. The aerosol load is evaluated in terms of 'aerosol optical depth' (AOD), the column-integrated quantity typically derived from satellite which optically quantifies the aerosol burden in the atmosphere. As the aerosol spatial distribution over South America is distinctly influenced by the typical wind circulation pattern, the study combines multi-year (2005–2009) aerosol and fire data from satellite observations with forward trajectory modeling, following a procedure similar to that applied by Barnaba et al. (2011) to investigate the impact of fires over Europe.

Up to now, the number of studies investigating the role of regions other than Amazonia and Cerrado on the continental aerosol load is limited and relevant results still show some uncertainties. Mielnicki et al. (2005) analyzed space-based data of CO and AOD in eight different regions of South America and showed that the seasonality of AOD in each region does not depend uniquely on BB aerosols produced locally, as particles transported from other BB areas also play a non-negligible role. However, that study did not attempt to quantitatively disclose this twofold contribution in the eight zones investigated. Based on both ground-based and satellite data, Hoelzemann et al. (2009) revealed the predominant BB signal in SA to derive from emissions in the Amazon region and in the south of Brazil and Bolivia. Yet, both these studies could not discern quantitatively what is the origin of the increasing AOD observed in the southern part of SA during the BB season.

To understand the influence such large anthropogenic perturbations are having at the continental scale, it is also important to assess the background state of the atmosphere in the region. The Amazon forest has been generally considered a pristine environment in the wet season, with aerosols mainly originated by local biogenic sources (Martin et al., 2010). Some studies have however highlighted how, in this period of the year, the aerosol field and its variability in the Amazon region are largely affected by long-range transport of both desert dust and smoke from Africa. In fact, based on satellite observations, Kaufman et al. (2005) revealed that if from June to September transport of (almost pure) dust mainly occurs towards the Caribbean, from December to March a mixture of dust and biomass burning smoke from savannah fires in the Sahel (e.g., Roberts et al., 2009) is transported both above and below the equator, thus reaching the Amazon forest. This was confirmed by following dedicated campaigns, as the African Monsoon Multidimensional Analyses, AMMA, (Formenti et al., 2008), the Dust Outflow Deposition to the Ocean, DODO (Formenti et al., 2008), the SAharan Mineral dUst ExperiMent, SAMUM (Ansmann et al., 2009), and the Dust And Biomass Experiment, DABEX, (Johnson et al., 2008a,b) whose result clearly showed mixing of dust and biomass burning aerosols in the air masses flowing from Africa to Northern South America.

In fact, beside the major BB-driven enhancement of AOD in the dry season, a secondary AOD peak is often observed in the wet season over the northern SA. Schafer et al. (2008) attributed this AOD enhancement to dust transport from western Africa based on a 10-year climatology of aerosol optical properties in 15 sites of the Amazon region. Conversely, based on a 13-year time series of satellite data, Bevan et al. (2009) hypothesized this enhancement to be related to Venezuela fires. Our study will also provide some further insights into this aspect.

2. Datasets

This study is based on different, 5-year long (2005–2009) datasets. A first dataset includes daily forward trajectory computations employing the NOAA Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Draxler and Hess, 1998). Two other main datasets are based on observations made by the MODIS sensor on board the NASA spacecraft Terra and include the MODIS-Terra aerosol optical depth (AOD) and the MODIS-Terra fire counts. Additionally, MODIS 'Fire Radiative Power' (FRP) data (Justice et al., 2006) were also used in sensitivity tests (Section 4.2) to evaluate the effects of a variable efficiency of different fire types in generating particles, which may change the ratio between the fire counts and the aerosols produced. FRP data used in this study come from the two MODIS instruments on board of the NASA Terra and Aqua platforms, these having overpass time of 10:30 am/10:30 pm LT and 1:30 pm/1:30 am LT, respectively. This double-platform dataset is used to evaluate possible effects on our results of the fire diurnal cycle.

A brief description of all these datasets is given below.

2.1. The forward trajectory simulations

A dataset of more than 100,000 forward trajectories from the HYSPLIT model is included in this study (Draxler and Hess, 1998). In particular, ten-days, 1 h-resolution, forward trajectories have been computed within the domain 15° N–55° S and 84° W–35° W. Trajectories are driven by the 1°-resolution NCEP analyses. We divide the domain in a regular 2.5°-resolution grid and start trajectories from those grid-cell centres where and when fires are detected. This resolution is chosen as a compromise between good spatial resolution of sources and acceptable computing time. A threshold of 1 fire-count/1000 km^2/day has been set for the single-trajectory computation. For the whole investigated period (2005–2009), a forward trajectory per day (at 10:30 LT) was computed. To ensure a boundary layer origin of the smoke and avoid ground effects, the starting altitude of the trajectories was set at 500 m above ground level (AGL). Some sensitivity tests were performed by changing the trajectories starting altitude within the first 1000 m and eliminating those trajectories for which the