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Biomass burning in the Amazon region: Aerosol source apportionment and associated health risk assessment

Nilmara de Oliveira Alves [a, *, 1], Joel Brito [b], Sofia Caumo [c], Andrea Arana [d], Sandra de Souza Hacon [e], Paulo Artaxo [b], Risto Hillamo [f], Kimmo Teinilä [f], Silvia Regina Batistuzzo de Medeiros [g], Pérola de Castro Vasconcellos [c]

[a] Biochemistry Department, Federal University of Rio Grande do Norte, Natal, Brazil
[b] Physics Institute, University of São Paulo, São Paulo, Brazil
[c] Chemistry Institute, University of São Paulo, São Paulo, Brazil
[d] National Institute for Amazonia Research, Manaus, Brazil
[e] National School of Public Health at Oswaldo Cruz Foundation, Rio de Janeiro, Brazil
[f] Finnish Meteorological Institute, Atmospheric Composition Research, Helsinki, Finland
[g] Cellular Biology and Genetics Department, Federal University of Rio Grande do Norte, Natal, Brazil

HIGHLIGHTS

- PM_{10}, OC, EC, anhydrous sugars and PAHs were quantified in Western Amazonia.
- Results are representative of the deforestation arc, home of over 10 million people.
- Factor analysis identified Biomass Burning, Fossil Fuel and Mix sources.
- During the dry season, the lung cancer risk largely exceeded the WHO guideline.

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ABSTRACT

The Brazilian Amazon represents about 40% of the world's remaining tropical rainforest. However, human activities have become important drivers of disturbance in that region. The majority of forest fire hotspots in the Amazon arc due to deforestation are impacting the health of the local population of over 10 million inhabitants. In this study we characterize western Amazonia biomass burning emissions through the quantification of 14 Polycyclic Aromatic Hydrocarbons (PAHs), Organic Carbon, Elemental Carbon and unique tracers of biomass burning such as levoglucosan. From the PAHs dataset a toxic equivalence factor is calculated estimating the carcinogenic and mutagenic potential of biomass burning emissions during the studied period. Peak concentration of PM_{10} during the dry seasons was observed to reach 60 μg m^{-3} on the 24 h average. Conversely, PM_{10} was relatively constant throughout the wet season indicating an overall stable balance between aerosol sources and sinks within the filter sampling resolution. Similar behavior is identified for OC and EC components. Levoglucosan was found in significant concentrations (up to 4 μg m^{-3}) during the dry season. Correspondingly, the estimated lung cancer risk calculated during the dry seasons largely exceeded the WHO health-based guideline. A source apportionment study was carried out through the use of Absolute Principal Factor Analysis (APFA), identifying a three-factor solution. The biomass burning factor is found to be the dominating aerosol source, having 75.4% of PM_{10} loading. The second factor depicts an important contribution of several PAHs without a single source class and therefore was considered as mixed sources factor, contributing to 6.3% of PM_{10}. The third factor was mainly associated with fossil fuel combustion emissions, contributing to 18.4% of PM_{10}. This work enhances the knowledge of aerosol sources and its

* Corresponding author. Universidade Federal do Rio Grande do Norte, Departamento de Bioquímica, CB – UFRN, Campus Universitário, Lagoa Nova, Zip Code 59072-970, Natal, RN, Brazil.
E-mail address: nilmaraoalves@gmail.com (N. de Oliveira Alves).
[1] Now at: School of Medicine of University of Sao Paulo.

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impact on climate variability and local population, on a site representative of the deforestation which occupies a significant fraction of the Amazon basin.

1. Introduction

The Brazilian Amazon embraces contains about 40% of the world's remaining tropical rainforest, covering 5.5 million km^2, corresponding to 61% of the area of Brazil. It is the largest and most species-rich biome of the planet. This region plays vital roles in maintaining biodiversity, regional hydrology and climate equilibrium, and terrestrial carbon storage (Malhi et al., 2008; Soares-Filho et al., 2006). However, agricultural expansion and climate variability have become important agents of disturbance in the Amazon basin (Davidson et al., 2012).

Fires have been consistently used in the Amazon as a clearing tool used to burn trees from recently cut forests so that agricultural or pastoral lands may be developed, being a major source of particulate matter (PM) during the Amazon dry season (Artaxo et al., 2013; Ten Hoeve et al., 2012). The majority of forest fire hotspots in the Amazon takes place in the deforestation arc, an area of roughly 500 000 km^2, with a population of over 10 million inhabitants (IBGE, 2014). Such large population suffers regularly from high level of pollutants resulting from biomass burning emissions (Andreae et al., 2004; Brito et al., 2014), with significant increase of occurrence of respiratory diseases during these periods (Carmo et al., 2010; Jacobson et al., 2014).

Carbonaceous material, a significant fraction of particle-phase emission from fires (Brito et al., 2014; Kondo et al., 2011), can be classified as organic carbon (OC) and elemental carbon (EC). While OC can be directly emitted to the atmosphere or formed from the oxidation and condensation of organic vapors, EC is primary and emitted from combustion sources. EC is known as an important contributor to radiative heating of the atmosphere (Cabada et al., 2004). An important group of organic compounds found in the atmosphere is composed by Polycyclic Aromatic Hydrocarbons (PAHs). They are emitted from a large variety of sources, including vehicular emissions (Brito et al., 2013; Martins et al., 2012), tobacco smoke (Ding et al., 2008), industrial activities (Lakhani, 2012; Wang et al., 2014) and biomass burning (Alves et al., 2011; De Oliveira Alves et al., 2014). The speciation of PAHs in ambient air is an increasing concern due to their associated carcinogenic and mutagenic potential (Samanta et al., 2002). The US Environmental Protection Agency has listed 16 PAHs as priority pollutants for control, however the health risk posed by PAHs exposure suggests a continuing need for their control through air quality management (Kim et al., 2013). Furthermore, PAHs may overcome large distances affecting sites far from where these pollutants are generated (Ravindra et al., 2008).

Mutagenic and DNA damage effects (Teixeira et al., 2012; Umbuzeiro et al., 2014) of PM are mainly associated to PAHs. A recent study in Greece shows that particles emitted from biomass combustion are more toxic than PM emitted from other sources, in particular to PAH levels. Moreover, higher lung cancer risk was estimated for infants and children (Sarigiannis et al., 2015). Other works assessed the lifetime cancer risks related to contributions of diet and inhalation to the overall PAH exposure of the population of Beijing in China and showed that diet accounted for about 85% of low-molecular-weight PAH (L-PAH) exposure, while inhalation accounted for approximately 57% of high-molecular-weight PAH (H-PAH) exposure of the Beijing population (Yu et al., 2015).

Here we characterize western Amazonia biomass burning emissions through the quantification of 14 PAHs, OC, EC and unique tracers of biomass burning such as Levoglucosan. From the PAHs dataset a toxic equivalence factor is calculated estimating the carcinogenic and mutagenic potential of biomass burning emissions during the period studied. Finally, the use of factor analysis on the dataset allows to not only apportion PM distinct sources affecting the sampling site, but to also characterize these sources in regarding to their PAHs content.

2. Methods

2.1. Site description and sample collection

Filter samples were collected in a governmental reservation located about 5 km north (usually upwind) of Porto Velho, a city in the state of Rondônia, western Amazon, a region with significant land use change since the 1980s. During the South American Biomass Burning Analysis (SAMBBA), which took place during the 2012 dry season period, fine organic aerosols mainly linked with biomass burning emissions, were observed with varying levels of atmospheric oxidation, in agreement with large number of fires distributed in the area (Brito et al., 2014).

The sampling was conducted during two distinct periods: the dry season (August–October/2011) and wet season (November/2011–March/2012). A high volume filter sampler (flow rate of 1.3 m^3 min^{-1}), sampling PM_{10} aerosols into quartz fiber filters, was deployed on the border of a 150 m radius grassland clearance at the southwest corner of 2000 ha of dense forest belonging to governmental reservation. The road that connects Porto Velho to governmental reservation cuts through large pasture areas and a handful of local businesses. No vehicular access is permitted within the biological reservation.

2.2. Instrumentation and analytical methods

Prior sampling, quartz fiber filters were pre-cleaned by heating in an oven at 800 °C for 8 h. Mass concentrations were obtained gravimetrically using an electronic microbalance with a readability of 1 μg (Mettler Toledo, model MX5) in a controlled-atmosphere room where filters were equilibrated for 24 h prior weighing.

OC and EC analysis was performed using thermal–optical transmittance (TOT) (Sunset Laboratory Inc.) (Birch and Cary, 1996). The filters were analyzed according to the EUSAAR2 protocol (Cavalli et al., 2010). The limit of detection to OC and EC were 5 μg cm^{-2} and 1 μg cm^{-2}, respectively.

Monosaccharide anhydrides, levoglucosan, mannosan, and galactosan, commonly used as tracers for biomass burning, were determined by high-performance anion-exchange chromatography with electrospray ionization mass spectrometry detection (HPAEC/ESI-MS). The analytical method is similar to the used in Saarnio et al. (2010), except that the used internal standard was methyl-β-D-arabinopyranoside (Saarnio et al., 2013). To examine the comparability of the great diversity of analytical methods used for analysis of levoglucosan, mannosan and galactosan in ambient aerosol filter samples, it is necessary to arrange intercomparison studies. The method used in this study has been twice