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Soil and biomass mercury emissions during a prescribed fire in the Amazonian rain forest

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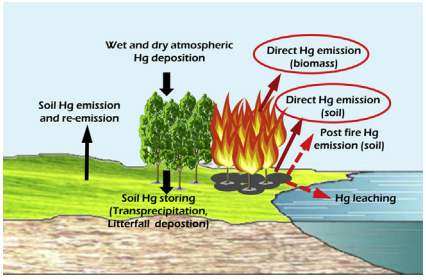
HIGHLIGHTS

- 4.1 ± 1.4 g mercury ha^{-1} were released from a prescribed fire in the Amazon basin.
- Litterfall and the soil O-horizon accounted for 78% of released Hg.
- Wood accounted for the smallest contribution emitted mercury.
- Gaseous mercury continued to be released from soil following the burn event.

GRAPHICAL ABSTRACT



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ABSTRACT

Mercury stored in forests can be volatilized to the atmosphere during fires. Many factors influence this process such as mercury concentration, vegetation loading and the soil temperature reached during the fire. We quantified mercury emissions from biomass and soil during a prescribed fire in Brazil using the difference in mercury burden in vegetation and soil before and after burning, and data were critically compared with those previously obtained in a similar experiment in another part of the Amazonia. The calculated mercury emission factor was 4.1 ± 1.4 g Hg ha^{-1}, with the main part (78%) originating from litterfall and O-horizon, and only 14% associated with live biomass. When considering the fuel burned loading, the emission factor ranged from 40 to 53 μg Hg kg^{-1}. Data were also obtained on soil temperature profile and on Hg speciation in soil in an effort to relate these parameters to Hg emissions.

1. Introduction

Forest canopies are effective in trapping atmospheric mercury (Hg) because they present a large adsorption and assimilation surface area for particulate and gaseous mercury (Fay and Gustin, 2007; Frescholtz et al., 2003). Mercury compounds that accumulate on foliage are then transferred to the soil by foliage wash off (by rainfall) and by litterfall deposition (Rea et al., 2002). In this manner, forest ecosystems act as an Hg sink, limiting the mobility of

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this element in the environment. In many regions, deforestation is destabilizing the entire ecosystem and among other impacts, it has been suggested that the Hg biogeochemical cycle is strongly affected (UNEP, 2013). Mercury leached from soils, is partially transferred toward water courses after deforestation (Comte et al., 2013; Farella et al., 2007; Fostier et al., 2000; Mailman and Bodaly, 2005; Patry et al., 2013; Roulet et al., 1999; Silveira et al., 2009) where it can be converted to methyl-mercury, a toxic Hg species that bio-accumulates in aquatic and terrestrial food chains (Lin and Pehkonen, 1999). According to the UNEP (2013), as much as 260 Mg Hg may have been released into rivers worldwide in 2010 due to this process. Mercury can also be volatilized during forest fires and therefore re-emitted to the atmosphere (Friedli et al., 2001; Veiga et al., 1994). Some studies have also shown significant mercury soil emissions after deforestation (Almeida et al., 2005; Magarelli and Fostier, 2005), including a companion paper in this issue (Carpi et al., 2014). On a global scale, biomass burning accounts for 8% of all current anthropogenic and natural mercury emissions (Pirrone et al., 2010), yet large uncertainties still remain on this estimative, which varied from 200 to 675 Mg Hg yr^{-1} (Friedli et al., 2009; Holmes et al., 2010).

Direct Hg emissions from forest fires are due to volatilization of Hg stored in biomass (Almeida et al., 2005; Friedli et al., 2009, 2001; Lin and Pehkonen, 1999; Magarelli and Fostier, 2005), and to thermal desorption of Hg present in soil (Do Valle et al., 2005; Engle et al., 2006; Harden et al., 2004; Michelazzo et al., 2010). Mercury emission estimates from forest fires have used emission factors (EF) for mercury that are a function of the total carbon budget, or a function of the burned surface area (Friedli et al., 2009). In both cases, EF estimates can be based on two different methodologies: one centered on plume composition, measured at ground level or by aircraft; and the second based on the change in the mercury pool in soils before and after the fire. Knowledge of the mercury partition above and below the forest surface is of critical importance in this second method. Also of critical importance in estimating mercury emissions is knowledge of the soil depth at which the temperature increase allows for Hg thermal desorption; in this process, soil temperature is also related to combustion completeness (the ratio of fuel consumed to total available fuel).

In the Amazonian region, clearing and biomass burning are part of the land conversion process that follows colonization (Browder et al., 2004; Sydenstricker-Neto, 2012), and 402,615 km^2 have been deforested since 1988, 35% of which has occurred within the last ten years (INPE, 2014). Although the importance of mercury emissions to the atmosphere from biomass burning was first recognized in the Amazonian region by Veiga et al. (1994), published data for this region still differ by over one order of magnitude: 6–108 Mg yr^{-1} (Friedli et al., 2009; Lacerda, 1995; Michelazzo et al., 2010; Veiga et al., 1994). These large variations, which reflect the large differences in Hg emission factor estimates, can be due to many factors such as the difference in the spatial distribution of above ground live biomass, the lack of data on soil emissions and the differences in methodologies used for emissions estimates. However, they also point to the lack of data on burn area assessment for small-scales fires and incorrect assumptions about fuel consumption (Friedli et al., 2009) as data are especially limited in Amazonia due to elevated costs and challenging logistics involved in setting up and monitoring measurement sites.

In order to address this lack of data, a large project was begun more than ten years ago which aimed at quantifying the main consumption and emission parameters of Amazonian forest clearing fires (Carvalho Jr. et al., 2010; Neto et al., 2011), including Hg emissions that were calculated based on differences in Hg pools before and after the fire for two clearing experiments in the Alta Floresta region (Mato Grosso state) (Michelazzo et al., 2010).

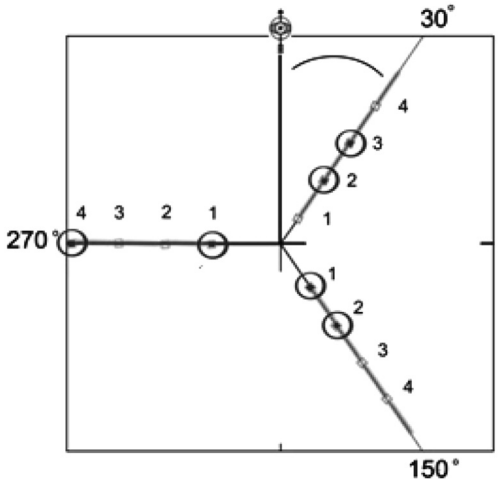

Fig. 1. Location of the soil sampling and soil temperature recording points (circles) among the twelve 2 × 2 m^2 areas selected for the biomass consumption study in the central 1 ha plot of the 2.25 ha field site (EMBRAPA farm, Acre, Brazil).

Because in this last work the experiments were performed on two adjacent areas of 4 ha each, data are not necessarily representative of Amazonia in general. The aim of the present work was therefore to assess direct Hg emission produced during a prescribed forest fire in another part of Amazonia (Rio Branco, Acre state) and to compare with the previous published data from Alta Floresta. Details on the previous study performed in the Alta Floresta field sites (AF) can be found in Christian et al. (2007), Neto et al. (2009) and Michelazzo et al. (2010).

2. Methodology

2.1. Field site and sampling

The study was carried out in the EMBRAPA (Brazilian Agricultural Research Corporation) farm located at 10 1′ 43″ S, 67 40′ 49″ W, at 14 km from the city of Rio Branco, Acre, Brazil in Southwest Amazonia. The regional climate is equatorial, hot and humid, type Am in the Köppen classification, with a dry season of approximately four months from June to September (Mesquita, 1996). The average precipitation is between 1600 and 2700 mm per year, the annual average temperature is 24 °C and the average relative humidity is 84% (Acre, 2014). The forest in this region is characterized as Ombrophilous Open Forest. The field site soil, characterized at EMBRAPA, was defined as typic dystrophic Argisoil according to the Brazilian soil taxonomy system (SiBCS, 2006).

The sequence for land clearing using fire in the Amazon begins in the dry season during June and July when the felling starts. Fires are initiated 2 or 3 months later, prior to the rainy season, after the biomass has dried out enough to sustain combustion (Carvalho Jr. et al., 2001). For this experiment, a square area of 150 × 150 m^2 (2.25 ha) of primary forest was selected. All vegetation was felled in early July and the site was burned on 29 September 2011. Before cutting the vegetation, a forest inventory was conducted in the central hectare. When the forest was felled, wood, bark and leave samples were collected from the 10 dominant tree species found in this area. Leaves were collected from one to nine trees of each species; 20 leaves per tree were randomly collected at different heights. Wood and bark were collected from three trees of each species. Litterfall was also collected at five points uniformly distributed around the area. At each sampling point, around 1 kg of litter was picked up from the ground in a ~20 m diameter circle and