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Gaseous mercury emissions from soil following forest loss and land use changes: Field experiments in the United States and Brazil

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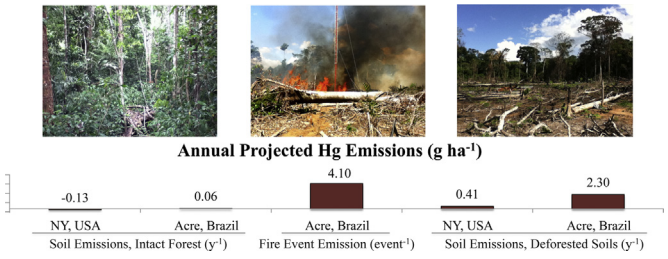
HIGHLIGHTS

- We examined the effect of deforestation on gaseous mercury emission from soil.
- Soils in intact forest soils were a net sink of gaseous mercury.
- After canopy loss, all soils were a strong source of gaseous mercury.
- Evidence shows elevated mercury emissions from soil continue more than 2 months.
- Deforested soils are estimated to contribute an additional 50% of the mercury emitted by fires.

GRAPHICAL ABSTRACT



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ABSTRACT

Forest ecosystems are a sink of atmospheric mercury, trapping the metal in the canopy, and storing it in the forest floor after litter fall. Fire liberates a portion of this mercury; however, little is known about the long-term release of mercury post deforestation. We conducted two large-scale experiments to study this phenomenon. In upstate New York, gaseous mercury emissions from soil were monitored continually using a Teflon dynamic surface flux chamber for two-weeks before and after cutting of the canopy on the edge of a deciduous forest. In Brazil, gaseous mercury emissions from soil were monitored in an intact Ombrophilous Open forest and an adjacent field site both before and after the field site was cleared by burning. In the intact forest, gaseous mercury emissions from soil averaged -0.73 ± 1.84 ng m^{-2} h^{-1} (24-h monitoring) at the New York site, and 0.33 ± 0.09 ng m^{-2} h^{-1} (daytime-only) at the Brazil site. After deforestation, gaseous mercury emissions from soil averaged 9.13 ± 2.08 ng m^{-2} h^{-1} in New York and 21.2 ± 0.35 ng m^{-2} h^{-1} at the Brazil site prior to burning. Gaseous mercury emissions averaged 74.9 ± 0.73 ng m^{-2} h^{-1} after burning of the cut forest in Brazil. Extrapolating our data, measured over several weeks to months, to a full year period, deforested soil is estimated to release an additional 2.30 g ha^{-1} yr^{-1} of gaseous mercury to the atmosphere in the Brazilian experiment and 0.41 g ha^{-1} yr^{-1} in the New York experiment. In Brazil, this represents an additional 50% of the mercury load released during the fire itself.

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1. Introduction

Gaseous mercury emissions from soil and water contribute significantly to the overall load of mercury in the atmosphere. Thus, developing good estimates of the load released from these sources is critical to addressing uncertainties in our understanding of the global mercury cycle (Lindberg et al., 2007). Mercury is known to be emitted during forest fires (Friedli et al., 2001; Veiga et al., 1994), and numerous studies have reported the emission of the metal during biomass burning (Friedli et al., 2003; Sigler et al., 2003; Turetsky et al., 2006), including a companion study at the same site in Acre, Brazil (Melendez-Perez et al., 2014). However, less is known about the effect that forest fires and other forms of deforestation have on the release of gaseous mercury from soil in the local environment following the deforestation event.

Elevated mercury emissions from soils are associated with several factors, including temperature (Carpi and Lindberg, 1998; Siegel and Siegel, 1988), sunlight (Carpi and Lindberg, 1997), or more specifically ultraviolet (UV) light (Bahlmann et al., 2006; Moore and Carpi, 2005), rainfall (Lindberg et al., 1999; Song and Van Heyst, 2005), and soil chemistry (Mauclair et al., 2008). Many of these variables would be expected to change significantly following large scale deforestation. Lacerda et al. and Almeida et al. hypothesized that lower soil mercury concentrations in pasture sites compared to field sites could be in part due to losses from soil independent of the burn event (Almeida et al., 2005; Lacerda et al., 2004). The potential for deforested soils to emit elevated levels of gaseous mercury was later confirmed by Magarelli and Fostier in the Negro River basin of Amazônia (Magarelli and Fostier, 2005). Using a surface flux chamber, Magarelli and Fostier found higher emissions of gaseous mercury from soils in deforested areas (2.75 ± 2.07 ng m^{-2} h^{-1}) compared to forested areas (0.034 ± 0.61 ng m^{-2} h^{-1}). Choi and Holsen have further shown that soil gaseous mercury flux during the leaf-off period within a deciduous forest experienced higher peaks than during the leaf-on periods (Choi and Holsen, 2009).

The current work builds on these previous studies in that it quantifies gaseous mercury emissions from soil before and after deforestation at two very different locations and environments: one in the state of New York in the United States, and one in the state of Acre in Brazil.

2. Methodology

2.1. Field sites

Two sites were examined. The first is located at 41° 23′ 50.35″ N, 74° 01′ 17.45″ W within the Black Rock Research Forest in Cornwall, New York, in the United States. The forest in this region is a typical northeast deciduous forest, and soil in the area is classified as a Swartswood gravelly loam in the Hollis class series (USDA, May 7, 2011). The regional climate is continental/microthermal with significant seasonal differences in temperature and radiation. The climate falls in the Dfa class on the Köppen classification system, and precipitation is equally distributed throughout the year with an annual average of 1240 mm. The specific monitoring site was at the edge of a deciduous forest, and covered directly with *Berberis vulgaris* and *Berberis thunbergil* (European and Japanese Barberry) 3–5 m high and at least 10 years in age. The forest in this area consists of over 1550 managed hectares, with dominant tree species consisting of *Quercus rubra* (red oak), *Acer saccharum* (sugar maple), *Carya* sect. *Carya* (hickory) and *Betula lenta* (black birch). The site is located adjacent to a Mercury Deposition Monitoring Network site (NY 99). No direct waterborne or airborne source of mercury exists within an 8 km radius of the site. The upper 5 cm of soil was collected and sent to the Cornell University Nutrient Analysis Laboratory (Ithaca, NY) for characterization. The soil had a pH in water of 5.0 and an organic matter content of 11.9%. Soil was air dried at room temperature, sieved, homogenized and analyzed in replicate in our laboratory with a Milestone™ DMA 80 Direct Mercury Analyzer. NIST Standard Reference Materials 1547 (peach leaves) and 1547 (San Joaquin soil) were used for instrument calibration and validation. The average concentration of mercury in the soil was 123 ± 11 ng g^{-1}. Two side-by-side 1 m^2 plots were monitored underneath the canopy for 7 days; the Barberry was then carefully removed by cutting so as not to disturb the soil on day 8, and monitoring continued after the cutting event for an additional week.

The second site is located at 10° 1′ 43″ S, 67° 40′ 49″ W at an EMBRAPA (Brazilian Agricultural Research Corporation) experimental field station 14 km from Rio Branco, Acre, Brazil in southwest Amazonia. The forest in this region is characterized as Ombrophilous Open Forest and the soil is defined as typic dystrophic Argisoil within the Brazilian soil taxonomy system (Salimon et al., 2009; Santos et al., 2006). 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; and the average precipitation is between 1600 and 2700 mm per year. The forest in the area was mature, with a canopy of 30–40 m, and was typical for the region, with vegetation consisting of *Carapa guianensis Aubl.* (andiroba), *Tetragastris altissima (Aubl.) Swart.* (breu-vermelho/haiawaballi), *Theobroma cacao* L. (cocoa), *Trichilia spec.* (Cajuerinho), *Quararibea guianensis* Aubl. (Envirasapotinha), *Metrodorea flavida* K. Krause (Pirarara), *Hevea brasiliensis* Muell. Arg. (Pará rubber tree/Seringueira), and other typical species. No direct waterborne or airborne source of mercury exists within a 10 km radius of the site. Sampling was done at a number of plots in Brazil to represent various field conditions. Soil was sampled at two depths, 0–2 cm, and 2–5 cm, and analyzed in replicate for mercury concentrations in our Brazilian laboratory with a Milestone™ DMA 80 Direct Mercury Analyzer (Melendez-Perez et al., 2014). Soil mercury concentrations are presented in Table 2 in the results section.

During early July 2011, a 150×150 m^2 (2.25 ha) area was prepared by cutting all trees and vegetation which were then allowed to dry on site for 2+ months. Detailed data regarding Hg concentrations in cut plant and leaf tissue is provided elsewhere (Melendez-Perez et al., 2014). Gaseous mercury emissions from soil in Brazil were studied at a number of plots, each 1 m^2, to mimic different conditions. The Forest plot was located in an area of intact forest that was approximately 20 m from the cut area and represented background forest soil fluxes. Three Field plots within the cut forest were monitored. The Field Litter plot was studied as found, with dry leaf litter intact and covering the soil. Given that we expected the leaf litter to burn off with the fire, we also removed the surface litter from two replicate Field Soil plots to mimic conditions after the fire cleared the site and get a better sense of pre-post fire impacts. Replicate plots were monitored to measure spatial variability and the effect of soil Hg concentrations on surface flux. All three Field plots were co-located within a single 6.25 m^2 area in the cut site. After burning, all three Field plots were monitored as found. As expected, litter on the Field Litter plot had been burned and appeared as ash. Both Field Soil plots had minimum ash on them after burning. Gaseous mercury emission was also monitored at a Pasture plot – an area that had been cleared by slash and burn deforestation some 10 years prior to our research and was now used for grazing. The purpose of this plot was to gauge the long-term effect of deforestation on soil mercury and gaseous mercury emissions.

On September 29, 2011, the cut area was cleared by burning the cut trees and dried vegetation on the site. Soil fluxes from the Field plots were studied for 2 days prior to burning over a 9-h sampling