Mercury in canopy leaves of French Guiana in remote areas

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Abstract

A study of total Hg concentration in the foliage of the canopy was carried out in two remote areas in French Guiana. The sampled canopy is representative of the French Guiana canopy. The concentration in the foliage, \(64 \pm 14 \text{ ng g}^{-1} \text{ (dry wt.)}\), is used to estimate the annual input of total Hg to the soil through the litterfall, found to be \(45 \pm 10 \mu \text{g m}^{-2} \text{ y}^{-1}\). As translocation is negligible, mercury in the canopy originates mainly from atmospheric uptake by the leaves and this litterfall deposit represents a direct atmospheric input from the background atmospheric load into the soil.

Keywords: Mercury; Canopy; Rainforest; Hg atmosphere soil transfer

1. Introduction

As in the Amazonian basin of Brazil, large areas of French Guiana (South America) have been subjected to gold mining since the 19th century. This activity uses large quantities of mercury (Hg) (1–4 kg Hg for 1 kg of gold produced), which are mainly lost in soil, river sediment and the atmosphere. In order to estimate, understand, and finally prevent the resultant Hg pollution, studying the Hg cycle has been a major goal of the last 20 years (see for example Schroeder W., 1998). To estimate the anthropogenic impact we must first evaluate the contribution of the two natural origins of the Hg present in soil: geological soil content and atmospheric deposition. Atmospheric uptake is an important process by which Hg accumulates in plants (see for example Lindberg et al., 1992, 1994; Munthe et al., 1995; Benesh et al., 2001). We focus here on the contribution of the background atmospheric deposit, measuring specifically the contribution from the leaves of the canopy through litterfall deposit.

Total Hg concentration in leaves has been measured by Roulet et al. (1999) in different parts of Brazil and in French Guiana; results have shown a higher content, close to double, at the French Guiana site (mean values in French Guiana ranging from 130 to 150 ng g\(^{-1}\), compared to 40–120 ng g\(^{-1}\) in Brazil). Is this high content representa-
tive of the entire French Guiana canopy in remote areas? Our goal here is to establish a representative value for this total Hg deposit in litterfall for the tropical rainforest of French Guiana. This requires first sampling representative species in the canopy, and second, performing this sampling in remote areas free from gold mining Hg pollution and from human settlement, to detect the contribution from the background atmospheric level. Previous estimates of Hg content in the tropical forest canopy have been made but not systematically.

2. Sampling and measurements

2.1. Study area

Two sampling sites were chosen. The first is the field station of ‘Les Nouragues’, the French CNRS observatory in a remote area (4°05’ N, 52°41’ W) situated 100 km away from the oceanic coast at an altitude of 50 m above sea level (asl). The site is under regular trade wind influence throughout the year with a prevailing northeast direction. This atmospheric circulation involves the first 1000 m of the atmosphere (the low troposphere), an air layer which carries most of the atmospheric load. This load in terms of gaseous compounds and aerosol is therefore of Atlantic origin and is representative of background levels. This has been tested at the site of Petit Saut in French Guiana (Mélières et al., 2003) through a continuous monitoring of the aerosol load using the $^{210}$Pb radionuclide, a major tracer of aerosol transport and deposit. Monitoring began in July, 1999 and still continues. This site is under the influence of air masses of similar origin to the sites of Les Nouragues and Pic Matecho; results show that the $^{210}$Pb air concentration at Petit Saut is close to 0.2 Bq m$^{-3}$ during both wet and dry seasons (Mélières et al., 2003), a value which is characteristic of an oceanic air mass in tropical regions, and similar to what give data for others studies (see the data base on lead-210 by Preiss et al., 2000). The trajectory of this oceanic air mass arriving at Les Nouragues precludes any large influence from the vast surrounding Amazonian regions where gold mining could load the atmosphere with Hg vapor. The only gold mining activities which exist close to the station are at ‘la Montagne Tortue’ (30 km north), and at Boulanger (60 km north-east). These places have restricted activity, and the atmospheric influence of Hg vapor released is assumed to be negligible over such a distance.

The second site is situated in the center of French Guiana (03°43’44.5” N, 53°02’18.4” W), 3 km south of Pic Matecho (590 m asl), at an altitude close to 250 m. This appears to be an ideal pristine site: no gold mining existed in this area, and there has been no human settlement during the 20th century. It is 150 km south of the Atlantic coast, 30 km north-east of the small village of Saul (≈200 inhabitants). As at the Nouragues station the air masses arriving from north-east do not cross any gold mining areas and come directly from the Atlantic; they can therefore be considered to be under the influence only of background atmospheric load. Thus at both sites atmospheric Hg can originate only from the natural background atmospheric load.

2.2. Sampling

At Les Nouragues, a large area has been equipped with five observation platforms in the upper canopy, between 35 and 40 m above the ground. This area has been extensively studied for 15 years (ecology, vegetation dynamic, biodiversity,…). Canopy walkways, with a total length of 108 m, connect the different observation platforms. The upper canopies of trees belonging to six different species have been sampled. Foliage was collected by selecting fully developed undamaged leaves (between 1 and 3 years old), cutting the leaves at the stalk. The leaves were placed directly into plastic bags, where they were stored. Foliage samples were collected on the emergents of three trees on which the platforms had been installed: Sapotaceae on the first platform, Ampelozisyphus americana (Rhamnaceae) on the second, and Quaribea sp. (Bombacaceae) on the third. The last three samples, Licania sp. (Chrisobalanaceae), Streculia sp. (Sterculiaceae) and Vouacapoua americana (Caealpiniaceae), were collected on trees whose canopies are between platforms 1 and 2. All these trees are situated on a hill (altitude 60–90 m) dominated by an ‘inselberg’ (a granite
mountain of altitude 430 m) and are representative of high forest on drained soil, a type of forest well represented in French Guiana. The sampled trees form the high level of the forest, between 30 and 35 m above the ground (Poncy et al., 1998). At the Pic Matecho site, the tree canopies of five different species were sampled in July, 2001. These trees were cut at the edge of a recent natural treefall; we sampled the trees at the same height as at the other site (upper canopy). Trees were 30–35 m high, on drained soil. The forest of this region is well known for its high biodiversity. The collected species were Chrisobalanaceae, Eperua falcata, Liane, Pourouma sp. and Caraipa sp. (Clusiaceae).

At Les Nouragues, collection was performed in 1999 and, for each tree, sampling was duplicated on two different leaves. In the Pic Matecho field campaign in 2001, 3–5 samplings of different leaves of the same tree were carried out in order to estimate more precisely the range of Hg concentration.

In order to be able to consider the measurements at those two sites to be representative of French Guiana forest we have to address two questions: Is the sampled forest at each site representative of the tropical rainforest in French Guiana? The inventory at the Nouragues station indicates density per hectare of 64–125 trees with diameter above 30 cm, and 468–680 of diameter above 10 cm; 550 tree species corresponding to 63 families have been censused at Les Nouragues (Poncy et al., 1998, 2001). None of them is dominant. At the very most 20 of them (including Vouacapoua americana) are more frequently found. The basal area, which is well correlated to the total biomass, is between 30 and 45 m² ha⁻¹. This is only slightly higher than the Amazonian forest (e.g. Valencia et al., 1994; Rankin-de Merona et al., 1992; Spichiger et al., 1996) but less than the value of 53 m² ha⁻¹ found in the very beautiful forest of Sãuíl, in central French Guiana, well known for its rich biodiversity (Mori et al., 1983). Pic Matecho, our second site, is situated in this region. All 11 specimens are common species and, taken together, constitute approximately 10% of the forested biomass (Prévo²st and Sabatier, 1996). They can therefore be considered as representative of the French Guiana forest and of the mean operating cycle of the tropical rainforest.

3. Analyses and results

After each campaign, the collected leaves were dried following the same procedure as used for sediments (2 days in an oven at 60°C). This procedure does not appear to affect the total Hg content in sediments. Dried leaves were then sealed in plastic bags and sent to the Centre d’Analyse du CNRS (Vernaison, France). The total Hg concentration was measured using the cold vapor technique with atomic absorption spectrometry detection (Ama 254, Spectra France). The dried leaves were directly placed in a cell and heated to 750°C and the Hg vapor content determined. The limit of analysis is 0.5 ng of Hg (the detection limit is ten times less), and the relative standard deviation is a few percent for 10 ng of Hg. The estimated measurement error is 0.1 ng. Mercury measurements were performed on the blade of the leaves and, in two cases, in the central nervation of the leaf. Results are presented in Table 1. In this table, the different measurements for each species correspond to different leaves on the same tree.

4. Discussion

4.1. Mean leaf concentration

At Les Nouragues, the total Hg concentration ranges from 32.4 to 114 ng g⁻¹, whereas at Pic Matecho concentration ranges from 52.4 to 103.0 ng g⁻¹. For a given species, dispersion appears to be small whereas leaves can be of different ages. Both measurements in the central nerve indicate that Hg concentration is systematically lower (5–10 times lower) than in the blade. The mean values obtained at Les Nouragues (59±28 ngHg g⁻¹) and at Pic Matecho (70±16 ngHg g⁻¹) cannot be considered to be significantly different. This leads to assume an overall mean concentration in the canopy of 64±14 ng g⁻¹ (with a confidence level of 95%), for the tropical rainforest of French Guiana.
Table 1
Total Hg concentration in the blade of the leaves and in the central nerve of the leaves (given in brackets)

<table>
<thead>
<tr>
<th>Family</th>
<th>Dry matter (mg)</th>
<th>Total Hg (ng g⁻¹)</th>
<th>Family</th>
<th>Dry matter (mg)</th>
<th>Total Hg (ng g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sapotaceae</td>
<td>106.9</td>
<td>36.7±1</td>
<td>Chrisobalanaceae</td>
<td>92.4</td>
<td>59.0±1</td>
</tr>
<tr>
<td></td>
<td>105.7</td>
<td>35.7±1</td>
<td></td>
<td>127.1</td>
<td>45.1±0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>108.1</td>
<td>50.8±1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>109.1</td>
<td>40.0±0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>108.0</td>
<td>57±0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(43.2)</td>
<td>(13.3±2.2)</td>
</tr>
<tr>
<td>Licania sp.</td>
<td>30.5</td>
<td>40.7±3.6</td>
<td>Eperua falcata</td>
<td>47.8</td>
<td>77.7±2.1</td>
</tr>
<tr>
<td></td>
<td>63.4</td>
<td>46.6±1.7</td>
<td></td>
<td>56.7</td>
<td>52.4±2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50.2</td>
<td>82±1.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>54.0</td>
<td>58.6±1.7</td>
</tr>
<tr>
<td>Sterculiaceae</td>
<td>42.8</td>
<td>65.7±2.7</td>
<td>Caraipa sp.</td>
<td>80.7</td>
<td>80.7±1.2</td>
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<tr>
<td></td>
<td>91.2</td>
<td>59.7±1.2</td>
<td></td>
<td>122.2</td>
<td>75.6±0.8</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>87.0</td>
<td>81.4±1.1</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(79.7)</td>
<td>(8.1±1.3)</td>
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<td>Strychnos sp.</td>
<td>108.7</td>
<td>68.4±1.3</td>
<td>Liane</td>
<td>65.3</td>
<td>65.2±1.5</td>
</tr>
<tr>
<td></td>
<td>147.2</td>
<td>62.5±0.9</td>
<td></td>
<td>88.3</td>
<td>53.1±1.1</td>
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<td></td>
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<td>88.3±1.3</td>
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<td>Vouacapoua</td>
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<td>Pouroama sp.</td>
<td>94.4</td>
<td>84.8±1</td>
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<tr>
<td>americana</td>
<td>62.7</td>
<td>37.9±1.8</td>
<td></td>
<td>63.0</td>
<td>82.9±1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80.5</td>
<td>91.6±1.2</td>
</tr>
<tr>
<td>Bombacaceae</td>
<td>56</td>
<td>114±1.9</td>
<td></td>
<td>93.0</td>
<td>103.0±1</td>
</tr>
<tr>
<td></td>
<td>94.8</td>
<td>105±1.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2. Comparison with other measurements

Total Hg concentration in leaves has been measured by Roulet et al. (1999) in different parts of Brazil (along the Tapajos Basin and in the Tocantins Basin) and at three sites in French Guiana (≈80 km south of Cayenne), and results have shown a higher content (mean value 142±50 ng g⁻¹) at the French Guiana site than in Brazil (mean value of 73±40 ng g⁻¹). Our results indicate a lower value (55% smaller) for the remote areas of French Guiana. Moreover, the measurements performed by Roulet et al. (1999) suggest a Hg content in the foliage similar in the remote areas of Brazil (the Tapajos and the Tocantins Basins) and in the remote areas of French Guiana. Few measurements exist in Europe in remote areas. Iverfeld (1991) measured the pine needle concentration in remote areas of Sweden and found systematically lower values (40 ng g⁻¹). Other measurements in spruce needles performed in Scandinavia (see Goldbold, 1994, for a review article) show similar values in the range of 40–50 ng g⁻¹.

4.3. Mean contribution of canopy to Hg content in soil

The French Guiana forest is sempervirent. Most tropical trees lose their leaves continuously, after a mean time of 4 years, in an asynchronous manner (Hadlik and Blanc, 1987). The litter deposit on soil has been estimated in tropical forest in different parts of the world. Results are quite homogeneous and the annual deposit is of the order of 7 tons of dry matter per hectare (Proctor, 1983,
1984; Leight, 1978). A more accurate estimate is in progress at Les Nouragues. The annual estimated litter deposit of 7 ton ha\(^{-1}\), together with the mean concentration in the leaves of 64±14 ngHg g\(^{-1}\), leads to an annual mean deposit on soil of 45±10 μgHg m\(^{-2}\) due to litterfall.

4.4. Origin of Hg in leaf canopy

There are two possible origins of the Hg present in canopy leaves: atmospheric uptake by foliage, and/or translocation (i.e. transfer of Hg from soil to leaves through the roots of the tree). This second process is usually believed to be negligible (see e.g., Gilmour and Miller, 1973; Beaufort et al., 1977; Lindberg et al., 1979; Goldbold and Hüttermann, 1988; Graydon et al., 2001; Rea et al., 2002), leaving Hg atmospheric load as the main contributor to Hg concentration in leaves. The Hg content of the atmosphere at the canopy level can be influenced by the soil emission. Literature suggests that this latter source is much less important than the global atmospheric load in unpolluted areas. Therefore, the Hg concentrations measured in the canopy foliage originate mainly from the atmosphere which, at these two sites, is representative of the background level.

This leads to an estimate for the background atmospheric contribution to the soil via litterfall of 45±10 μgHg m\(^{-2}\) in the French Guiana rainforest.

4.5. Atmosphere–soil transfer

In tropical rainforests, the Hg present in the atmosphere can be deposited on the soil mainly via 3 processes: rainfall, throughfall and litterfall deposits. In a forested area the rain lands on the soil after passing through the canopy and becomes enriched in Hg (throughfall deposit); during this transfer, the wash-off of dry deposited Hg compounds from the leaf surface appears to be the most important source of Hg, rather than foliage leaching (Rea et al., 2000, 2001). The third type of atmosphere–soil transfer operates through the foliage deposition/uptake, followed by the litterfall deposit. Measurements performed over two growing seasons on foliar Hg concentration indicate that atmospheric Hg accumulates during the growing season in living foliage (Rea et al., 2002). This may be illustrated by the 5–10 times lower concentration that we found in the central nervation of the leaf (Table 1), compared to the concentration found in the blade of the leaves (living cells). Absorbed Hg may be released by evaporation and/or leaching but these two mechanisms are shown to be of minor importance (Lodenius et al., 2001).

Different studies have focused on these mechanisms. For example, Iverfeld (1991) estimates these three components separately at the site of Gardsjön, Sweden. The measured components are total Hg rainfall deposit (12 μg m\(^{-2}\) year\(^{-1}\)), and throughfall deposit (17–19 μg m\(^{-2}\) year\(^{-1}\)); litterfall deposit was estimated (25 μg m\(^{-2}\) year\(^{-1}\)). This clearly shows the amplifying role of the foliage in transmitting the atmospheric mercury to the soil: the total Hg deposit through rainfall would be 12 μg m\(^{-2}\) year\(^{-1}\) on unforested soil, but close to 40 μg m\(^{-2}\) year\(^{-1}\) (throughfall + litterfall) in forested areas. Here the throughfall represents 72% of the litterfall. A similar ratio was found in the review article by Schroeder and Munthe (1998) on mercury deposition in precipitation, throughfall and litterfall in forested ecosystems of boreal forest in Sweden (Iverfeld, 1991; Munthe et al., 1995) and of temperate forests in USA (Lindberg, 1996). When averaged separately, rainfall, throughfall and litterfall are, respectively, 10, 15 and 20 μg m\(^{-2}\) year\(^{-1}\). Here the throughfall represents 75% of the litterfall: the deposition in such forested areas (throughfall + litterfall) is significantly greater than deposition in precipitation only (rainfall). A recent study estimating throughfall and measuring litterfall in deciduous forests in USA (Rea et al., 2002) leads to a comparable order of magnitude.

Here, in the tropical rainforest of French Guiana, the litterfall deposit mechanism, alone, represents ~45±10 μg m\(^{-2}\) year\(^{-1}\) of input to soil. This is therefore a low estimate of the atmospheric contribution to soil, as throughfall deposit (not measured here) should also be included.

The fact that temperate (deciduous) and boreal (evergreen) forests display a similar ratio of litterfall to throughfall, is a good indication that this
ratio can be extended to tropical forests. If the same ratio, (0.7), is assumed, the Hg flux due to throughfall may reach 30 μg m⁻² year⁻¹, thus yielding a total deposition flux of 75 μg m⁻² year⁻¹.

5. Conclusion

The purpose of this study was to estimate the canopy contribution to the Hg present in the soils of the French Guiana tropical rainforest through the litterfall deposit only. This canopy contribution originates mainly from the atmospheric background load. A study of Hg concentrations in the foliage of the canopy was carried out in two remote areas where gold mining has not occurred and which are free from any other anthropogenic influences. The sampling (11 species) of the canopy is representative of the French Guiana canopy. The mean average concentration found in the foliage was 64±14 ng g⁻¹ (dry wt.). Using an annual litterfall deposit of 7 ton ha⁻¹, a value typical of tropical rainforests, these results lead us to estimate the annual input of total Hg to the soil through the litterfall to be ~45±10 μg m⁻² year⁻¹. As translocation is believed to be negligible, mercury in the canopy originates mainly from atmospheric uptake by the leaves. This measured flux, therefore, represents a direct atmospheric input into the soil; in fact it represents the lower limit of this atmospheric deposit, as deposition due to throughfall must also be included in the total atmospheric deposit to soil in a forested area. This mechanism for transferring Hg from atmosphere to soil contributes partly to the Hg content in of remote areas in the French Guiana tropical rainforest.

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