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Mercury storage in surface soils in a central Washington forest and estimated release during the 2001 Rex Creek Fire

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ABSTRACT

Recent investigations indicate that wildfires provide a significant flux of mercury (Hg) from terrestrial ecosystems to the atmosphere. However, little is known about how geographic location, climate, stand age, and tree species affect Hg accumulation prior to burning and loss during burning. Soil cores collected in sites burned during the summer 2001 Rex Creek Fire in the eastern Cascade Mountains (Washington State, USA) and in adjacent unburned control sites indicate that Hg loss from soils during the Rex Creek Fire averaged 6.7 (±2.5) g Hg ha^{-1}. This soil profile-based estimate of Hg release is higher than a previous estimate for the same fire based on airborne measurements of Hg and CO concentrations in smoke. This study has implications for global estimates of Hg storage in forests and release to the atmosphere during wildfires.

1. Introduction

Mercury is a toxic trace metal that can accumulate in terrestrial and aquatic ecosystems. Gaseous elemental Hg (Hg^0) is the dominant atmospheric species and has a relatively long residence time (~1 year) that results in global distribution of Hg emissions. In the atmosphere, Hg^0 is oxidized to reactive mercury (Hg^{2+}), which is rapidly deposited (Lin and Pehkonen, 1999). Once deposited, Hg can be reduced to the toxic species methylmercury, which bioaccumulates in aquatic and terrestrial food webs (Hightower, 2004; Mahaffey, 1999). Elevated methylmercury concentrations are often found in fish species at the top of food webs (Boening, 2000) and this has prompted guidelines restricting fish consumption by sensitive populations (Mahaffey, 1999). There is a need to better understand the terrestrial Hg cycle and to investigate the potential for various sources of Hg to enter ecosystems. Anthropogenic point sources of Hg to the atmosphere have been relatively well-quantified in the USA, but natural sources, and in particular wildfires, have not been as well constrained.

Mercury inputs to forest ecosystems are associated with wet and dry atmospheric depositions, and to a lesser extent, assimilation via stomatal uptake (Rea et al., 2002). Mercury that is deposited to forests (and subsequently revolatilized during wildfires) is associated with upwind emissions of Hg from natural (e.g. volcanoes) and anthropogenic sources (e.g. coal-fired power plants) of Hg. Leaf area index (LAI), defined as the amount of leaf or needle surface area per unit ground area (Kashian et al., 2005), is one control on Hg deposition to a given location, though Hg accumulation to foliage is species-specific (Rea et al., 2000; Munthe et al., 1998). Due to leaching of foliage during precipitation events as well as litterfall and subsequent litter decomposition, Hg in forests is predominantly complexed with soil organic matter (SOM), rather than associated with living vegetation (Rea et al., 2000; Grigal et al., 2000; Schwesig and Matzner, 2000; Skyllberg et al., 2000; Biester

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et al., 2002). Mercury storage in soil depends on landscape position, stand age, species composition, amount of SOM, and burn frequency (Munthe et al., 1998).

The amount of Hg released during a wildfire is limited by the amount of Hg stored in the ecosystem, particularly in the soil, prior to burning. The severity of a fire, which is related to the temperature and duration of heating through the soil column (DeBano et al., 1998), is therefore an important control on Hg and SOM combustion and emission to the atmosphere. Fire severity varies across the landscape and can be influenced by variations in fuel availability, soil moisture, topography, weather, and fire dynamics (Flannigan and Wotton, 2001; Pyne et al., 1996). During natural wildfires, elevated soil temperatures sufficient to decompose the Hg-humic acid bond (~200–330 °C; Biester and Scholz, 1997) can extend from the fuel-rich organic (O) horizon into the A horizons, though typically no deeper unless there is a significant accumulation of fuel at the surface (e.g. a large log or slash/burn during a controlled burn; DeBano et al., 1998; Preisler et al., 2000). Laboratory combustion of vegetation indicates that Hg is almost completely mobilized from organic matter by fire, predominantly as Hg^0 (Friedli et al., 2001). However, airborne measurements of smoke released during wildfires indicate that up to 13% of the volatilized Hg in smoke plumes is associated with particulate matter (Friedli et al., 2003a). Several recent studies conducted in North America have indicated that Hg release during forest fires may represent an important input to the global Hg cycle (Friedli et al., 2003a; Biswas et al., 2007; Engle et al., 2006a; Friedli et al., 2003b; Harden et al., 2004; Sigler et al., 2003). However, due to differences in the methods employed and the forests investigated in these studies it has been difficult to directly compare Hg release estimates. Mercury emissions during wildfires have been evaluated using two contrasting methods (1) the soil profile method wherein Hg release is estimated based on the difference in Hg stored in soils at paired unburned (control) and burned sample areas (Biswas et al., 2007; Engle et al., 2006a; Harden et al., 2004) and (2) the Hg:carbon monoxide (CO) method wherein Hg release is estimated using the ratio of Hg^0 to CO in the smoke plume of a fire and using estimates of the carbon content of the burned ecosystem (Friedli et al., 2001; Friedli et al., 2003a,b; Sigler et al., 2003; Brunke et al., 2001). Mercury release estimates using the soil profile method have generally been higher than estimates using the Hg:CO method, but a direct comparison of the two methods on a single fire has not previously been made. Here we quantify Hg storage in a conifer forest in central Washington and estimate Hg release during the Rex Creek Fire that occurred in this region in 2001. This is the same fire for which Hg emissions to the atmosphere were estimated using the Hg:CO method (Friedli et al., 2003b), which provides an opportunity to compare Hg estimates resulting from these contrasting methodologies.

2. Experimental work

2.1. *Fire description and experimental design*

The Rex Creek Fire occurred in the central Cascade Mountain Range in Washington State (USA) from August 12 to October 1, 2001 (Fig. 1). This area ranges in elevation from ~1000 to 2500 m and is characterized by steep topography. Soils here are thin and poorly developed, and as a result the O, A, and B horizons are poorly defined. In general, at conifer forest locations the O and A horizons together comprise 3 to 4 cm depth, while at meadow locations the O and A horizons together comprise 1 to 2 cm depth. Conifer species, including lodgepole pine (*Pinus contorta*), subalpine fir (*Abies lasiocarpa*), whitebark pine (*Pinus albicaulis*, particularly at higher elevations), and ponderosa pine (*Pinus ponderosa*, particularly at lower elevations) account for >95% of the vegetation, with the remainder covered by shrubs and grasses. This region burns frequently and the area burned during the Rex Creek Fire included a mosaic of stand ages from ~30 years (last burned during the 1970 Safety Harbor Fire) to a maximum of ~250 years. Intermittent precipitation that occurred preceding

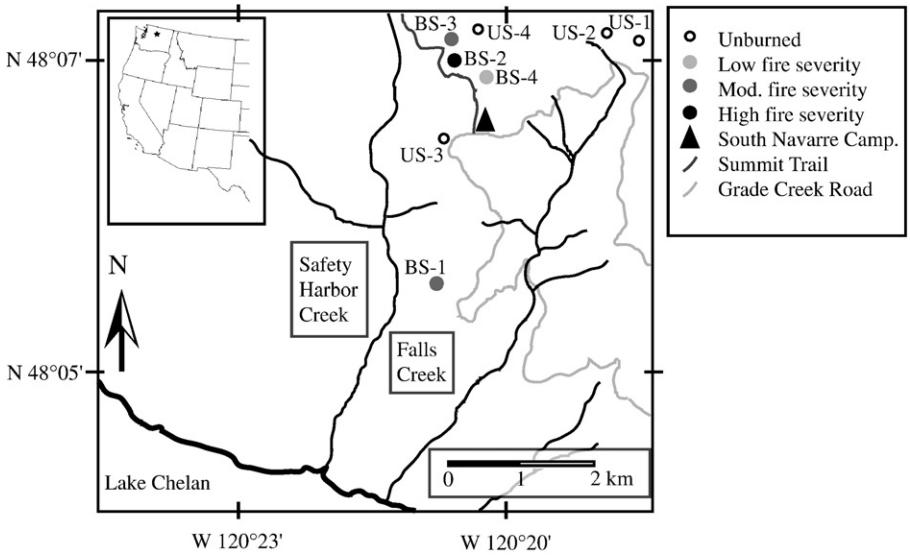

Fig. 1 – Map of sampling locations at the Rex Creek Fire (August–October 2001), central Cascade Range, WA, USA (open symbols represent unburned sites and filled symbols represent burned sites).