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EMISSION OF METHANE AND OTHER TRACE GASES
FROM THE AMAZON VARZEA

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1.0 SUMMARY OF RESULTS

The Amazon River is bordered by an extensive floodplain, or "varzea." The varzea, an area of 100,000 km² in Brazil alone, extends from the bed of the Amazon landward to the slope of the terra firme, and consists of fertile alluvial soils with gallery forests, grasslands, lakes (Lagos), flooded fields and swamps, and intermediate channels ("paranas"). It is periodically inundated by the annual 10 m rise and fall of the main channel; such that during high water much of the land will be 6-8 m deep. At this point the lakes become deep enough to stratify, on a time scale of weeks. As the river falls, land is re-exposed and lake levels drop to 1-2 m.

As part of the ABLE/AGE-IIa experiment (July-August 1985, early falling water), we proposed to measure the distributions and fluxes of methane and other trace gases from the various Amazon floodplain environments. These were determined during both a large scale, quasi-synoptic survey along a 2000-km reach of the Amazon river and an intensive local study (by J. Melack, R. Harriss et al.) covering a six-week period. The environments studied included the major rivers, connecting channels (paranas), floating macrophyte beds, flooded forests, open lakes and recently wetted soils. The results are summarized below; see the attached manuscripts for detail.

The results from both the large scale and intensive studies were in general agreement. Measured rates of methane emission averaged about 300 mg m⁻² d⁻¹, but with considerable variance, and were comparable to or higher than previously reported

emissions from similar temperate zone environments. In general, areas covered by floating macrophytes showed the highest emissions. Individual "hotspots" had among the highest rates ever observed, over $10 \text{ g m}^{-2} \text{ d}^{-1}$. Data taken during the CAMREX program (University of Washington, NSF-funded), which covered a three year period, suggest that there are significant spatial and temporal trends in dissolved methane concentration (fluxes were calculated, not measured directly), but the magnitude of the flux calculated for other times of the year is probably comparable to the AGE-IIa measurements.

The high methane emissions appear to result because about 50% of the organic matter fixed on the floodplain (either terrestrial or aquatic) that is oxidized in the water is decomposed anaerobically via methanogenesis. A redox gradient exists, with flowing waters being the most oxidized and still varzea waters being the most reduced. Ebullition accounted for 70-90% of the measured flux. Measured fluxes of methane to the atmosphere appear to be significantly correlated with surface water dissolved methane concentrations. Diffusive fluxes appear to be directly related to the dissipation of turbulent kinetic energy in the upper mixed layer; mixing rates were obtained from measurements of thermal structure and meteorological conditions. From AGE-IIa data, the $\delta^{13}\text{C}$ of CH_4 dissolved in anaerobic bottom waters and in bubbles released from the sediments is considerably lighter upstream, -65 o/oo , than downstream, -45 o/oo , with the bubbles being about 5 o/oo lighter than the dissolved CH_4 in the water column.

Extrapolation from the AGE-IIa measurements to the entire Amazon basin and adjacent regions would yield methane emissions to the troposphere of 10-20 Tg/y. It is important to note that the AGE-IIa fluxes were obtained during one time period, and that extrapolation to a full year is tentative. However, if this extrapolation is reasonable, the estimate represents a significant fraction of the total global source of between 200 and 550 Tg/y (Seiler 1984, Khalil and Rasmussen 1983, and others).

Our results to date, which are based on sampling limited in time and space, are very provocative, but not conclusive. Based on these results, we pose the following hypotheses concerning the overall magnitude and dynamics of methane flux in the Amazon:

Hypothesis 1. Mean Methane Emissions to the Troposphere

The dominant source of CH₄ to the Amazon troposphere is the floodplain (varzea). The mean annual flux is on the order of 300 mg m⁻² d⁻¹. This flux is the integral of considerable variance in mechanisms of emission and spatial and temporal distributions:

(a) Temporally, high emission rates are expected during rising waters, due to the entrainment and decomposition of terrestrially-derived plant material, whereas during falling water rates are expected to be high due to the die off and decay of the floating macrophyte vegetation, reduced hydrostatic pressure and release of accumulated gas.

(b) Spatially, two regions should dominate the flux; upriver in the Japura confluence zone and downriver near Obidos. The Rio Japura is the region of the strongest redox gradients from mainstem to the floodplain, especially during high water periods. Downriver, lakes are larger, rounder, and more oxygenated due to greater wind mixing. Although emissions per unit area from open waters in this area are probably less than upriver, the more extensive macrophyte cover may result in high emissions from this area also.

(c) The $\delta^{13}\text{C}$ composition of the CH₄ emitted to the atmosphere upriver is lighter than the global average, while that emitted downriver is comparable.

Hypothesis 2. CH₄ and CO₂ Source Dynamics

High CH₄ production in the varzea is a function of a particular sequence of organic matter oxidation that is established as a function of carbon fixed in the water and in the bordering terrestrial zone and degree and timing of inundation and physical mixing:

(a) Net carbon oxidation on the floodplain is on the order of 1700 mg m⁻² d⁻¹. Approximately 50% of this oxidation is anaerobic, as methanogenesis, with about 20% of the carbon lost to the atmosphere as CH₄.

(b) Although ebullition appears to be the major pathway of transport to the atmosphere, the relative importance of diffusion may increase during rising water and, especially, during periods of lake overturn and venting.

(c) The dissolved CH₄ is isotopically heavier than bubble CH₄ because dissolved CH₄ is the residual after CH₄ oxidation (which fractionates towards heavier carbon). The downstream trend is due both to a greater percentage of C-4 (isotopically heavy) plant material in the sediments downriver and to increased rates of CH₄ oxidation that result from greater physical mixing and, hence, greater oxygen input in the downriver lakes.

II. MANUSCRIPTS SUPPORTED BY THIS GRANT

Richey, J.E., A.H. Devol, S.C. Wofsy, R. Victoria, and M.N.G. Ribeiro. (in review). Oxidation and reduction rates for organic carbon in the Amazon mainstream, tributaries, and floodplain, inferred from distributions of dissolved gases. *Limnol. Oceanogr.*

Devol, A.H., J.E. Richey, W.A. Clark, S. King, and L.A. Martinelli. (in review). Methane emissions from the Amazon floodplain. *J. Geophys. Res.*

Quay, P.D., S. King, D. Wilbur, S. Wofsy, and J. Richey. (in prep., soon-to-be-submitted). $^{13}\text{C}/^{12}\text{C}$ of atmospheric CO_2 in the Amazon Basin: forest and river sources. *J. Geophys. Res.* [not included].