The emission of biogenic hydrogen sulfide from Amazonian floodplain lakes

By W. L. F. BRINKMANN and U. DE. M SANTOS, *Instituto Nacional de Pesquisas da Amazonia (INPA), Manaus, Amazonas, Brasil*

ABSTRACT

The emission of hydrogen sulfide from Amazonian floodplain lakes was detected mainly during the period of falling water of the Amazon river, which peaks out in September and October. Hydrogen sulfide was present even in some surface water samples (up to 0.40 mg at. H_2S-S/1). A part of the emitted hydrogen sulfide is recycled on a regional or local scale by means of biospheric trap mechanisms and eventual rainout, sustaining the tight sulfur cycle of the Amazonian tropics. But a certain amount of the emitted hydrogen sulfide contributes to the atmospheric sulfur budget. Under cold front conditions, however, the emitted hydrogen sulfide is rapidly recycled into the tropical forest stands.

Introduction

The 'Hyleia Amazonica' covers an area of approximately 5 mill. km^2, about 2% of which are flood plains of the main river system, the Amazon. At high water level the river plains are completely flooded except for some 'terra firme' islands. At low water level, however, many shallow lakes fall dry. The seasonal rise and fall of the water level, which is in the order of 8 m–14 m, determines the ecological conditions in the lakes and the temporarily flooded fringe forests (Fig. 1).

The duration and intensity of the floods in central Amazonia depends on: (1) the total amount of rainfall deposited in the upper drainage basin of the Amazon river and its main tributaries during the preceding months, (2) the final gage height of the preceding low water and to a minor extent (3) on the melting water draining the Andean part of the watershed. Consequently, the flood water level in the lakes, the duration of inundation of the fringe forests (Igapó) and the extension of the flood area vary considerably from year to year. The same is true for the development and density of the aquatic plant communities.

Methods

A modified Winkler method was used for the oxygen analyses. The method is time-consuming, but the results obtained are accurate. Some test measurements undertaken with a portable oxygen probe were abandoned as hydrogen sulfide interfered uncontrollably with the oxygen readout.

Hydrogen sulfide was determined by a iodimetric titration method (IBP, 1971) and photometrically (Freier, 1964). Using a 5-cm cuvette at 380 nm the range of the latter method is 0.010–3.000 mg at. H_2S–S/1. At very low concentrations of hydrogen sulfide in lake waters the methylene blue method was performed as a control procedure. To avoid any loss of sulfide by evaporation and oxidation the sulfide sampled was immediately stabilized as cadmium sulfide in colloidal solution with gelatine. But the method is far too sensitive to be used without considerable modifications in the total range of hydrogen sulfide concentrations present in the lake waters analyzed. The general sampling technique for hydrogen sulfide compares with oxygen sampling procedures.

The vertical and seasonal distribution of hydrogen sulfide was studied in 4 central Amazonian floodplain lakes from February 1970 to July 1971. Sampling was done in intervals of 10–15 days. During cold front conditions, however, water was collected every 6 hours.

Results

In the period of rising water, sulfates are carried into the lake systems by the rivers. The peak of the rain season coincides with the

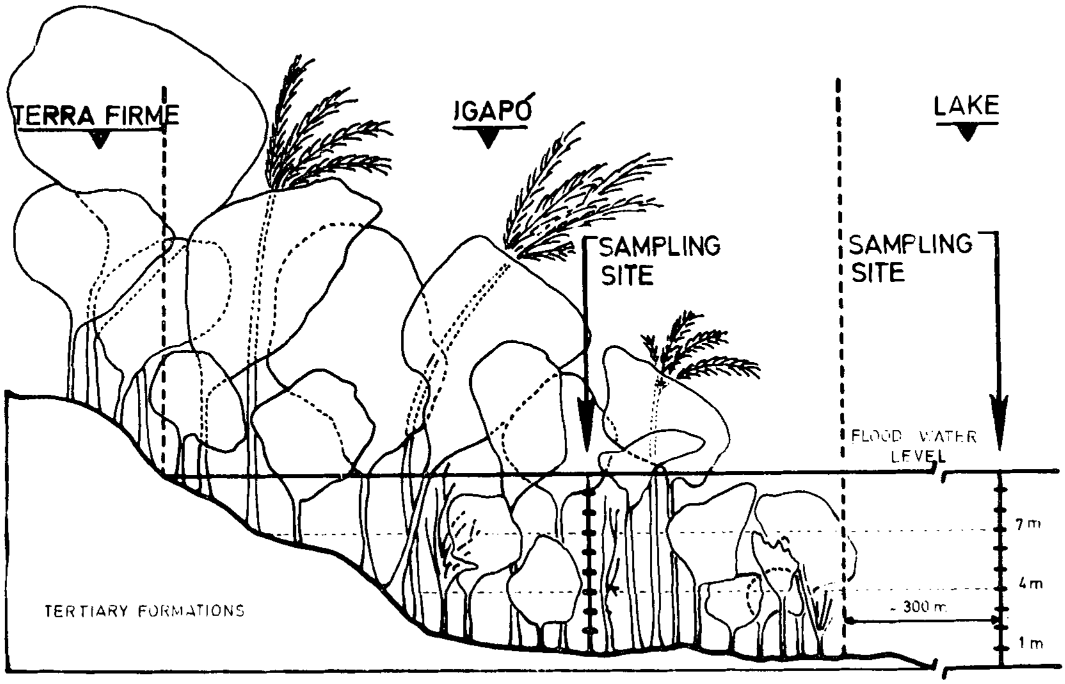

Fig. 1. Eco-trasect of central Amazonian floodplain lakes (Lago Jaraqui, Lago Calado, Lago Jutai, and Lago do Castanho).

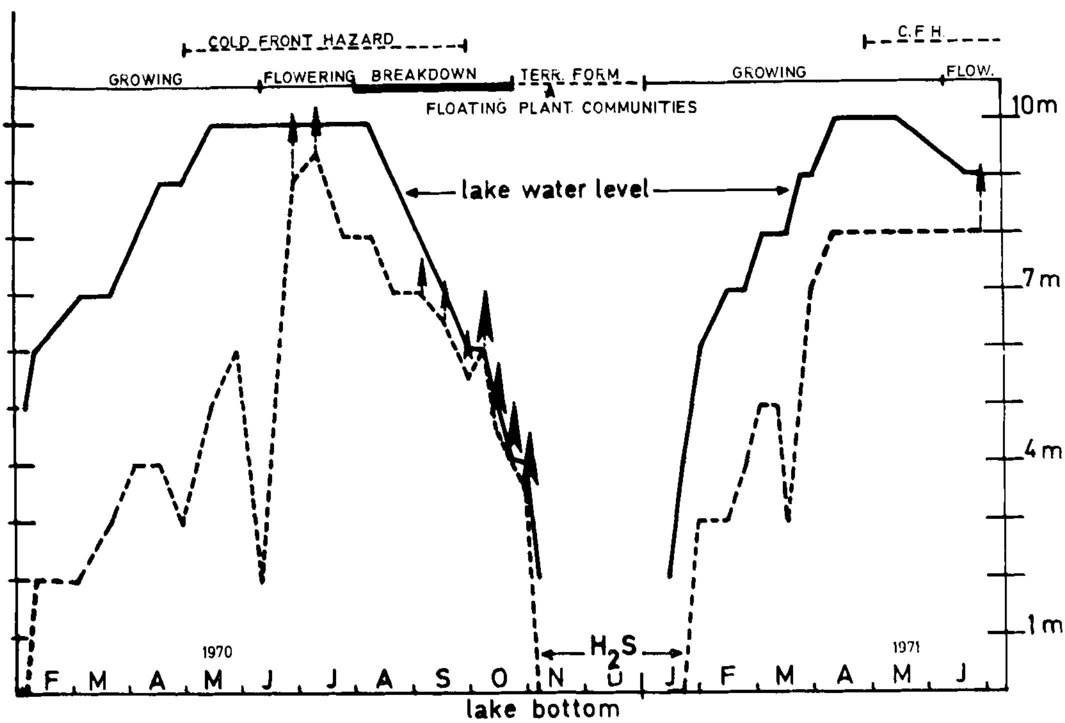

Fig. 2. Distribution pattern of gage height (*m*) and hydrogen sulfide (H_2S) in a central Amazonian floodplain lake (Lago do Castanho).

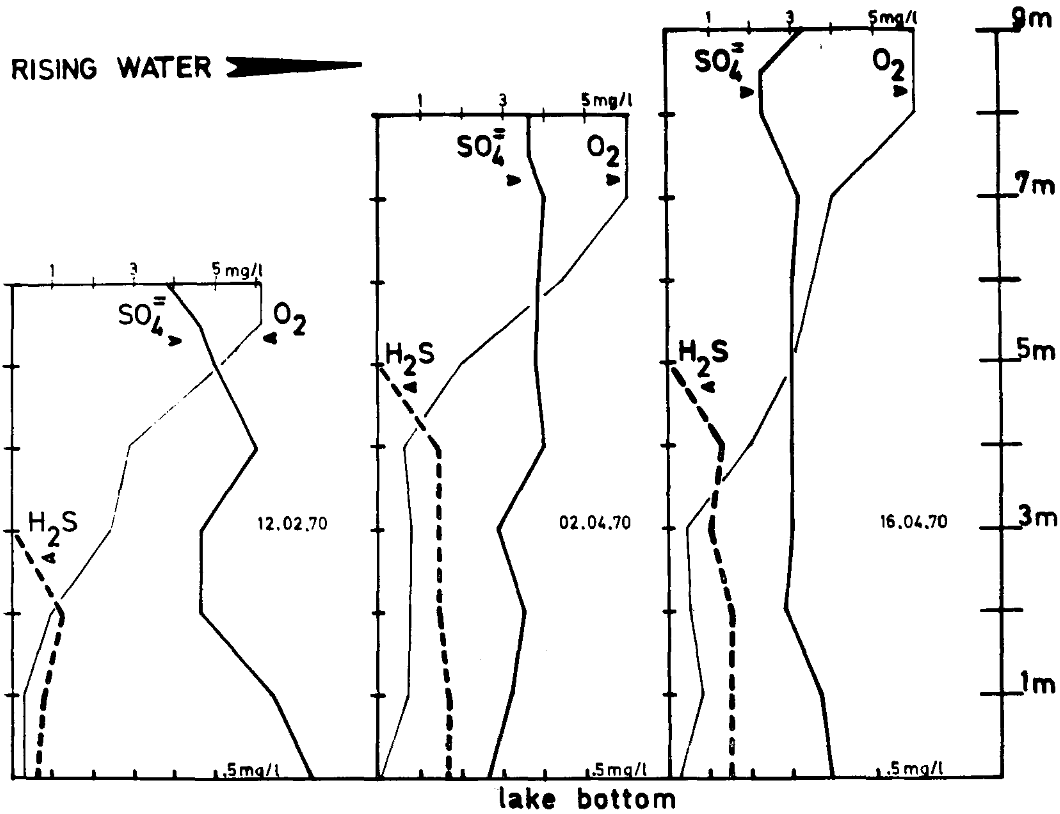

Fig. 3. Distribution pattern of oxygen (O_2), sulfate (SO_4) and hydrogen sulfide (H_2S) during the period of rising water in a central Amazonian floodplain lake (Lago do Casthano).

period of recharge of the lake systems. Thus heavy and frequent rains deposit a considerable amount of sulfates in the lakes. The aquatic plant communities, mainly *Paspalum fasciculum, Paspalum repens* and *Echnochloa polystachya* (Junk, 1970), burst out in an explosive growth, which leads to a marked loss of sulfates from the lake waters to the aquatic sulfur standing crop. As decomposing organic matter at the bottom of the lake is scarce, the production of hydrogen sulfide in the period of rising water is poor (0.05–0.20 mg at. H_2S–S/l) and comes mainly from the reduction of sulfates (Fig. 2). Some traces of hydrogen sulfide escaping from the bottom layer through the barrier of thermoclines are rapidly oxidized and bring about a more or less prominent peak in the sulfate concentrations just above the thermocline (Fig. 3). The distribution of hydrogen sulfide in the lakes is such that normally the barrier of thermoclines and the increasing pressure keep the hydrogen sulfide away from the upper part of the epilimnion.

The situation changes completely when cold fronts strike in the area. Due to rapid cooling of the surface waters, together with strong winds, an anomalous turbulent transfer of surface waters into the depths is generated. The thermal stratification in the lakes disintegrates in a few hours, causing the exchange of chemical compounds and gases from bottom to surface. Hydrogen sulfide, normally limited to the bottom layer, pervades a great part of the water bodies (Fig. 4). As a matter of fact, the presence of hydrogen sulfide (0.30–0.90 mg at. H_2S–S/1) does not exclude the presence of oxygen, although oxygen saturation of the water is extremely low all over the vertical profile. Mostly, cold front conditions culminate in a serious fishkill, as observed on June 27 (Fig. 4). At that occasion the odor of hydrogen sulfide was in the air at various locations of the lake

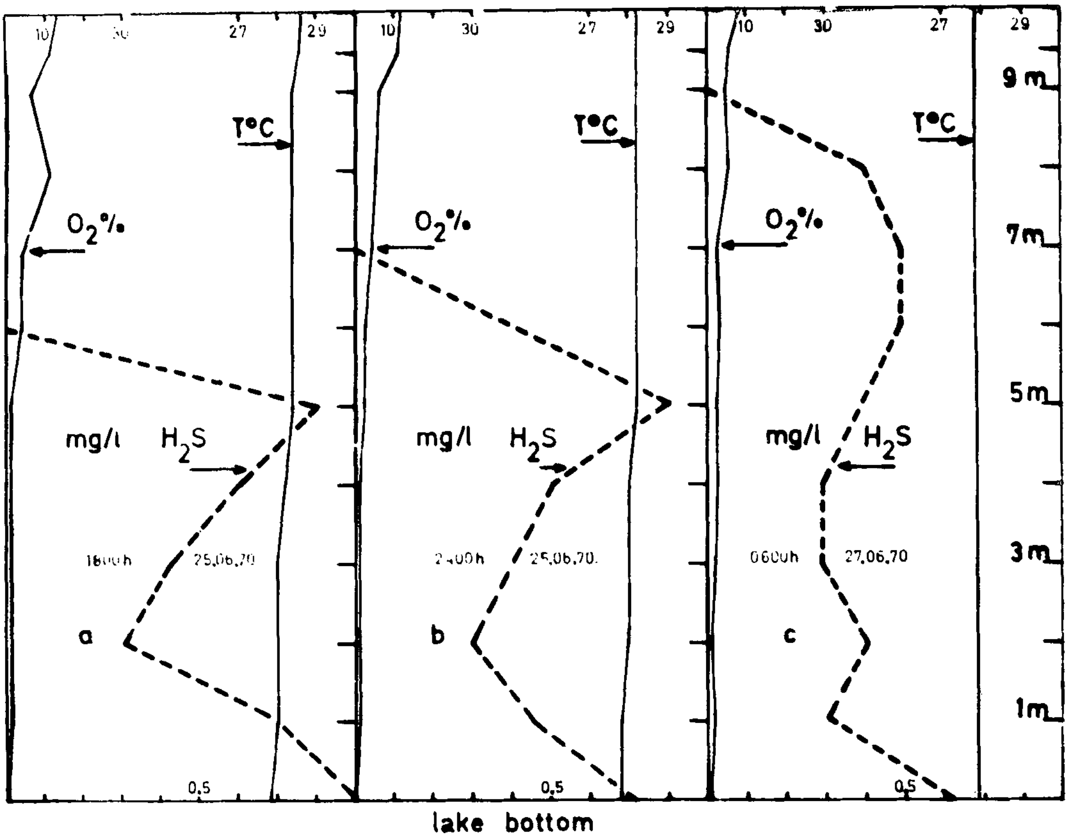

Fig. 4. Distribution pattern of temperature (°C), oxygen (O_2) and hydrogen sulfide (H_2S) in a central Amazonian floodplain lake (Lago do Castanho) under cold front conditions.

area. To avoid the toxic impact of undissociated hydrogen sulfide, fish have to concentrate in the near-surface layer. The oxygen concentrations in the near-surface zone are extremely low so that fish are subject to serious harm or even death depending on their specific tolerance-ranges to the actual oxygen deficit (Brinkmann & Santos, 1973). Obviously, hydrogen sulfide was emitted from the lake waters to the atmosphere during cold front conditions. But rainfall frequency in those days was such that a greater part of atmospheric sulfur was immediately recycled into the biosphere by atmospheric washout. Another part is lost by retention on epiphytes and epiphylls of the surrounding forests or even by direct foliar absorption.

The impact of cold fronts on the Igapó areas was studied in June 1971 (Fig. 5). The free circulation of water between the open lake and the flooded fringe forests was retarded by the dense forest stands. But, the impact of strong winds on the canopy areas of the fringe forests caused an Igapó-specific turbulent mixing of the waters due to the stirring effect of swaying trees. Hydrogen sulfide (0.20–0.90 mg at. H_2S–S/1) was brought up to the surface layer, where the oxygen saturation was considerably higher than in the open lake. Although isothermal conditions were almost complete on June 26, the bottom layers remained free of oxygen. A serious fishkill was observed on June 25 in late afternoon. Hydrogen sulfide escaped into the atmosphere at various points, but a great part certainly was rapidly intercepted by numerous epiphytes and epiphylls which are primarily yeasts, fungi, bacteria, algae and protozoa.

Doubtless the emission of hydrogen sulfide from central Amazonian floodplain lakes and flooded fringe forests under cold front conditions is real. But the atmospheric sulfur gen-

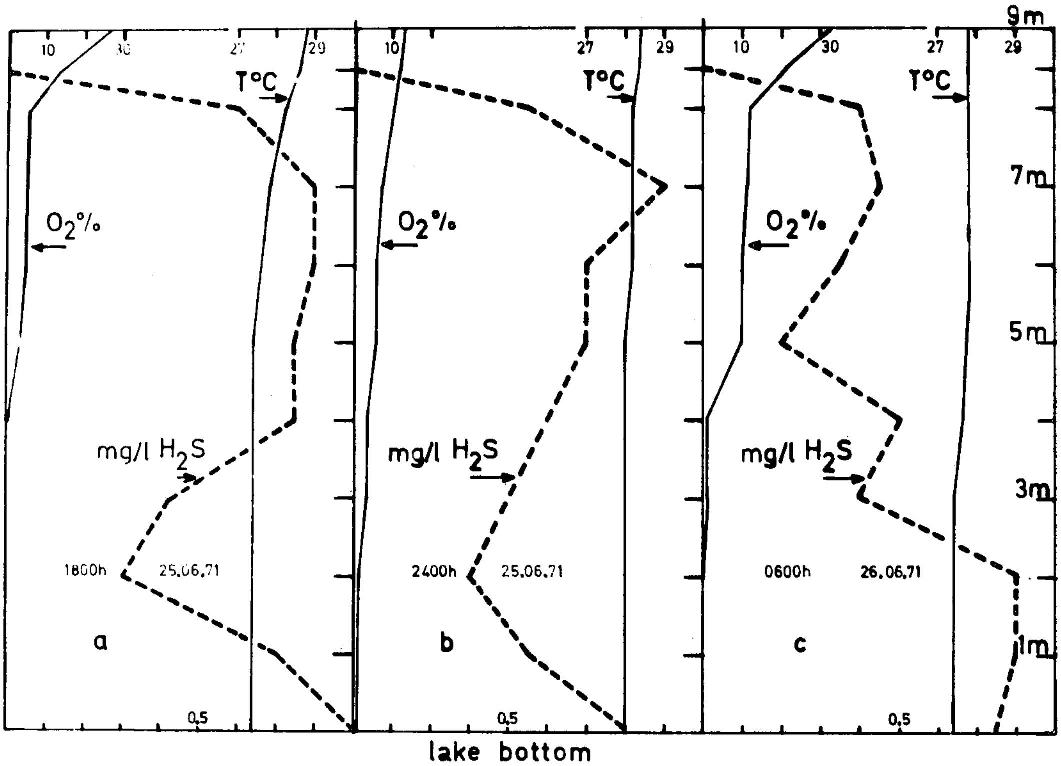

Fig. 5. Distribution pattern of temperature (°C), oxygen (O_2) and hydrogen sulfide (H_2S) in the flooded fringe forest (Igapó) of a central Amazonian floodplain lake (Lago do Castanho) under cold front conditions.

erated is rapidly recycled into the river basins due to unfavorable atmospheric conditions such as the high frequency of convective rains and the high atmospheric humidity. In the Igapós, however, released sulfur is trapped shortly after the emission from the water surface by epiphytal and epiphyllic communities in the canopy areas of the fringe forests. In fact, the emitted sulfur will contribute to the tight sulfur cycle in central Amazonia on a regional or local scale.

Assuming a water year to be normal, the floods of the Amazon river system breek in late June. In the lakes, however, the aquatic plant communities are fully developed and flowering. The lakes are partly covered with floating vegetation. The productivity of the 'floating meadows' is 5–8 to/ha per vegetation period (Junk, 1970). The extensive rootsystems of the floating vegetation accumulate a considerable amount of suspended matter by filtering the lake water. The vertical distribution of bacteria was such that a productivity peak was observed in the near-surface layer followed by a marked decline and a secondary peak near the bottom of the lake (Schmidt, 1969). The vertical distribution and concentration pattern of hydrogen sulfide in all 4 lakes studied compared well, while the oxygen curves reflected the differences in size, distribution and density of aquatic plant communities and the marked effect of rain forest streams draining in the lakes.

In the period of falling water a complete breakdown of the aquatic plant population is observed (Fig. 2). Partly, the floating vegetation drifts off the lake systems. The major part, however, will contribute to the mineral budget of the respective lake. A considerable amount of organic sulfur is fixed to the aquatic standing crop during the period of rapid growth, mainly synthesized in proteins. The mineralization of the accumulated organic sulfur compounds in a series of decomposition processes partly leads to the formation of hydrogen sul-

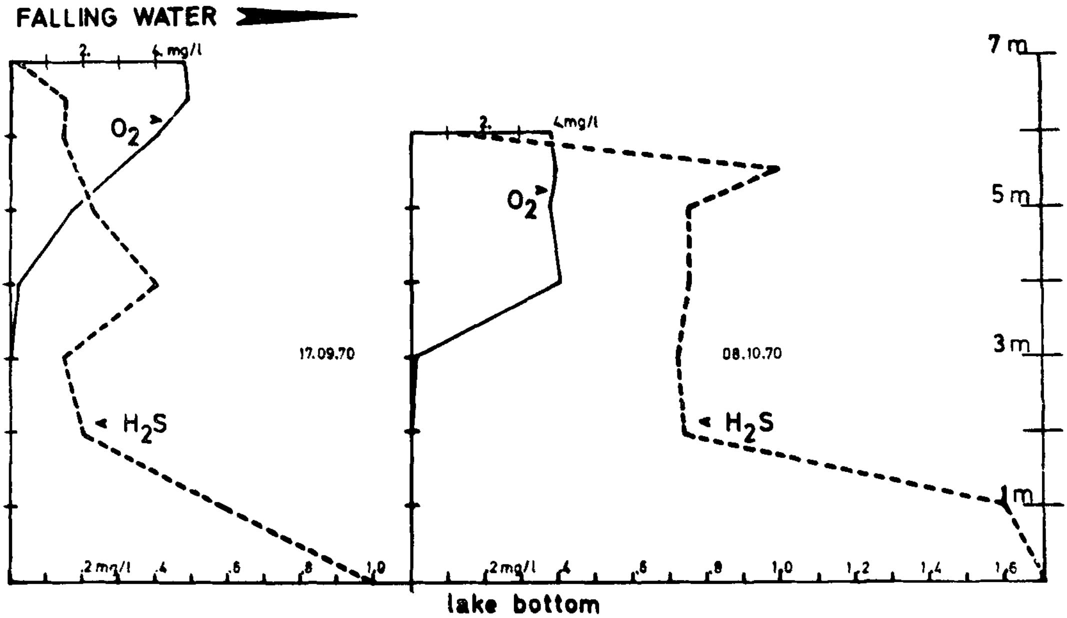

Fig. 6. Distribution pattern of oxygen (O_2) and hydrogen sulfide (H_2S) during the period of falling water in a central Amazonian floodplain lake (Lago do Castanho).

fide in the oxygen-free bottom layer (Fig. 6). As mineralization processes are fovared by high temperatures in the lake water, the rapidly generated hydrogen sulfide by organic matter decay contributes to the hydrogen sulfide concentrations derived from sulfate reduction. Consequently the hydrogen sulfide levels in the lake waters reach the yearly maximum (about 2.0 mg at. H_2S–S/l). Obviously with falling water hydrogen sulfide is present all over the vertical water profile and even encountered in the surface waters, although the corresponding oxygen content is quite high. This is due to (1) the increased production of hydrogen sulfide in the hypolimnion, (2) the growing turbulent mixing of the lake waters by draining into the main river system and, (3) the continuous decrease in pressure with falling gage height in the lake (Fig. 6). The most striking evidence of hydrogen sulfide emission from waters of central Amazonian floodplain lakes to the atmosphere was discovered in the period of falling water. The events coincide with the peak of the dry season. Rainfall frequency is low and torrential downpours are followed by a couple of days without rain. Surface temperatures of the lakes are between 31°C and 33°C, while more than 40°C were recorded at the welted surface of the 'floating meadows'. Under these particular conditions we suppose a certain contribution of sulfur from aquatic origin to the atmospheric sulfur budget to occur, although its amount still has to be gaged by atmospheric sampling.

During the period of falling water some floodplain lakes lose their connection with the Amazon river system. The larger lake systems, however, have a permanent connection to the Amazon by small channels. The latter lakes were studied. In late October gage height was 2 and 4 meters at Lago Jutai and Lago do Castanho. The vertical distribution of hydrogen sulfide remained as previously shown, but the hydrogen sulfide concentrations decreased considerably (0.15–0.45 mg at. H_2S–S/l). Some days later the emission and production of hydrogen sulfide was stopped completely. Some 'terra firme' tropical wet forest streams, draining into the lakes, gained influence on the chemical composition of the lake waters and washed great quantities of the organic detritus into the main river system. A great part of the lake area had fallen dry and some aquatic plants such as *Paspalum repens* gave growth to their terrestrial forms (Fig. 2).

Conclusions

The emission of hydrogen sulfide from central Amazonian floodplain lakes under cold front conditions was real (Fig. 2). But, much of the released sulfur is rapidly recycled into the biosphere by rainout. Another fraction is directly absorbed from the atmosphere by plants. Especially in the canopy areas retention rate of gasses are high due to the abundance of epiphytes and epiphyll. The contribution of emitted hydrogen sulfide to the atmospheric sulfur budget is considered insignificant, although on a regional and local scale it is of importance in sustaining the tight sulfur cycle of the Amazonian tropics.

In the period of falling water, however, a considerable amount of hydrogen sulfide is emitted to the atmosphere (Fig. 2). The production of hydrogen sulfide in the oxygen-free bottom layers of the lakes is favored by a rapid breakdown of the floating plant population. The organic sulfur standing crop is rapidly mineralized to various decay products of which hydrogen sulfide is one of the most important. Atmospheric conditions are favorable as the increased production of hydrogen sulfide in the lakes coincides with the peak of the dry season, when rainfall frequency is low. At the same time the water pressure decreases daily. Although a part of the emitted hydrogen sulfide will be recycled into the biosphere of the Amazon river basin by retention processes, biogenic trap mechanisms and eventual rainout, a certain amount is released to the atmosphere, being a real contribution to the atmospheric sulfur budget.

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ВЫДЕЛЕНИЕ БИОГЕННОГО СЕРОВОДОРОДА ИЗ ОЗЕР, ОБРАЗУЮЩИХСЯ ПРИ РАЗЛИВАХ АМАЗОНКИ

Выделение сероводорода из озер, образующихся при разливах Амазонки, было зарегистрировано в основном в период падения уровня реки, минимум которого приходится на сентябрь и октябрь. Сероводород присутствовал даже в пробах воды, взятых с поверхности (в концентрациях до 0,40 *мг/л*). Часть выделяющегося сероводорода снова попадает в цикл его круговорота в пределах данной области, благодаря наличию механизма биосферных ловушек или дождям, что поддерживает в твердых рамках цикл круговорота серы в тропиках Амазонки. Но определенное количество выделяющегося сероводорода попадает в общий бюджет серы в атмосфере. Однако в условиях холодного фронта выделяющийся сероводород быстро попадает в новый цикл в области тропических лесов.