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# BIOMASS BURNING IN AMAZONIA: SEASONAL EFFECTS ON ATMOSPHERIC $O_3$ AND CO

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RESUMO-NOTAS/ABSTRACT-NOTES

The practice of shifting agriculture and the need for the colonization of new land areas determine each year considerable amounts of biomass burnings in the Brazilian Amazon region. This paper describes new results on the effects of these burnings on the composition of the lower atmosphere. Simultaneous measurements of $O_3$ and CO are described at two sites: one within the burning region of central Brazil, Cuiabá (16°S, 56°W), and another one away from it, Natal (6°S, 35°W). The data obtained so far covers the 1987, 1988 dry season periods, when the burning intensity is maximum (July, August, September), and the wet season period of 1988, when practically no burnings occur. Both sites show minimum concentrations of $O_3$ and CO in the wet season, with monthly averages in March of about 12 and 14 ppbv (parts per billion by volume) for Cuiabá, and about 10 and 80 ppbv, for Natal. While the seasonal increase at Natal is of the order of a factor of 2, the seasonal increase at Cuiabá for 1987 was about a factor of 4, and a factor of 6 for 1988. For the month of September 1987, $O_3$ and CO had concentrations of 23 and 110 ppbv for Natal, whereas at Cuiabá these concentrations were 41 and 470 ppbv. The larger concentrations were 41 and 470 ppbv. The larger concentrations observed in September correlate well with the larger number of fires detected by the infrared radiomater on the NOAA-9 satellite.

OBSERVAÇÕES/REMARKS

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# BIOMASS BURNING IN AMAZONIA: SEASONAL EFFECTS ON ATMOSPHERIC $O_3$ AND CO

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Abstract. The practice of shifting agriculture and the need for the colonization of new land areas determine each year considerable amounts of biomass burnings in the Brazilian Amazon region. This paper describes new results on the effects of these burnings on the composition of the lower atmosphere. Simultaneous measurements of $O_3$ and CO are described at two sites: one within the burning region of central Brazil, Cuiabá ($16^0$S, $56^0$W), and another one away from it, Natal ($6^0$S, $35^0$W). The data obtained so far covers the 1987, 1988 dry season periods, when the burning intensity is maximum (July, August, September), and the wet season period of 1988, when practically no burnings occur. Both sites show minimum concentrations of $O_3$ and CO in the wet season, with monthly averages in March of about 12 and 140 ppbv (parts per billion by volume) for Cuiabá, and about 10 and 80 ppbv, for Natal. While the seasonal increase at Natal is of the order of a factor of 2, the seasonal increase at Cuiabá for 1987 was about a factor of 4, and a factor of 6 for 1988. For the month of September 1987, $O_3$ and CO had concentrations of 23 and 110 ppbv for Natal, whereas at Cuiabá these concentrations were 41 and 470 ppbv. The larger concentrations observed in September correlate well with the larger number of fires detected by the infrared radiometer on the NOAA-9 satellite.

## Introduction

Besides natural sources, CO is also produced from biomass burning (Crutzen et al., 1985), and special field campaigns have been organized to study this CO source (Greenberg et al., 1985; Crutzen et al., 1985; Kirchhoff and Marinho, 1989) and its associated production of ozone (Fishman et al., 1986; Kirchhoff, 1988; Sachse et al., 1988). A review on tropospheric ozone has recently been published by Logan (1985). On a global basis it is calculated (Crutzen et al., 1985) that a total of $8 \times 10^{14}$g of CO are emitted to the atmosphere every year by biomass burning activities, especially in the tropics. The industrial source, on the other hand, should be responsible for an emission rate of $6 \times 10^{14}$g of CO per year (Seiler, 1974).

Burning of phytomass in the tropics is related to ancient agricultural practices. The type of agriculture most practiced in tropical land is

the so called slash-and-burn or shifting agriculture. Vegetation is cut and trees are felled and this is burnt after drying in the sun. The cleared area is then used for a few years for crops. It is abandoned when the harvest yield becomes low and a new clearing is made. Seiler and Crutzen (1980) give other details on this practice.

Only sporadic measurement campaigns have been undertaken to study biomass burning in Brazil. This report describes the first effort to obtain data on a systematic, continuous basis, to obtain CO and $O_3$ concentrations between the seasonal maximum and minimum periods. Measurements of $O_3$ and CO have been made at two sites: one in the burning area and another one outside of the direct influence of biomass burning.

## Results and Discussion

### Sampling sites

Biomass burning activities have been monitored near Cuiabá (15.6$^0$S, 56.1$^0$W), located well within the major burning area (see Plate 1). For comparison marine air from the northeast shore of Brazil has also been sampled, at Natal (6$^0$S, 35$^0$W), a site well outside the direct biomass burning area of central Brazil. Ozone has been measured systematically in the troposphere and stratosphere, using sondes (Kirchhoff et al., 1983; Barnes et al., 1987, Logan and Kirchhoff, 1986). For this work, ozone concentrations have been measured continuously at the surface, 1.5 m above ground, using the ultraviolet absorption technique. The basic CO measurement technique has been described by Kirchhoff and Marinho (1989).

### CO and $O_3$ data

Carbon monoxide concentrations are measured from air samples collected three times a week at noon. The monthly average $O_3$ concentrations are computed from the daily averages, which in turn are averages of the 24 hour hourly means. Figure 1 shows the monthly average CO and $O_3$ concentrations for Cuiabá and Natal, from August 1987 to October 1988, covering more than a complete seasonal cycle with two yearly maxima and one period of minimum concentration. The Natal concentrations are shown by the hatched areas in Figure 1. The maximum concentrations for CO are seen in September, for Cuiabá, with minima in the January-May period. The maximum CO for Natal is observed in September-October. The ozone concentration variation seems to follow the CO variation quite closely. Both Cuiabá and Natal have maximum concentration in September.

It is interesting to note, from Figure 1, that there is no practical difference for $O_3$, and to a lesser extent for CO (because the data is noisier) between the two stations, in the wet season period. The same $O_3$ concentration averages can be seen at Cuiabá and Natal, between December and June. The same CO concentrations were observed, for both stations in April and May. On the other hand, in the dry season, the concentrations at Cuiabá are many times larger than those at Natal. While the seasonal variation at Natal is of the order of a factor of 2, at Cuiabá it is a factor of 4 for 1987, and more than a factor of 6 for 1988.

Several measurement sites and field expeditions organized by Seiler and co-workers (Seiler, 1974; Seiler et al., 1984) as well as results for the Pacific (Heidt et al., 1980) and Atlantic oceans (Fraser et al., 1986) show seasonal variations for CO less than a factor of 2. Also, the absolute values reported are below about 100 ppbv. Our maximum concentrations of between 400 and 650 ppbv for the remote site at Cuiabá are very large in comparison. These absolute values are based on the Rasmussen scale. We have determined from the comparison of calibration gases that the absolute values should be 30% larger using the Seiler calibration scale.

Previous ozone measurements in other tropical areas, for example in tropical Africa (Cros et al., 1987), in the Venezuelan savannah (Sanhueza et al., 1985), for Hawaii (Oltmans and Komhyr, 1986) and for tropical Asia (Ogawa and Komala, 1988) all show seasonal variations around a factor of 2 or less for the ozone concentration near the ground, as show our own results for Natal. Even for higher latitudes, the seasonal variation of daily average values, is usually not much larger than a factor of 2 in either eastern or western sites of the USA (Logan, 1987). Evidently, for Cuiabá, a large fraction of the seasonal increase of $O_3$ must be credited to the burning activity (Zimmerman et al., 1978; Fishman et al., 1979), probably through oxidation of the CO directly injected into the lower atmosphere by the fires, as described, for example, in Levy (1971), Logan (1985), and Jacob and Wofsy (1988). The other ingredients necessary for photochemical production of $O_3$, OH and UV light, are plentyful at these low latitudes (Kirchhoff et al., 1988).

As mentioned before, the seasonal maxima in CO and $O_3$ must be attributed to biomass burning. Such a correlation, however, has never been shown, except for sporadic cases. A positive correlation can be shown using two auxiliary indexes. The annual distribution of the rain intensity, which clearly defines wet and dry seasons, and the number of large forest fires as

detected from a special radiometer on board of the NOAA-9 satellite. For this satellite, a horizontal resolution at the surface of 1.1 km, at the nadir point, can be achieved. Its orbit is quasi-circular, quasi-polar, sun-sincronous (Kidwell, 1985). The Advanced Very High Resolution Radiometer (AVHRR) on board NOAA-9 can transmit images by the High Resolution Picture Transmission (HRPT) system in 5 spectral bands. In the visible band the image can detect clouds and smoke plumes, besides the details on the terrain. In the infrared band 3 (3.55 to 3.93 μm) the sensitivity is largest for temperature differences, being able to detect the fires themselves. The images are processed by a cluster synthesis automatic algorithm which provides groupings of elementary areas, pixels, of similar spectral characteristics. Only signals above a minimum threshold are classified as fires.

Figure 2 shows the 1987 precipitation amount for Cuiabá, in mm of rain accumulated in periods of 10 days. During the dry season less than about 2 mm of rain have been observed in intervals of 10 consecutive days. Largest rainfall occurred in December and February. Also shown in Figure 2 is the amount of fires as detected from the satellite images, in units of 1000 pixels, also observed in intervals of 10 days. As can be seen, the large burnings that we are considering were restricted to the dry season period, and were more intense during September. This high correlation between small amounts of rain and large number of fires, in the dry season, and the further correlation between the maximum number of fires in September and maximum concentrations of CO and $O_3$, seem to be strong evidence to link the biomass burning to the production of CO and $O_3$, beyond the limits of normal seasonal variations that occur outside the burning region. If we consider these as the background values, that is, values that would be measured in the absence of biomass burning, then the effect of the fires is to raise the CO and $O_3$ concentrations by a factor of between 2 and 3 above the background values.

Plate 1 shows a NOAA-9 image in the infrared spectral band, taken on 01 September 1987, showing a large amount of fires in the Brazilian Amazon region. Some points of reference are given which can help to estimate distances: the location of the cities of Manaus, Porto Velho, Cuiabá, Brasília, and Belém. Most of the fires are in the north of the state of Mato Grosso and along the Belém-Brasília road, the major ground transportation link between North and South in Central Brazil. This information can be used to estimate the size of the burned areas. One difficulty is to account for the limited

resolution of the satellite sensor. In practice, experiments are made where some areas observed by the satellite, are also observed and measured, simultaneously, by instruments carried on low flying aircraft. Work on the dtermination of absolute values for the burned areas is in progress and will be reported elsewhere.

## Summary and Conclusions

We report the first complete annual cycle of simultaneous $O_3$ and CO measurements under the direct influence of biomass burning in the Amazon region. The impact of the fires is evaluated by comparison of the same $O_3$ and CO measurements in a region outside of the burning area. We do not only speculate that the larger concentrations seen in Cuiabá are the result of emissions from the burnings but we show additional evidence pointing to the excellent correlation between rainfall minima and the number of fires as detected from satellite. For one day in September, the phenomena is shown by a satellite snapshot (Plate 1) in the infrared band which shows very clearly the extent of the fires.

The peak burning season for 1987 and 1988 was September. For 1987, the $O_3$ and CO concentrations wer about 4 times larger compared to the wet season period. In 1988 this factor was even larger, when the $O_3$ and CO concentrations in September were about 6 times larger than the wet season averages. Our simultaneous measurements made at Natal, and results obtained by other workers for other regions in the tropics, show seasonal variations that generally are less than a factor of 2. This shows that, in addition to the expected natural variation, and in comparison with the wet season, biomass burning in Amazonia is responsible for almost triplicating the CO and $O_3$ concentrations in the dry season.

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Fig. 1. Monthly average concentrations of CO and $O_3$ showing the seasonal variation between the two dry season maxima (September) and the wet season minimum (February-April). Cuiabá represents the biomass burning area whereas Natal, a marine site, is shown for comparison (hatched).

Fig. 2. Distribution of the 1987 precipitation intensity for Cuiabá, measured in mm of rain accumulated in 10 days. The lower panel shows the relative number os fires detected from satellite NOAA-9 in the period.

Plate 1. Satellite image in the infrared band showing numerous fires in the Brazilian Amazon region on 01 September 1987.

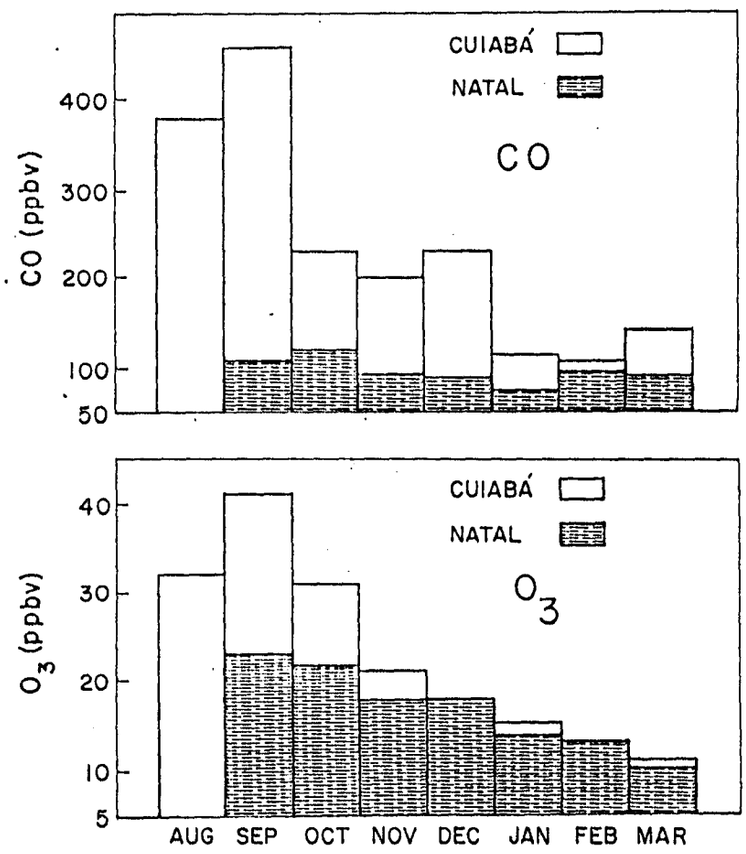
CUIABÁ
NATAL
CO
CO (ppbv)
400
300
200
100
50
CUIABÁ
NATAL
$O_3$
$O_3$ (ppbv)
40
30
20
10
5
AUG SEP OCT NOV DEC JAN FEB MAR

Fig. 1

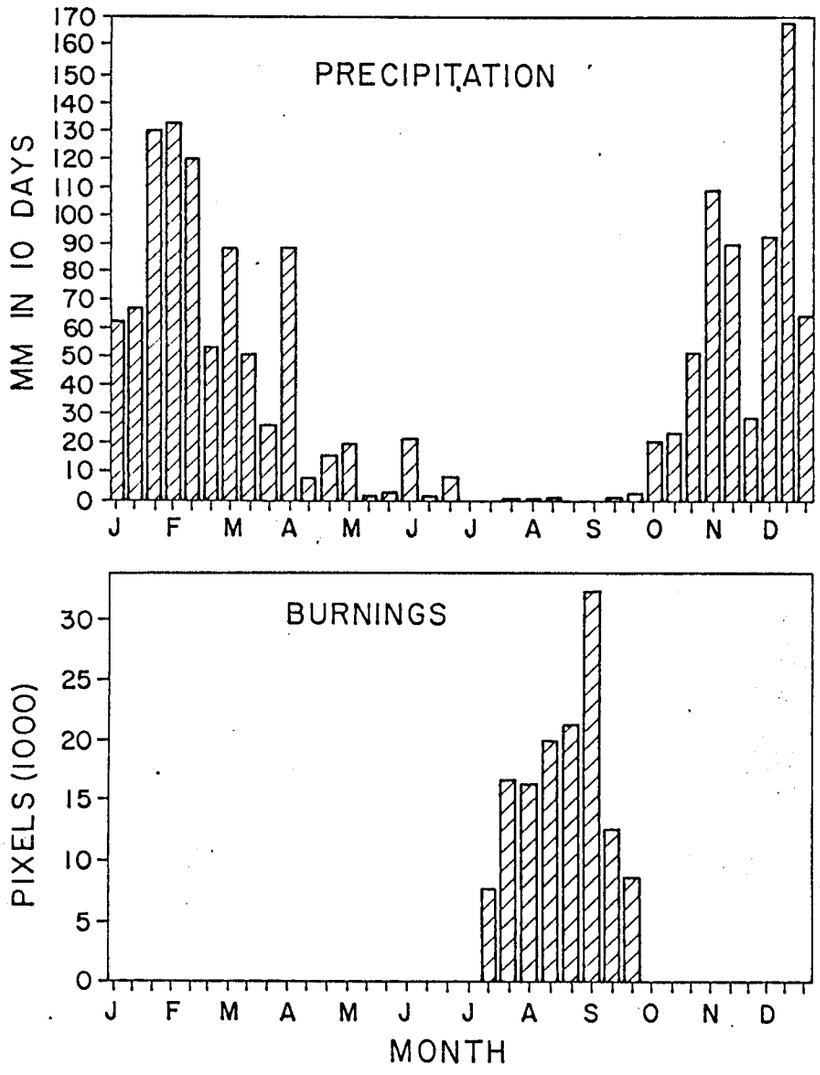
PRECIPITATION
MM IN 10 DAYS
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
J F M A M J J A S O N D
BURNINGS
PIXELS (1000)
30
25
20
15
10
5
0
J F M A M J J A S O N D
MONTH

Fig. 2

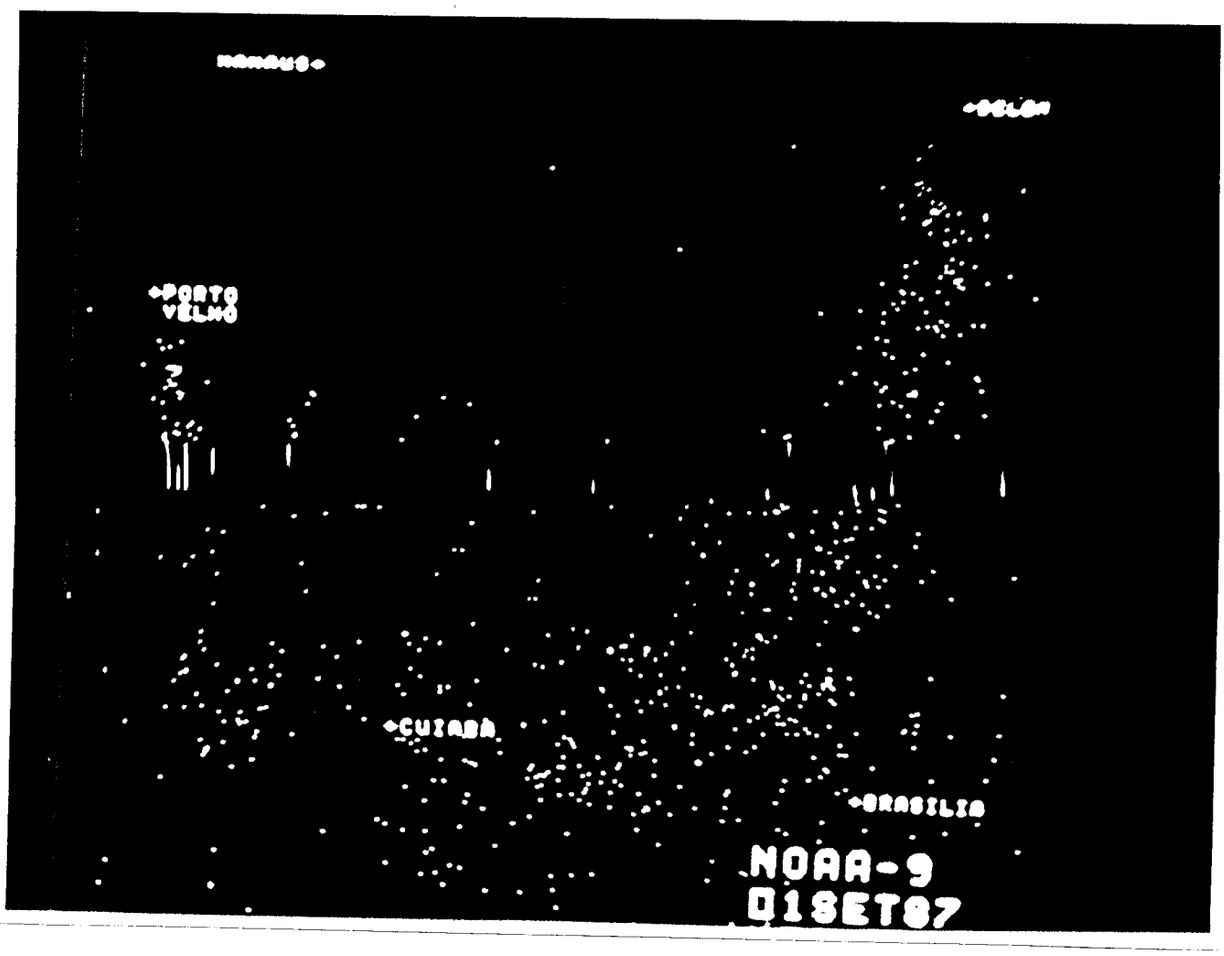


Plate 1

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