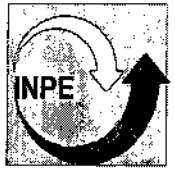
Geoprocessamento

- Tratamento computacional de dados geográficos
- Tres visões de Geoprocessamento

  Produção de mapas: geração e visualização de dados espaciais

  Bancos de dados espaciais: armazenamento e recuperação de informação espacial

  Análise espacial: combinação de informações espaciais



BIOMASS BURNING IN AMAZONIA: PRODUCTION OF CO_2, CO AND O_3 AND ITS GLOBAL IMPACT

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ABSTRACT

Biomass burning in Amazonia is a regular and systematic practice during the local dry season. Based on several years of measurements of atmospheric O_3, CO, and CO_2 in Amazonia, during dry and wet season periods, it is shown that local modifications of the atmosphere have been underestimated, especially by the local population. The local contribution of biomass burning is such that the O_3 concentration in the dry season is about twice as large as compared to the wet season, whereas the CO and CO_2 concentrations increase by as much as a factor of 4 to 7 times the wet season value. On the other hand, contrary to current belief, our data indicate that the global effect of biomass burning in the topics has been largely overestimated, being actually two orders of magnitude less than values that have been cited in the literature for the last decade.

INTRODUCTION

Burning of phytomass is related to ancient agricultural practices. The type of agriculture most practiced in tropical lands is the so called slash-and-burn or shifting agriculture. Vegetation is cut and trees are felled and this is burned 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) and Fearnside (1987) give other details on this practice. In Amazonia, in recent years, another type of biomass burning has increased considerably, due to colonization and land development, which is deforestation and burning of virgin forest.

Ozone and carbon monoxide (O_3 and CO) are important constituents of the lower atmosphere, having active participation in a number of chemical reactions. CO_2 is important for the global carbon cycle and its role in the Greenhouse effect. Besides being a powerful oxidant, ozone is important through its photoloysis, which produces the very reactive oxygen atom in the excited 1D state, which can dissociate the otherwise very stable water vapor molecule, to produce the hydroxil

radical (Levy, 1971; Wofsy, 1976). This OH molecule starts most of the loss processes of relatively stable gases of the troposphere such as CO and CH_4, in addition to many man-made trace gases. Besides its chemical importance, ozone concentrations seem to have increased in the lower atmosphere. Measurements of ozone during several years have indicated a positive trend for some stations in Germany (Feister and Warmbt, 1987; Logan, 1985), showing concentration increases between about 1 and 3% a year. Other stations in Europe seem to have measured much less ozone in the early half of the century than today, indicating also a trend for ozone concentration increases (Bojkov, 1986). Since ozone makes also a significant contribution to the Greenhouse effect, and since high ozone concentrations can harm crop yields (Heck et al., 1984) the assessment of trends require not only very accurate measurements of ozone at several points on the Globe, but also systematic long term measurement programs.

There has been much interest, in recent years, to study ozone in the tropics, where the reaction rates are expected to be much faster due to the higher UV intensities that reach the equatorial troposphere (Crutzen et al., 1985). It has been shown that ozone can be produced in the troposphere (e.g. Fishman et al., 1979) by the reaction of CO with OH in the presence of the nitrogen oxides NO and NO_2, and ultraviolet light, and there is strong evidence that large forest fires can contribute to excess O_3 in the tropics (Crutzen et al., 1985; Delany et al., 1985; Fishman et al., 1986; Kirchhoff et al., 1988). In collaboration with NASA a long term program is in effect to obtain ozone profiles at Natal (6°S, 35°W) twice a month since 1978 using ECC sondes (Kirchhoff et al., 1981; 1983), and sporadic rocket campaigns have been made to study the upper stratosphere at Natal (Barnes et al., 1987).

Carbon dioxide and water vapor are the major gases produced from biomass burnings. Other important gases for the atmosphere like CO, NO, H_2, and N_2O are produced in much smaller proportions. The relative ratio between the excess (over the background values) of these gases released from burnings to the excess of CO_2, have been

shown to be relatively constant. For CO this ratio is 8.5% (Andreae et al., 1988). Presently it is easier to measure CO than CO_2 and therefore it is often preferred to measure CO and deduce CO_2 from above ratio. From the total combusted organic carbon, CO represents between 5 and 20%. This makes the enhancement of the CO concentration from biomass burning effects much easier to detect than the corresponding CO_2 enhancements (Andreae et al., 1988).

In the tropical areas of Brazil, there are basically 4 different types of biomass burning: forest fires, savannah (cerrado) fires; burning of sugar cane fields before harvesting, and burning of grass and other low vegetation in city areas. Among these different types of burning, some are useful, having an economic justification, since it is much less expensive to a specific land owner to clear an area by setting fire on it. A large percentage of all burnings, however, are unnecessary, fulfill no specific need, and bring no benefits. On the contrary, a large amount of burnings each year causes severe property damage, loss of flora and fauna in National Parks, loss of soil fertility, kills insects and small animals, and as we will show, deteriorates the quality of the air. More than that, unnecessary, careless biomass burning, causes each year the loss of human lives (See for example, recent article in the local newspaper "O Vale Paraíbano", of 23 July 1989, describing a severe car crash on Via Dutra caused by roadside fires with intense smoke, where 8 persons were killed). Every year such events are repeated. Numerous airports in the Amazon region remain closed for many days per year for lack of visibility, so dense are the smoke clouds. If the local land owner gets economic benefits from burning, in many cases out of control burnings cause severe damage at a high cost to others.

It is important to clearly state that there is no such thing as spontaneous fires. In tropical regions there is no lightning without immediate strong rain. I have never witnessed a spontaneous fire start, on the contrary, for the great majority of city fires, for example, especially recently started ones, one can see people walking or standing nearby appreciating the fire, sometimes children. We

Brazilians love to lit a little fire. Most of us are in fact unaware of the possible danger. There is even a religious tone to making a fire. At the end of the wet season, in June, we celebrate several Saint's days, and this is done in outdoor parties where fires are especially lit and played with. It is, therefore, not an easy task to change the tradition of putting fire on everything.

OBJETIVE OF PAPER

The goal is to show recent data on atmospheric O_3, CO, and CO_2, and their enhancements because of biomass burning. We show that the effect is mostly negative on a local scale, but that its global effect is not as large as has been claimed without dispute for the last decade.

RESULTS

Ozone concentrations have been measured continuously at the surface, 1.5 m above ground, using the ultraviolet absorption technique. Ozone profiles have also been obtained using ECC ozonesondes at Natal and Manaus (Logan and Kirchhoff, 1986).

The basic CO measurement technique used is chromatographic separation followed by mercury vapor detection (Seiler, 1974). This technique has much better chromatographic resolution and measurement precision, as well as linearity of response, as compared, for example, with the FID technique, for low concentrations in the ppbv (parts per billion by volume) range. The carrier gas is dried and filtered to eliminate interference from reducing gases. Sulfur dioxide and hydrocarbons, which could react with mercuric oxide at the reaction chamber temperatures are eliminated on a routine basis since the instrument is dedicated to the measurement of CO only. Samples are individually injected and the concentration is determined by comparison with calibration gases. Injection into the flow system is accomplished by initial transference to a 2 ml sample loop which is, after extensive flushing with sample air, introduced into the main flow using a six-

port valve. The operation is very simple and fast and has excellent resolution and precision. Around 100 ppbv, typical precision is 0.2%. Each sample is analyzed in about 5 minutes. The samples are collected by a small portable air pump that pressurizes stainless steel cans of 800 ml volume, electropolished internally and especially manufactured for air sampling purposes, developed by R. Rasmussen, Oregon Graduate Center. For the present analysis, all samples have been analyzed in the lab in less than a week's time after sampling, and typically after 2 or 3 days. Information on vertical profiles is obtained from Crutzen et al. (1985) and Sachse et al. (1988).

Fig. 1 shows the geographic location of the area under study, and the main remote measurement sites at Cuiabá, Manaus, and Natal, used in this study.

Fig. 2 shows air mass trajectories. It shows the major burning area strip between 5 and 20°S. For a point near Cuiabá three air mass trajectories have been calculated to show the long range transport characteristics of the region. Between 850 and 500 mb, air masses from the heavy burning area are brought to the Cuiabá region. At 850 mb, in the mixed layer, the air is transported towards Cuiabá from the north-northeast, near the area where numerous fires normally develop. Each arrow represents the transit time of 6 hours. At 500 mb the air masses come from the direction of Rondônia, another state where much burning takes place. The high pressure center of anti-cyclonic circulation that is present over central Brazil in July, in the case shown, is responsible for the transport of air masses to the south. It is possible, however, through a relatively small displacement of this center, to produce north-northwest air transport, as described for example in Browell et al. (1988), and Kirchhoff et al. (1988). These trajectories and the location of Cuiabá show that this is an excellent site for biomass burning studies. Kirchhoff et al. (1989) show a satellite immage in the infrared around Cuiabá, with numerous fires in the region.

Fig. 3 shows the monthly average CO and O_3 concentrations for Cuiabá and Natal, from August 1987 to October 1988 covering two periods of yearly maxima. The Natal concentrations are shown by the hatched bars. The maximum concentrations for CO are seen in the month of 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 concentrations in September. A seasonal variation is also clearly seen in the data reported by Cros et al. (1987) for equatorial Africa. The data obtained on board of ships show a more complex character, being different over different longitudinal belts (Winkler, 1988). The data for Asia (Ogawa and Komala, 1988) and the results for Australia (Fraser et al., 1986) and data for much higher latitudes (Feister and Warmbt, 1987), all show seasonal variations near the surface of the order of a factor of 2 or less. The O_3 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). For Cuiabá, the ratio between maxima and minima (Fig. 3) is of the order of a factor of 4 for 1987, and of more than a factor of 6 for 1988.

Fig. 4 shows the two "typical" CO profiles used in the calculations that follow. There is one "minimum" case and another one considered to be a representative "maximum" case.

DISCUSSION

The data collected so far indicate two important results, in two different perspectives. From the micro point of view, that is, in terms of local modifications to the lower atmosphere, it is clear that the excess production of certain gases has been underestimated by the local population which believes that burnings cause no harmful effects. Average O_3 excesses of a factor of 2 and sporadic concentrations as high as 100 ppbv of O_3, observed at Cuiabá, are clearly not expected for a remote site like Cuiabá. Excesses, of CO

and CO_2 are even larger. One may safely conclude that biomass burning adds considerable amounts of toxic gases to the lower atmosphere.

From the macro point of view or the global influence of biomass buring in the topics, it was believed until recently that its effect was negligible in comparison to fuel burning (Robinson and Robbins, 1970). A decade later, Crutzen et al. (1979) showed that biomass burning is responsible for the production of several gases, and that intense burnings could cause considerable modifications to the natural atmosphere. That paper also calculated a worldwide CO_2 emission flux on the basis of estimates of burnt areas, burnt biomasses, and converting dry matter to carbon by a constant factor of 0.45. The resulting figure was between 2 and 4 x 10^{15} gC per year for the CO_2 flux, giving for CO a flux of 840 MTY (million tons per year) of CO. Several years earlier Seiler (1974) estimated the total CO emission from fuel combustion to be 640 MTY of CO, and thus it became established after 1979 that both sources, the industrial and biomass burning ones, are of the same order of magnitude. Table 1 shows the global contributions for CO_2 and CO from biomass burning used by several authors over the last decade, showing that virtually the original estimate by Crutzen et al. (1979) was not changed or seriously disputed.

Our data seem to suggest a much smaller effect of burnings in the tropics on a global scale. To show this, a simple calculation is performed next, using our own data and the general vertical distribution expected on the basis of measurements by Crutzen et al. (1985) and Sachse et al., (1988). The yearly emission of CO_2 from biomass burning will be calculated for estimated minimum and maximum conditions, assuming that our data are representative for all burning areas in the tropics. Figure 4 shows the extreme cases believed to be representative in terms of the excess CO distribution with height. The background atmosphere is represented by a profile of about 100 ppbv of CO uniformily distributed with height and the excess CO is distributed roughly in the triangular form shown in Fig. 4a. Fig. 4b shows what is believed to be a resonable maximum average distribution.

To calculate the flux only the total burned area needs still to be known.

This figure has been evaluated from daily satellite NOAA-9 immages, using different spectral bands. Taking account of the limited spatial resolution of the satellite picture, the best estimate of total burnt area per year is between a minimum of 80 x 10^3 km^2 and maximum of the order of 200 10^3 km^2. The emissions can now be calculated, being proportional to the product of

$$\int Cdh$$

and the total burnt area S, where C is the concentration and dh a differential height interval. With appropriate transformation of units the results for CO are,

$$F_{MIN} = 0.08 \text{ MTY},$$

$$F_{MAX} = 0.89 \text{ MTY},$$

only for the Brazilian Amazon contribution. These figures can be easily extrapolated worldwide (all tropics) using the reasonable assumption that the ratio of burnt area over total area is the same in all tropics. For the maximum case, this would produce a global CO flux of 7 MTY.

Comparing this result with the literature value of about 620 MTY, this means that our maximum calculation case is still two orders of magnitude lower than the values used by the authors of Table 1. It seems, therefore, that the global impact of biomass burning in the tropics has been largely overestimated in the literature.

In terms of relative contributions the Brazilian Amazon would contribute only about 13% globally, considering uniform characteristics for the burning and assuming a 4% (our maximum case)

burnt area annually of forest and savannah areas. The corresponding CO_2 flux is 35.8 MTY of C, as shown in Table 1 and 2.

CONCLUSIONS

Our data show that biomass burning in Amazonia has a very strong effect on the local lower atmosphere, doubling the O_3 concentration and increasing the CO and CO_2 concentrations by factors of between 4 and 7. These results were obtained by comparing data of a burning area station (Cuiabá) to a non burning area station (Natal), and the general feeling is that these resuits are representative for other Amazonian locations as well.

Using the CO data in two extreme (low and high) cases, the calculated worldwide (total tropics) flux obtained in a simple calculation is much less than presently accepted values in the literature, by a factor of almost two orders of magnitude, even in the maximum case calculation. This result contradicts the present belief of a much larger effect in global terms, but in fact it only disagrees with one earlier calculation, since all estimates of global CO_2 production from biomass burning are in fact a result of the original estimates by Crutzen et al. (1979). It is concluded that the CO_2 production from biomass burning in the tropics is much smaller than the industrial CO_2 source.

ACKNOWLEDGEMENTS

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REFERENCES

ANDREAE, M. O., et al., Biomass emissions and associated haze layers over Amazonia, J. Geophys. Res., 93, 1509-1527, 1988.

BARNES, R. A., A. R. BANDY, and A. L. TORRES, ECC ozonesonde accuracy and precision, J. Geophys. Res., 90, 7881-7888, 1985.

BARNES, R. A., A. C. HOLLAND, and V. W. J. H. KIRCHHOFF, Equatorial ozone profiles from the ground to 51 km during the Southern Hemisphere Autumn, J. Geophys. Res., 92, 5573-5583, 1987.

BOJKOV, R. D., Surface ozone during the second half of the nineteenth century, J. Climate and App. Met., 25, 343-352, 1986.

BROWELL, E. V., C. L. GREGORY, R. C. HARRISS, and V. W. J. H. KIRCHHOFF, Tropospheric ozone and aerosols distributions across the Amazon Basin, J. Geophys. Res., 93, 1431-1451, 1988.

BROWELL, E. V., et al., A survey of ozone concentrations in Amazonia's wet season, in preparation, 1989.

CHAMEIDES, W., and J. C. G. WALKER, A photochemical theory of tropospheric ozone, J. Geophys. Res., 78, 8751-8760, 1973.

CHAMEIDES, W., and J. C. G. WALKER, A time dependent photochemical model for ozone near the ground, J. Geophys. Res., 81, 413-420. 1976.

CROS, B., R. DELMAS, B. CLIRAC, J. L. MDEMBI, and J. FONTAN, Survey of ozone concentrations in an equatorial region during the rainy season, J. Geophys. Res., 92, 9772-9778, 1987.

CRUTZEN, P. J., The role of NO and NO_2 in the chemistry of the troposhere and stratosphere, Ann. Earth Planet. Sci., 7, 443-472, 1979.

CRUTZEN, P. J., L. E. HEIDT, J. P. KRASNEC, W. L. POLLOCK, and W. SEILER, Biomass burning as a source of atmopsheric gases CO, H_2, N_2O, NO, CH_3Cl, and COS, Nature, 282, 253-256, 1979.

CRUTZEN, P. J., A. C. DELANY, J. GREENBERG, P. HAAGENSON, L. HEIDT, R. LUEB, W. POLLOCK, W. SEILER, A. WARTBURG, and P. ZIMMERMANN, Tropospheric chemical composition measurements in Brazil during the dry season, J. Atmos. Chem., 2, 233-256, 1985.

DELANY, A. C., P. HAAGENSON, S. WALTERS, A. F. WARTBURG, and P. J. CRUTZEN, Photochemically produced ozone in the emission from large-scale tropical vegetation fires, J. Geophys. Res., 90, 2425-2429, 1985.

FEARNSIDE, P. M., Causes of deforestation in the Brazilian Amazon, in The Geophysiology of Amazonia, Robert E. Dickinson, ed., John Wiley, New York, 1987.

FEISTER, V., and W. WARMBT, Long-term measurements of surface ozone in the German Democratic Republic, J. Atmos. Chem., 5, 1-21, 1987.

FISHMAN, J., S. SOLOMON, and P. J. CRUTZEN, Observational and theoretical evidence in support of a significant in situ photochemical source of tropospheric ozone, Tellus, 31, 432-436, 1979.

FISHMAN, J., P. MINNIS, and H. G. REICHLE, Jr., Use of satellite data to study tropospheric ozone in the tropics, J. Geophys. Res., 91, 14451-14465, 1986.

FRASER, P. J., P. HYSON, R. A. RASMUSSEN, A. J. CRAWFORD, and M. A. K. KHALIL, Methane, carbon monoxide and methylchloroform in the Southern Hemisphere, J. Atmos. Chem., 4, 3-42, 1986.

GREENBERG, J. P., P. R. ZIMMERMANN, L. HEIDT, and W. POLLOCK, Hydrocarbon and carbon monoxide emissions from biomass burning in Brazil, J. Geophys. Res., 89, 1350-1354, 1984.

HARRISS, R. C., et al., The NASA GTE-ABLE-2B experiment, in preparation, 1989.

HEIDT, L. E., J. P. KRASNEC, R. A. LUEB, W. H. POLLOCK, B. E. HENRY, and P. J. CRUTZEN, Latitudinal distributions of CO and CH_4 over the Pacific, J. Geophys. Res., 85, 7329-7336, 1980.

HECK, W. W., W. W. CURE, J. O. RAWLINGS, L. J. ZARAGOZA, A.S. HEAGLE, H. E. HEGGESTAD, R. J. KOHUT, L. W. KRESS, and P. J. TEMPLE, Assessing impacts of ozone on agricultural crops: I, Overview, J. Air Pollut. Contr. Assoc., 34, 729-735, 1984.

KIRCHHOFF, V. W. J. H., Y. SAHAI, and A. G. MOTTA, First ozone profiles measured with ECC sondes at Natal (5.9°S, 35.2°W), Geophys. Res. Lett., 8, 1171-1172, 1981.

KIRCHHOFF, V. W. J. H., E. HILSENRATH, A. G. MOTTA, Y. SAHAI, and R. A. MEDRANO-B., Equatorial ozone characteristics as measured at Natal (5.9°S, 35.2°W), J. Geophys. Res., 88, 5812-6818, 1983.

KIRCHHOFF, V. W. J. H., and E. V. A. MARINHO, Surface CO results from the ABLE-2B expedition to Amazonia, EOS, Transactions, 68, 247, 1988a.

KIRCHHOFF, V. W. J. H., and E. V. A. MARINHO, A survey of continental concentrations of atmopsheric CO in the Southern Hemisphere, Atmos. Environm., 23, 461-466, 1988b.

KIRCHHOFF, V. W. J. H., E. V. BROWELL, and G. L. GREGORY, Ozone measurements in the troposphere of an Amazonian rain forest environment, J. Geophys. Res., 93, 15850-15860, 1988.

KIRCHHOFF, V. W. J. H., and E. V. A. MARINHO, Surface carbon monoxide measurements in Amazonia, in preparation, 1989.

KIRCHHOFF, V. W. J. H., and I. M. O. DA SILVA, Ozone measurements in Amazonia: Dry season x Wet season, in preparation, 1989.

KIRCHHOFF, V. W. J. H., A. W. SETZER, and M. C. PEREIRA, Biomass burning in Amazonia: Seasonal effects on atmospheric O_3 and CO, Geophys. Res. Lett., 5, 469-472, 1989.

LEVY, H., II, Normal atmosphere: large radical and formaldehyde concentrations predicted, Science, 173, 141-143, 1971.

LOGAN, J. A., Tropospheric ozone: seasonal behaviour, trends, and anthropogenic influence, J. Geophys. Res., 90, 10463-10482, 1985.

LOGAN, J. A., The ozone problem in rural areas of the United States, NATO workshop on Tropospheric Ozone, proceedings, D. Reidel, 1987.

LOGAN, J. A., and V. W. J. H. KIRCHHOFF, Seasonal variations of tropospheric ozone at Natal, Brazil, J. Geophys. Res., 91, 7875-7881, 1986.

OGAWA, T., and N. KOMALA, Diurnal and seasonal variations of the tropospheric ozone in tropical Asia, Quadrennial Ozone Symposium, Gottingen, August 4-13, 1988.

RASMUSSEN, R. A., and M. A. K. KHALIL, Atmospheric isoprene, EOS, 66, 39, 1985.

RASMUSSEN, R. A., and M. A. K. KHALIL, Isoprene over the Amazon Basin, J. Geophys. Res., 93, 1417-1421, 1988.

ROBINSON, E., and R. C. ROBBINS, The fate of atmospheric pollutants, in Global Effects of Environmental Pollution, W. F. Singer, ed., Reidel, Dordrecht, 1970.

SACHSE, G. W., R. C. HARRISS, J. FISHMAN, G. F. HILL, and D. R. CAHOON, Carbon monoxide in the atmosphere over the Amazon Basin during the 1985 dry season, J. Geophys. Res.,, 93, 1422-1430, 1988.

SEILER, W., The cycle of atmospheric CO, Tellus, 26, 117-135, 1974.

SEILER, W., and P. J. CRUTZEN, Estimates of gross and net fluxes of carbon between the biosphere and the atmosphere from biomass burning, Climatic Change, 2, 226-247, 1980.

SEILER, W., H. GIEHL, E. G. BRUNKE, and E. HALLIDAY, The seasonality of CO abundance in the Southern Hemisphere, Tellus, 36, 219-231, 1984.

WINKLER, P., Surface ozone over the Atlantic Ocean, J. Atmos. Chem., 7, 73-91, 1988.

WOFSY, S. C., Interactions of CH_4 and CO in the earth's atmosphere, Ann. Rev. Earth and Planet. Sci., 4, 442-469, 1976.

ZIMMERMAN, P. R., R. B. CHATFIELD, J. FISHMAN, P. J. CRUTZEN, and P. L. HANST, Estimates on the production of CO and H_2 from the oxidation of hydrocarbon emissions from vegetation, Geophys. Res. Lett., 5, 679-682, 1978.

FIGURE CAPTIONS

Figure 1 - Location of Brasil in South America in **a** and the map of Brasil and its ecological sites in **b**. Also shown are the remote sites of this study in Cuiabá, Manaus, and Natal.

Figure 2 - The region around 10°S, 60°W, which is most severely subject to biomass burning yearly. The rectangular area of Figure 1 is shown, with backward air mass trajectories near Cuiabá at three different pressure levels. The size of each arrow represents a time period of 6 hours. Air masses at the lower heights reach the Cuiabá area coming from regions of severe burnings.

Figure 3 - 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).

Figure 4 - Representative minimum (MIN) and maximum (MAX) concentration profiles for CO, for emission calculations.

Table 1. Global emissions of CO_2 and CO from biomass burning based on estimates of vegetation dry mass, converted to gC by the empirical factor 0.45. Units for CO_2 are millions of tons per year (MTY) of Carbon, but CO is expressed in MTY of CO.

	CO_2	CO
Robinson and Robbins(1970)	Negligible	Negligible
Seiler (1974)	-	640 (FUEL)
Crutzen et al. (1979)	3000	840
Seiler and Crutzen (1980)	3060	-
Greenberg et al. (1984)	3100	800
Crutzen et al. (1985)	2000-3300	800
Andreae et al. (1988)	3100	620
This work	35,8	7

Table 2. Contribution from biomass burning of emissions of CO_2 and CO from forest and savannah areas of the tropics, and of the Brazilian Amazon.

	All tropics	Brazilian Amazon
Area ($10^6 km^2$)	39.5	5.0
Max Area burned/year (%)	4.0	4.0
Min Area burned/year	1.6	1.6
Emission of CO_2 (MTY of C)	35.8	4.3
Emission of CO (MTY of CO)	7.0	0.89

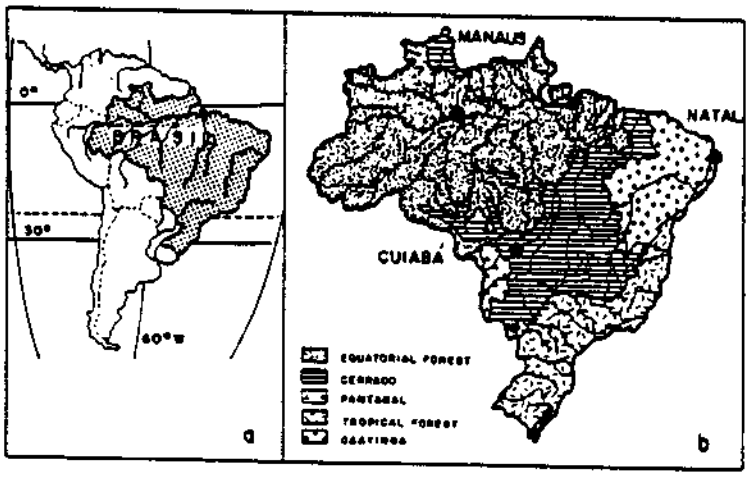

0°
30°
60°W
a
MANAUS
NATAL
CUIABÁ
EQUATORIAL FOREST
CERRADO
PANTANAL
TROPICAL FOREST
CAATINGA
b

Fig. 1

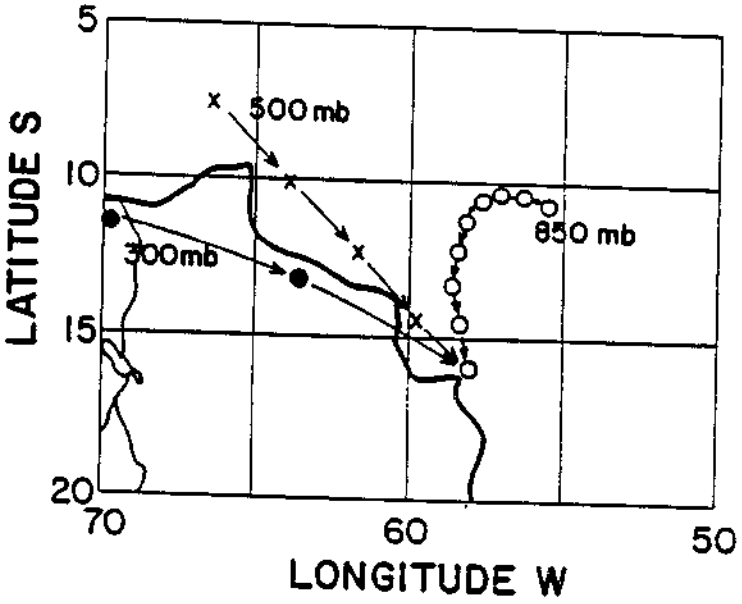
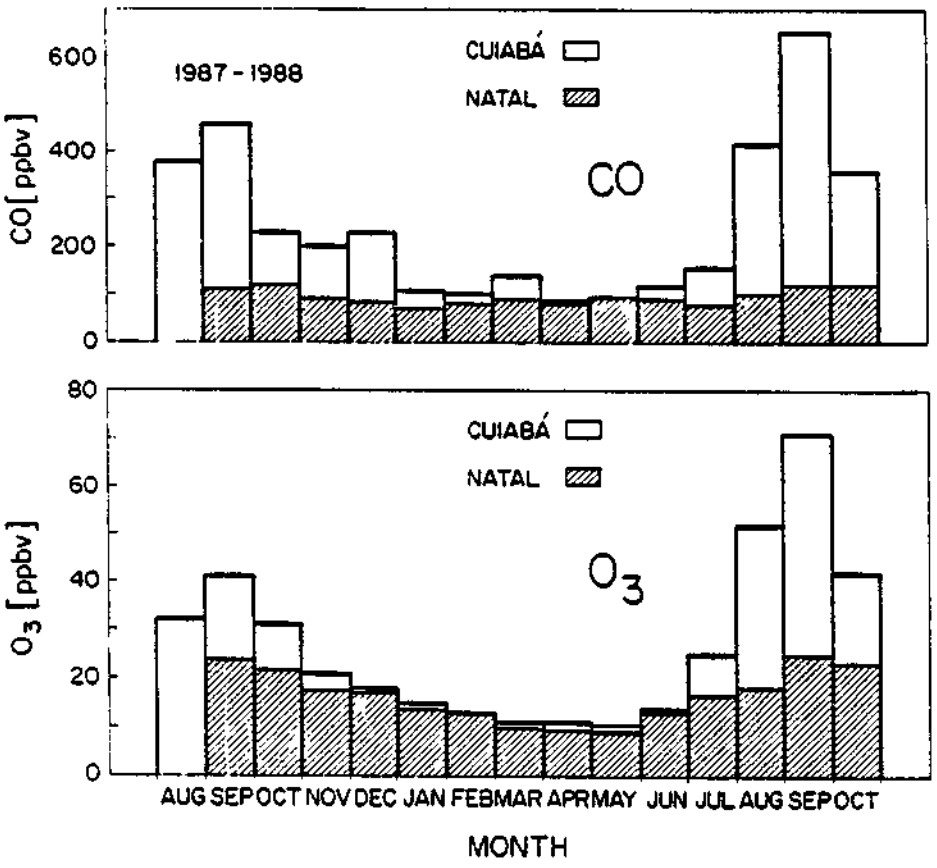


Fig. 2


1987 - 1988
CUIABÁ
NATAL
CO
CO[ppbv]
600
400
200
0
CUIABÁ
NATAL
O3
O3 [ppbv]
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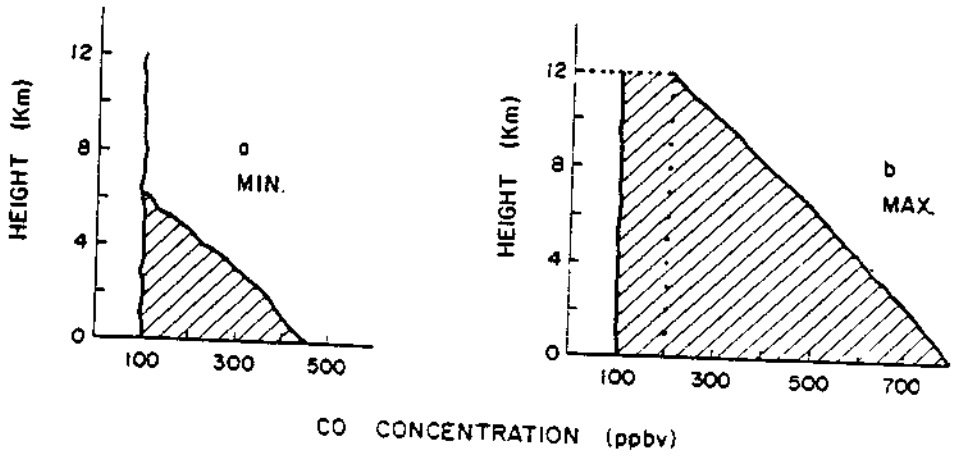
AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT
MONTH

Fig. 3


HEIGHT (Km)
12
8
4
0
100
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a
MIN.
HEIGHT (Km)
12
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500
700
b
MAX.
CO CONCENTRATION (ppbv)

Fig. 4