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BIOMASS BURNING EMISSIONS IN THE CERRADO OF BRAZIL COMPUTED WITH REMOTE SENSING DATA AND GIS

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ABSTRACT

Biomass burning is a common human activity in much of the developing tropical world where it has wide-ranging environmental impacts. Fire, a large component of tropical deforestation, is often used to clear broad expanses of land for shifting agriculture and cattle ranching. Frequent burning in the tropical savannas creates problems distinct from those of burning in the primary forest. In Brazil, much of the burning occurs in the Cerrado, which occupies approximately 1,800,000 km², primarily on the great plateau in Central Brazil. Wildland and agricultural fires are sources of regional air pollution in Central Brazil, and release a large number of trace gases, including greenhouse and other chemically active species. Knowledge of trace gas emissions from biomass burning in Brazil, however, is limited by a number of factors, most notably lack of relative emission factors for gases from specific fire types/fuels and accurate estimates of temporal and spatial distribution and extent of fire activity. We present estimates of trace gas emissions during September 1992 that incorporate a digital map of vegetation classes, pyrogenic emission factors calculated from ground and aircraft missions, and Instituto Nacional de Pesquisas Espaciais (INPE) fire products derived from Advanced Very High Resolution Radiometer (AVHRR) data. The regional emissions calculated from AVHRR estimates of fire activity provide an independent estimate for future comparison with results obtained by the National Aeronautics and Space Administration (NASA) Transport and Atmospheric Chemistry Near the Equator - Atlantic (TRACE-A) experiments.

INTRODUCTION

Biomass burning plays an important role in the annual fluxes of many trace gases to the troposphere (Crutzen *et al.*, 1979). Global biomass combustion could be a major source of the radiation-absorbing gas methane (CH_4). Judging from fire measurements in North America, emissions provide a potentially strong global source of some non-greenhouse gases such as carbon monoxide (CO) and nitric oxide (NO), which affect the rate at which CH_4 is removed from the atmosphere, and ammonia (NH_3) (Hegg *et al.* 1988, 1990), which is a primary alkaline trace gas and is a major source of nitrogen deposition in downwind areas. Although the tropics have been identified as the major source of trace gases from biomass combustion (Seiler and Crutzen, 1980; Seiler and Conrad 1987; Crutzen *et al.* 1985; Robinson 1988; Crutzen and Andreae, 1990); only rough estimates of the contribution of biomass burning to the tropospheric trace gas budget are available (Robinson, 1989).

A major cause of uncertainty in the contribution of biomass combustion to trace gas generation is the amount of area burned (Seiler and Crutzen, 1980; Matson and Ojima, 1990; Robinson, 1989), especially in tropical ecosystems. A number of investigators have shown the potential for detecting and mapping areas with active fires over large regions using weather satellite sensors, including the Advanced Very High Resolution Radiometer (AVHRR) on board National Oceanographic and Atmospheric Administration (NOAA) series satellites (Setzer and Pereira, 1991a, b; Pereira and Setzer, 1993; Langaas, 1993) and the Visible Infrared Spin Scan Radiometer Atmospheric Sounder (VAS) aboard the Geostationary Operational Environmental Satellite (GOES) (Prins and Menzel, 1992). This work was based on procedures for detection of high intensity heat sources (Matson and Dozier, 1981; Lee and Tag, 1990) with the thermal infrared bands of AVHRR.

At a more local scale, fire scars have been observed using Landsat imagery since the launch of ERTS-1. For example, burned grassland glades in Kibale Forest, Uganda were noted on Landsat Multispectral Scanner (MSS) data acquired in February, 1973 (Hamilton, 1984). Landsat Thematic Mapper (TM) band 4, a near infrared band, has been found to be particularly useful in distinguishing fire scars in the tropical forests of the Amazon Basin (Pereira and Setzer, 1993) and in areas dominated by vegetation typical of the Cerrado and Caatinga.

The Insitituto Nacional de Pesquisas Espaciais (INPE) has developed a product based on the 3.5-3.9 µm AVHRR band, mapping relative frequencies of high intensity heat sources at a weekly time scale as part of an operational program (Setzer and Pereira, 1991b). Estimates of area burned were derived by comparison with observations of burn scars with Landsat TM imagery. Trace gas emissions from 1987 fires in Amazonia (Setzer and Periera 1991a) were based on this product, along with published information on biomass, combustion factors, and emission factors.

The Cerrado or savanna, the second largest ecosystem in Brazil, is approximately one third the size of the Legal Amazon. As in the Amazon, burning in the Cerrado commonly occurs as a result of human practices to clear and manage land. Unlike the situation with the Amazon, however, the scarcity of published Cerrado research contributes to the lack of publicity and understanding of biomass burning in the Cerrado. We present estimates of area burned in the Cerrado based on the INPE AVHRR-based fire product, as well as estimates of biomass burned and of resultant trace gas emissions, which were computed using an approach similar to that of Setzer and Pereira (1991a), that is, by combining estimates of area burned with published information on biomass, burning efficiency, and fire behavior of cerrado formations, as well as published trace gas emission rates.

STUDY AREA

The Cerrado spans an area of 1,500,000 km² on the great plateau of Central Brazil and 300,000 km² of additional patches located in the Amazon region, the Caatinga, the tropical seasonal forests, and the Pantanal (Coutinho, 1990, Coutinho, 1982). The distribution of the Cerrado mosaic is primarily due to edaphic conditions and the interplay of physical environmental factors (Cole, 1986; Coutinho, 1982; and Eiten, 1982). Cerrado occurs on more infertile, usually deep latosol soils that range from very sandy to very claylike (Eiten, 1978). The main factors limiting cerrado vegetation include oligotrophy, aluminum and/or manganese toxicity, laterite hard-pans, and fire activity (Coutinho, 1982). Two edaphic factors determine whether mesophytic forest or cerrado occurs: 1) soil fertility, including aluminium concentration, and 2) the limiting amount of available soil water in the dry season. The richer upland soils support forest, while the poorer supports cerrado (Eiten, 1982).

Cerrado formations, with the physiognomic characteristics of savanna, can be considered as wide ecotones decreasing in biomass from cerradão (scleromorphic forest formation) to campo limpo ("clean field" or grassland formation). Cerrado formations have in common herbaceous/undershrub and tree/shrub species in varying amounts. The grass stratum is comprised of perennial species (Cole, 1986). Local names for the cerrado vegetation types include cerradão (dense woodland), cerrado "sensu stricto" (intermediate savanna formation), campo cerrado (open woodland), campo sujo ("dirty field" or low tree and shrub savanna), and campo limpo. The first three have a distinctive and well-defined grass-dominated ground layer with trees and shrubs of variable but generally low stature distributed at varying densities to produce woodland, parkland and low tree and shrub savanna. The cerradão and campo cerrado are classified as semi-deciduous tropical woodlands and the campo sujo and campo limpo as tall grass savannas (Cole, 1986). The cerrado plant diversity represents approximately 2400 species (Coutinho, 1990).

Annual fires, clearing, and subsequent recovery of vegetation change the physiognomy to a lower and more open cerrado form until the original form returns (Eiten, 1982). Agriculture areas in the Cerrado consist of pastures, crops, and reforestation areas. Pastures have the most extensive coverage in agricultural areas (Ministério das Minas e Energia, Projeto RADAMBRASIL, 1982) and consist of perennial grasses (Cole, 1986). The principal cause of fire in the Cerrado is due to burning of pastures to increase the grazing capacity. After burn-off, vegetation sprouts, thus furnishing cattle with palatable, green feed, rich in protein, cellulose, and salts. Previously, pasture burn-off occurred on average at intervals of three years. However, due to the transformation of the subsistence economy, current burn-offs happen every one to two years, posing risk to the ecological equilibrium of the whole region.

Cerrado also provides favorable low-cost land for intensive cultivation of cereals to satisfy the demand of foodstuffs for export, thus increasing the incidence and area of Cerrado converted to agriculture (Coutinho, 1990). Crops of this region include rice, beans, corn, soybean, wheat, and sugar cane. Large land owners typically do not burn, but instead use modern farming equipment to clear fields and disc the phytomass residue into the soil. Soybean and rice fields of 50-500 ha in size are commonly burned. At the end of the dry season (August - September), additional burning of large areas of the cerrado create new agricultural areas, the second great cause of burn-offs (Coutinho, 1990). Lightning strikes frequently cause fires in sugar cane fields during the fire season (July - September/October) (personal communication, D. Bellis, USFS) adding to the agricultural component of combustion products in the troposphere.

METHODS

Data

Fire behavior and emissions vary as a function of ecosystem and environmental characteristics. Therefore, it is necessary to stratify land area into unique, functionally-different ecological classes (ecozones) having characteristic and predictable fire dynamics and trace gas emissions. To define cerrado classes by fuel characteristics, we used as a base map, the digitized map version of the 1988 IBGE vegetation map of Brazil and literature references (Guild *et al.*, 1993). The base map, Mapa de Vegetação do Brasil (see figure 1), is a product from Projeto RADAMBRASIL (published by Fundacaõ and Instituto Brasileiro de Desenvoluimento Fiorestal, 1988). Translation of RADAMBRASIL cerrado classes to literature references of cerrado classes is as follows:

Literature	»	RADAMBRASIL
Cerradão	»	Arborea Densa
Cerrado Sensu Stricto	»	Arborea Aberta
Campo Cerrado	»	Parque
Campo Sujo & Limpo	»	Gramineo-Lenhosa

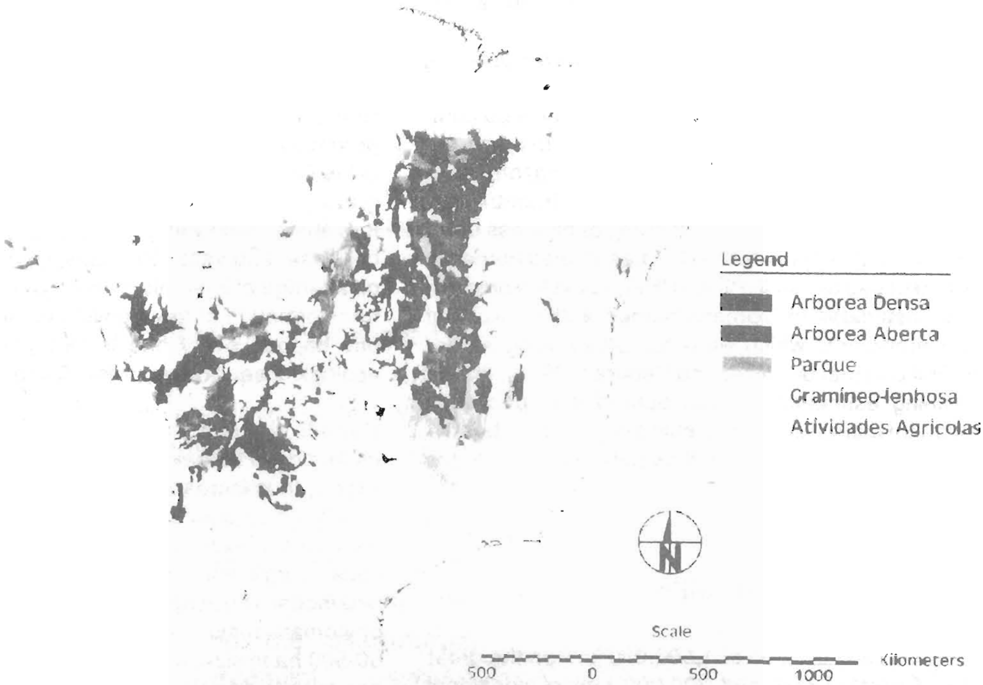

Figure 1. Brazil vegetation map of cerrado classes. Source: Projecto RADAMBRASIL. Digitized by Eros Data Center and distributed by UNEP/GRID.

This translation was determined by comparing cerrado class descriptions and cerrado terminology by Eiten, 1971; Goodland and Pollard, 1973; Goodland, 1971; Sarmiento, 1984; Cole, 1986; and Veloso *et al.* 1991.

INPE Brazil fire data for 1992 was used to determine the location and the distribution of fires in the Cerrado. The INPE fire product is based on AVHRR Local Area Coverage (LAC) imagery, with an area (pixel size) of 1.2 km2, from early afternoon overpasses of the NOAA-9 or NOAA-11 satellite. Pixels near the saturation temperature of 320 °K of band 3, the 3.5-3.9 μm thermal infrared band, are associated with fires (Pereira, 1988; Pereira, Setzer, and dos Santos, 1991), by comparison of their locations with burn scars mapped with Landsat TM imagery and aircraft photophraphy. On average, the areas of fires on AVHRR (no. pixels x 1.2 km^2 per pixel) are about 1.4 times the fire area mapped with Landsat TM (no. pixels x 0.0009 km^2). As part of an operational program to monitor fires, INPE flags the AVHRR "fire pixels" and determines their locations (latitude and longitude) and reports them to cooperating Brazilian agencies (Setzer and Pereira, 1991a). The INPE fire product used in this report was generated on a weekly basis by aggregation of this data over time (NOAA overpasses) and space (latititude/longitude). The 1992 products consist of counts of "fire pixels" in grid cells of 1.0-degree latitude by 0.5-degree longitude from 7° N to 40° S and from 75° W to 34.5° W. Also, the number of satellite overpasses and average counts per overpass (day) associated with each grid cell were reported, because the number of overpasses used in the aggregation of counts varies by cell. This is due to a nine-day cycle in orbits of the NOAA satellite's shift. Additionally, only a central portion of the imagery is used for fire detection to avoid areas of degraded spatial resolution and atmospheric degradation of data around the edges of AVHRR scenes.

Computations

A geographic information system (GIS) allows manipulation and integration of multiple georeferenced spatial data layers at different map scales for computation and analysis. We used the GIS to integrate the fuel-characterized cerrado map with the INPE AVHRR-derived fire product data and to compute emissions. The computation of emissions followed a standard method which is based on the rate at which fuel carbon burns. The rates and accompanying properties are all estimated as averages on a regional (10-500 ha) scale. For a given geographical region, the calculation used may be written

$$N_\ell = \sum_{\ell=1}^{\ell_{max}} \left(\eta_\ell^{flame} f_\ell^{flame} + \eta_\ell^{smolder} f_\ell^{smolder}\right) \bullet c_\ell b_\ell^{above\text{-}gr} f_\ell^{burned} a_\ell^{burned} \qquad (1)$$

where the emmissions rate of chemical species *i*, N_p may be calculated as the sum over distinct vegetation-type/biomass-content categories l, and are dependent on the following factors: area burned, a_ℓ^{burned} (described below); the above-ground biomass and the fraction of such biomass burned, $b_\ell^{above\text{-}gr.}$ and f_ℓ^{burned} (Cummings *et al.*, 1993 and Ward et al. 1992); the proportion by weight of carbon in the dry above-ground biomass, c_ℓ; and a weighted sum of emission factors for each species during flaming combustion η_ℓ^{flame} and smoldering combustion, $\eta_\ell^{smolder}$ (Lobert *et al.*, 1991). The weights that allow these emission factors to be combined properly are f_ℓ^{flame} (90%) and $f_\ell^{smolder}$ (10%), and are the fractions of the total burned biomass consumed by flaming and smoldering combustion (Ward *et al.*, 1992). Carbon content of biomass, c_ℓ, of 50% is assumed for all cerrado classes (Edwards *et al.*, 1980). For computation of emissions with nitrogen-containing compounds, it was appropriate to multiply by the nitrogen content of vegetation as ratioed to dry biomass (in place of the carbon concentration); we used the estimates of 1.15% for Arborea Densa/ Aberta and Parque and 2.02% for Gramineo-Lenhosa and agriculture (Rodin and Bazilevich, 1967). The nitrogen concentration for the agriculture class (Atividades Agricolas), primarily pasture with perennial grasses, was assigned the same value as cerrado perennial grassland (Gramineo-Lenhosa), assuming similar composition of species. The emission factors used are ratios of pollutant emitted to the moles of carbon or nitrogen burned. These calculations followed the technique and emission-factor estimates of Lobert *et al.*, 1991. In estimating the emissions of halogenated species, we used the emission factors estimated by Manö and Andreae, 1994.

To spatially compute emissions in the Cerrado region (Figure 1) of Brazil, involved combining cerrado vegetation class (map scale: 1:5,000,000) and the average number of fires per day by 0.5-degree cell. We used the GIS to calculate the proportion of each cerrado class occurring in each 0.5-degree cell. Next, an adjusted number of fires parameter, a result of the average number of fires per week divided by an over-estimate factor, was calculated. The over-estimate factor of 1.37, developed by Setzer (Setzer and Pereira, 1991a), takes into account fires that do not actually burn the entire area of the 0.5-degree grid cell, due to high temperature saturation of the pixel. The overestimate is approximately 37% in NOAA-9 images when compared to Landsat TM images in northern Mato Grosso (Setzer and Pereira, 1991a). The following calculation determines adjusted number of fires:

adjusted number of fires = (Ave number of fires/day) • (7 days/week)/(1.37). (2)

To obtain the area burned by each cerrado vegetation class, the adjusted number of fires was multiplied by 1.2 km^2, which is the area covered in one pixel at nadir (Setzer and Pereira, 1991a), and by the proportion of each cerrado class in a pixel. The calculation for area burned by cerrado vegetation class is:

$$a_\ell^{burned}\,(km^2) = \text{(adjusted no. of fires)}(1.2\ km^2) \bullet \text{(cerrado prop.)}. \qquad (3)$$

Above-ground biomass by cerrado class was calculated using above-ground fuel biomass and combustion factor information (Table 1) from field experiments around Brasilia (Cummings *et al.*, 1993; Ward *et al.* 1992). Above-ground fuel biomass and combustion factor for the agriculture class (Atividades Agricolas) were assigned the same value as for the cerrado perennial grassland (Gramineo-Lenhosa), again assuming similar species composition.

CERRADO CLASS	$b_\ell^{above\text{-}gr}$ kg/m²	f_ℓ^{burned} km²
Arborea Densa	1.925	0.520
Arborea Aberta	1.551	0.740
Parque	0.863	0.970
Gramineo-lenhosa	0.722	1.000
Atividades Agricolas	0.722	1.000

Table 1. Above-ground fuel biomass and combustion factor.

The calculation for amount of biomass burned for each cerrado class is:

$$\text{biomass burned (kg)} = f_\ell^{burned} \bullet b_\ell^{above\text{-}gr.}\,(kg\ m^{-2}) \bullet a_\ell^{burned}\,(km^2) \bullet \frac{10^4\,m^2}{km^2} \qquad (4)$$

RESULTS

Using this technique, we estimated that during three weeks of September 1992, burning in the Cerrado totaled 54,108 km^2. Of this total, half of the burning occurred in Arborea Aberta type cerrado with a total burn area of 27,224 km^2 (Figure 2, top). Cerrado agriculture areas and Parque-type cerrado followed in burn area with a total of 11,976 km^2 and 9,770 km^2, respectively. This method shows that the total amount of biomass burned in September was highest in Arborea Aberta, agricultural areas, and Parque with estimates of 31.2 Tg; 8.6 Tg; and 8.2 Tg respectively (Figure 2, center). The amount of biomass burned per km^2 in the Cerrado was highest in Arborea Aberta, while Arborea Densa was almost as high and the other classes were relatively low (Figure 2, bottom). Arborea Aberta had not only distinctly higher fire incidence, but also a somewhat higher content of burnable biomass (Figure 2, bottom), due to relatively low above-ground biomass (Table 1).

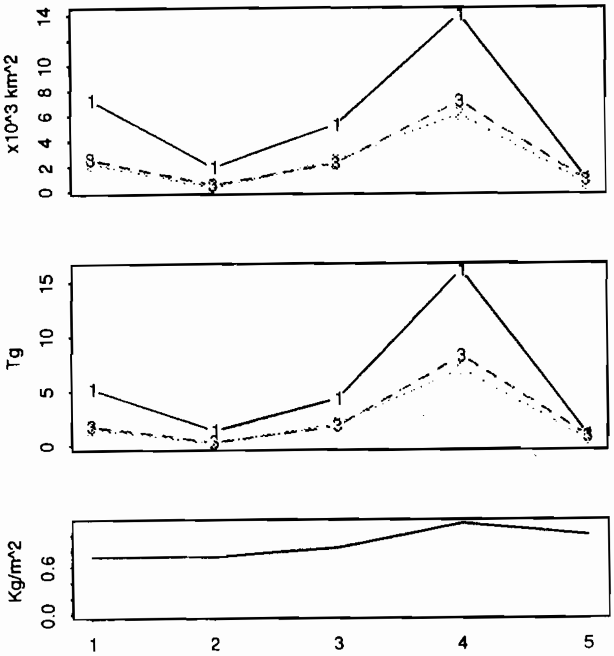

Figure 2. Plots by cerrado vegetation type (see legend at bottom of figure) for: top) area burned (curve 1 - Sept. 4-10, curve 2 - Sept. 11-18, curve 3 - Sept. 19-24, 1992); center) biomass burned (curves 1, 2, 3 as for part 1); and bottom) biomass burned per unit area burned (biomass/area * fraction burned).

The higher estimated burning during the week of September 4-10 compared to the other two weeks considered may be explained by the appearance of mid-September rains and associated cloud cover; those fires that did occur under these clouds were also presumably largely masked from satellite observation. The lines marking weeks 1, 2, and 3 of the study period in Figure 2, top and center, show that as much burning occurred in the first week as in the subsequent two weeks combined.

Gas species emitted from Cerrado biomass burning during three weeks in September 1992 prior to the TRACE-A mission are shown in Table 2. Most of these estimates follow in proportion to the biomass burned according to the emission technique and parameters of Lobert et al (1991). The carbon monoxide emission estimate is relatively low compared to the biomass burned since we assumed 90% of the combustion was during the flaming phase. We have also included estimates for the emission of methyl bromide and methyl chloride. While the mass of emissions is not large, the atmospheric effects of these emissions are of particular concern in assessing perturbations to the stratospheric ozone cycle.

DISCUSSION

Estimates of emissions from biomass burning and associated factors, such as area and biomass burmed, in the

	Arborea Densa	Arborea Aberta	Parque	Gramineo-Lenhosa	Atividades Agricolas	Total
BURN AREA (km2)	2.37E+03	2.72E+04	9.77E+03	2.77E+03	1.20E+04	5.41E+04
BIOMASS BURNED (kg)	2.37E+09	3.12E+10	8.18E+09	2.03E+09	8.65E+09	5.25E+10
TgC in Species Emitted						
CO	3.04E-02	4.01E-01	1.05E-01	2.60E-02	1.11E-01	6.73E-01
CH4	2.96E-03	3.91E-02	1.02E-02	2.54E-03	1.08E-02	6.56E-02
C2H6	8.56E-04	1.13E-02	2.95E-03	7.32E-04	3.12E-03	1.89E-02
C2H4	2.33E-03	3.07E-02	8.02E-03	1.99E-03	8.48E-03	5.15E-02
C2H2	1.28E-03	1.68E-02	4.41E-03	1.09E-03	4.66E-03	2.83E-02
C3H8	3.52E-04	4.64E-03	1.21E-03	3.01E-04	1.28E-03	7.79E-03
C3H6	3.91E-03	5.16E-02	1.35E-02	3.35E-03	1.43E-02	8.66E-02
HCHO	1.19E-04	1.57E-03	4.10E-04	1.02E-04	4.34E-04	2.63E-03
OTHER ALDEHYDES	6.62E-04	8.73E-03	2.28E-03	5.66E-04	2.41E-03	1.47E+07
C3H6O	1.09E-04	1.44E-03	3.76E-04	9.33E-05	3.98E-04	2.41E-03
C6H6	3.74E-03	4.92E-02	1.29E-02	3.19E-03	1.36E-02	8.27E-02
OTHER AROMATICS	2.01E-03	2.65E-02	6.94E-03	1.72E-03	7.33E-03	4.45E-02
CH3Br	1.50E-03	1.40E-02	3.12E-03	1.12E-03	3.11E-05	1.98E-02
CH3Cl	2.47E-04	2.70E-03	6.53E-04	2.07E-04	3.72E-13	3.81E-03
TgN in Species Emitted						
NO	2.60E-03	3.98E-02	1.10E-02	5.00E-03	2.56E-02	8.40E-02
NH3	3.15E-04	4.84E-03	1.33E-03	6.08E-04	3.14E-03	1.02E-02
HNO3	1.44E-04	1.99E-03	5.31E-04	2.23E-04	1.07E-03	3.96E-03

Table 2. Cerrado biomass burning emissions by species for September 1992.

Brazilian Cerrado were computed using a GIS to integrate digitized map information (vegetation associations), a fire product developed from weather satellite imagery, published information on the characteristics of the cerrado vegetation and on emission factors. Approximately 3% of the Cerrado burned during the three week period in September preceeding the TRACE-A mission, with most of the burning occuring in natural areas of mixed shrub and grass or in areas of the cerrado used as pasture. Estimates for seventeen types of gaseous emissions, due to combustion of plant carbon and nitrogen, are reported.

While this report shows that detailed computations may be made by combining a variety of data sources, limitations in the accuracy of the data must be recognized. The vegetation map used for this study was produced in 1988 and based on the 1982 Projecto RADAMBRASIL results. Therefore, the map underestimates changes due to deforestation and changes in patterns of agriculture. Also, all agriculture in Cerrado was assumed to be pasture, because it is known that it predominates and is frequently burned to renew growth, but there are extensive areas of rice, soybeans, and other crops. If these crops are heavily fertilized and burned, they could be intense sources of nitrogenous emissions. Our estimates of these emissions may therefore be too small. Also, more estimates of above-ground fuel biomass by class, i.e., more field experiements in all areas of the Cerrado are needed.

We have made limited comparisons of our emissions estimates to those that have been based on journal literature (Andreae et al, 1988) and governmental body (FAO, Hao et al, 1990) sources. Hao's survey suggests 140 million hectares of Tropical America Savanna burns each year, and that a large fraction (over half) of that savanna is contained within the Brazilian Cerrado vegetation types we studied. Our direct technique suggested only 5.4 million hectares burned during our three week period. Andreae's estimates of carbon dioxide and carbon monoxide emitted annually in Tropical South America (all vegetation types) run much are also much higher than our three-week estimates. There are clear difficulties in comparing one three-week period in 1992 with climatologically averaged estimates made for annual emissions. Nevertheless, we find only a rather small portion of burning and emissions within Tropical South America which could be attributed to cerrado-vegetation regions during our study period, a period at or just after the usual maximum in burning in the main Cerrado region south of the tropical forests.

The interpretation of fire pixel counts in terms of area burned is likely to be the major source of uncertainty in our calculations. The INPE fire product, derived from weather satellite data, provides information on fires on a weekly basis for all of Brazil. Studies have verified the fire locations indicated from the processing of the satellite data (Pereira *et al.*, 1991). Some of the counts may be large areas of bright soils rather than fires, because the 3.5-3.9 μm band used for fire detection is in the transition zone from the reflective to emissive part of the electro-magneitic spectrum (Setzer and Verstraete, 1994). The more prevalent problem may be non-observation of fires, either because they are not burning at the time of the satellite overpass, or because they are obscured by clouds or dense plumes of smoke. We are currently developing methods to map fire scars, rather than active fires, to avoid these problems.

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ADDENDUM

Biomass Burning Emissions in the Cerrado of Brazil Computed with Remote Sensing Data and GIS

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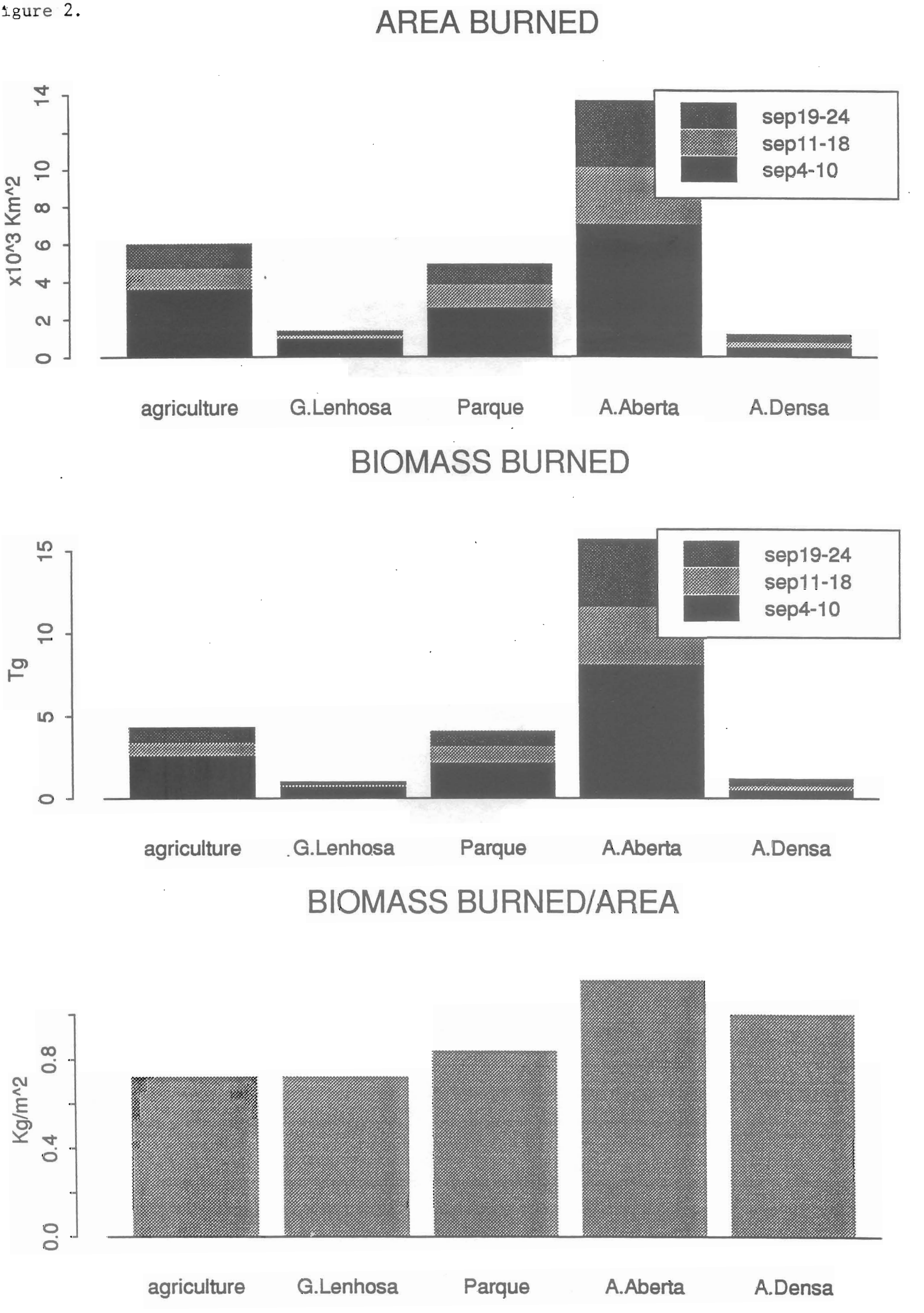
The data (counts of fire pixels) in the INPE fire products was doubled, due inadvertantly to an error in data processing. This resulted in a doubling of estimates for burn area, biomass burned and for the gas emissions reported in Figure 2, Table 2, and the text in the Results and Discussion sections. Attached are corrected versions of Figure 2 and Table 2.

igure 2.



AREA BURNED
x10^3 Km^2
0
2
4
6
8
10
14
sep19-24
sep11-18
sep4-10
agriculture
G.Lenhosa
Parque
A.Aberta
A.Densa
BIOMASS BURNED
Tg
0
5
10
15
sep19-24
sep11-18
sep4-10
agriculture
G.Lenhosa
Parque
A.Aberta
A.Densa
BIOMASS BURNED/AREA
Kg/m^2
0.0
0.4
0.8
agriculture
G.Lenhosa
Parque
A.Aberta
A.Densa

Table 2.

September 1992 Summary of Burn Area (km2); Biomass Burned (kg); and Trace Gases Emitted

	Arborea Densa	Arborea Aberta	Parque	Gramineo-Lenhosa	Atividades Agricolas	Total
BURN AREA (km2)	1.18E+03	1.36E+04	4.89E+03	1.38E+03	5.99E+03	2.71E+04
BIOMASS BURNED (kg)	1.19E+09	1.56E+10	4.09E+09	1.01E+09	4.32E+09	2.62E+10
TgC in Species Emitted						
CO	1.52E-02	2.00E-01	5.24E-02	1.30E-02	5.54E-02	3.36E-01
CH4	1.48E-03	1.95E-02	5.11E-03	1.27E-03	5.41E-03	3.28E-02
C2H6	4.28E-04	5.64E-03	1.48E-03	3.66E-04	1.56E-03	9.47E-03
C2H4	1.16E-03	1.53E-02	4.01E-03	9.94E-04	4.24E-03	2.57E-02
C2H2	6.39E-04	8.42E-03	2.20E-03	5.46E-04	2.33E-03	1.41E-02
C3H8	1.76E-04	2.32E-03	6.07E-04	1.51E-04	6.42E-04	3.90E-03
C3H6	1.96E-03	2.58E-02	6.75E-03	1.67E-03	7.14E-03	4.33E-02
HCHO	5.95E-05	7.84E-04	2.05E-04	5.08E-05	2.17E-04	1.32E-03
OTHER ALDEHYDES	3.31E-04	4.36E-03	1.14E-03	2.83E-04	1.21E-03	1.47E+07
C3H6O	5.46E-05	7.19E-04	1.88E-04	4.67E-05	1.99E-04	1.21E-03
C6H6	1.87E-03	2.46E-02	6.44E-03	1.60E-03	6.81E-03	4.13E-02
OTHER AROMATICS	1.01E-03	1.32E-02	3.47E-03	8.60E-04	3.67E-03	2.22E-02
CH3Br	7.51E-04	7.02E-03	1.56E-03	5.58E-04	1.56E-05	9.90E-03
CH3Cl	1.24E-04	1.35E-03	3.26E-04	1.04E-04	1.86E-13	1.90E-03
TgN in Species Emitted						
NO	1.30E-03	1.99E-02	5.48E-03	2.50E-03	1.28E-02	4.20E-02
NH3	1.57E-04	2.42E-03	6.67E-04	3.04E-04	1.57E-03	5.12E-03
HNO3	7.20E-05	9.97E-04	2.66E-04	1.12E-04	5.35E-04	1.98E-03