Ozone Concentrations in the Brazilian Amazonia During BASE-A

Alberto W. Setzer, Volker W. J. H. Kirchhoff, and Marcos C. Pereira

Ozone measurements in the Brazilian Amazon Basin have been conducted recently at ground level and with soundings (Kirchhoff, 1988; Kirchhoff et al., 1988) and in aircraft (Browell et al., 1988). Continuous surface data exist since 1985 for a site close to Cuiabá, Mato Grosso (MT), in the southern fringe of the Amazon forest (Kirchhoff, 1990), and strong effects of biomass burning have been detected in ozone concentrations during the dry season, from June through October (Kirchhoff et al., 1989b; Kirchhoff, 1990). The dry season coincides with the burning season, for centuries a time when fire has been used to clear areas where forest was recently cut and let to dry, or to renew pastures and agricultural land. The tropospheric ozone which results is produced by complex and multiple photochemical reactions between different compounds emitted by biomass burning (Fishman et al., 1979).

Ozone monthly averages in southern Amazonia have ranged from a maximum of almost 80 parts per billion (ppb) in September during the peak of the burning to 10 to 20 ppb in the wet season, from December to April. The low values are comparable to those found year round in nonpolluted sites such as Natal, at the Brazilian northeast coast (Kirchhoff, 1990).

Detection of fires in the Brazilian Amazonia with band 3 (3.55μ to 3.93μ) thermal images of the Advanced Very High Resolution Radiometer (AVHRR) on board the meteorological NOAA series satellites was developed by Pereira (1988) and is in operational use (Setzer and Pereira, 1990a, 1990b, 1991a, and 1991b). Coupling of pixels containing fires detected in such images and atmospheric contamination hundreds of kilometers downwind in Amazonia has been reported (Andreae et al., 1988; Kirchhoff et al., 1989). Total number of fire pixels detected in the dry season in the Brazilian Amazonia were about 315,000 in 1987, and 210,000 in 1988.

In this chapter results of ozone measurements made on board the Brazilian Institute for Space Research (INPE) airplane during the first week of September 1989 are presented and analyzed in relation to the temporal and geographical location of fires detected by the satellite before and during the sampling period.

Methodology

Ozone measurements were made with an ultraviolet photometric analyzer producing continuous recordings on a paper chart. Readings are in parts per billion by volume (ppbv), and precision is 1 to 2 ppbv. Calibration was made prior to the experiment as recommended by the manufacturer of the instrument, and dial adjustments before each flight. Air intake at 2 liters per minute was through a special port at the side of the fuselage, close to the cockpit to avoid contamination from engine exhaust. The airplane used was a two-engine Embraer Bandeirante EMB-101 also loaded with other research equipment for the Biomass Burning Airborne and Spaceborne Experiment–Amazonia (BASE-A) experiment as described by Kaufman et al. (1990).

Figure 13.1 shows INPE's airplane trajectory and Figure 13.2 the flight levels during BASE-A. Flight 1 from S. J. Campos, São Paulo (SP) to Brasilia, Federal District (DF), on 1 September was over land of varied uses but mainly agricultural and with sugar cane plantations that are burned before harvesting (see Kirchhoff et al., 1989a, for ozone associated with such burnings). Flight 2, from Brasilia to Porto Nacional, Tocantins (TO), on 2 September, was over savanna-type vegetation (*cerrado*) where open pasture is the predominant feature and where fire is regularly used to renew the grasses. Flight 3 on 2 September began with the transition from *cerrado* to forest and ended in Alta Floresta, MT, an area of fast forest conversion to large ranches. Flight 7 on 6 September covered forested areas where some deforestation is taking place, until Santarem, Pará (PA). Flight 8 on 6 September to Manaus was over relatively untouched forest. Flight 9 on 7 September to Porto Velho, Rondônia (RO), saw an increase in deforestation and fires

Figure 13.1 Approximate trajectory of the flights during BASE-A.

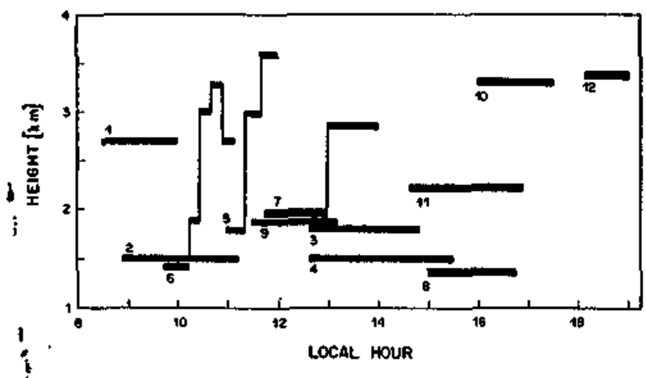

Figure 13.2 Height (km) and local times of flights shown in Figure 13.1.

toward Rondônia. Flight 10 on 8 September was over a region where extensive deforestation and burning took and was taking place, in the vicinity of the BR-364 road, and over *cerrado* areas close to Cuiabá, MT, also dominated by the use of fire. Flight 11 on 9 September to Uberlandia, Minas Gerais (MG), covered areas of intense agriculture, mainly soybean plantations, where fire was being used to burn grasses and weeds before plowing. The area covered in flight 12 on 10 September, the last one, was similar to the first one. Vertical profiles up to about 4 km were obtained over Alta Floresta, Santarem, and Cuiabá. Figure 13.2 shows altitudes and times of the flights.

The fire detection technique is based on the work originally presented by Matson et al. (1984). Band 3 (3.55μ–3.95μ) AVHRR thermal images were recorded daily by INPE at Cachoeira Paulista, SP, and screened for "hot" pixels with nominal radiometric brightness temperature between 316°K and 320°K, the former being the saturation limit of the sensor. As shown by Pereira (1988) and verified by field work, this range indicates major fires occurring at the time the image was produced by the NOAA satellite, around 2 to 4 P.M. local time. Morning or night satellite passes are not used, since fires are usually lit after noontime and die a few hours later. Fires with fronts Smaller than about 100 m or fires under dense canopies have not been detected by the threshold used. The thermal images and results used by BASE-A were the same produced by INPE in its operational program (Setzer and Pereira, 1990a, 1990b, 1991a, 1991b) to detect fires in Brazil in near-real time.

Results and Discussion

The number of satellite image pixels with fires detected in AVHRR band 3 during BASE-A and for two preceding days for rectangles surrounding Brazilian Amazon states and other states where flights took place was obtained. In 1989 rains were above normal for Central and North Brazil, which contributed to a reduction in the biomass burning activity compared to previous years; August and September had 50 to 100 mm over the normal (INEMET, 1990; INPE, 1990). Figure 13.3 shows ozone concentrations in ppbv for the transit flights, and represents data after flight altitude and ozone readings were stable. Figure 13.4 shows vertical profiles of ozone for Santarem, Alta Floresta, and Cuiabá.

The general pattern observed is that ozone concentrations were higher in *cerrado* and deforestation areas. Flight 1 measured about 40 ppbv, possibly caused by diverse agricultural fires in the region and by downwind combustion products brought by prevailing westerly and northwesterly winds from fires in Goiás, Mato Grosso do Sul, and Mato Grosso. Fire pixels for the previous day (31 August) in the areas limited by rectangles surrounding the states, and therefore including areas of a few states, numbered 184 for São Paulo, 9344 for Minas Gerais, 7266 for Goiás, 45 for Mato Grosso do Sul, and 1098 for Mato Grosso. Ozone ranged from 50 to 65 ppbv between Brasília and Porto Nacional during flight 2 and would probably have been higher for a flight in the afternoon when ozone-producing photochemical reactions

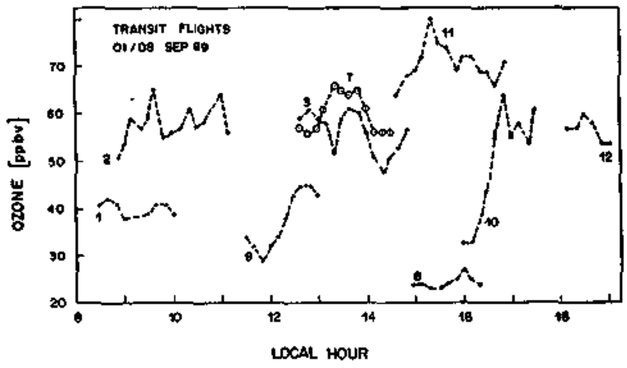

Figure 13.3 Ozone concentrations (ppbv) for flights of Figure 13.1.

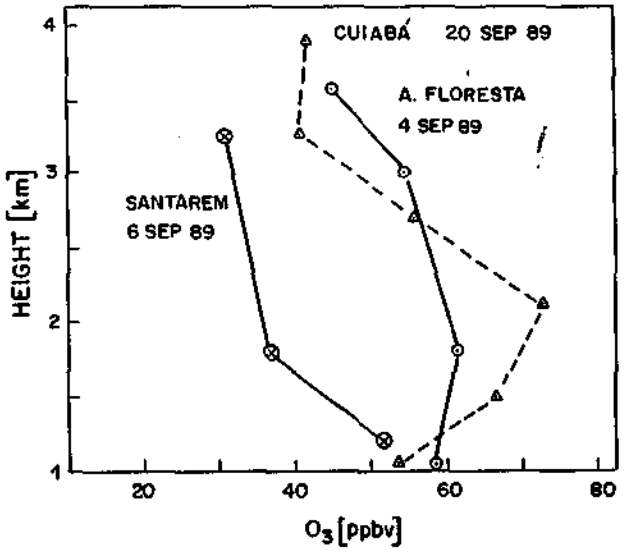

Figure 13.4 Ozone vertical profiles for flight 6 over Alta Floresta, Mato Grosso (MT), and flight 7 to Santarem, Pará (PA). The Cuiabá, MT, profile for 20 September was obtained after the experiment, with 1270 fire pixels for the Mato Grosso rectangle.

are more efficient. Fires for the rectangles in the previous day (1 September) were 4187 for Goiás. Ozone was also in the 50 to 60 ppbv range during flight 3 to northern Mato Grosso in the afternoon, and the fires numbered 8479 in the Tocantins rectangle for that day (2 September). Flight 7 would have kept the same range of ozone if it had not crossed the plumes from fires in South Pará carried by easterly winds, which caused an increase to about 65 ppbv; fires in the Pará rectangle in that day (6 September) were 514. Flight 8 had the minimum ozone readings of the experiment, in the 25 ppbv range; the Amazon state rectangle had 326 fires on that day (6 September), but most of them in parts of Rondônia and Acre are included in the rectangle and do not affect the ozone readings. Flight 9 shows an increase from 30 to 50 ppbv as the plane approached the Rondônia state, where biomass burning is common. Flight 10 shows a steep increase in ozone, from 35 to 60 ppbv as the plane moved into areas of more intense deforestation and burning in general; fires in the Rondônia rectangle that day (7 September) numbered 1142, and in Mato Grosso, 2922. The highest concentrations, in the 60 to 80 ppbv range, were in flight 11, which measured effects not only of regional fires but also from upwind fires in Mato Grosso and Rondônia; numbers of fires in the rectangles for the flight that day (8 September) in Goiás were 1277, 1640 for Mato Grosso, and 282 for Rondônia. The last flight, number 12, had concentrations of about 60 ppbv due to regional as well as upwind fires.

Without considering the size of fires, type of vegetation burned, combustion efficiency, or transport of pollutants, the above data indicate that ozone concentrations varied from an 80 ppbv range in a region with one or more fires per 1000 km^2 to 20 ppbv with less than 0.5 fires per 1000 km^2. Therefore, the larger the extent of biomass burning on a synoptic scale, the higher the ozone tropospheric concentration.

Conclusion

Tropospheric ozone is known as a biomass burning indirect by-product. This work has shown through in situ measurements of ozone and satellite detection of fires that on a synoptic scale concentrations rise sharply in regions of more intense burning.

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