NOTES AND CORRESPONDENCE

Pilot Analysis of Hourly Rainfall in Central and Eastern Amazonia

ELEN M. C. CUTRIM
Geography Department, Western Michigan University, Kalamazoo, Michigan

DAVID W. MARTIN
Space Science and Engineering Center, University of Wisconsin—Madison, Madison, Wisconsin

DEAN G. BUTZOW
Geography Department, Western Michigan University, Kalamazoo, Michigan

ISA M. SILVA
Departamento de Meteorologia, Universidade Federal do Parà, Belém, Para, Brazil

ELENA YULAEVA
International Research Institute for Climate Prediction, Scripps Institute of Oceanography, University of California, San Diego, La Jolla, California

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ABSTRACT

This paper presents results of a pilot study of rainfall along the part of the Amazon River that flows through Brazil. Rain was measured at three stations, one for each of three regimes: coastal, interior bottomland, and interior upland. For each station the record from 1 January 1988 through 31 December 1990 was parsed into accumulation periods of 1 h. Storms on the coast tended to be more showery than those in the interior and storms in the interior upland tended to be more showery than those in the interior lowland. The diurnal cycle varied with distance from the Amazon River as well as with distance from the Atlantic coast.

1. Introduction

For the most part historical records of rainfall within Amazonia consist of daily observations employing a variety of instruments and procedures. Driven in part by numerical weather prediction, global change, and demand for freshwater, lately government institutions have taken steps to acquire better records. Since 1988, one of these institutions, the Federal University of Pará (UFPa), has maintained a small network of recording gauges within a corridor along the Amazon River between Manaus (03°09′S, 59°59′W) and Belém (1°28′S, 48°27′W).

Figueroa and Nobre (1990) indicate a mean annual rainfall of 2300 mm within this ‘‘Amazon corridor.’’ At the coast end (near 48°W), on average 3000 mm of rain falls each year. At the interior end (near 60°W), about 2400 mm falls. Westward (upriver) from the east end of the corridor the annual average rainfall first sags to a minimum of about 1800 mm (near 54°W) and then rises to a maximum of about 2450 mm (near 58°W).

Across Amazonia most rain falls from clouds of convective origin (Hjelmfelt 1978; Salati and Vose 1984; Lloyd 1990). True to their convective origin, individual falls of rain, or storms, tend to be brief and local (also see United Nations 1981). Occasionally, a single station records rain through a full day or longer (Hjelmfelt 1978).

Along the Amazon corridor, rain varies diurnally. Analyzing both synoptic observations and autographic records of rain from stations at the east end of the corridor, Kousky (1980) found that the phase of the diurnal cycle changes across the coast. On the seaward side it peaks at night; on the landward side, at midday. At shoreline sites [e.g., Soure (00°44′S, 48°31′W)] the phase of the diurnal cycle depends on the angle of the trade winds

Corresponding author address: Prof. Elen M. C. Cutrim, Geography Department, Western Michigan University, Kalamazoo, MI 49008.
E-mail: cutrim@wmich.edu

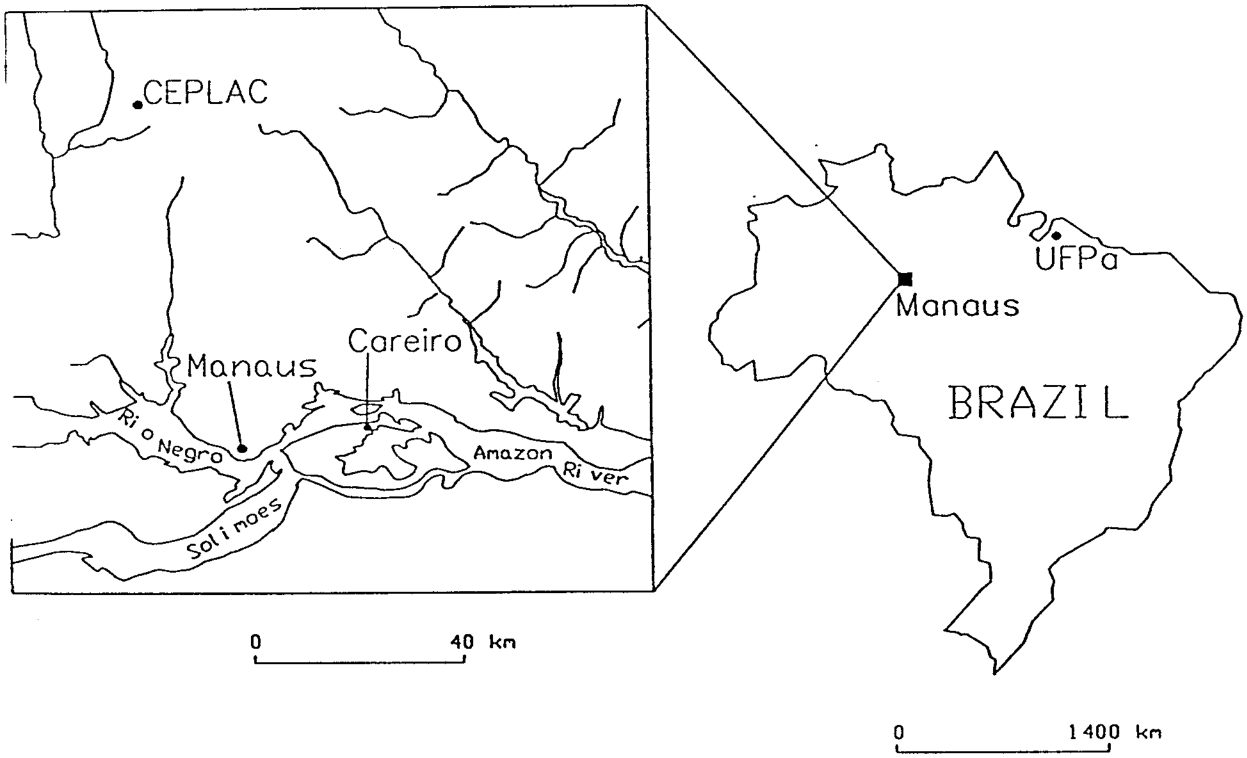


FIG. 1. Station map, with Manaus.

relative to the coast. When the trades blow onshore, an orientation typical of the wet season, nocturnal rains tend to fall landward of the coast; otherwise, they fall seaward.

Inland from the coastal plain the afternoon peak diminishes (Kousky 1980) and (at least along the Amazon River) a morning peak emerges. At Santarém (02°25′S, 54°47′W), a station roughly midway between Belém and Manaus, the morning peak effectively replaces the afternoon peak (Nechet 1993).

At the western end of the corridor, where we might expect to find a marked diurnal cycle peaking in the afternoon, records conflict. Whereas Lloyd (1990) found an afternoon peak in rain probabilities at Reserva Ducke (2°57′S, 59°57′W), Nechet (1992) found both early morning and midafternoon peaks (morning dominant) in rain probability at Manaus.

Although it includes only the months January through May, in several respects a 4-yr satellite-based mapping of morning–evening convective rainfall difference (Negri et al. 1994) clarifies gauge observations of the diurnal cycle in corridor rainfall. First, the coastal axis of morning rains lies closer to the shore than the coastal axis of evening rains. Second, the coastal axis of evening rains weakens across the Amazon River (just west of Marajó Island). Third, except at this crossing, morning rains dominate along the Amazon River. Last, Manaus lies between the Amazon River axis of morning rains (and its extension northwestward along the Rio Negro) and a cell of evening rains over highlands north and northwest of the station.

TABLE 1. Geographical coordinates of the stations.

Station	Latitude	Longitude	Altitude (m)
UFPa	1°28′18″S	48°27′09″W	5
Careiro	3°05′44″S	59°44′03″W	26
CEPLAC	2°33′44″S	60°01′59″W	85

The locations of Santarém and Manaus (on the Amazon River and the Rio Negro, respectively) and of Reserva Ducke (about 40 km north of the port of Manaus), together with the difference map of Negri et al. (1994), suggest a modulation of the diurnal cycle by a river breeze. Reports of diminished rainfall along the Amazon and its main tributaries (Cutrim 1983, p. 69; Molion and Dallarosa 1990; Ribeiro and Adis 1984), observations of riverine gaps in afternoon fields of cumulus clouds (Anderson et al. 1966; Cutrim et al. 1995), and measurements of circulations normal to the Amazon River near Manaus (de Oliveira and Fitzjarrald 1993) tend to support such a hypothesis.

Lloyd (1990) constructed model storms for two sites in the Amazon corridor. For Reserva Ducke, near the upstream (interior) end of the corridor, he used a gauge record of hourly rainfall. A storm was defined as any fall of rain—not necessarily continuous—preceded and followed by three or more hours without rain. Applying this definition to the Reserva Ducke record led to a model storm that rains at a rate of 5.2 mm h^{-1} for 2 h,

TABLE 2. Statistics of 1988–90 hourly rain rate.

		Station		
Sample	Statistic	Careiro	UFPa	CEPLAC
All hours	Hours of data	25 496	26 010	25 518
	Mean rate (mm h^{-1})	0.24	0.28	0.33
	Median rate (mm h^{-1})	0.0	0.0	0.0
	Variance (mm^2 h^{-2})	3.12	3.46	5.57
	Skewness	0.41	0.45	0.42
Rain hours	Hours of data	2073	2858	2466
	Raining hours (%)	8.1	11.0	9.7
	Mean rate (mm h^{-1})	3.03	2.60	3.56
	Median rate (mm h^{-1})	1.00	0.70	0.98
	Variance (mm^2 h^{-2})	31.18	25.80	47.87
	Skewness	1.10	1.12	1.12

beginning at 1300 local time (LT), on 3 out of 5 days. For Belém, near the downstream (coastal) end of the corridor, Lloyd drew upon the studies of Ratisbona (1976), Hjelmfelt (1978), and Kousky (1980). There the model storm rains at a rate of 10.8 mm h^{-1} for 1 h, beginning (presumably) at 1500 LT, on 2 out of 3 days.

Here we raise three questions. All apply to the lower corridor of the Amazon River.

- In respect to timing, duration, and intensity, are storms on the coast like those of the interior?
- In the interior, are storms of the floodplain like those of the upland?
- Does the Lloyd model storm fit the observed regimes of rainfall?

This paper uses the UFPa records to address each of these questions.

2. The UFPa records of hourly rainfall

The UFPa rain gauge network was designed to contrast rainfall in coastal Amazonia (Belém) with rainfall in central Amazonia (Manaus), and (in central Amazonia) to observe the land–river influence on the rain (Fig. 1 and Table 1). The UFPa station is located on the Guamá campus, about 300 m from the northern margin of the Guamá river; Careiro station is located in a lowland várzea pasture on Careiro Island (near the confluence of the Amazon and Negro rivers); and CEPLAC station is located on the experimental field of the Brazilian Executive Commission for Cacao Production Planning (CEPLAC), 70 km northwest of the port of Manaus. The experimental field of cacao trees at CEPLAC is surrounded by ''terra firme'' rain forest. All gauges were installed on grassy exposed sites, according to the recommendations of the World Meteorological Organization.

Identical mechanically operated recording rain gauges of a combination type—weighing gauge with siphon—were installed at the Careiro, CEPLAC, and UFPa stations. Daily, at 0700 LT, the station operator places a fresh chart on the rain gauge. Monthly, the operator sends the pluviograms to the UFPa Department of Meteorology. There, the analog tracing on a pluviogram is transformed into a digital record of 1-h resolution and 0.1-mm rain resolution. Then the data files are displayed and checked for errors. In the course of a gauge network check in June 1993, an error in calibration was detected and corrected in the CEPLAC pluviograph.

For each of the three stations 9 yr of data have been processed. The present, preliminary analysis includes only the first three years of the record, 1 January 1988 through 31 December 1990. Here a *storm* is defined as at least 1 h of rain (of 0.1 mm or more) bounded on either side by at least 1 h without rain. An *interlude* is at least 1 h without rain bounded on either side by a storm. An *event* is a storm and the interlude that follows it. A *rain hour* is any hour that records rain. A *rain day* is any 24-h period, beginning with the first hour after 0000 UTC, which contains one or more rain hours. Missing data ranged from 1% of the nominal record at UFPa to 3% at CEPLAC. Except as noted below, we did not attempt to fill gaps in the records. Therefore each of the three hourly records underestimates total rainfall.

3. Results

a. Careiro—An interior, floodplain station

1) OVERVIEW

Over the full 3-yr record the gauge at Careiro logged 25 496 h of data (Table 2). It recorded rain in 2073 h, or 8.1% of the time in operation. These 2073 h yielded a total of 6283 mm of rain. Rain fell at an absolute mean rate of 0.24 mm h^{-1}; at a conditional mean rate (i.e., during the hours with precipitation) of 3.0 mm h^{-1}. Even for the rain-only sample, variation (here, the standard deviation of rain rate) exceeded the mean. The skewness value (1.1) implies a long tail on the right side of the distributions of hourly rain rates.

A plot of hourly rain rate at Careiro for 1988 (Fig. 2a) suggests a wet climate modulated by midyear drying. Rain fell mostly as showers, sometimes isolated (e.g., near hour 4950) and sometimes bunched (e.g., near

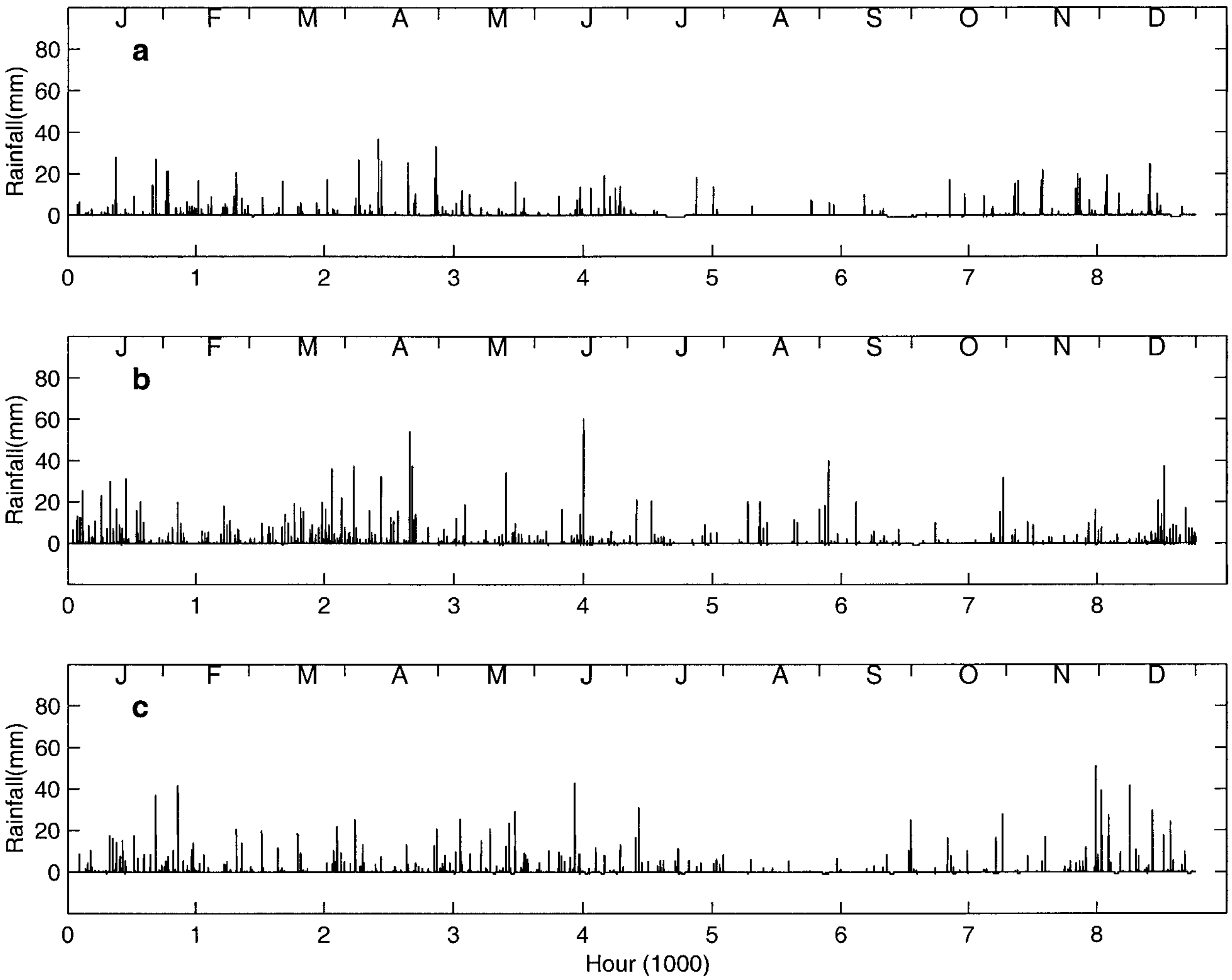


FIG. 2. Time series of hourly rainfall for 1988. (a) Careiro, (b) UFPa, (c) CEPLAC.

hour 4200). Up to 38 mm of rain fell in a single hour. Occasionally rain fell through long periods (e.g., near hour 1000). Together with Fig. 2a, plots of cumulative hourly rain for each of the 3 yr (not shown) suggest rather abrupt transitions from season to season and more variability in the wet seasons than in the dry seasons.

The 3-yr ogive (plot of cumulative frequency) for rain hours as a function of hourly rain rate (Fig. 3, dashed line) yields a median value of 0.9 mm h^{-1}, a third quartile value of 3.2 mm h^{-1}, and a 90% value of 8.3 mm h^{-1}. Thirteen percent of rain hours recorded the threshold rate, 0.1 mm h^{-1}. The corresponding ogive for rain-

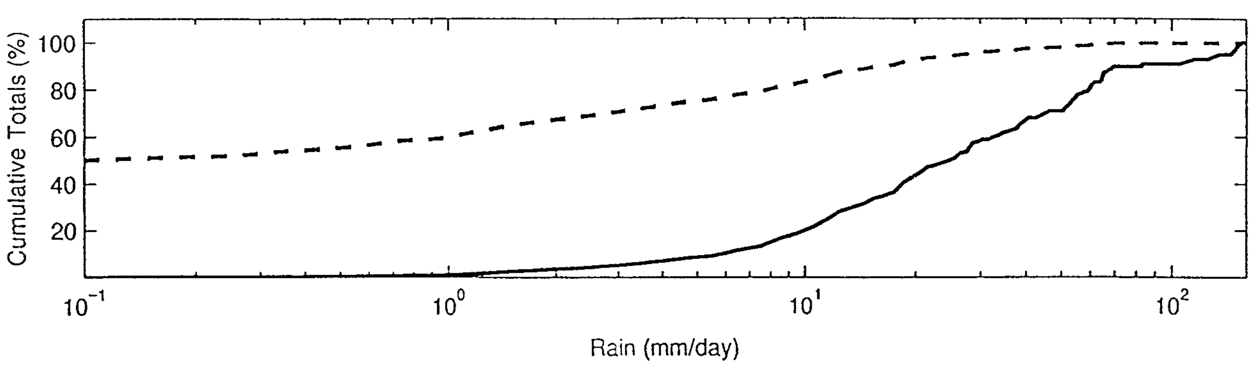


FIG. 3. Cumulative frequency of rain hours (dashed line) and cumulative frequency of rainfalls (solid line) for Careiro, 1988–90.

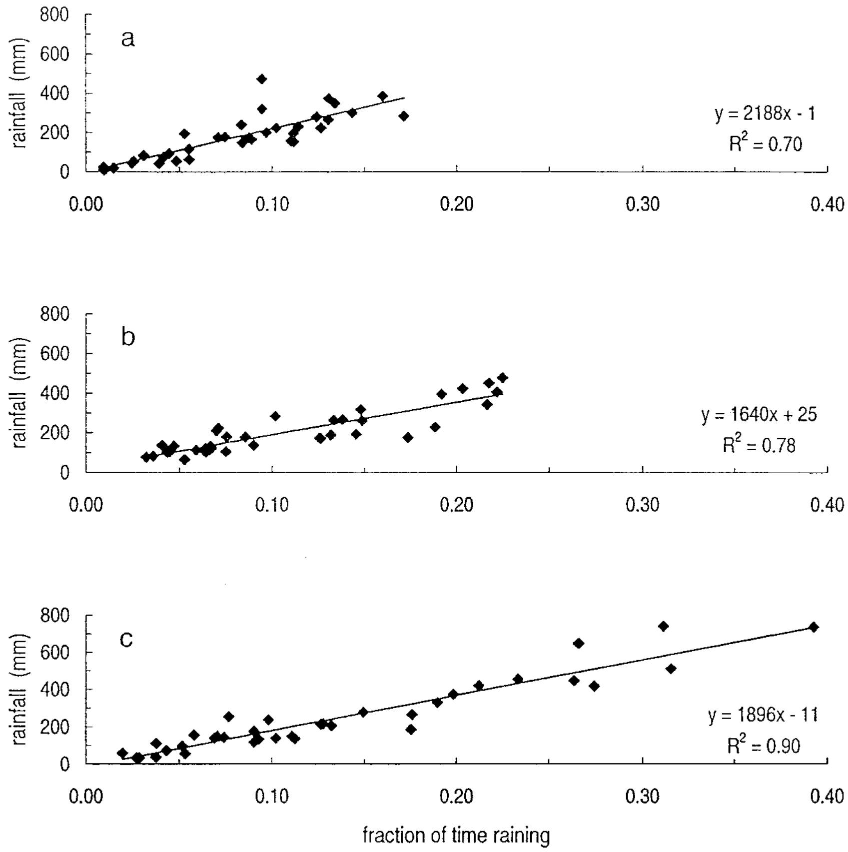


FIG. 4. Scatterplot relating fraction of time raining to rainfall. Each point represents an individual month: (a) Careiro, (b) CEPLAC, (c) UFPa.

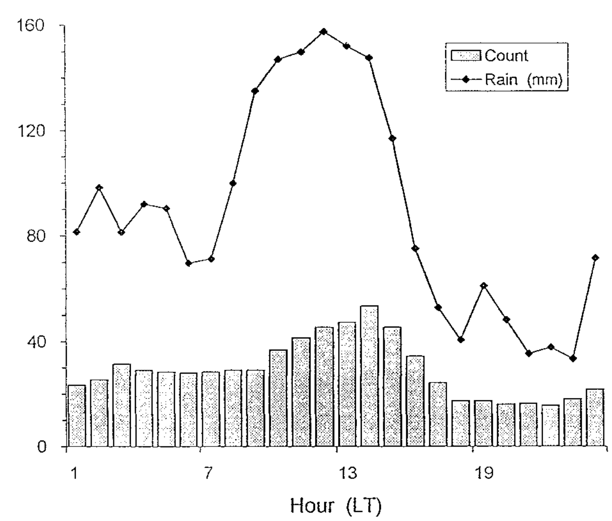


FIG. 5. Diurnal variation of rain hours (bars) and rainfall (line) at Careiro for the period 1 January 1988 through 31 December 1990. The number 1 corresponds to the rainfall for the hour ending at 0100.

falls (Fig. 3, solid line) indicates that the lightest half of hourly falls accounted for about 6% of the total fall recorded at Careiro and the lightest three-quarters of hourly falls accounted for only 21% of the total fall. On the other hand, the heaviest 10% of hourly falls accounted for nearly 55% of the total fall and the heaviest 5% for 35% of the total fall.

On the 3-yr ogive for rain days as a function of rain rate (not shown), the median value jumped to 5.7 mm h^{-1}; the third quartile rate, to 12 mm h^{-1}. Daily rainfalls at the median or lower values accounted for 12% of the 3-yr rainfall. Falls at the third quartile rate or lower accounted for 30% of the 3-yr rainfall.

From the hourly time series, following Morrissey and Krajewski (1993), month by month we calculated the fraction of time raining, or wet fraction. These values were plotted against rain accumulated for corresponding months (Fig. 4a). They indicate a linear increase in accumulation as wet fraction increases. The regression line in Fig. 4a underscores this point.

2) Diurnal cycle

Accumulated hour by hour through the day, rainfall at Careiro exhibits a bimodal profile (Fig. 5); however,

Table 3. Statistics of storms, interludes, and events, 1988–90.

		Station					
		Careiro (867 cases)		UFPa (1352 cases)		CEPLAC (1121 cases)	
	Variable	Mean	Variance	Mean	Variance	Mean	Variance
Storm	Duration*	2.4	4.0	2.1	2.9	2.2	3.4
	Accumulation	7.3	193	5.5	85	7.9	214
	Rate	2.4	10.2	2.4	15.2	3.0	19.2
Interlude	Duration	27.8	2297	17.3	545	21.1	924
Event	Duration	30.2	2294	19.4	548	23.3	927
	Rate	0.6	1.2	0.6	2.0	0.8	2.8

* Units of duration are h or h^2; of accumulation, mm or mm^2; of rate mm h^{-1} or mm h^{-2}.

Monte Carlo tests indicated that only the primary peak is statistically significant at a 95% confidence level. Forty-six percent of all rain fell in the 6 h around local noon; 24% fell in the 6 h following midnight. By 1–2 h the main peak in rain accumulation led the main peak in rain count.

3) Storms, interludes, and events

At Careiro 867 rainstorms occurred during the 3-yr study period (Table 3). On average, each storm lasted 2.4 h. An average storm yielded 7.3 mm of rain. Thus, over a storm rain fell at an average rate of 2.4 mm h^{-1}; over an event, at an average rate of 0.6 mm h^{-1}.

Variation in the duration of a storm roughly equalled the average. For both storm accumulation and interlude, variation roughly equalled twice the average.

Relative frequencies for each of the rain event parameters at Careiro can be fairly well approximated with the gamma function. The parameters of each analytical probability density function are shown in Table 4. More than 45% of the storms lasted only 1 h, but almost 5% lasted more than 8 h (Fig. 6a). About 40% of the storms yielded falls of 1 mm or less; almost 10% yielded falls of 20 mm or more (Fig. 6b). One storm dropped 150.5 mm of rain. In about 60% of the storms rain rate averaged 2 mm h^{-1} or less; in 20% of the storms it averaged 4 mm h^{-1} or higher (Fig. 6b, inset). Interludes of 6–12 h followed 50% of storms (Fig. 6c). Interludes of 3 days or longer followed 10% of storms. One interlude lasted 24 days.

Reflecting the dominance of interlude duration over storm duration, the distribution of event duration (not shown) indicates that three out of four events lasted 6–36 h; one in nine lasted 66 h or longer. In three out of four events, rain fell at rates of 1 mm h^{-1} or less; in one out of 10, rain fell at rates of 1.8 mm h^{-1} or higher.

Table 4. Parameters for an analytical fit of the gamma distribution to certain variables at Careiro.

	Parameter*	
Variable	α	β
Duration	2.11	0.88 h^{-1}
Rain	0.51	0.071 mm^{-1}
Rain rate	0.75	0.32 h mm^{-1}
Interlude	0.71	0.026 h^{-1}

* $f(x) = [\beta/\Gamma(\alpha)]x^{\alpha-1}e^{-\beta x}$.

b. Comparisons with Careiro

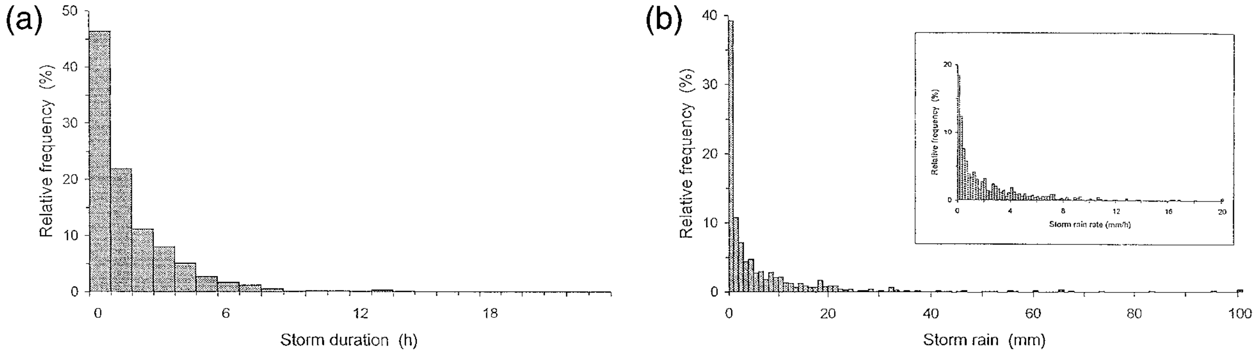
1) UFPa

The gauge at UFPa logged more rain hours of data than Careiro (Table 2). Even if its rain hours are reduced in proportion to the difference in log hours, UFPa's rain hours exceed Careiro's rain hours by about a third. Nevertheless, owing to significantly lower rates (in the mean, 15%; in the median, 30%), UFPa rainfall exceeded Careiro rainfall by less than 20%.

Compared with Careiro, the plot of hourly rain rate at UFPa in 1988 (Fig. 2b) suggests a more showery, less stratiform regime of rain. It also suggests less variability at the intraseasonal scale. The ogive for UFPa rain hours as a function of UFPa hourly rain rate (not shown) adds to the evidence for a more showery regime at UFPa. At UFPa in 50% of all rain hours rain fell at rates of 0.7 mm h^{-1} or less; in 75%, 2.6 mm h^{-1} or less; and in 90% 6.8 mm h^{-1} or less. Twenty-two percent of rain hours recorded the threshold rate. At UFPa the lightest half of hourly falls accounted for about 2% of the total fall and the lightest three-quarters of hourly falls accounted for about 13% of the total fall.

Except for values less than 0.09, the wet-fraction plot for UFPa (Fig. 4b) indicates lighter rain rates than at Careiro. Rain hours and rainfall each show a strong peak (Fig. 7). (Nearly 73% of the rain fell in the 6-h period beginning at 1400 LT.) This diurnal peak is significant at 99.9% confidence level as per Monte Carlo calculations. In contrast to Careiro, this peak occurred in the late afternoon. But rather than leading, the peak in rain accumulation phased with the peak in rain count.

For the 3-yr period, UFPa registered more than one-and-one-half times the number of events registered at Careiro (Table 3). In the mean, UFPa storms ended about 12% sooner and yielded 25% less rain than Careiro



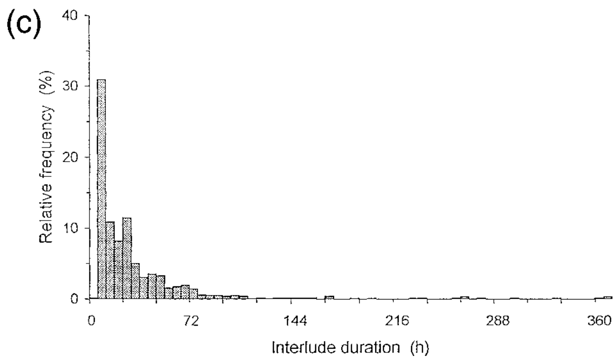


FIG. 6. Relative frequencies for storms at Careiro. (a) Duration, (b) rain and rain rate, (c) duration of interludes. The bin at 100 mm for rain includes all values of 100.0 and higher; that at 20 for rain rate includes all values of 20.0 and higher. The bin at 364 for duration of interludes includes all interludes longer than 360 h.

storms. Although storm lifetime and storm rainfall both varied less than at Careiro, storm rain rate varied more.

More than any other statistic, interlude distinguishes the two stations. On average, UFPa's interludes lasted slightly over 17 h (Table 3). Interludes of up to 12 h followed nearly 50% of storms and interludes of up to 48 h followed more than 90% of storms (not shown). On average, UFPa's interludes ended nearly 40% sooner than Careiro's interludes; measured by standard deviation, their variation came to 50% of that of interludes at Careiro.

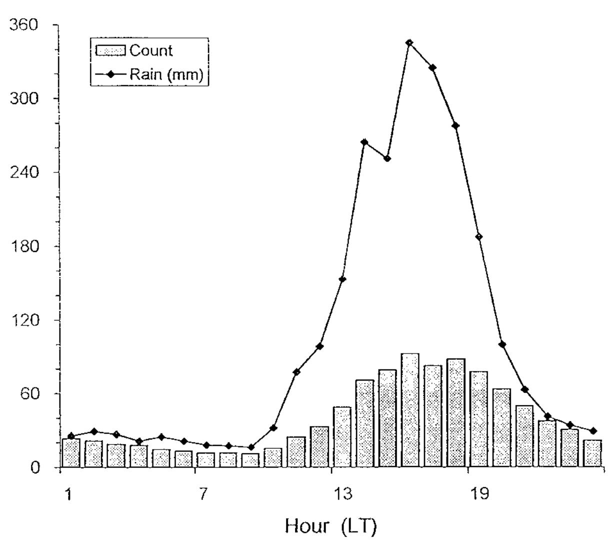


FIG. 7. Diurnal variation of rain hours (bars) and rainfall (line) at UFPa for the period 1 January 1988 through 31 December 1990.

2) CEPLAC

The gauge at CEPLAC logged more rain hours of data than Careiro, but fewer than UFPa (Table 2). Even if its rain hours are reduced in proportion to the difference in log hours, CEPLAC's rain hours exceed Careiro's rain hours by about 20%. On average, rain at CEPLAC fell more heavily than at Careiro. Together with more rain hours, this led to nearly 40% more rain. Apparently, the showery rains of a heavier rather than lighter intensity led to the large variance in conditional rain rate, which is nearly twice the variance at UFPa.

The plot of hourly rain rate at CEPLAC for 1988 (Fig. 2c) suggests a rain regime more like UFPa than Careiro. The ogive for CEPLAC rain hours as a function of CEPLAC hourly rain rate (not shown) underscores

TABLE 5. Mean storm parameters, 1988–90.

	Station					
	Careiro		UFPa		CEPLAC	
Stage	Duration (h)	Rate (mm h^{-1})	Duration (h)	Rate (mm h^{-1})	Duration (h)	Rate (mm h^{-1})
Early	0.4	2.0	0.4	1.5	0.4	2.5
Peak	1.0	4.7	1.0	4.1	1.0	5.5
Late	1.0	1.8	0.7	1.1	0.9	1.8

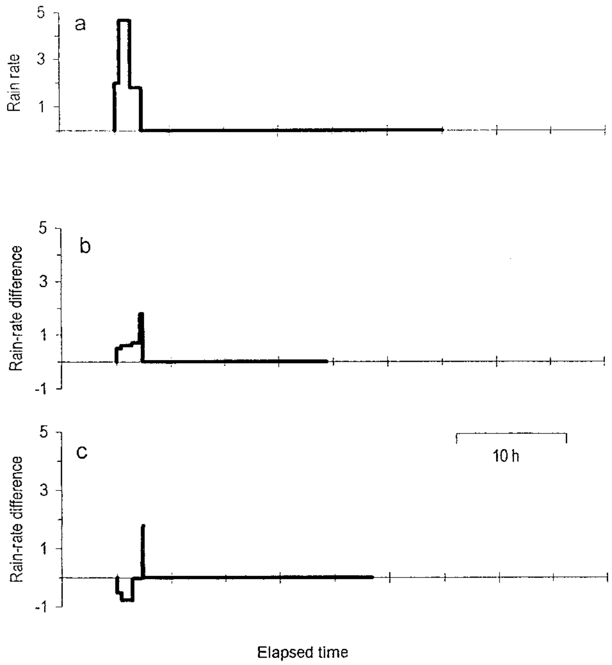


Fig. 8. Model events sketched from a uniform time of onset: (a) Careiro, (b) Careiro minus UFPa, (c) Careiro minus CEPLAC.

the similarity of the rain regimes at CEPLAC and UFPa. At CEPLAC half of all rain hours yielded 0.62 mm or less; three-quarters, 2.5 mm or less; and 90%, 7 mm or less. Seventeen percent of rain hours recorded the threshold rate (0.1 mm h^{-1}). At CEPLAC the lightest half of hourly falls accounted for about 3% of the total fall and the lightest three-quarters of hourly falls accounted for about 17% of the total fall. As indicated in Table 2, CEPLAC differs from UFPa chiefly in the intensity of its showers, which tend to be heavier.

The wet-fraction plot for CEPLAC (Fig. 4c) also indicates conditional rain rates more like UFPa than Careiro. In strength of the linear relationship between monthly rainfall and fraction of time raining, CEPLAC stands alone. There this relationship explains fully 90% of the variance between the two variables.

At CEPLAC the diurnal cycle of rain hours (not shown) resembles UFPa more than Careiro. As with rainfall, it differs most from UFPa in the phasing of the peak, which occurs early in the evening rather than late in the afternoon.

c. Model storms

Keying on the highest rain rate, we partition a storm into three stages: early, peak and late. Early represents all hours and all rates prior to the hour of the peak rain rate. Late represents all hours and all rates subsequent to the hour of the peak rain rate. Peak represents just the hour of maximum rain rate. If the maximum occurs in the first hour, a storm's early stage vanishes. If the maximum occurs in the last hour, a storm's late stage vanishes. If a storm lasts exactly 1 h, both early and late stages vanish. For storm stages Table 5 gives means. Together with interludes, Fig. 8 plots these storm means and storm mean differences.

For all stations each rate and (except for peak) each duration varied so much only in the average of hundreds of cases does a pattern emerge. This variability notwithstanding, at Careiro (Fig. 8a), on average a storm lasted 2.4 h. Nearly two-thirds of storm rain fell during the peak stage. Despite slightly higher rates during the early stage, two-thirds of the remaining rain fell during the late stage of the average storm. Fig. 5 suggests a late-morning onset.

In Fig. 8 UFPa (Fig. 8b) differed from Careiro (Fig. 8a) mainly in recording lower intensities and a shorter event. Figures 5 and 7 suggest at UFPa a retarded onset for this event (early afternoon rather than late morning). In Fig. 8 CEPLAC (Fig. 8c) differed from Careiro mainly in recording higher early and peak rates. In addition, the diurnal rainfall plot for CEPLAC (not shown) suggests a late afternoon rather than late morning onset.

4. Conclusions

This study examined rain recorded at three stations over the three years beginning on 1 January 1988. The records resolve hourly rain rates. One station occupies the coast; one, interior bottom land; one, interior upland. All lie along or near the Amazon River.

For the 3-yr record, storms on the coast (UFPa station) tended to be more showery than those in the interior; storms in the interior upland (CEPLAC station) tended to be more showery than those in the interior lowland (Careiro station). The diurnal cycle varied with distance from the Amazon River as well as with distance from the Atlantic coast.

Careiro differed from Lloyd's (1990) Reserva Ducke model storm mainly in the late morning rather than early afternoon onset. CEPLAC differed from the Reserva Ducke model in its late afternoon onset. UFPa differed from Lloyd's Belém model storm in three main respects: first, rain rate (half that of the Lloyd storm); second, rain duration (twice that of the Lloyd storm); and third, event duration (half that of the Lloyd storm).

The study could now be repeated for 9-yr records. The longer records might yield firm answers to questions of the sort we raised in section 1. They also might enable us to address the issue of interannual variability in rainfall of Amazonia. For now, variability in interludes as well as variability in the diurnal cycle lead us to advise caution in applications of the Lloyd storm model.

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REFERENCES

Anderson, R. K., E. W. Ferguson, and V. J. Oliver, 1966: The use of satellite pictures in weather analysis and forecasting. Tech. Note 75, World Meteorological Organization, Geneva, Switzerland, 184 pp. [Available from World Meteorological Organization, 7 bis, avenue de la Paix, CH-1211 Geneva 2, Switzerland.]

Cutrim, E. M. C., 1983: Estimating monthly rainfall from geostationary satellite imagery over Amazônia, Brazil. Ph.D. dissertation, University of Michigan, 107 pp.

——, D. W. Martin, and R. Rabin, 1995: Enhancement of cumulus clouds over deforested lands in Amazônia. *Bull. Amer. Meteor. Soc.,* **76,** 1801–1805.

de Oliveira, A. P., and D. R. Fitzjarrald, 1993: The Amazon river breeze and the local boundary layer: I. Observations. *Bound.-Layer Meteor.,* **63,** 141–162.

Figueroa, S. N., and C. A. Nobre, 1990: Precipitation distribution over central and western tropical South America. *Climanalise,* **5,** 36–45.

Hjelmfelt, A. T., Jr., 1978: Amazon Basin hydrometeorology. *ASCE J. Hydraul. Division,* **104,** 887–897.

Kousky, V. E., 1980: Diurnal rainfall variation in Northeast Brazil. *Mon. Wea. Rev.,* **108,** 488–498.

Lloyd, C. R., 1990: The temporal distribution of Amazônian rainfall and its implications for forest interception. *Quart. J. Roy. Meteor. Soc.,* **116,** 1487–1494.

Molion, L. C. B., and R. L. G. Dallarosa, 1990: Pluviometria da Amazônia: Sâo os dados confiáveis? *Climanalise,* **5,** 37–41.

Morrissey, M. L., and W. F. Krajewski, 1993: A point process model for tropical rainfall. *J. Geophys. Res.,* **98,** 16 639–16 652.

Nechet, D., 1992: Variabilidade diurna de precipitaçãoe de trovoadas em Manaus-AM. *Proc. 7 Congresso Brasileiro de Meteorologia,* São Paulo, Brazil, Brazilian Society of Meteorology, 243–247.

——, 1993: Variabilidade diurna de precipitação em Santarém-PA. *Bol. Geografia Teorética,* **23** (45–46), 144–149.

Negri, A. J., R. F. Adler, E. J. Nelkin, and G. J. Huffman, 1994: Regional rainfall climatologies derived from Special Sensor Microwave Imager (SSM/I) data. *Bull. Amer. Meteor. Soc.,* **75,** 1165–1182.

Ratisbona, L. R., 1976: The climate of Brazil. *World Survey of Climatology,* W. Schwerdtfeger, Ed., Elsevier, 219–269.

Ribeiro, M. de N. G., and J. Adis, 1984: Local rainfall variability—A potential bias for bioecological studies in the central Amazon. *Acta Amazon.,* **14,** 159–174.

Salati, E., and P. B. Vose, 1984: Amazon basin: A system in equilibrium. *Science,* **225,** 129–138.

United Nations, 1981: *Vegetation Map of South America Explanatory Notes.* United Nations Educational, Scientific and Cultural Organization, 189 pp.