RAINFALL MONITORING: THE EPSAT-NIGER SETUP AND ITS USE FOR HAPEX-SAHEL

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ABSTRACT

The EPSAT-Niger (Estimation des Précipitations par SATellite au NIGER) experiment has been designed to improve our understanding of the precipitation systems of Sudano-Sahelian Africa, particularly with the aim of developing operational rainfall estimation algorithms for this region. It is based on the combined use of a very dense raingauge network (107 raingauges over a study area of 16 000 km^2 in 1992) and C-band weather radar system. The experiment has lasted for five years (1989-1993), the complete setup having operated for four years (1990-1993). Each field campaign was the object of a detailed report (LEBEL *et al.*, 1991, TAUPIN *et al.*, 1992 and 1993). The aim of this paper is thus to summarize the main features of the experimental setup and its evolution since the start of the project. A first analysis of the raingauge data set is also presented. The Sahelian rainfall appears to be highly intermittent both in time and space. Despite significant differences in the seasonal totals for each year, the characteristics of the rainfall events were found to vary little from one year to another. A more detailed study of the rainfall distribution is presented for 1992.

RÉSUMÉ

L'expérience EPSAT-Niger (Estimation des Précipitations par SATellite au NIGER) a été conçue pour améliorer la compréhension des systèmes précipitants de l'Afrique soudano-sahélienne, particulièrement en vue de favoriser le développement d'algorithmes opérationnels d'estimation des pluies sur cette région. Le dispositif est constitué d'un réseau dense de pluviographes à mémoire statique (107 appareils couvrant une surface de 16.000 km^2 en 1992 associé à un radar météorologique bande C. Il a fonctionné pendant cinq années (1989-1993) dont les quatre dernières au complet. Chaque campagne a fait l'objet d'un rapport détaillé annuel rédigé en français (LEBEL *et al.*, 1991, TAUPIN *et al.*, 1992 and 1993). Le but de cet article est donc uniquement de résumer les principaux traits de l'expérience et de son évolution. Une première analyse du jeu de données pluviographiques est également présentée. La pluie au Sahel apparaît comme fortement intermittente à la fois dans l'espace et dans le temps. Cependant, malgré des différences significatives entre les totaux observés chaque année, les caractéristiques moyennes des événements pluvieux restent stables d'une année sur l'autre. Une présentation plus détaillée de la répartition spatio-temporelle de la pluie est fournie pour 1992.

1. GENERAL OBJECTIVES

The EPSAT-Niger experiment was started even before the experimental design of HAPEX-Sahel was definitely determined. The original goal of EPSAT-Niger, as stated in LEBEL *et al.* (1992) was six fold:

1 - providing an understanding of the dynamics of the Mesoscale Convective Systems in the Sahel and the associated space-time distribution of rainfall;
2 - studying the influence of ground truth accuracy on the satellite data validation;
3 - comparing ground and satellite-based rainfall estimates;
4 - investigating the dependence of the spatial variability on the rainfall integration in time;
5 - deriving from the above the optimal combination of sensors to be used for rainfall estimation at these scales, taking into account the required degree of accuracy and the size of the elementary zones of estimation;
6 - improving the current satellite algorithms or developing new ones by using different types of data or calibration procedures.

For that purpose it was decided that a combination of a dense recording raingauge network and of a weather radar system was necessary. This setup became part of HAPEX-Sahel at the beginning of the long-term monitoring period, in 1991, with the particular objective of providing accurate areal rainfall estimates over the required space (from 1 x 1 km^2 to 100 x 100 km^2) and time (from 5 minutes to the rainy season) scales. The regular and complete coverage of the one degree square would also allow to characterize the spatial variability over the entire study area, both during the Intensive Observation Period (IOP) and the long-term monitoring period. Since the measurements began in 1989 and were to continue until 1993, another important objective was to provide the relevant long-term perspective and to observe at least some of the interannual rainfall variability.

2. SPATIAL AND TEMPORAL COVERAGE

2.1. Area of study

The EPSAT-Niger project is located in the Sahel around the town of Niamey (Niger). The relief is fairly uniform, between 175 m and 275 m, and so has little effect on the region's rainfall systems. The mean annual rainfall is about 560 mm (564 for the 1905-1989 period, and 562 for the 1950-1989 period) with a north to south increasing gradient of about 100 mm per degree of latitude, in the order of 1 mm/km (fig. 1). The past twenty years (1968-1989) have seen a lasting drought with an average annual rainfall of 495 mm.

The preliminary study in 1989 covered the Degree Square (DS) bounded by latitudes 13° N-14° N and longitudes 2° E-3° E. However as this zone coincides with less than 25% of the working area of the Niamey Airport radar it was decided to extend the network to the west from 1990. While the initial situation only allowed the study of the attenuation patterns across the convective front of the passing squall lines, the extension zone allows the same surveillance of the stratiform part which follows after. Thus the EPSAT-Niger Study Area (SA) was enlarged to a rectangle of latitudes 13° N-14° N and longitudes 1° 40 E - 3° E (≈ 16 000 km^2; fig. 2). As for the radar, it permits the survey of an area of about 400 000 km^2, with a quantitative assessment of rainfall possible over an inner circle of 120 km in radius (that is a surface of around 50 000 km^2).

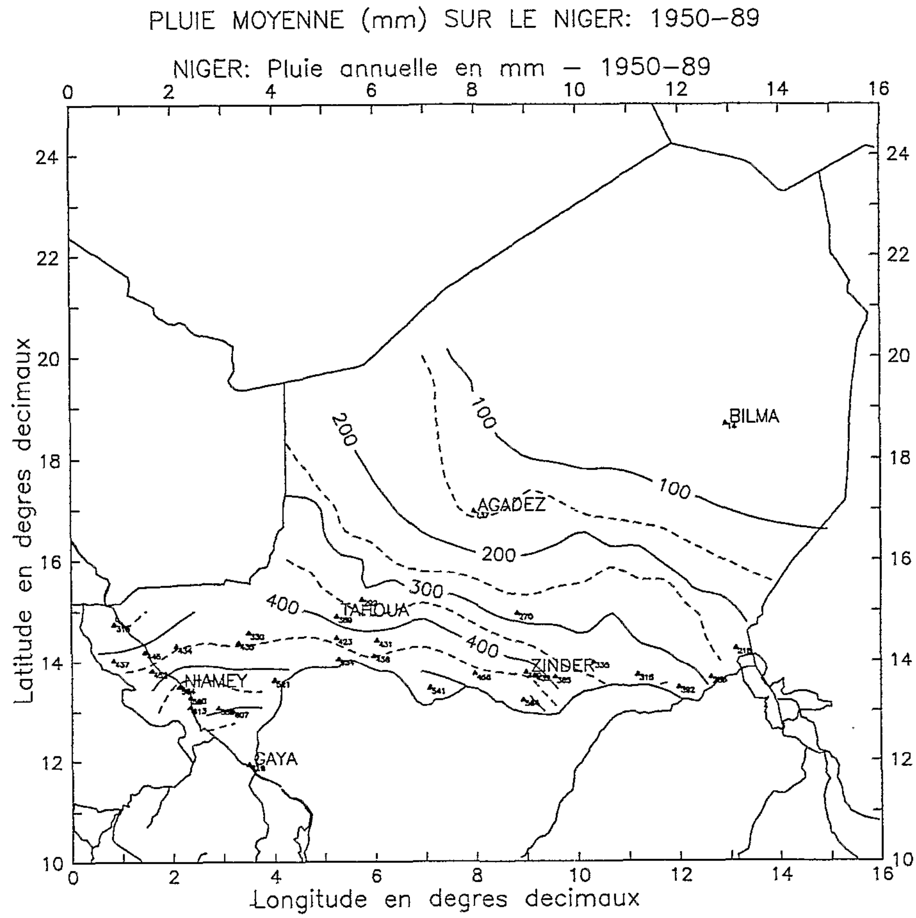

Figure 1. Mean annual rainfall map over the Niger (1950-1989).
The EPSAT-Niger study area is the square surrounding Niamey.

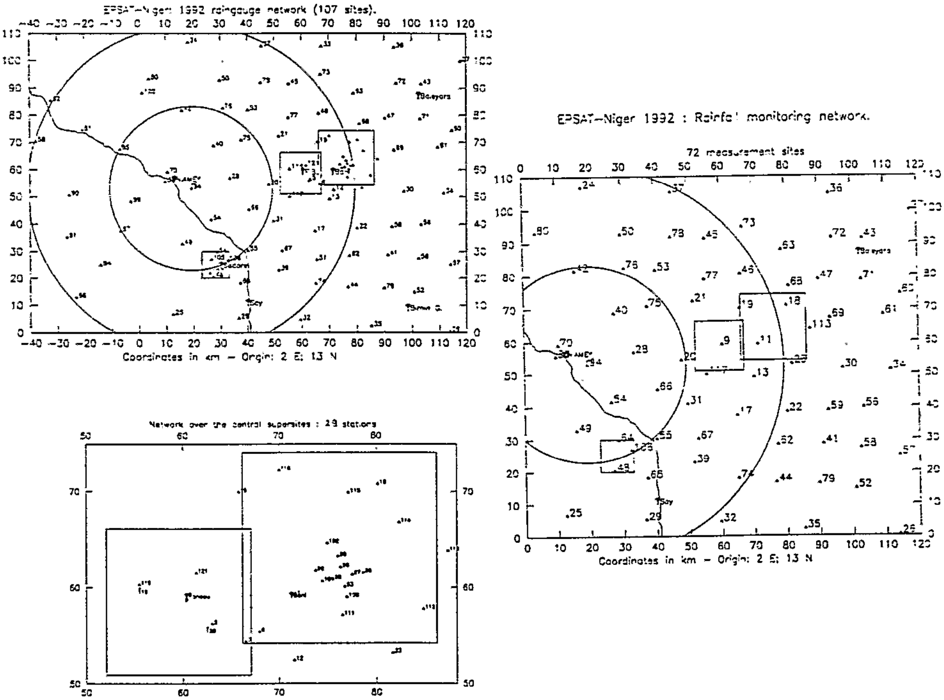

Figure 2. The recording raingauge network in 1992. **a:** Entire network; **b:** Target Area network; **c:** Basic monitoring network. The basic network is evenly distributed and is used in sampling studies at the DS scale, the local effect of the Target Areas oversampling being removed. See definitions of these various networks in the text.

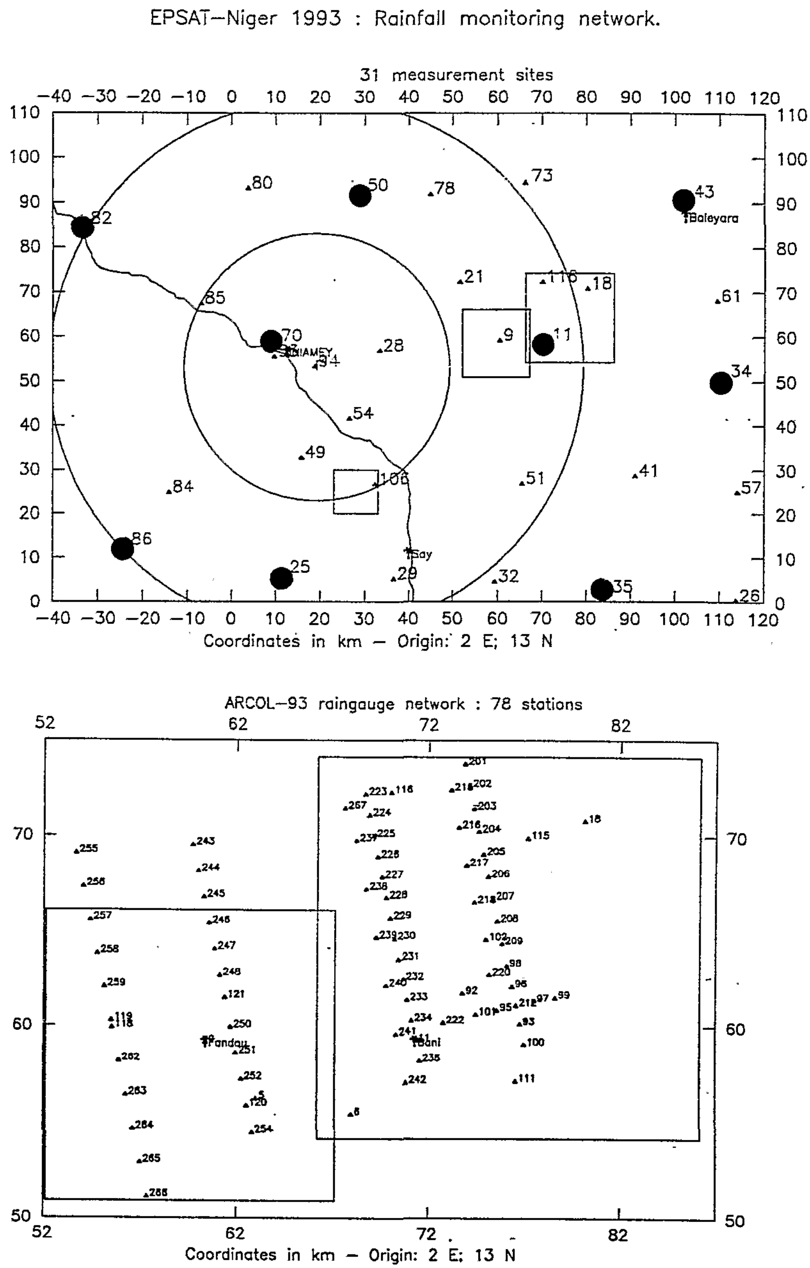

Figure 3. The recording raingauge network in 1993. The stations marked with an heavy circle are intended at being left in operation for the next decade.

$$Z = \int N(D) D^6 dD$$

where D is the diameter of the hydrometeors and $N(D)$ is the probability density function of the number of hydrometeors of diameter D per unit of volume.

Z may be converted into a rainfall intensity (R) averaged over the radar pixel volume, through a so-called Z-R relationship; its general form is:

$$Z = aR^b$$

where Z is given in $mm^6.\ m^{-3}$ and R in mm/h. First values of $a = 200$ and $b = 1.6$ were derived from the raindrop size distribution proposed by MARSHALL and PALMER (1948) for stratiform rainfall. Since then many different sets of values have been proposed for a and b, typically ranging from 150 to 500 for a and from 1 to 2 for b.

The raingauge network provides direct point rainfall measurements over the ENSA (16,000 km^2). Tip-bucket raingauges of cone diameter 400 cm^2 were used. To prevent severe problems of blockage by sand and to allow full protection of the apparatus with 1.2 m fencing, the rims were set at 1.5 m above ground-level. Two sites were equipped with a second ground-level raingauge for control purposes. These were installed in a square pit and surrounded by a slatted metal grid to prevent insplash.

Each tip, being equivalent to 0.5 mm of rainfall, is recorded to the nearest second on EPROM or EEPROM cartridge. Thus it is possible to produce an accurate hyetogram. The recorders batteries are recharged by solar panel either directly or through a regulator. Both systems were used although the first was preferred due to frequent regulator failure during 1989. Initially cadmium-nickel batteries were used, however they were found to be unsuited to the Sahelian climate and so were gradually replaced with lead batteries. Normal working voltage for the apparatus was 12 v but functioning is unaffected as long as the voltage remains greater than 11 v.

3.2. Temporal resolution

Since the raingauge acquisition system records the time of tipping to the nearest second, the temporal resolution is a function of the rainfall intensity, as shown in table 1.

The radar measurement is instantaneous. It takes about one minute at normal speed to complete one revolution. A radar image is thus made of instantaneous reflectivities with a time separation of one minute between the first and the last radial.

Table 1. Time separation (= period of integration), in seconds, between two successive bucket tippings as a function of rainfall intensity (mm/h).

Rainfall intensity	1	5	10	20	30	60	120	180	360	900
Period of integration	1 800	360	180	90	60	30	15	10	5	2

Table 2. Width (tangential resolution) and altitude (both in metres) of the beam centre for an elevation angle of 0.8°. The sphericity of the earth is taken into account. Distance in kilometres.

Distance	20	30	40	50	60	70	80	90	100	120	150	200	250	300
Width	523	785	1 046	1 308	1 570	1 832	2 093	2 355	2 617	3 140	3 926	5 234	6 542	7 852
Altitude	302	471	652	845	1 049	1 265	1 493	1 733	1 984	2 522	3 417	5 145	7 172	9 482

3.3. Spatial resolution

The raingauge measurement is considered a point measurement, since the area of the collector is only 400 cm^2.

The radar provides an area-averaged value over pixels of increasing area when moving away from the radar. The radial resolution, as set by the SANAGA digitization procedure, is 500 m when working in the 250 km range mode, and 750 m when working in the 350 km range mode. This resolution is decreased to 250 m when working either in the 50 km or 100 km range modes. The tangential resolution is equal to r.α, where r is the distance from the radar and α is the beam width in radians (α = 0.0262 for the Niamey radar). Since most of the HAPEX-Sahel study area is within the 100 km circle centred on the radar, the tangential resolution of the radar data remains below 2.6 km. It is between 1.3 and 2.0 km over the Central Super-Sites (table 2).

3.4. Temporal sampling

The temporal sampling of the raingauge measurement is equal to the temporal resolution. That is, the raingauge measures every q seconds a value accumulated over the period θ (table 1).θ is not a constant since, as shown in table 1, it varies with the intensity of precipitations.

During rainy events the radar was running permanently. The temporal sampling of the acquisition was set to 15 minutes when the storm was outside the DS, to 10 minutes when the storm was entering the DS, but not still covering the Central Super-Sites, and to 5 minutes when intense rainfall was recorded over the Central Super-Sites (this is the period when sampling at the low elevation angle of 0.8°; sampling at the medium elevation angle of 1.2° was performed every 15 minutes).

3.5. Spatial sampling

The density of the raingauge network varies depending on the zone considered (table 3). The less heavily instrumented zone is the adjoining extension zone to the west of the DS, with an average of gauge area of 400-500 km^2. Over the DS, one has to distinguish between the basic monitoring network and the Target Area (TA)[1] network (table 4). The basic monitoring network is evenly distributed, its pattern being a regular grid with nodes spaced at about 13 km, that is an average density of one gauge for 170 km^2. The location and the extension of the TA changed between 1990 and 1992. In 1990 it was a 400 km^2 covered by 18 gauges. The minimum distance between gauges was decreased to 1 km at the centre of the TA. In 1991 the TA was moved 10 km to the east and 5 km to the west so as to coincide with the East Central Super-Site (ECSS). The number of gauges and the pattern of their distribution were kept. In 1992 the TA was enlarged to the west so as to include both the ECSS and WCSS (West Central Super-Site). Several sub- target areas may be identified (table 5), labelled C0 (875 km^2; 29 gauges; 30.2 km^2 per gauge) to C4 (25 km^2; 9 gauges; 2.8 km^2 per gauge). The raingauge distribution is shown for 1992 in figure 2 and for 1993 in figure 3.

1 Whereas the Super-site refers to a concept defined specifically for HAPEX-Sahel (GOUTORBE *et al.*, 1994), the Target Areas correspond only to a local increase of the raingauge network density so as to provide better insight into the small-scale rainfall variability. Changes were made in 1991 and 1992 in the network design over the main Target Area so as to make it coincide with the Central Super-site.

Table 3. The raingauge network over the EPSAT-Niger study area (16,000 km²).

	1990	1991	1992	1993
Total number of sites	93	96(99)*	107	107
Basic Network	79	88	82	31
Extension zone only : 1° 40′ - 2° 00′ E/ 13° 00′ - 14° 00′ N (4,000 km²)				
Number of sites	10	8	10	4
Area per site (km²)	400	500	400	1000

* 3 stations in Ouallam, north to the 14° latitude boundary.

Table 4. The raingauge network over the one Degree Square (Reference Zone).

Reference zone (area = 12 000 km²)				
	1990	1991	1992	1993
Total number of sites	83	88	97	103
Number of sites of the basic network	69	70	72	27
Area per site (km²) (basic network)	174	171	166	444
Target zone (area = 400 km²; coordinates changed between 1990 and 1992)				
Number of sites	18	18	19	
area per site (km²)	22	22	21	NA

Table 5. The raingauge network over the Super-Sites in 1992.

	East Central Super-Site			Central (East + West)*		South
	C4 (5 x 5)	C3 (13 x 13)	C2 (20 x 20)	C1 (30 x 25)	C0 (35 x 25)	S0 (10 x 10)
Coordinates : EPSAT	X: 73.7 - 78.7 Y: 60.0 - 65.0	X: 70.0 - 83.0 Y: 59.3 - 72.3	X: 66.2 - 86.2 Y: 54.1 - 74.1	X: 57 - 87 Y: 50 - 75	X: 52 - 87 Y: 50 - 75	X: 23 - 33 Y: 20 - 30
Geographic Longitude (X) Latitude (Y)			2°36. 77′ 2°47. 88′ 13°29. 21′ 13°40. 00′	2°31. 61′ 2°48. 32′ 13°26. 96′ 13°40. 50′	2°28. 83′ 2°48. 32′ 13°26. 96′ 13°40. 50′	2°12. 75′ 2°18. 30′ 13°10. 80′ 13°16. 20′
Area (km²)	25	169	400	750	875	100
Numb. of gauges	9	15	19	27	29	5
Area/gauge (km²)	2.8	11.3	21.1	27.8	30.2	20

* EPSAT coordinates of the WCSS: X = 52.1 - 67.1; Y = 50.9 - 66.1

Table 6. The periods of operation of the EPSAT-Niger raingauge network, and the number of stations available for the calculation of the seasonal rainfall. The rainy season is taken as the period 15-04-15-10, except in 1991, where the storm of the 14-04 is included, and in 1992, where the two storms observed the 10-04 are also included. For the basic network (last column), the first number is for the DS only, while the second is for the whole SA.

Year	End of installation	First rain (> = 1 mm)	First DS event	Last DS event	Total number of stations rainy season	Number stations basic network, rainy season
1990	15.05	19.05	28.05	17.09	74	60 (60)
1991	15.05	14.04	14.04	4.10	52	36 (41)
1992	1.05	7.04	10.04	15.09	98	70 (80)
1993	15.04	27.04	30.05	9.10	99	26 (30)

Table 7. Proportion of the seasonal rain falling during the DS events. The raw values, corresponding to the bucket tippings are given in column 3 (DS-averaged, computed by kriging of the point measurements), and then corrected by the annual average bottle/bucket ratio in order to obtain values (R1) that are comparable to the reference bottle seasonal rainfall (R2).

Year	Total number	CER: Cumulative Event Rainfall	Correction factor bucket -> bottle	Corrected CER (R1)	Seasonal rainfall(R2)	R1/R2 (%)
1990	39	408 mm	- 8.6%	373 mm	396	94
1991	47	520 mm	- 5.4%	491 mm	522	94
1992	48	505 mm	- 4.5%	482 mm	511	94
1993	38	424 mm	- 5.0%	403 mm	460	88
Total	172			437 mm	472	93

3.6. Data collected

3.6.1. Raingauge data

At the end of the rainy season, all the raingauges but a dozen are removed from the field in order to be checked in the laboratory. This also protects the gauges from the dust and the heat of the dry season, and lowers the gardien costs. Possible rain during the dry season is monitored by the dozen gauges left permanently in the field (see fig. 3). The installation for the next rainy season is started in March so as to get the entire network in operation for mid-April: the long-term (1905-1989) statistics of the Niamey meteorological station show that 99% of the rainfall is recorded between the 15th of April and the 15th of October, and 95% between the 15th of May and the 15th of October. In 1991, the installation started latter and the network was fully operational only in mid-May. Unluckily the rainy season started especially early that year: 40 mm of rainfall was recorded over the DS between the 15th of April and the 15th of May, that is 8% of the seasonal total. Table 6 summarizes the periods of operation of the network for each year.

A total of 172 rainy events were observed over the period 1990-1993. A rainy event is defined with respect to the network observations as follows: at least 30% of the raingauges in operation must record rainfall over the event period; at least one station must record more than 2.5 mm of rainfall; the rainfall must not stop over the entire network for longer than half an hour (otherwise the event is considered to have ended at the time when it stopped at the station(s) having recorded the last rainfall). Obviously this definition is contingent upon the area of the study zone (these events will therefore be referred to as "DS events" thereafter) as well as the network density. Nevertheless, the EPSAT-Niger network appeared to be dense enough so as to give a good estimation of the rainy areas. When simulating networks of smaller density in 1990, 1991 and 1992, down to the density of the 1993 basic network, the number of DS events changed only by one or two units. On the other hand the SA is relatively small as compared to the extension of the Sahelian Mesoscale Convective Systems (MCS's), which often cover several hundred of kilometres in the south-to-north direction, while affecting a still larger area in the east-to-west direction (these systems move westward at an average speed of 60 km/h and their life time is normally of several hours). Consequently the "DS events" account for most of the DS rainfall as may be seen from table 7. Only MCS's which circulate far to the north or south and that affect only the DS at its margins, or very local convection do not belong to the DS events sample. The characteristics of the DS events and their comparison with those of what may be defined as "point events" are further studied in section 5. The comprehensive list of the 172 events is given in appendix 2.

3.6.2. Radar data

Radar data were acquired only on an alert-to-storm basis. The protocol called for the DMN personnel on duty to inform the EPSAT-Niger team when a storm was approaching the DS. Generally this procedure proved to be efficient, except for a few cases (especially in 1990 and 1991). In addition to these 'storm miss', failures of either the external power supply or of various components of the radar system were other causes of no radar acquisition. Major breakdowns, leading to an early stop of the acquisition campaign, were undergone in 1990 (13 September) and in 1993 (19 August). In spite of these various problems, about two thirds of the major DS events were recorded by the radar. In 1992 37 acquisition were carried out, 26 of them corresponding to a major DS event. The radar was out of operation until the 20 of June. Thus, the 10 first rainy events of the season were missed. After that date all the major events except three (30 June, 31 July, 30 August) were recorded by the weather radar system. Table 8 gives a summary of the radar operations from 1990 to 1993 (see also Lebel *et al.*, 1991, Taupin *et al.*, 1992 and Taupin *et al.*, 1993b).

Table 8. The periods of operation of the weather radar.

Year	Period of full operation	Total number of events recorded	Number of DS events recorded
1990	8.6 - 13.09	25	17
1991	7.6 - 17.09	26	22
1992	20.6 - 14.09	37	26
1993	29.5 - 19.08	24	18

4. MEASUREMENT ACCURACY

The raingauge measurement is prone to three types of errors: i) the bucket tipping occurring for a rain depth slightly different from the normal value of 0.5 mm, resulting in an overestimation or underestimation of the cumulative rainfall; ii) a possible drift of the internal clock of the recording system, resulting in time lags between the raingauges and thus a distorted view of the rainfall field at small time steps; iii) the aerodynamic effect of the sensor onto the airflow around it, resulting generally in an underestimation of the precipitation.

The first type of error is checked by collecting the rain water after tipping in a bottle. The bottle cumulative rainfall depth was compared, each year and for all the stations, to the bucket tipping recorded rain depth. In average it was found that the bucket values overestimated the bottle value by a factor 1.05 (Taupin *et al.*, 1992, 1993b). This is due to an early tipping of the bucket, caused by the wind and/or high rainfall intensities. To account for this overestimation, two data bases were developed: one at the time step of 24 hours is bottle-corrected, thus eliminating the bucket-induced errors in the computation of cumulative rainfall for time steps equal or greater than one day; the other at a time step of 5 minutes is not corrected since it is impossible to determine which correction to apply (it should not be a constant, since it likely depends on the rainfall intensity).

The second type of errors is easily corrected since it was verified that, when they exist, the drifts of the internal clocks are constant. The exact time is noted when installing the EEPROM memory and when unloading it. A linear correction of all the tipping times recorded on the memory is then applied in the laboratory when processing it.

The last type of errors is never known exactly. For a given gauge design, it mostly depends on the site of the gauge, the wind speed and the rainfall intensity. To obtain an estimate of this error two ground raingauges were installed beside two standard EPSAT-Niger raingauges at Banizoumbou (station N° 11) and Kollo (station N° 54). The comparison between the ground and the 1.5 m measurements showed no significant differences between the two, neither at the 5 minutes time step, nor at the event time scale (Taupin *et al.*, 1993, Taupin and Lebel, 1994). At Banizoumbou for instance the equation of the regression curve between the event ground rainfall (Y) and the event 1.5 m rainfall (X) is: Y = - 0.19 + 1.006 X, with a determination coefficient r^2 equal to .996 (n = 33). Other comparisons carried out on the Southern Super-Site, using ground gauges set up by the team of the Institute of Hydrology of Wallingford, brought in similar results, with the exception of one site where differences of up to 30% were measured for some periods. A water balance study carried out by Gaze (1993), using the soil moisture measurements available to him concluded that the EPSAT-Niger value was the most realistic of the two measurements. Other comparisons were carried out with the data of the CNRM/4M team of Meteo-France (each unit of the 12 automatic weather stations network was collocated with an EPSAT-Niger gauge, see Bessemoulin and Puech, this volume, for details), showing no great differences between the EPSAT-Niger and 4M measurements.

Regarding the radar, the possible sources of error are numerous (see Wilson and Brandes, 1979, and Zawadzki, 1984, for a review). At this stage of the data processing no meaningful figure on the accuracy of the radar derived rainfall estimates can be given.

5. PRELIMINARY ANALYSIS OF THE RAINGAUGE DATA SET

5.1. Rainfall climatology during the long-term monitoring period

5.1.1. Seasonal rainfall

The rainy season is defined as the period extending from the 10th of April to the 10th of October. In average over the period 1990-1993, 99% of the annual rain fell during that period, which is in agreement with the long-term statistics of the Niamey meteorological station. As already mentioned in section 3.6, the number of available measurements of the point seasonal rainfall is function of the date of completion of the raingauge installation. It is also a function of the possible lacunae in the records. Nevertheless, the bottle cumulative rainfall may allow to make up for buckets rainfall lacunae. The installation of the network was generally not completed until the beginning of May. In 1990 and 1992, this did not prevent from knowing the seasonal rainfall at most stations (74 in 1990, 98 in 1992, table 6). In 1991 the rainfall started earlier and the seasonal rainfall was measured at only 52 stations. In 1993 the installation of the basic network of 31 stations was completed by the 10th of April. The statistics of the seasonal rainfall for the stations of **the basic network over the DS** are given in table 9 (the stations of the extension zone and of the target area are put aside so as to obtain a regular sampling of the DS). In 1992 for instance the seasonal rainfall is available at 98 stations (out of a total of 107 gauges), 70 of which are part of the DS basic network (the seasonal rainfall is thus missing at only 2 stations of the DS basic network).

The area-averaged values over the DS and the super-sites are also given in table 10. The DS average over the period 1990-1993 (472 mm) is a little smaller than the 1968-1989 average (495 mm) of the Niamey station, 1968-1989 being a dry period (25% less rainfall than during the years 1950-1967).

The year 1990 was especially dry with an average over the DS of less than 400 mm. The years 1991 (522 mm) and 1992 (511 mm) were wetter than the 1968-1989 period, slightly in deficit as compared to the 1950-1989 long-term average (566 mm) recorded at the Niamey-Aéroport station. The west and east central super-sites recorded a 1990-1993 average (481 and 479 mm) close to the DS average and the southern super-site recorded an expectedly higher value (538 mm). The ECSS rainfall was within 10 mm of the DS averages for each year except in 1991, where it was 38 mm (7%) greater than the DS average.

The rainfall observed over the DS reflected the general trend over the entire Niger, with the years 1990 and 1993 being dry and the years 1991 and 1992 receiving a reasonable amount of rain (fig.4). In 1991 the rainfall over the country was globally equivalent to the 1950-1989 average and the DS was comparatively drier even though it was the wettest of the four years of HAPEX-Sahel.

Taupin *et al.* (1993) have evidenced that the spatial variability of the seasonal rainfall was much larger than generally expected. Most of the variability is concentrated in the first 30 to 50 kilometres, so that two stations separated by more than 50 kilometres are, in average, uncorrelated. No systematic pattern of low or high rainfall was observed, and the areas of maximum and minimum rainfall changed from one year to another (fig. 5). Gradients of more than one hundred mm of rain over a few kilometres have been recorded: 150 mm over 6 kilometres in 1990 in the ECSS; 320 mm over 27 kilometres in 1991 (Taupin *et al.*, 1993), 275 mm over 9 kilometres in 1992 in the SSS (see fig. 11 below). Each year the minimum value recorded over the network was half of the maximum.

Table 9. Statistics of the point rainfall values recorded by the basic network stations of the DS over the rainy season (10-04 - 10-10), compared to the statistics of the Niamey Aéroport station (N.A.) for three periods. Rainfall values are in mm.

Sample	N. Stat. n	Mean (μ_p)	S.D. (s)	Mini (m)	Maxi (M)	C.V.(%) (s/μ_p)	$(M-m)/\mu_p$ (%)	Niamey Aero/ORST.
EPSAT 1990	60	396	63	292	659	16,0	93	474/399
EPSAT 1991	36	523	95	341	725	18.2	74	434/541
EPSAT 1992	70	513	71	389	782	13,9	77	607/488
EPSAT 1993	30	459	83.9	315	622	18.6	65	399/447
N.A. 50-89	40	566	123	294	980	22	114	Median: 549
N.A. 50-67	18	654	145	454	940	22	74	Median: 627
N.A. 68-89	22	495	108	294	689	22	80	Median: 499

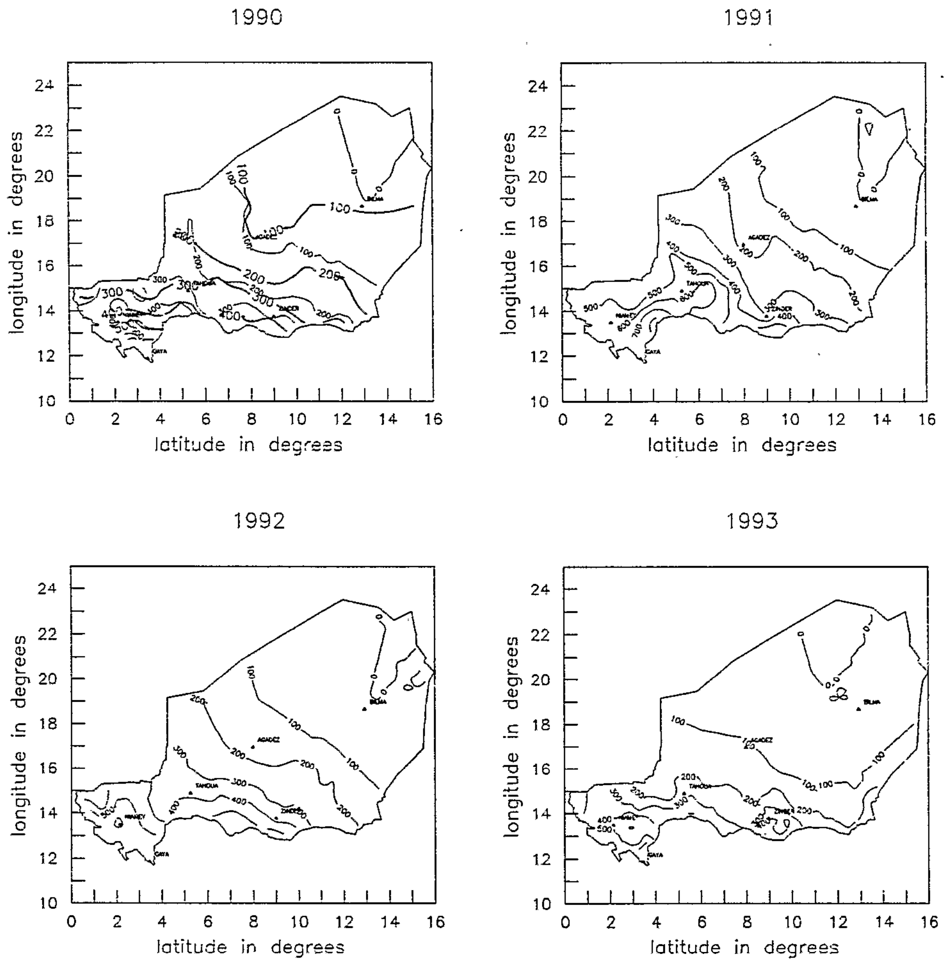

Figure 4. Annual rainfall over the Niger for each year of the period 1990-1993. Overlaid on the 1990 map are the isohyets of the mean annual rainfall over the dry period 1968-1989 (thick lines). The 1990 isohyets are shifted southward as compared to the 1968-1989 isohyets indicating a dry year all over Niger. In 1991 the isohyets are shifted northward and in 1992 as well, even though less markedly. 1993 was drier than both 1990 and the mean over 1968-1989.

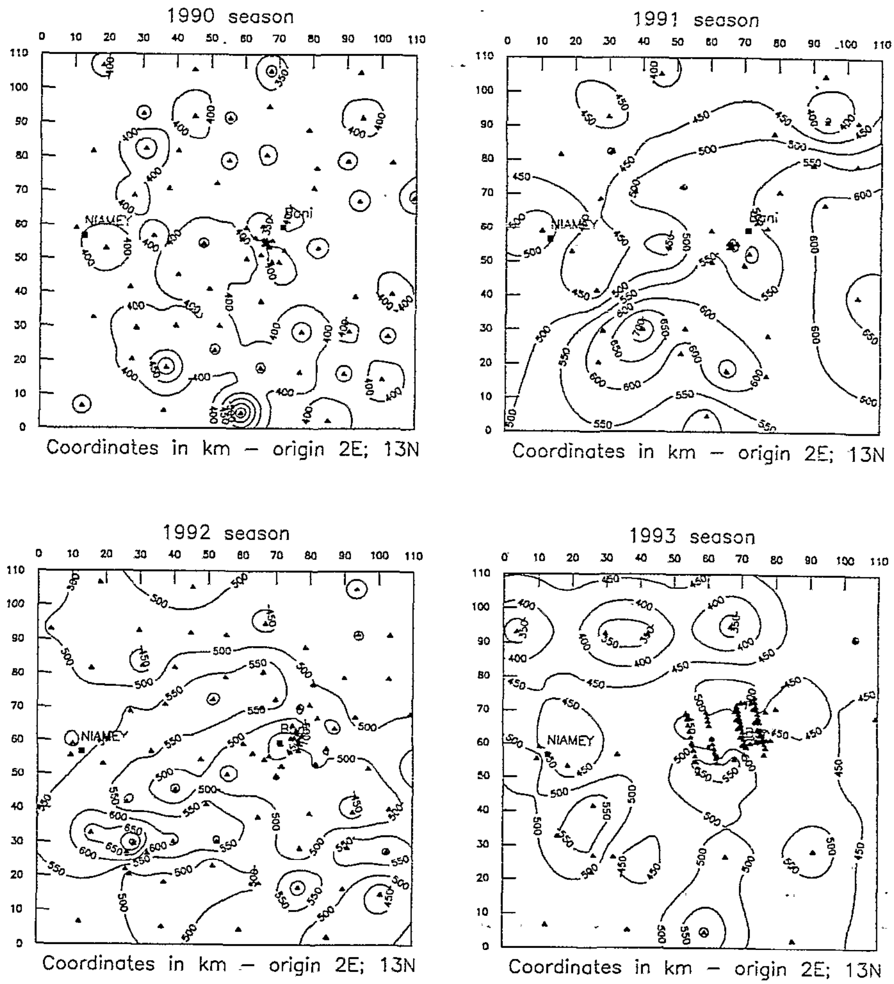

Figure 5. Isohyets of the seasonal rainfall over the EPSAT-Niger study area (1990, 1991, 1992, 1993).

Table 10. Area-averaged seasonal rainfall (10-04 - 10-10) over the DS and the Super-Sites, computed by kriging of the point values. Areal estimates are given with their standard deviation of estimation error. The point value recorded at Banizoumbou is given to illustrate the spatial averaging effect.

	μ_p (basic net.)	Mean of all stations	DS (12,000 km^2)	SSS (100 km^2)	WCSS (225 km^2)	ECSS (400 km^2)	Banizoum. (ECSS)
1990	396	405 (74)	396 ± 2	419 ± 23	386 ± 15	385 ± 15	402
1991	523	524 (52)	522 ± 4	627 ± 19	537 ± 16	560 ± 14	494
1992	513	513 (98)	511 ± 3	603 ± 10	493 ± 14	500 ± 6	410
1993	*459*	*477* (99)	*460*	502 ± 13	501 ± 6	470 ± 3	458
Mean	473	480	472	538	481	479	441

Table 11. Statistics of the rainfall events (rainfall in mm; durations in hours: minutes). Mean ± Stan. Dev. are the mean and the standard deviation of the series of the DS-averaged event rainfall, obtained by kriging of the bucket values. The corrected values are obtained after correcting the bucket value by the bottle/bucket ratio given in table 7.

	Number	Mean and Stan. Dev.	Corrected Values	Minimum over the DS	Maximum over the DS	Maximum point value	Minimum duration	Maximum duration
1990	39	10.5 ± 8.1	9.6 ± 7.4	0.9	27.2	103	2:50	11:10
1991	47	11.2 ± 8.9	10.5 ± 8.4	0.5	36.4	162	2:10	16:40
1992	48	10.5 ± 9.9	10.0 ± 9.5	0.5	43.4	92	1:35	11:45
1993	38	11.1 ± 9.0	10.5 ± 8.5	0.2	37.3	96	0:30	9:05

Table 12. Proportion of the seasonal rainfall and of the number of events accounted for by the storms covering: a) 70% (or over) of the study area; b) 90% (or over) of the study area. For the percentage of rainfall, two figures are given: the first is with respect to the rain associated to DS events, while the second is with respect to the total DS-averaged seasonal rainfall (hence including rainfall associated to isolated, or small extension, showers).

	70% of raingauges recording rainfall				90% of raingauges recording rainfall			
	% Number	% Rainfall	Average 70-100%	Average 30-70%	% Number	% Rainfall	Average 90-100%	Average 30-90%
1990	60	84-79	14,7	3,8	32	61-57	19,6	5,9
1991	72	91-85	13,2	3,6	39	65-61	17,6	6,0
1992	60	89-84	16,2	3,0	33	64-60	20,9	5,9

5.1.2 Rainy events

The concept of DS event has been defined above (section 3.6.1). It allows to identify the storms that are significant in terms of their spatial extension. From table 7 it is seen that those DS events account for a stable proportion of the seasonal rainfall (94-95% each year). The DS event rainfall is the DS-averaged rainfall, accumulated over an entire event. It will be further denoted as $R_{DS/E}$, the point event rainfall being noted $R_{p/E}$. The mean of $R_{DS/E}$ for all the events of a given season is stable from one year to another. Some elementary statistics are given in table 11. Note that the maximum point value (the maximum event cumulative point rainfall measured over the whole network for all the events of a given season) seems to be loosely connected to the maximum $R_{DS/E}$. The strongest value of $R_{DS/E}$ was observed in 1992 (43.4 mm), the very same year where the maximum of $R_{p/E}$ was the smallest. The typical duration of a DS event is a few hours. It has never exceeded 17 hours.

A more precise classification of the rainy events was carried out based on their spatial extension as measured from the gauge network (fig. 6). Between 80 and 85% of the seasonal rainfall (85-90% of the event seasonal rainfall) is produced by storms affecting more than 70% of the study area, even though they represent only 60% of the number of DS events. As for events affecting more than 90% of the study area, they still account for about 60% of the seasonal rainfall (65% of the event seasonal rainfall), despite the fact that they represent only one third of the DS events. Moreover for this category of storms the average of $R_{DS/E}$ is almost twice as large as that of the whole sample (18-20 mm against 10.5 mm, table 12).

Additional information about the 1990 and 1991 campaigns may be found in LEBEL *et al.* (1991) and TAUPIN *et al.* (1992).

5.2. Some features of the rainfall distribution in 1992

5.2.1. Distribution in time

The 1992 seasonal rainfall was relatively abundant over the DS, at least by the standards of the past 20 years (fig. 7). However its distribution in time along the season was far from normal, with a drought until mid-July and heavy rainfall concentrated after the 15th of August, as may be seen from the daily rainfall hyetograms given for six stations in figure 8 and the list of rainfall events given in appendix 2. The isohyetal maps of the 10 day rainfall (fig. 16 at the end of this paper) show that, until the end of June, the centre of the DS has been regularly drier than the average except for the last ten day period. This is especially true for the period 11-05 - 31-05 and for the period 11-06 - 20-06. The east was also generally drier than the average, except during the period 01-06 - 10-06. Note that during this early part of the rainy season the north of the DS received more rain than the central super-sites (see the 21-05 - 31-05 and 01-06 - 10-06 maps). The first ten day period of July was unusually dry everywhere, with nevertheless some rain in the south. The period 11-07 - 31-07 was rainy, but again the centre of the DS received less rainfall than most of the study area. The 20-07 was the starting of a dry period in the north that will last for one month. The rainfall for the period 01-08 - 20-08 was far below normal with only the south-western and south-eastern parts of the DS receiving more than 50 mm. Then the rainfall became less abundant in the south than in the north for the remaining of the rainy season. The third ten day period of August marked the beginning of a series of rain events that were especially productive over the central super-sites, as may be seen from the graph of the scaled cumulative rainfall over the ECSS shown in figure 9. The rainy season virtually ended the 15th of September (last DS event), even though some isolated showers were still observed until early October. The concentration of most of the major rain events over the central super-sites after mid-August resulted in heavy surface runoff (DESCONNETS *et al.*, this volume).

5.2.2. Rainfall over the super-sites

The areal seasonal rainfall over the two central super-sites (493 mm over the WCSS and 500 mm over the ECSS) was only slightly inferior to the DS average rainfall (511 mm, table 10). This is the result of the heavy rainfall that was observed during the IOP, which was much stronger over the centre of the DS than elsewhere. The contribution of the IOP to the seasonal total is 49% for the WCSS, whereas it is 38% for the DS, and 31% for the SSS. In fact, whereas the SSS recorded 100 mm more rainfall than the central super-sites over the season (fig. 10), its deficit relative to the WCSS was about 50 mm during the IOP (fig. 11). It should also be noted that the absolute point maximum seasonal rainfall (782 mm) was recorded in the SSS (Diokoti), and that the minimum value of the ECSS (Banizoumbou: 410 mm) is hardly larger than the absolute minimum (389 mm

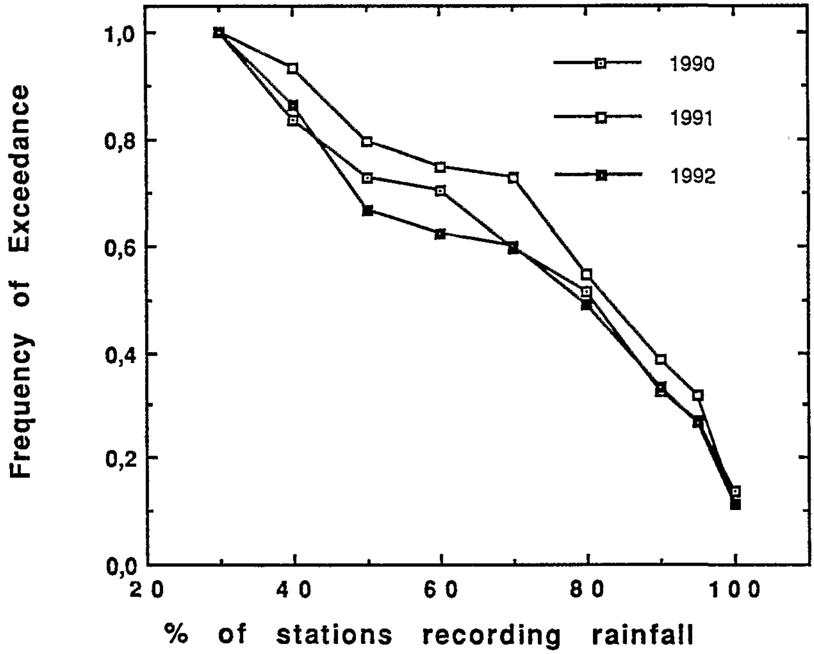

Figure 6. Cumulative distribution of the number of rainy events as a function of their spatial extension.

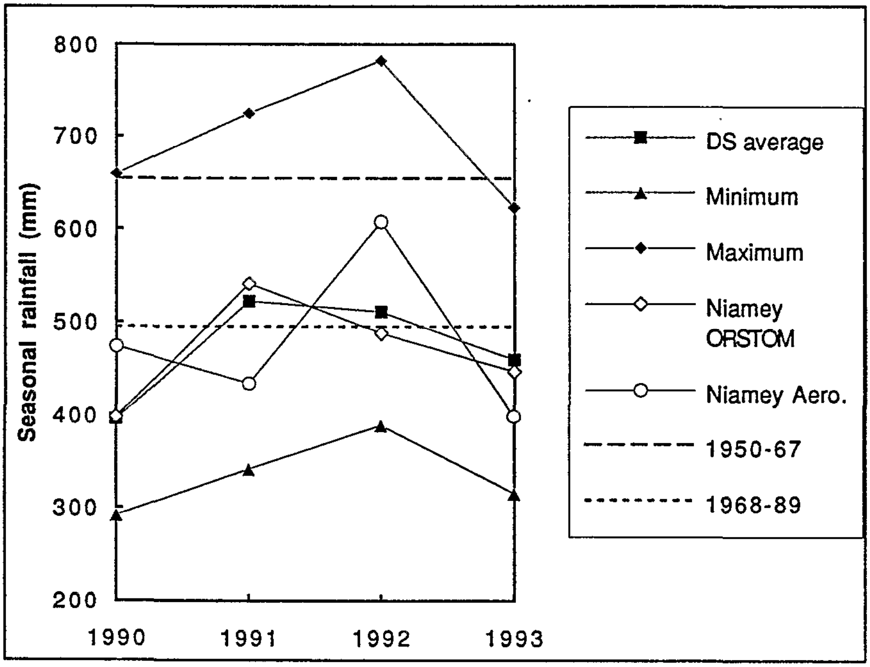

Figure 7. Seasonal rainfall 1990-1993: DS average and extrema.

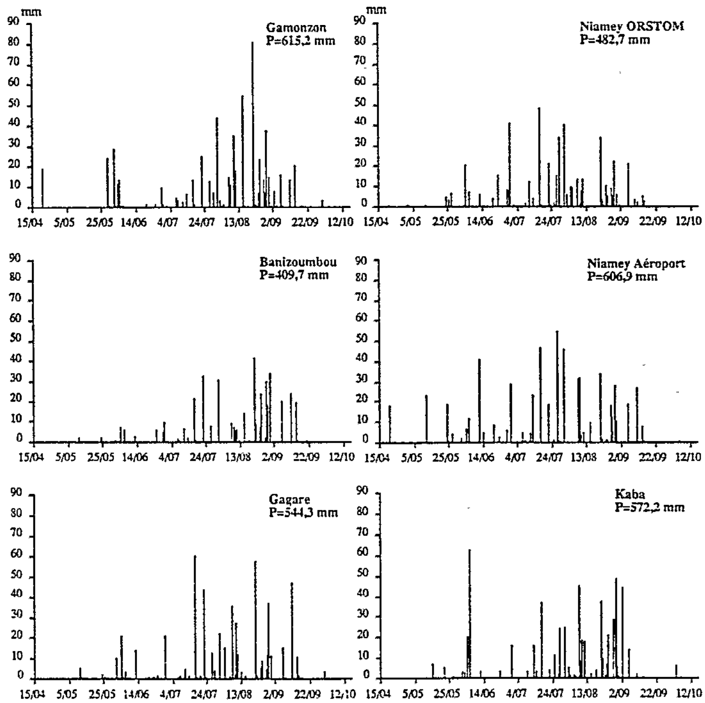

Figure 8. Daily rainfall at six stations in 1992.

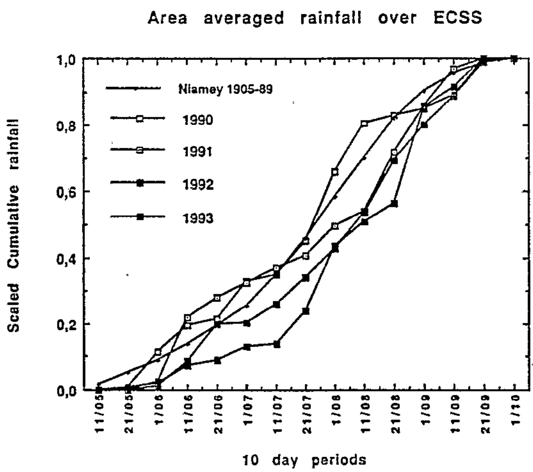

Figure 9. Cumulative time distribution of the 10 day rainfall over the East Central Super-site.

at Tierendji). The rainfall gradients over the SSS were especially steep, whether considered over the whole season or during the IOP only (fig. 10 and 11). Another interesting feature of the 1992 rainy season is that the minimum total was observed in the south of the DS. This confirms earlier statements by LEBEL *et al.* (1991) and TAUPIN *et al.* (1992) that, for a given year, the south-to-north rainfall gradient is strongly noised by a local variability independent of the latitude.

5.2.3. Rainfall events

The rainy season was made of 48 DS storms accounting for 94% of the seasonal DS rainfall (table 7). Thus, the isolated convective storms and the MCS's passing over the margins of the DS contributed weakly to the DS rainfall. The mean DS event rainfall was similar to that of the other years, but the variability was greater. The coefficient of variation of the series of DS event rainfall was close to 1.0 in 1992, whereas it was around 0.8 in 1991 (table 11). A Pearson III distribution (fig. 12) was fitted to the experimental event rainfall distribution. The distribution of the point event rainfall ($R_{p/E}$) at Diokoti is also shown in figure 13 and can be compared to that of the DS event rainfall $R_{DS/E}$ (the event separation criteria for the point series are: rainfall must exceed 1 mm and 30 minutes of no rainfall must separate two consecutive events).

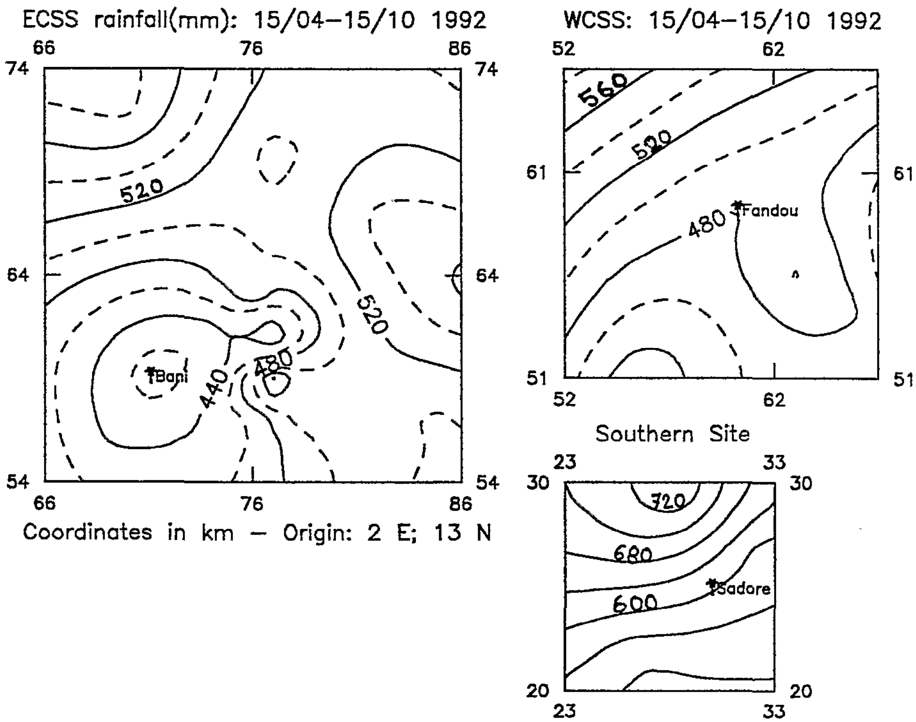

Figure 10. Isohyets of the 1992 seasonal rainfall over the Super-Sites.

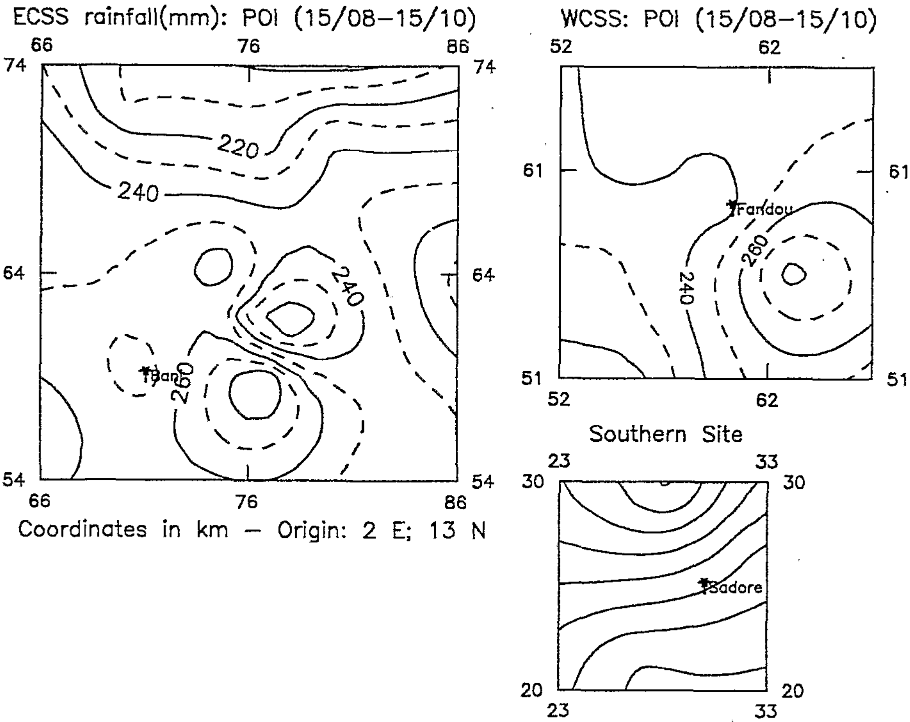

Figure 11. Isohyets of the IOP rainfall over the Super-Sites.

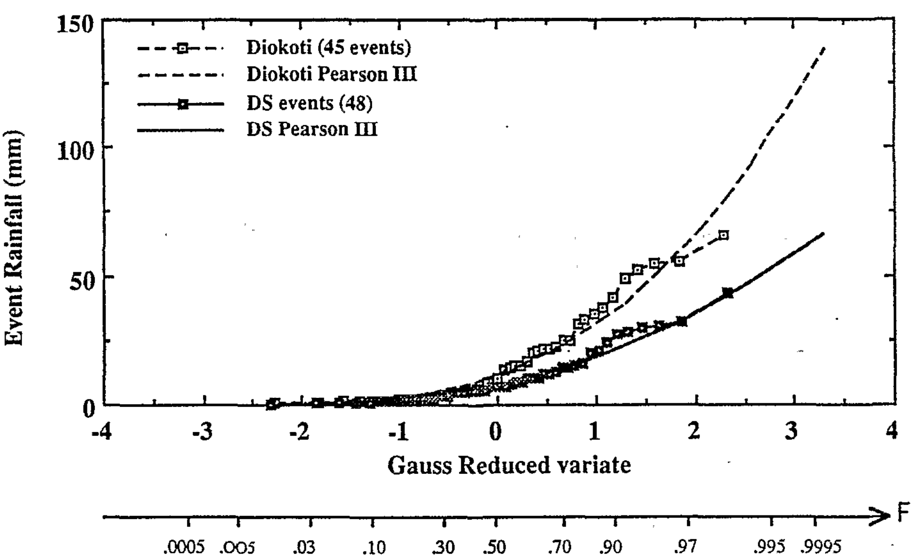

Figure 12. Distribution of the event rainfall for Diokoti (mean = 17.3 mm; standard deviation = 17.4 mm: coefficient of variation = 1.02) and over the DS (mean = 10.5 mm: standard deviation = 9.8 mm; coefficient of variation = 0.94), in 1992. The model fitted to the observations is a two parameters Pearson III distribution (the third parameter, the position parameter, is set equal to 0).

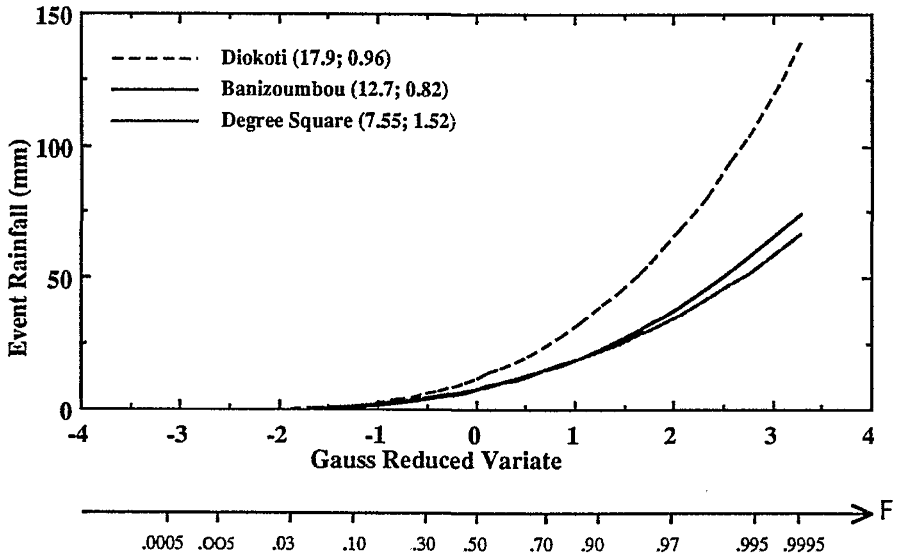

Figure 13. Comparison of the three Pearson III models fitted to the event rainfall distributions at Banizoumbou (seasonal rainfall : 410 mm), Diokoti (seasonal rainfall : 782 mm) and over the DS (seasonal rainfall : 511 mm). The figures in parenthesis are the parameters of the model (scale parameter; shape parameter).

With this definition of the point rainfall event, the number of events at Diokoti (45), Banizoumbou (44) and over the DS (48) is very similar. Since the season rainfall was almost twice as large at Diokoti as it was at Banizoumbou, the mean event rainfall is consequently much higher for Diokoti (17.3 mm) than for Banizoumbou (10.4 mm). Even though TAUPIN *et al.* (1993a) have shown that, in average, the seasonal total is well correlated to the number of rainfall events, the above figures point to the possibility of exceptionally large mean event rainfall at a given location as a main factor in getting large seasonal totals (this is different from having a single extremely strong event creating alone a local high of the seasonal rainfall). The stationarity in space and time of the moments of the mean event rainfall distribution will thus have to be thoroughly investigated since it is the basic assumption of many rainfall models (see e.g. RODRIGUEZ-ITURBE and EAGLESON, 1987).

The event rainfall distribution models for Banizoumbou, Diokoti and the DS are shown in figure 13. The smoothing effect of space-averaging is apparent, the DS distribution model having the smallest scale parameter s, and the largest shape parameter λ. The coefficient of asymmetry (equal to $1/(2\lambda^{1/2})$, for a Pearson III distribution) is 2.2 at Banizoumbou, while it is 1.6 for the DS, the two distributions having a similar mean event rainfall of 10.5 mm.

Another important parameter of the space-time distribution of the rainfall events is the number of days between two consecutive storms. If one considers that the rainy season started the 11th of may (the first two storms observed in early April having been followed by a drought of one month), the average number of days between two consecutive storms was equal to 3.5 for the period before the IOP, while it was equal to 1.6 for the rainy part of the IOP (17th August - 15th September). In figures 14 and 15 are given the isohyetal map of the event rainfall and the corresponding hyetograms at six stations, for one of the last storm of 1992 (12th September, which is a golden day). The rainfall was maximum over the centre of the study area.

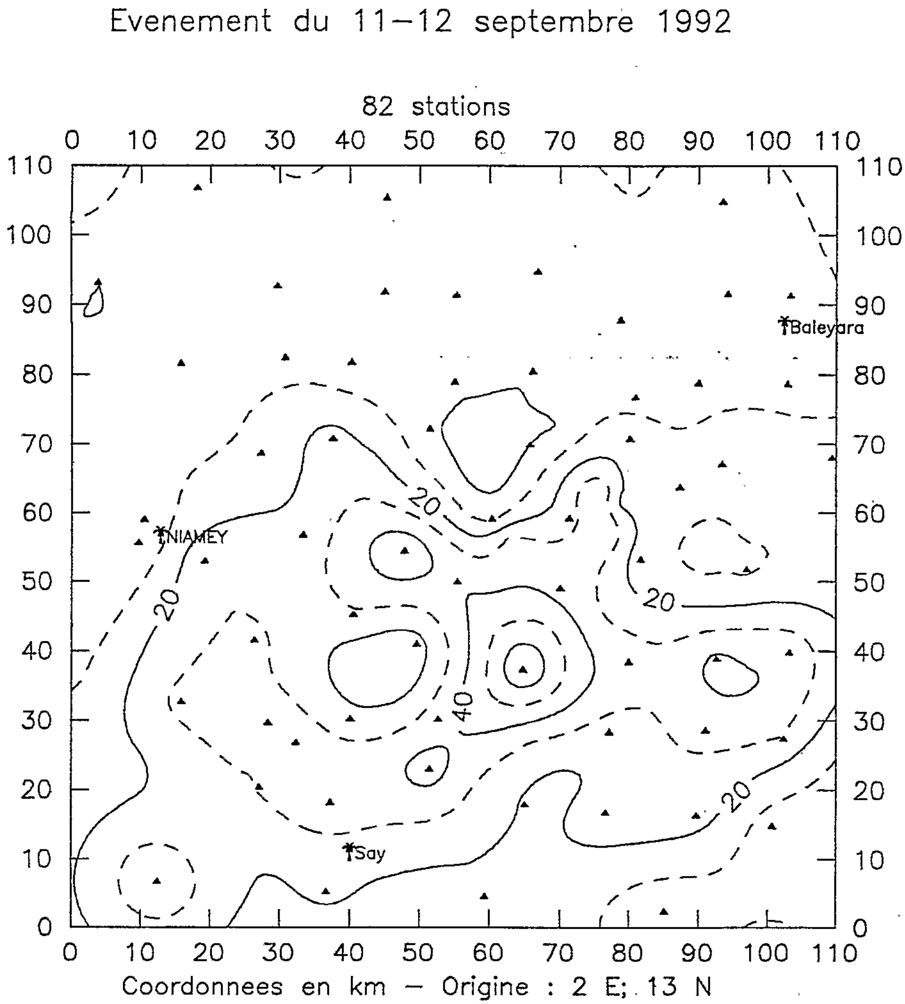

Figure 14. Isohyetal map of the September 12 storm.

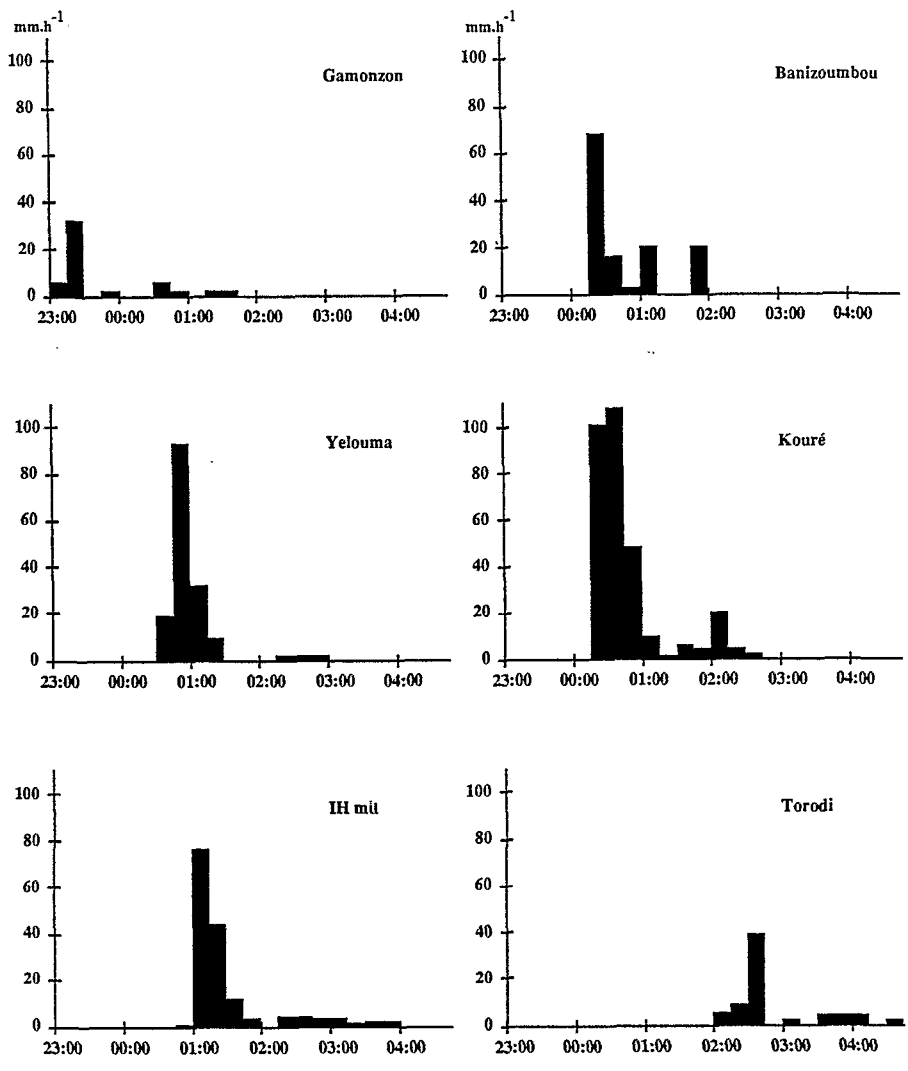

Figure 15. Hyetograms of the September 12 storm (time step: 5 minutes) for six stations from the north-east to the south-west, through the super-sites (Stations Banizoumbou, ECSS and IH Mil, SSS).

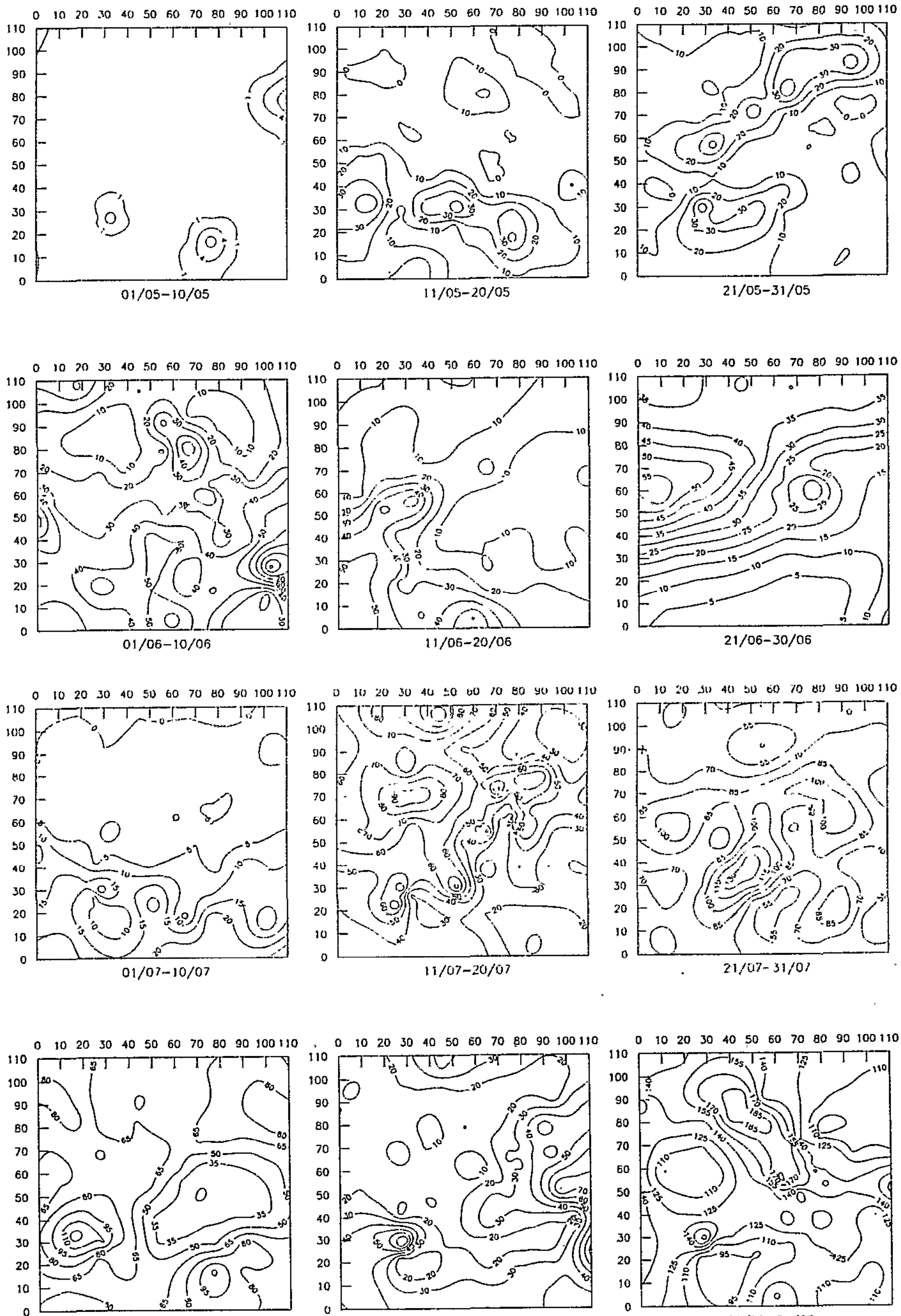

Figure 16. Ten day rainfall isohyetal maps (1992).

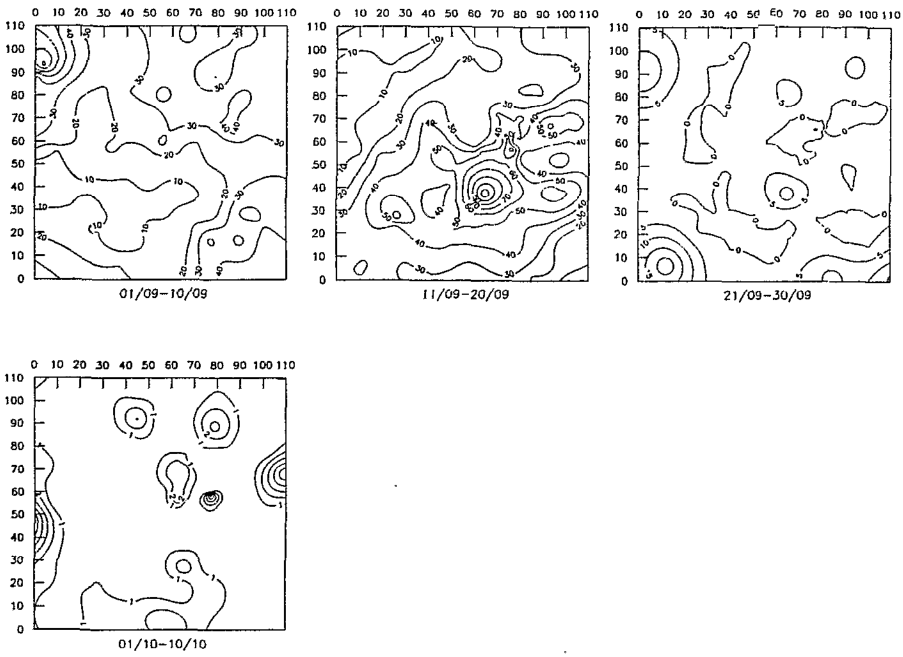

Figure 16. (continued). Ten day rainfall isohyetal maps (1992).

6. CONCLUSION

The four years of full operation of the EPSAT-Niger experimental setup lead to the collection of a rainfall data set for the Sahelian zone that is unique from the point of view of both the spatial and temporal sampling frequencies. It has permitted to monitor the rainfall conditions during the long-term monitoring period of HAPEX-Sahel, indicating that the 1990-1993 average rainfall over the study area was close to the average of the past twenty years dry period. The year 1992 was wetter than the 1990-1993 average, but the rainfall distribution along the rainy season was unusual with a deficit of more than 50% of the scaled cumulative rainfall at mid-July. The first half of the IOP (17th August-15th September) was especially rainy, accounting for almost 50% of the seasonal rainfall over the central super-sites. Except for an isolated shower in the west of the study area in early October, no rain was recorded during the second half of the IOP, allowing for the observation of the drying down of the soil and the vegetation.

The main rainfall statistics at the season and event time scales were consistent from one year to another. The spatial variability of the seasonal rainfall was always large, with strong local gradients. A seasonal rainfall difference of 275 mm was observed over a distance of 9 kilometres in 1992. The mean event rainfall was 10.0 ± 0.5 mm each year. Despite the high spatial variability, it is believed that the EPSAT-Niger network was sufficiently dense, over the DS and over the super-sites, so as to permit an appropriate estimation of the rainfall over the various areas of interest to most of the HAPEX-Sahel investigators. These areas range from the NOAA pixel (1 x 1 km^2) to the whole DS (110 x 110 km^2) and it will be analysed in a forthcoming paper how the requirements of the different teams can be met.

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APPENDIX 1

Coordinates of the raingauge stations

All the raingauges were positioned using a GPS positioning system, providing an accuracy in the order of 20 metres. From that, two set of coordinates were used for rainfall mapping and areal averaging. The first, called the EPSAT Coordinates system, is a cylindric projection, with the origin set at 13° N, 2° E. The second is the UTM system corresponding to the projection used for the IGN 1/200,000 map of 1975 (Clark ellipsoid, 1880). The best fit between the two systems is obtained by superposing the center of the one degree square in each system (13° 30′, 2° 30′).

Table A1-1. List of the EPSAT-Niger stations, with their years of operation: EPSAT-Niger 1990-1992 and basic network of 1993.

N°	NAME	Latitude (° ′)	Longit. (° ′)	X EPSAT	Y EPSAT	X UTM	Y UTM	Years Oper.
1	Gassanamari NW	13 29.87	2 36.36	65,48	55,36	457372	1492085	90-91
2	Gassanamari NE	13 29.87	2 36.91	66,47	55,36	458364	1492084	90-91
3	Gassanamari SE	13 29.34	2 36.94	66,53	54,38	458392	1491101	90-92
4	Gassanamari SW	13 29.30	2 36.39	65,54	54,30	457400	1491041	90-91
5	Bazanga Bangou	13 30.33	2 34.99	63,01	56,21	454878	1492949	90-92
6	Komakoukou	13 29.89	2 37 74	67,96	55,40	459837	1492112	90-93
7	Fetokadie	13 28.76	2 37.22	67,21	53,30	458902	1490055	90
8	Balal Sagui	13 27.60	2 35.93	64,72	51,15	456583	1487909	90
9	Fandou Beri	13 31.91	2 33.52	60,36	59,14	452238	1495872	90-93
10	Banka Dey	13 32.12	2 36.21	65,20	59,53	457108	1496232	90
11	Banizoumbou	13 31.97	2 39.62	71,34	59,25	463239	1495947	90-93
12	Gasseyda	13 28.29	2 39.75	71,59	52,43	463470	1489158	90-92
13	Kampa zarma	13 26.48	2 38.89	70,05	49,08	461902	1485843	90-92
14	Fandobong	13 26.47	2 37.72	67,95	49,06	459797	1485815	90
15	Yelouma est	13 26.96	2 33.57	60,47	49,97	452312	1486749	90-91
16	Gassan Kournie	13 30.06	2 32.84	59,14	55,71	450999	1492465	90
17	Koure	13 20.19	2 35.93	64,75	37,42	456561	1474240	90-93
18	Darey	13 38.20	2 44.53	80,14	70,80	472119	1507424	90-93
19	Tafakoira	13 37.75	2 36.56	65,80	69,96	457756	1506614	90-92
20	Gagare	13 29.37	2 26.56	47,83	54,43	439693	1491198	90-92
21	Beri koira	13 38.99	2 28.61	51,49	72,26	443428	1508914	90-93
22	Tollo	13 20.76	2 44.40	80,01	38,48	471844	1475294	90-92
23	Tigo zeno	13 28.70	2 45.34	81,66	53,19	473543	1489914	90-92
24	Foy Fandou	13 57.62	2 10.09	18,13	106,79	410138	1543353	90-92
25	Debere Gati	13 03.66	2 06.86	12,38	6,78	403987	1443932	90-93
26	Koure Kobade	13 00.28	3 03.00	113,71	0,52	505422	1437530	90-93
27	Damana	13 53.83	3 05.53	117,79	99,76	509964	1536225	90-92
28	Berkiawal	13 30.68	2 18.51	33,33	56,86	425178	1493662	90-93
29	Kare	13 02.87	2 20.31	36,65	5,32	428289	1442384	90-93
30	Zouzou Beri	13 27.95	2 53.82	96,94	51,8	488845	1488521	90-92
31	Winde gorou	13 22.14	2 27.51	49,57	41,03	441377	1477862	90-92

N°	NAME	Latitude (° ')	Longit. (° ')	X EPSAT	Y EPSAT	X UTM	Y UTM	Years Oper.
32	Tanaberi	13 02.50	2 32.88	59,34	4,63	450997	1441658	90-93
33	Dey Tegui	13 56.77	2 37.42	67,25	105,21	459343	1541661	90-92
34	Gamonzon	13 27.67	3 01.90	111,49	51,28	503428	1487997	90-93
35	Yiladde	13 01.27	2 47.16	85,12	2,35	476807	1439351	90-93
36	Ko Fandou	13 56.57	2 51.99	93,43	104,84	485567	1541265	90-92
37	Tomgom	13 56.85	2 25.17	45,23	105,36	437289	1541859	90-92
38	Niamey Poudrie	13 30.29	2 08.03	14,46	56,14	406266	1492984	90
39	Gorbikoi Kaina	13 12.42	2 28.52	51,43	23,02	443144	1459950	90-92
40	Wari	13 37.09	2 15.22	27,39	68,74	419262	1505475	90-92
41	Harikanassou	13 15.46	2 50.47	90,99	28,65	482787	1465517	90-93
42	Hassou Bangou	13 44.06	2 08.72	15,69	81,66	407588	1518386	90-92
43	Alkama	13 49.31	2 57.46	103,32	91,39	495437	1527899	90-93
44	Maroberi Zeno	13 09.02	2 42.47	76,61	16,72	468329	1453643	90-92
45	Kiran Mili	13 49.34	2 30.75	55,29	91,44	447313	1527982	90-92
46	Kolo Diogono	13 43.44	2 36.77	66,15	80,51	458133	1517088	90-92
47	Agharous	13 42.52	2 50.02	89,99	78,8	482009	1515372	90-92
48	Djakindji	13 11.04	2 15.04	27,12	20,46	418786	1457462	90-92
49	Guilahel	13 17.69	2 08.75	15,77	32,79	407479	1469756	90-93
50	Gardama Kouara	13 50.06	2 16.55	29,78	92,78	421738	1529399	90-93
51	Koure Sud	13 14.51	2 36.30	65,45	26,89	457206	1463795	90-93
52	Tierendji	13 07.96	2 55.81	100,68	14,75	492443	1451690	90-92
53	Bangou Bobo	13 44.15	2 22.36	40,22	81,82	432187	1518464	90-92
54	Kollo	13 22.45	2 14.66	26,42	41,61	418187	1478507	90-93
55	Sekoukou	13 16.37	2 22.21	40,04	30,34	431785	1467256	90-92
56	Kolbou Zarma	13 21.47	2 57.26	103,18	39,79	495067	1476570	90-92
57	Sandideye	13 13.52	3 03.23	114,01	25,06	505839	1461918	90-93
58	Gourmandey	13 14.78	2 56.75	102,32	27,39	494132	1464253	90-92
59	Niabere Djambe	13 20.99	2 51.36	92,56	38,90	484418	1475683	90-92
60	Borgoberi	13 40.15	3 03.67	114,57	74,41	506609	1511004	90-92
61	Kaligorou	13 36.74	3 00.78	109,40	68,09	501412	1504706	90-93
62	Kodo	13 15.32	2 42.78	77,13	28,39	468915	1465253	90-92
63	Djoure	13 47.41	2 43.78	78,73	87,87	470786	1524413	90-92
64	Diokoti	13 16.05	2 15.75	28,39	29,75	420107	1466705	90-92
65	Ganki Bassarou	13 09.84	2 20.63	37,21	18,24	428895	1455222	90-92
66	Guessel Bodi	13 24.46	2 22.46	40,46	45,33	432274	1482184	90-92
67	Karabeji	13 16.33	2 29.23	52,69	30,26	444453	1467166	90-92
68	Nine Founo	13 41.44	2 44.98	80,93	76,80	472936	1513383	90-92
69	Tondi Kire	13 36.21	2 51.86	93,35	67,11	485336	1503758	90-92
70	Niamey ORSTOM	13 31.87	2 05.80	10,44	59,07	402248	1495917	90-93
71	Holo	13 42.42	2 57.21	102,93	78,62	494984	1515182	90-92
72	Timborane Soli	13 49.42	2 52.35	94,13	91,59	486220	1528086	90-92
73	Kokorbe Fandou	13 51.16	2 37.18	66,85	94,82	458906	1531341	90-93

N°	NAME	Latitude (° ′)	Longit. (° ′)	X EPSAT	Y EPSAT	X UTM	Y UTM	Years Oper.
74	Borne 253	13 09.69	2 36.05	65,02	17,96	456741	1454887	90-92
75	Bangou Tawey	13 38.23	2 20.90	37,61	70,85	429514	1507565	90-92
76	Tondi Gamey	13 44.51	2 17.11	30,78	82,49	422728	1519166	90-92
77	Mare Kire	13 42.60	2 30.61	55,07	78,95	447047	1515573	90-92
78	Massi Koubou	13 49.61	2 25.00	44,95	91,94	436956	1528528	90-93
79	Nioumey	13 08.81	2 49.71	89,67	16,33	481425	1453262	90-92
80	Gorou Goussa	13 50.30	2 02.13	3,83	93,22	395770	1529920	90-93
81	Karma	13 40.24	1 48.48	- 20,79	74,58	371089	1511474	90-92
82	Koyria	13 46.00	1 42.00	- 32,38	85,25	359458	1522165	90-93
83	Niamey IRI	13 30.00	2 05.35	09,63	55,60	401424	1492480	90-93
84	Bololadie	13 13.48	1 52.20	- 14,06	24,98	377563	1462133	90-93
85	Boubon Golf	13 36.40	1 56.15	-6,93	67,46	384879	1504344	90-93
86	Torodi	13 07.00	1 47.10	- 23,27	12,97	368294	1450225	90-93
87	Gouroua	13 20.24	1 56.24	-6,78	37,51	384900	1474543	90-92
88	Kaba	13 38.00	1 38.92	- 37,94	70,43	353819	1507447	90-92
89	Bougoum	13 26.00	1 58.36	- 2,95	48,19	388795	1485156	90-92
90	Kare Bangou	13 27.28	1 45.72	- 25,72	50,56	365980	1487627	90-92
91	Kossey	13 19.00	1 45.20	- 26,67	35,21	364971	1472362	90-92
92	SD Rive droite	13 33.31	2 40.99	73,80	61,73	465707	1498432	90-93
93	SDC1 Sofia Bang	13 32.44	2 42.64	76,77	60,12	468681	1496800	90-93
94	Niamey Aero.	13 28.79	2 10.39	18,71	53,36	410496	1490205	90-93
95	SDC2 Jupe	13 32.84	2 41.97	75,56	60,86	467479	1497539	91-93
96	SDC3	13 33.50	2 42.41	76,35	62,09	468292	1498766	91-93
97	SDC4	13 33.09	2 43.05	77,51	61,33	469434	1497997	91-93
98	SD Rive gauche	13 34.10	2 42.25	76,06	63,20	467993	1499872	91-93
99	SD Plateau 2 No	13 33.19	2 43.67	78,62	61,51	470546	1498180	91-93
100	SD Plateau 1 Su	13 31.85	2 42.76	76,99	59,03	468920	1495725	91-93
101	SD Exutoire	13 32.72	2 41.36	74,47	60,64	466397	1497325	91-93
102	SD Village	13 34.85	2 41.66	74,99	64,59	466943	1501256	91-93
103	Ouallam B	14 18.92	1 58.11	- 3,39	146,27	388765	1582702	91
104	Ouallam C	14 17.82	1 56.03	- 7,12	144,23	385011	1580691	91
105	IH Jachere	13 14.63	2 14.65	26,41	27,11	418113	1464100	91-93
106	IH Mil	13 14.48	2 17.94	32,35	26,84	424041	1463806	91-93
107	IH Plateau	13 11.89	2 14.37	25,91	22,04	417586	1459033	91-93
108	Ouallam D	14 17.58	1 55.60	- 7,89	143,78	384230	1580264	91
111	Korto	13 30.82	2 42.51	76,55	57,12	468467	1493821	93
112	Tigo Tegui	13 31.17	2 47.10	84,81	57,77	476734	1494457	92
113	Boundou Warou	13 34.41	2 48.51	87,33	63,77	479294	1500445	92
114	Kokaina	13 36.04	2 45.73	82,31	66,79	474278	1503429	92
115	Darey Bangou	13 37.72	2 42.87	77,16	69,91	469113	1506537	93
116	Wankama	13 39.00	2 38.91	70,02	72,28	461996	1508911	93
117	Yelouma village	13 26.97	2 30.80	55,48	49,98	447320	1486758	92

N°	NAME	Latitude (° ')	Longit. (° ')	X EPSAT	Y EPSAT	X UTM	Y UTM	Years Oper.
118	WC jachère	13 32.54	2 30.81	55,47	60,31	447371	1497018	93
119	WC mil	13 32.33	2 30.83	55,50	59,92	447400	1496649	93
120	WC brousse tigré	13 30.13	2 34.72	62,52	55,84	454396	1492582	93
121	WC jachère deg.	13 33.19	2 34.08	61,36	61,51	453264	1498205	93
122	Danguey Gorou	13 47.49	2 00.73	01,31	88,01	393227	1524739	92

Table A1-2. List of the ARCOL stations.

N°	NAME	Latitude (° ')	Longit. (° ')	X EPSAT	Y EPSAT	X UTM	Y UTM	Years Oper.
201	LA1SA	13 39.80	2 41.05	73,87	73,78	465843	1510381	93
202	LA1SB	13 39.17	2 41.18	74,11	72,60	466082	1509213	93
203	LA1SC	13 38.53	2 41.31	74,36	71,43	466321	1508045	93
204	LA1SD	13 37.90	2 41.44	74,60	70,25	466529	1506878	93
205	LA1SE	13 37.27	2 41.58	74,84	69,08	466798	1505710	93
206	LA1SF	13 36.63	2 41.71	75,09	67,90	467037	1504543	93
207	LA1SG	13 36.00	2 41.84	75,33	66,73	467246	1503375	93
208	LA1SH	13 35.36	2 41.98	75,57	65,55	467515	1502208	93
209	LA1SI	13 34.73	2 42.11	75,82	64,38	467754	1501040	93
212	LA1SL	13 32.97	2 42.52	76,56	61,10	468472	1497783	93
215	LA2SA	13 39.07	2 40.65	73,17	72,41	465120	1509030	93
216	LA2SB	13 38.01	2 40.87	73,57	70,46	465508	1507094	93
217	LA2SC	13 36.95	2 41.10	73,98	68,50	465926	1505128	93
218	LA2SD	13 35.90	2 41.32	74,38	66,54	466314	1503192	93
220	LA2SF	13 33.84	2 41.75	75,17	62,72	467091	1499382	93
222	LA2SH	13 32.48	2 40.43	72,80	60,20	464713	1496897	93
223	LE1SA	13 38.94	2 38.15	68,66	72,18	460613	1508791	93
224	LE1SB	13 38.36	2 38.27	68,88	71,10	460822	1507746	93
225	LE1SC	13 37.78	2 38.39	69,11	70,02	461031	1506670	93
226	LE1SD	13 37.20	2 38.52	69,33	68,94	461270	1505595	93
227	LE1SE	13 36.61	2 38.64	69,55	67,87	461478	1504520	93
228	LE1SF	13 36.03	2 38.76	69,78	66,79	461717	1503444	93
229	LE1SG	13 35.45	2 38.88	70,00	65,71	461926	1502369	93
230	LE1SH	13 34.87	2 39.00	70,22	64,64	462135	1501293	93
231	LE1SI	13 34.29	2 39.13	70,45	63,56	462374	1500218	93
232	LE1SJ	13 33.71	2 39.25	70,67	62,48	462583	1499173	93
233	LE1SK	13 33.13	2 39.37	70,89	61,40	462791	1498098	93
234	LE1SL	13 32.55	2 39.49	71,12	60,33	463000	1497022	93
236	LE1SN	13 31.38	2 39.74	71,56	58,17	463448	1494871	93
237	LE2SA	13 37.65	2 37.89	68,20	69,78	460129	1506426	93
238	LE2SB	13 36.27	2 38.18	68,73	67,23	460666	1503876	93
239	LE2SC	13 34.90	2 38.47	69,26	64,69	461173	1501356	93
240	LE2SD	13 33.52	2 38.76	69,78	62,14	461710	1498806	93
241	LE2SE	13 32.15	2 39.04	70,31	59,59	462188	1496286	93
242	LE2SF	13 30.78	2 39.33	70,84	57,05	462725	1493767	93
243	LISA	13 37.52	2 33.15	59,68	69,55	451595	1506195	93
244	LISB	13 36.78	2 33.31	59,96	68,18	451893	1504843	93
245	LISC	13 36.04	2 33.47	60,25	66,81	452161	1503460	93
246	LISD	13 35.30	2 33.62	60,53	65,44	452429	1502108	93
247	LISE	13 34.56	2 33.78	60,82	64,07	452727	1500755	93

N°	NAME	Latitude (° ')	Longit. (° ')	X EPSAT	Y EPSAT	X UTM	Y UTM	Years Oper.
248	LISF	13 33.82	2 33.93	61,10	62,69	452995	1499373	93
250	LISH	13 32.34	2 34.25	61,67	59,95	453562	1496638	93
251	LISI	13 31.60	2 34.40	61,95	58,58	453830	1495286	93
252	LISJ	13 30.86	2 34.56	62,24	57,21	454128	1493934	93
254	LISL	13 29.38	2 34.87	62,80	54,47	454665	1491199	93
255	LOSA	13 37.29	2 29.80	53,64	69,12	445555	1505776	93
256	LOSB	13 36.34	2 30.00	54,01	67,36	445912	1504025	93
257	LOSC	13 35.39	2 30.20	54,37	65,60	446269	1502273	93
258	LOSD	13 34.44	2 30.40	54,74	63,84	446626	1500521	93
259	LOSE	13 33.49	2 30.60	55,10	62,07	446983	1498770	93
262	LOSH	13 31.43	2 31.04	55,90	58,25	447757	1494990	93
263	LOSI	13 30.48	2 31.24	56,26	56,49	448115	1493238	93
264	LOSJ	13 29.52	2 31.44	56,63	54,73	448472	1491456	93
265	LOSK	13 28.57	2 31.64	56,99	52,97	448829	1489704	93
266	LOSL	13 27.62	2 31.84	57,36	51,20	449187	1487953	93
267	Wankama Ouest	13 38.56	2 37.55	67,58	71,46	459531	1508116	93

APPENDIX 2

Rainfall events recorded by the EPSAT-Niger raingauges network from 1990 to 1993

Table A2-1. List of the 39 DS events for 1990. N is the number of gauges having recorded rainfall for the given event. DS average in mm, other rainfall values in 1/10 mm.

Begining of rain over the network		End of rain over the network		Spatial characteristics			Maximum of the point rainfall over the period T					
				Duration (mn)	DS Average	N	T = 5′	T = 10′	T = 15′	T = 30′	T = 60′	Event
7/05	19h10′	7/05	22h20′	195	4.0	24	104	190	276	391	425	425
23/05	4h10′	23/05	6h35′	150	3.4	35	106	202	267	394	425	425
28/05	22h25′	29/05	5h20′	420	29.9	68	146	241	323	569	747	775
7/06	3h 0′	7/06	4h30′	95	2.8	25	120	239	314	442	455	455
7/06	23h50′	8/06	3h45′	240	6.8	57	115	214	325	586	726	745
12/06	23h30′	13/06	4h35′	310	4.9	63	85	154	215	254	288	300
17/06	17h25′	17/06	21h 5′	225	6.6	47	119	206	303	509	588	590
22/06	1h20′	22/06	5h20′	245	4.2	58	80	108	131	226	315	320
24/06	21h 5′	25/06	3h 5′	365	28.9	80	214	359	493	660	705	790
27/06	16h45′	28/06	5h55′	795	3.9	40	121	196	271	347	451	595
29/06	20h20′	29/06	23h20′	185	4.9	32	85	153	222	318	325	325
3/07	8h30	3/07	13h35′	310	8.1	73	67	130	176	282	480	570
5/07	16h55′	5/07	21h10′	260	8.0	32	132	204	275	449	670	685
8/07	1h25′	8/07	4h55′	215	6.9	42	300	453	523	615	625	645
9/07	3h55′	9/07	6h40′	170	1.0	35	56	104	155	240	295	295
12/07	5h30′	12/07	14h45′	560	17.3	81	132	222	298	425	530	600
15/07	8h 5′	15/07	10h30′	150	4.3	36	147	267	358	526	570	570
15/07	12h35′	15/07	15h30′	180	6.1	74	76	141	171	200	210	230
18/07	8h20′	18/07	15h40′	445	10.5	70	137	261	357	470	470	470
21/07	11h45′	21/07	15h55′	255	5.8	51	111	221	311	440	465	465
21/07	20h55′	22/07	2h45′	355	3.1	41	69	107	144	188	190	215
22/07	3h35′	22/07	11h30′	480	5.3	63	44	79	107	150	185	400
23/07	5h20′	23/07	11h 0′	345	17.8	77	108	186	266	383	430	430
27/07	8h15′	27/07	13h50′	340	25.6	80	114	210	290	460	541	600
31/07	2h40′	31/07	7h10′	275	12.6	68	120	215	296	406	545	550
2/08	22h45′	3/08	2h30′	230	5.0	42	107	156	210	297	340	350
4/08	0h35′	4/08	8h40′	490	26.9	82	139	250	339	489	525	580
8/08	18h15′	9/08	1h40′	450	20.9	83	120	222	319	374	420	490
14/08	13h45′	14/08	16h40′	180	1.2	28	29	45	53	70	70	85
17/08	18h10′	18/08	1h20′	435	17.0	71	150	242	317	451	551	820
24/08	22h10′	25/08	4h40′	395	12.1	74	201	277	332	392	410	480
28/08	21h30′	29/08	2h25′	300	3.5	55	75	112	161	215	215	250
29/08	11h 0′	29/08	15h30′	275	4.5	74	78	155	201	274	285	285
1/09	22h 0′	2/09	6h55′	540	22.3	86	159	261	359	592	662	1025
5/09	0h15′	5/09	5h25′	315	10.6	82	142	243	331	470	480	495
7/09	11h10′	7/09	16h40′	335	14.0	71	100	189	269	472	643	720
11/09	0h55′	11/09	5h45′	295	2.3	33	90	175	256	361	432	500
13/09	21h50′	14/09	2h35′	290	16.4	87	131	249	308	423	455	480
17/09	17h35′	18/09	0h40′	430	18.5	86	140	258	341	520	735	830

Table A2-2. List of the 47 DS events for 1991. N is the number of gauges having recorded rainfall for the given event. DS average in mm, other rainfall values in 1/10 mm.

Begining of rain over the network		End of rain over the network		Spatial characteristics			Maximum of the point rainfall over the period T					
				Duration (mn)	DS Average	N	T = 5′	T = 10′	T = 15′	T = 30′	T = 60′	Event
14/04	9h 5′	14/04	10h55′	115	0.5	6	63	110	146	219	288	330
28/04	3h 5′	28/04	7h55′	295	8.4	30	62	121	170	239	344	425
4/05	8h 5′	4/05	13h15′	315	23.5	44	84	165	229	377	512	655
16/05	0h25′	16/05	6h25′	365	5.0	36	97	175	226	377	420	520
20/05	9h50′	20/05	13h 5′	200	4.5	61	67	112	133	190	250	300
24/05	6h45′	24/05	19h25′	765	20.1	61	105	203	290	478	694	1105
25/05	13h20′	25/05	15h30′	135	0.9	33	54	90	97	135	135	135
25/05	15h45′	25/05	21h 0′	320	3.9	35	86	171	252	473	645	660
26/05	1h10′	26/05	8h 0′	415	11.4	75	61	110	149	293	450	645
26/05	13h40′	27/05	6h15′	1000	33.6	76	119	201	249	471	845	1620
27/05	11h40′	27/05	16h 0′	265	1.4	32	46	69	88	100	170	190
28/05	10h25′	28/05	15h40′	320	4.7	57	72	121	140	201	220	225
1/06	0h 5′	1/06	2h10′	130	7.0	56	115	171	206	210	315	315
3/06	1h 5′	3/06	7h 0′	360	14.1	82	136	208	255	329	335	380
7/06	11h 0′	7/06	13h45′	170	6.2	72	104	165	214	245	245	245
11/06	20h50′	12/06	0h25′	220	11.9	74	150	294	320	425	432	480
15/06	5h30′	15/06	9h10′	225	10.7	74	157	269	378	521	545	545
20/06	22h40′	21/06	5h25′	410	3.9	54	72	135	183	319	410	435
19/06	5h40′	21/06	8h25′	170	0.9	66	21	32	39	50	65	70
23/06	4h30′	23/06	6h55′	150	2.8	82	61	101	115	115	115	125
26/06	20h35′	27/06	4h20′	470	26.8	87	115	227	319	512	732	815
30/06	8h20′	30/06	11h10′	175	8.8	48	164	307	412	475	530	535
4/07	6h35′	4/07	11h50′	320	8.1	73	122	188	250	343	389	440
8/07	5h20′	8/07	10h15′	300	13.4	75	86	167	233	364	470	500
14/07	6h20′	14/07	11h40′	325	16.9	75	129	232	310	446	528	600
17/07	9h50′	17/07	14h40′	295	11.6	68	107	173	215	365	650	675
18/07	7h45′	18/07	10h50′	190	1.0	47	37	63	69	70	85	90
20/07	8h25′	20/07	16h35′	495	19.6	89	147	246	322	425	607	700
25/07	14h55′	25/07	19h35′	285	12.1	86	120	193	228	346	380	405
26/07	16h25′	26/07	18h25′	125	3.5	40	103	186	251	275	275	275
30/07	16h20′	30/07	20h55′	280	6.6	59	110	203	260	358	395	475
3/08	21h25′	4/08	7h10′	590	36.4	85	110	204	296	517	623	825
6/08	14h40′	6/08	18h 5′	210	1.6	58	53	100	144	185	195	235
7/08	3h35′	7/08	7h15′	225	4.9	51	81	138	201	270	305	330
8/08	7h50′	8/08	14h35′	410	15.1	85	83	158	211	323	365	405
10/08	17h25′	11/08	0h50′	450	15.9	79	135	243	324	514	690	770
14/08	3h30′	14/08	6h50′	205	3.5	27	71	135	174	214	215	215
17/08	2h30′	17/08	7h40′	315	19.8	87	157	286	377	463	520	565
18/08	5h35′	18/08	11h20′	350	7.6	80	74	135	200	312	345	375
20/08	6h20′	20/08	11h50′	335	30.9	87	130	201	249	364	440	530
23/08	10h15′	23/08	15h15′	305	5.4	61	92	179	264	412	445	495
26/08	1h55′	26/08	7h20′	330	14.7	86	116	219	294	433	470	510
29/08	18h15′	30/08	0h30′	380	15.1	91	106	180	253	331	360	580
31/08	21h 0′	1/09	2h 5′	310	8.6	88	66	117	160	266	368	400
2/09	19h55′	3/09	0h45′	295	11.7	90	108	173	236	356	410	440
3/10	23h25′	4/10	4h30′	310	21.4	74	103	183	238	338	425	490
4/10	5h15′	4/10	7h55′	165	3.4	63	15	24	29	48	75	90

Table A2-3. List of the 48 DS events for 1992. N is the number of gauges having recorded rainfall for the given event. DS average in mm, other rainfall values in 1/10 mm.

Begining of rain over the network		End of rain over the network		Spatial characteristics			Maximum of the point rainfall over the period T					
				Duration (mn)	DS Average	N	T = 5′	T = 10′	T = 15′	T = 30′	T = 60′	Event
10/04	9h25′	10/04	11h45′	145	1.2	21	21	31	44	65	65	65
10/04	20h40′	11/04	1h40′	305	5.0	31	70	131	186	260	270	350
11/05	18h 5′	12/05	1h15′	435	6.0	97	173	263	312	384	450	500
25/05	14h 5′	25/05	17h25′	205	5.6	42	115	182	250	338	517	520
28/05	0h 5′	28/05	4h55′	295	3.1	32	71	130	171	278	292	420
1/06	16h40′	1/06	20h50′	255	12.6	78	213	316	385	522	626	630
3/06	22h30′	4/06	1h10′	165	1.5	38	60	106	124	135	135	135
4/06	20h40′	5/06	4h 0′	445	9.0	88	95	158	205	370	435	505
6/06	18h10′	6/06	23h40′	335	10.6	93	204	305	408	569	620	625
12/06	23h15′	13/06	2h30′	200	7.4	75	152	277	353	513	515	515
20/06	5h10′	20/06	10h35′	330	7.7	59	111	208	257	311	325	335
23/06	22h35′	24/06	1h 0′	150	4.9	38	107	188	231	260	260	260
25/06	7h30′	25/06	10h45′	200	1.9	55	73	128	166	260	305	340
30/06	4h55′	30/06	9h45′	295	20.5	100	289	380	423	472	551	570
7/07	14h30′	7/07	17h30′	185	4.1	91	86	171	189	215	220	220
11/07	10h55′	11/07	14h35′	225	7.4	82	87	140	165	228	270	290
13/07	13h 5′	13/07	18h 5′	305	12.4	88	85	160	227	296	440	555
18/07	0h10′	18/07	8h25′	500	27.8	103	126	247	343	488	567	700
20/07	13h10′	20/07	16h55′	230	2.2	32	79	136	184	267	295	295
22/07	14h30′	22/07	19h40′	315	30.1	102	157	276	389	582	688	745
27/07	14h50′	27/07	20h45′	360	8.8	98	106	199	302	405	560	570
28/07	12h 5′	28/07	15h20′	200	3.2	44	119	234	303	439	565	565
31/07	13h15′	31/07	20h20′	430	31.7	101	134	236	319	476	580	885
4/08	14h45′	4/08	19h10′	270	5.0	42	85	168	243	460	673	680
5/08	15h 5′	5/08	18h25′	205	2.9	40	114	207	295	403	425	575
8/08	13h20′	8/08	21h20′	485	24.3	98	159	253	352	626	660	700
10/08	3h45′	10/08	12h25′	525	29.3	100	91	178	252	447	565	680
11/08	21h25′	12/08	2h 0′	280	7.1	92	108	147	185	275	280	305
13/08	6h25′	13/08	12h 0′	340	2.4	32	84	126	141	167	200	350
15/08	23h 0′	16/08	4h25′	330	14.3	85	100	198	280	481	745	910
18/08	6h55′	18/08	10h55′	245	2.6	51	53	92	106	135	146	175
21/08	21h20′	22/08	9h 0′	705	43.4	104	105	167	227	395	560	920
22/08	22h25′	23/08	0h25′	125	0.6	43	98	123	129	160	185	185
24/08	20h 5′	25/08	0h45′	285	2.3	62	80	130	162	247	265	265
25/08	8h20′	25/08	12h25′	250	5.9	80	113	163	175	202	265	270
25/08	16h25′	25/08	18h 0′	100	0.4	34	54	78	93	125	130	140
25/08	19h 5′	26/08	0h45′	345	19.9	89	79	143	206	285	414	510
27/08	9h45′	27/08	14h10′	270	10.1	97	102	195	280	407	415	425
28/08	5h35′	28/08	8h55′	205	0.9	36	31	48	50	50	55	80
28/08	10h15′	28/08	17h10′	420	11.8	100	136	252	312	371	375	420
29/08	1h55′	29/08	6h55′	305	5.9	84	78	132	191	287	380	480
30/08	2h10′	30/08	10h10′	485	26.9	105	112	204	264	326	355	430
30/08	17h 0′	30/08	21h20′	265	10.4	88	152	278	339	380	380	410
2/09	12h15′	2/09	20h30′	500	7.3	56	96	180	244	362	478	590
6/09	22h25′	7/09	5h 5′	405	15.1	101	122	234	270	331	370	460
11/09	23h 0′	12/09	4h40′	345	16.2	88	136	242	336	547	667	715
14/09	20h 0′	15/09	2h35′	400	14.3	105	62	110	159	222	257	425
15/09	12h 0′	15/09	14h55′	180	0.5	47	48	69	77	80	85	90

Table A2-4. List of the 38 DS events for 1993. N is the number of gauges having recorded rainfall for the given event. DS average in mm, other rainfall values in 1/10 mm.

Begining of rain over the network		End of rain over the network		Spatial characteristics			Maximum of the point rainfall over the period T					
				Duration (mn)	DS Average	N	T = 5′	T = 10′	T = 15′	T = 30′	T = 60′	Event
30/05	16h15′	30/05	17h55′	105	1.1	41	70	136	151	200	200	200
31/05	2h20′	31/05	2h45′	30	0.2	34	18	22	25	25	25	25
1/06	23h10′	2/06	2h50′	225	12.6	84	101	186	268	418	480	485
3/06	6h 0′	3/06	10h55′	300	5.6	90	62	113	138	220	235	245
6/06	2h 0′	6/06	7h55′	360	10.4	97	74	137	191	235	284	370
13/06	20h45′	14/06	3h25′	405	25	97	111	208	294	439	689	790
16/06	19h20′	17/06	0h10′	295	7	86	120	222	289	315	315	315
30/06	0h40′	30/06	4h35′	240	5.6	34	69	124	159	229	250	260
3/07	7h 0′	3/07	9h 0′	125	6.5	34	100	168	220	314	320	325
6/07	7h55′	6/07	10h40′	170	2.8	85	95	173	248	289	315	315
7/07	20h35′	8/07	4h 0′	450	12.5	96	142	250	326	591	715	740
10/07	6h10′	10/07	13h10′	425	16.9	65	120	206	292	438	728	915
14/07	0h20′	14/07	4h50′	275	9.8	101	114	190	253	320	320	335
16/07	17h 0′	16/07	18h 5′	70	2.8	76	117	173	235	285	285	285
16/07	20h40′	17/07	0h40′	245	4.4	101	71	119	150	177	185	185
19/07	0h10′	19/07	5h40′	335	11.6	104	97	191	248	352	458	470
21/07	20h45′	22/07	2h10′	330	15	104	111	193	280	448	490	525
23/07	15h20′	23/07	19h35′	260	9.1	51	130	213	291	365	370	375
30/07	6h20′	30/07	11h 0′	285	20	104	115	196	251	333	340	385
31/07	14h50′	31/07	18h50′	245	4.9	97	90	151	215	260	270	275
2/08	19h15′	2/08	21h15′	125	9	34	118	230	289	418	500	500
5/08	5h45′	5/08	11h35′	355	25.2	103	96	175	240	306	341	410
8/08	2h55′	8/08	8h20′	330	19.6	100	93	162	220	358	499	530
9/08	18h15′	9/08	22h50′	280	8.8	59	88	150	190	287	530	540
13/08	14h25′	13/08	22h40′	500	37.3	104	124	232	316	453	583	695
17/08	21h40′	18/08	3h 5′	330	28.7	105	109	183	247	350	405	450
19/08	11h35′	19/08	13h50′	140	4.3	96	121	173	215	220	220	220
22/08	2h25′	22/08	10h15′	475	28	105	115	220	311	541	808	955
27/08	4h 5′	27/08	7h45′	225	2.9	43	39	61	81	129	135	135
29/08	23h50′	30/08	8h50′	545	16.4	90	117	203	286	425	519	595
30/08	18h30′	30/08	23h30′	305	2.6	62	51	76	103	188	210	275
31/08	9h10′	31/08	13h40′	275	5.4	36	107	205	301	404	415	425
1/09	6h20′	1/09	9h40′	205	2.1	61	51	95	113	125	130	130
3/09	3h 0′	3/09	8h10′	315	18.6	103	143	248	341	559	641	660
13/09	7h45′	13/09	12h10′	270	6.2	90	139	256	339	477	595	610
18/09	1h25′	18/09	7h 5′	345	19.3	105	81	157	206	303	330	370
26/09	21h35′	26/09	22h55′	85	2.5	79	105	186	229	308	320	320
9/10	3h50′	9/10	6h 0′	135	2.9	87	44	85	109	195	205	205