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HYETOGRAM ANALYSIS FOR SAHELIAN MESOSCALE CONVECTIVE SYSTEMS

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Introduction

Many hydrological phenomena such as soil erosion rates and flood magnitudes use the rainfall process as an indicator or input. It is well known that the nature of the precipitation process is complex and that its spatio-temporal pattern has a great influence on these different hydrological processes. That it is important to improve our knowledge of the spatio-temporal feature of the rainfall process. This is particulary true for the sahelian countries where there is a luck of rainfall data.

To this end, the EPSAT-Niger project is conducted by the ORSTOM with the collaboration of the Niger National Direction of meteorology (**Lebel and al.**, 1992). Its aim is to improve our understanding of the sahel storm systems and to produce algorithms for sahelian rainfall estimation via sattelite and radar. It is based on the combined used of a dense raingauge network and a weather C-band radar. Since the beginning of the experiment in 1989, three years of spatio-temporal rainfall data have been collected(1990, 1991 and 1992).

The next phase of the project is an intensive analysis of the available data in order to produce a guideline of the sahelian rainfall properties at different time and space scales. All these analysis have as objective to produce an efficient mean areal rainfall estimation for the calibration of the radar or satellite data. The present study consists in analyzing the hyetogram of the sahelian convective systems in order to produce a classification of the different systems. This classification will be used to improve the climatological kriging used for the estimation of the mean areal rainfall (**Bastin and al.**, 1984). The particularity of this technique will also allows us to understand the main characteristics of the sahelian mesoscale convective systems. Thus, the spatio-temporal pattern of the convective systems recorded by the EPSAT-Niger network in 1990 and 1991 are charcterized by using the crossing technique. The technique is used on the ponctual and the mean areal hyetogram rainfall for each event. Since the technique consists in giving an order and a class type to each hyetogram (ponctual or mean), a classification based on the order and or the class type can be performed.

Area and data for the study

The area for the study is the pilot zone of the EPSAT-NIGER experiment; it is located near Niamey (Niger). It covers an area of 110 160 km^2. This area has been equipped with a high density, static memory raingauge network consisting of 97 and 99 raingauges in 1990 and 1991 (**Taupin and al.**, 1992). During the two rainy seasons, 37 and 47 significant rainfall events have been respectively recorded by the EPSAT-Niger raingauge network. For each rainfall event and for each raingauge, the basic rainfall data are available in the form of time series of five minutes cumulative rainfalls. This is also possible with the software PLUIE to extract a field for a time step multiple of 5min. To conserve the dynamic feature of the rainfall event, for all gauges, the

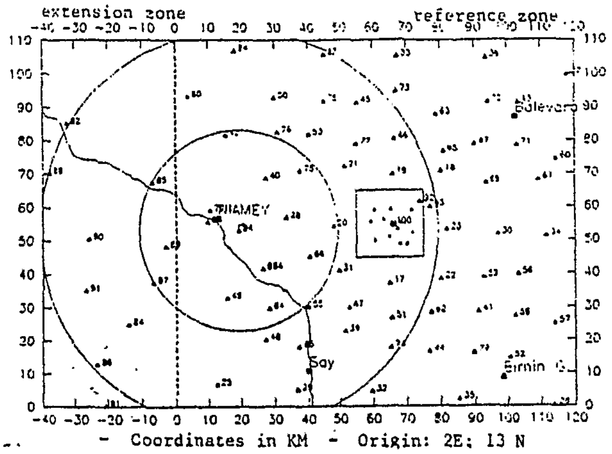


Figure 1: EPSAT-NIGER Raingauge network, 1990 (Lebel et al.,1992)

origin of the time series is considered at the begining of the event through out the network. The basic pattern of the network is a regular grid, with a 12 12 km^2 mesh. A target area with a large density is set in the central easten sector. Note that the climatic condition (precipitation regime) of the sahelian region particularly the study area is characterized by the succession of one dry season (October to May) and one rainy season (June to September). The limits of the two seasons vary. For the years 1990 and 1991, the rainy season are respectively began on 23 May and 14 April and terminated respectively on 17 September and 4 October. The major events are composed of the square lines. In a recent study, it was observed that these systems (square lines) contribute to more than sixty percent of the annual total rainfall for the season (Taupin and al., 1993).

Methods

The analysis of the spatio-temporal pattern of the rainfall process can be done by using different characteristic parameters or features. The hyetograms recorded at the different raingauges of a network characterize the spatio-temporal parttern of the events. The analyses are based on the different recorded hyetograms for each rainfall event. Two kinds of analysis are performed. The first one consists in determining the temporal characteristic of the different hyetograms. The second one consists in characterizing the dynamic feature of the rainfall event through out the study area. The ponctual temporal hyetogram is used in the first anlysis and the mean areal hyetograph is used in the second one.

Many parameters or functions are available in the literature for the characterization of the temporal feature of a time series. Best known are the correlogram function, the variogram function, and the fractal dimension. Because of the limit on the size of the cumul rainfall time series for a given rainfall event, these functions are of little use for the characterization of the temporal pattern of the hyetogram. The well known approach for the characterization of the hyetogram rainfall is that of the standardized hyetogram as used by Huff (1967). The particularity of the standardized hyetogram (SH) is that for a given climatic region, it is possible to characterize the different storm systems by a limited number of typical standardized hyetograms. But these are not easy to establish.

In the same way Kottegoda and Kassim (1991) proposed a sytematic characterization of the hyetogram which allows a direct classification of events. This method based also on the standardized hyetogram applies the properties of the crossing technique on the standardized hyetogram. The method consists in assigning an order and a class to a given hyetogram depending on the feature of the correpondant standardized hyetogram. This feature is determined by comparing the standardized hyetogram to that standardized for a fictive constant uniform rainfall process recorded at the same gauge(SU). This other standardized hyetogram corresponds to the bisector of the plot system of the standardized hyetogram of the study. Note that the standardized hyetogram is a cumulative one. It is a strict increasing function and the limited coordinates are (1,1). Depending on the position of the SH against the SU an order n (n=1, 2,3,..etc) and a class a or b is associated to the hyetogram.

These parameters are defined as follows. If x is the number of intersection points bettween SH and SU besides the two ends points ((0,0) and (1,1)), then the order of the SH is given as x+1. If the part of the SH profile before the first intersection point (or if the profile of the SH is that of SH with 1 as order) is under the SU profile, then the class of SH is a. Otherwise, it is b. The class b characterizes rainfall events which begun with maximum intensities. Figure 2 from Kottegoda and Kassim (1991) presents examples of storm structure types. It provides a schematic representation of the storm group types, which is made up of three or more basic types subdivized as 1a, 1b, 2a, 2b, 3a, 3b and so on.

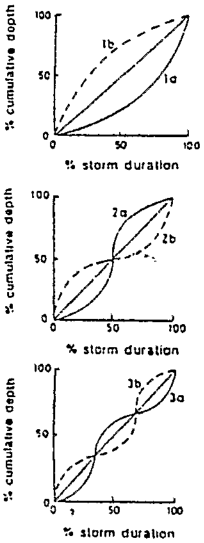


Figure 2: Classification of storm structure types.

A hyetogram which has a large order number such as 4, 5 and so on represents a storm system composed with a sucessive bands of showers. Thus, for a given rainfall event, the spatial representation of the order number of hyetogram at different recording gauges will give a kind of spatio-temporal pattern for the event and also indicates the dynamic activity of the storm through out the network (birth and death of cells).

The second analysis is performed on the mean areal hyetogram of each rainfall event. Given a rainfall event and a time step, a series of rainfall fields can be extraced through the network raingauges. For each field, the mean areal rainfall is estimated by the arithmetic method by considering only the gauges where it rains above zero. So the time series constitued by the different means represents the mean areal hyetogram of the rainfall event through out the raingauge network. It gives an average of the dymanic feature of the event. The procedure of crossing is applied. The object is to produce a systematic classification of the different events for the climatological structural analysis in kriging. By assuming that the standardized mean areal hyetogram characterizes the spatio-temporal feature of the event, two events belonging to the same profile type (order of their mean areal hyetograms) can be grouped as belonging to the same family.

Since the time step is important to the definition of the hyetogram rainfall, its influence on this classification is studied by considering four different time steps: 5, 10, 15, and 30 minutes.

Results

For each of the 37 and 47 significant rainfall events recorded by the EPSAT-NIGER raingauge network in 1990 and 1991, the technique of crossing is applied firstly on each punctual hyetogram rainfall and secondly on the mean areal hyetogram rainfall for the event. using the crossing technique, the order and the class of each hyetogram is determined. To assess the influence of the smoothing introduced by the discretisation level of the hyetogram on the order and the class, different time steps are considered. Because of the small duration of the convective system at a given raingauge (an average of 120 min), it is hasardous and futil to consider a time step up to the 5min basic one. So the analysis at different time steps is performed only on the mean areal rainfall hyetograph where the mean duration of the rainfall event through out the network is about 5 hours. These time steps are 5 min, 10 min, 15 min, and 30 min.

Tables 1 and 2 present the different order and class of some selected rainfall events at five selected gauges for the two rainy seasons. These gauges are: Gamonzon, Ko Fandou, Massi Koubou, Orstom and Banizounbou. They are located on the figure 1 at the different coordinates (111.49, 51.28), (93.43, 104.84), (44.95, 91.94), (10.44, 59.07) and (71.34, 59.25). Also tables 3 and 4 present, for the same events, the order and class for the mean areal rainfall hyetogram at different time steps. The selected rainfall events are characterized by a mean areal rainfall through out the network greater than 19 mm for 1991 and 17 mm for 1990. They are also characterized by their large spatial extension through out the network. These events are the prototype of the square line. Their characteristics (duration, acumulation, gauge records) are summarized in tables 5 and 6. Figure 3 presents the profiles of the mean areal hyetogram of the 03/08/91 event for the time steps 5min, 10min, 15min and 30min. we observe for this event a variation of profile type (order and class) with the time step as has been observed for many other events.

Table 1: class and order of punctual hyetogram of some selected rainfall events in 1990 at five different gauges (Gamonzon, Banizounbou sol, Ko Fando, Orstom, et Massi koubou)

Events	Gamonzon	Ko Fando	Massi	Orstom	Banizou
28/05	1 b	1 b	1 b	1 b	1 b
24/06	1 b	2 b	2 b	3 b	1 b
12/07	1 b	1 b	(*)	2 b	1 b
23/07	(*)	(*)	(*)	1 b	4 a
27/07	2 b	2 a	1 b	(*)	1 b
04/08	1 b	1 b	1 b	1 b	1 b
08/08	1 b	3 b	1 b	1 b	2 a
01/09	1 b	1 b	1 b	1 b	1 b
17/09	1 b	1 b	1 b	(*)	1 b

(*) = No sufficient recording

Table 2: class and order of punctual hyetogram of some selected rainfall events in 1991 at five different gauges (Gamonzon, Banizounbou sol, Ko Fando, Orstom, et Massi koubou)

Events	Gamonzon	Ko Fando	Massi	Orstom	Banizou
04/05	1 b	(*)	(*)	1 b	1 b
24/05	2 b	1 b	4 a	1 b	2 a
26/05	2 a	2 a	3 a	1 b	1 b
26/06	1 b	1 b	1 b	1 b	(*)
20/07	1 b	2 b	1 b	1 b	(*)
03/08	1 b	1 b	2 a	1 b	(*)
17/08	1 b	1 b	1 b	1 b	2 a
20/08	1 b	1 b	1 b	1 b	1 b
03/10	(*)	1 b	1 b	1 b	1 b

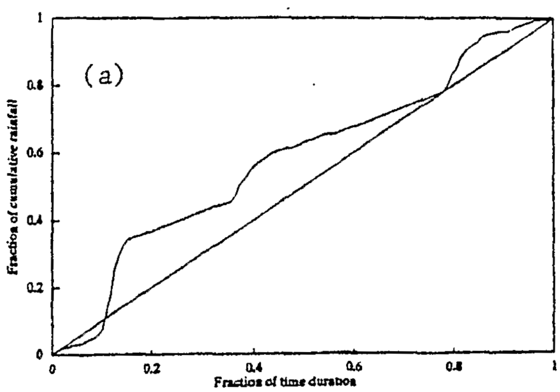
(*) = No sufficient recording.

Table 3: Order and class of 1990 selected rainfall events for different time steps (Δt=5, 10, 15, 30 min)

Events	Δt=5min	Δt=10min	Δt=15min	Δt=30min
28/05	2 a	1 b	1 b	1 b
24/06	2 a	1 b	1 b	1 b
12/07	3 a	2 a	1 b	1 b
23/07	2 a	2 a	2 a	2 a
27/07	2 a	1 b	1 b	1 b
04/08	2 b	1 b	1 b	1 b
08/08	2 b	1 b	1 b	1 b
01/09	3 a	2 a	1 b	1 b
17/09	3 b	2 a	2 a	1 b

Table 4: Order and class of 1991 selected rainfall events for different time steps (Δt=5, 10, 15, 30 min)

Events	Δt=5min	Δt=10min	Δt=15min	Δt=30min
04/05	2 a	1 b	1 b	1 b
24/05	3 b	3 b	2 a	1 b
26/05	1 b	2 b	2 a	1 b
26/06	2 b	1 b	1 b	1 b
20/07	2 b	2 b	2 b	1 b
03/08	3 a	2 a	1 b	1 b
17/08	2 a	1 b	1 b	1 b
20/08	2 a	1 b	1 b	1 b
03/10	2 a	1 b	1 b	1 b



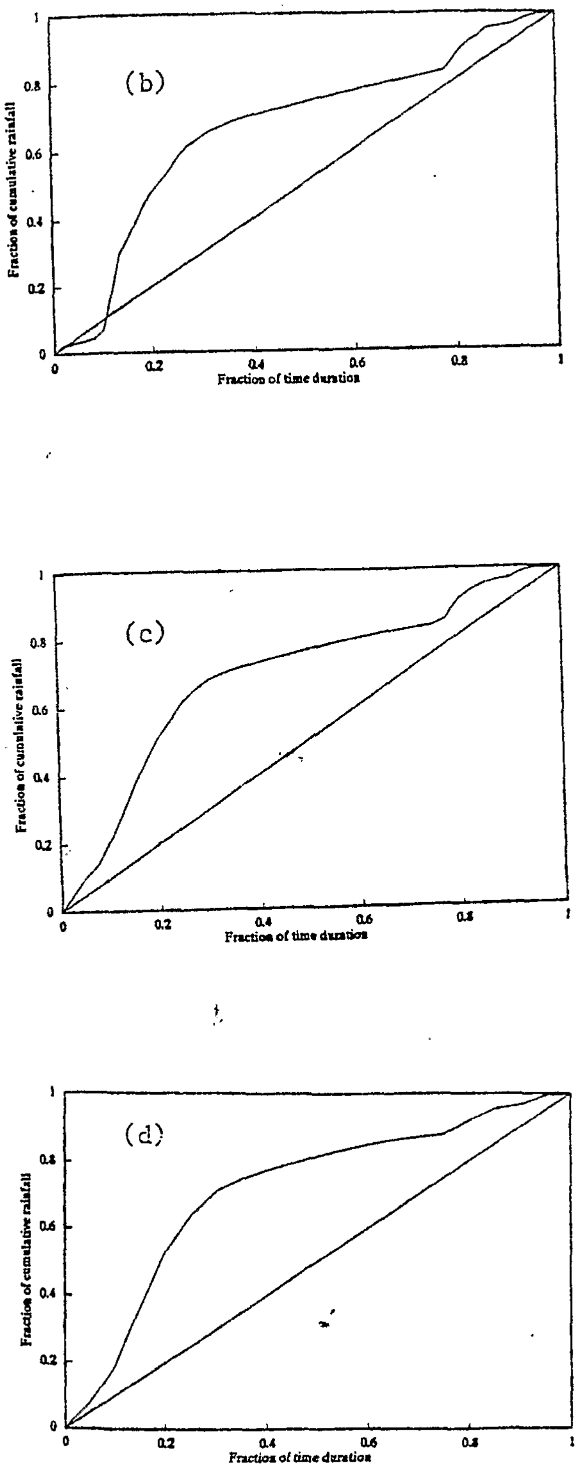


Figure 3: Profiles of the 03/08/91 rainfall event: (a)Δt=5min, (b)Δt=10min, (c)Δt=15min and (d)Δt=30min

Table 5: Some characteristics of selected rainfall events in 1990 (duration D; mean areal Pm; number of recording gauges, N)

Rainfall event	D (min)	Pm (mm)	N
28/05	435	23.6	68
24/06	365	27.2	78
12/07	570	17.6	79
27/07	345	19.4	75
23/07	340	23.9	75
04/08	450	27.1	83
08/08	450	20.8	86
01/09	550	17.1	86
17/09	430	19.4	69

Table 6: Some characteristics of selected rainfall events in 1991 (duration D; mean areal Pm; number of recording gauges, N)

Rainfall event	D (min)	Pm (mm)	N
04/05	315	23.5	42
24/05	765	20.1	59
26/05	1000	33.6	75
26/06	470	26.8	88
20/07	495	19.6	89
03/08	590	36.4	84
17/08	315	19.8	85
20/08	335	30.9	85
03/10	310	21.4	72

Discussion

The analysis of the class and order of the different punctual and mean areal rainfall events recorded through out the EPSAT-Niger raingauge network in 1990 and 1991 leads us to the following observations:

1) more than ninety percent of the punctual hyetograms have 1 as an order which means that the majority of storm rainfall systems observed in the Sahel are composed of a group cells. Little systems are composed of sucessive bands and showers. But for the mean areal heytograms this percentage decreases to sixty. This is normal because contrary to the punctual

hyetogram, the mean areal hyetogram takes into consideration the dynamic activity of the whole system through out a large area (birth and death of cells). For large time steps, because of the smothing, the order and the class of hyetograms can change. Generally the order decreases with an increasing in the time step (table 3 and 4).

2) also almost all punctual hyetograms are of class b. This means that the rainfall events in the Sahelian begin generally with maximum intensities which agrees with meteorological observations. For the mean areal hyetograms, the percentage of hyetograms which have b as class decreases. This can be explained first by the dynamic activity of the system in a large area and second in the fact that the system can be in its initial or maturing stage or in its dissipating stage. With an increasing in time step, almost rainfall profiles belong to the 1b type (tables 3 and 4)

3) These results indicate that the order of the event is never related to the duration or the cumul of the rainfall event contrary to the study done by Kottegoda and Kassim (1991) on the rainfall data recorded around the city of Birmingham.

4) considering the 15 minute time step, for each of the two rainy seasons, the rainfall events fall according to their order into two significant groups (orders 1 and 2). There were in 1990 25 events and 7 events belonging, orders 1 and 2. In 1991 these numbers are respectively to 24 and 14.

Conclusion

The properties of the crossing technique are applied on the standardized punctual and mean areal rainfall hyetograms of the rainfall events recorded by the EPSAT-NIGER raingauge network during 1990 and 1991 rainy seasons. The aim of this study is first to analyze the spatio-temporal pattern of the different rainfall event and second to produce a rainfall events classification to be used for climatological kriging based on the mean areal hyetogram analysis.

Analysis of the punctual hyetogram based on the crossing technique agrees wit meteorological observations that storms in the Sahel begin rapidly with a maximum intensity and that there is few storm systems are composed of successive bands or showers. There is no relation between the order of the hyetogram and the corresponding duration or total cumul. The profile type is a function of the time steps and the order of the profile decreases with an increase in the time steps. By considering the time step of 15 min two significant groups are obtained for the rainfall events of the two seasons.

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