레이더 자료를 이용한 강우입자분포의 통계적 분석 연구

테노리오 리카르도*, 권병혁*, 이동인**

Rain Cell Size Distribution Using Radar Data During Squall Line Episodes

Ricardo S. Tenorio, Byung-Hyuk Kwon, Dong-In Lee

요 약

서아프리카에 위치한 니제르의 니아메이 지역에서 C-밴드 레이더를 이용하여 관측된 강우 세포의 분포를 통계적 방법으로 분석하였다. 본 연구에 사용된 자료는 1988년부터 실시된 EPSAT 실험 [*Etude des Precipitation par SATellite* (Satellites Study of Precipitation)] 기간 동안에 동경 2 10' 32", 북위 13 28' 38"에서 C-밴드 레이더와 주변 10,000 km^2 의 지역에 설치된 약 100개의 레인게이지로부터 수집 되었다. 레이더 수평면 영상 자료에서 레이더 반사도를 구하였고, 별도의 등치선 프로그램을 이용하여 강우 세포의 분포를 분석하였다. 정의된 임계 강우율에 따라 24700개의 등치선을 구하였고, 각 강우 세포의 면적을 계산하여 통계 분석을 하였다. 임의의 크기를 갖는 강우 세포의 수는 강우 세포 반경의 역지수함수 분포를 보였으며, 강우 세포 반경의 평균은 1.4 km 그리고 중앙값은 0.69 km의 결과를 얻었다. 임계값을 이용하는 강수 평가에 대하여 본 연구 결과의 의미를 논의한다.

ABSTRACT

The main objective of this paper is to present the rain cell size distribution observed during squall line episodes in the Sudano-Sahelian region. The used data were collected during the EPSAT Program [*Etude des Precipitation par SATellite* (Satellites Study of Precipitation)] which has been developed since 1988, on an experimental area located near Niamey, Niger (2 10' 32"E, 13 28' 38"N). The data were obtained with a C-band radar and a network composed of

*아라고아스대학교 기상학과
**부경대학교 환경대기과학과
접수일자 : 2000. 9. 20.

approximately 100 raingages over a 10,000 km^2 area. In this work a culling of the squall line episodes was made for the 1992 rainy season. After radar data calibration using the raingage network, a number of PPI (Plan Position Indicator) images were generated. Each image was then treated in order to obtain a series of radar reflectivity (Z) maps. To describe the cell distribution, a contouring program was used to analyze the areas with rain rate greater than or equal to the contour threshold ($R \geq \tau$). 24700 contours were generated, where each isopleth belongs to a predefined threshold. Computing each cell surface and relating its area to an equi-circle (a circle having the same area as the cell), a statistical analysis was made. The results show that the number of rain cells having a given size is an inverse exponential function of the equivalent radius. The average and median equivalent radii are 1.4 and 0.69 km respectively. Implications of these results for the precipitation estimation using threshold methods are discussed.

I. INTRODUCTION

A statistical knowledge of rain cell size distribution as a function of the rain rate, is very useful in many scientific and applied domains, for example to conceive the microwave space systems for the observation of rain fields in the future. Indeed, with such systems it is assumed for the estimation of the rain rate that in the resolution cell (or pixel) the "target" is homogeneous. Now, with the microwave systems, the pixel resolution on a low orbit, is greater than some kilometers. Are the rain cells smaller or larger than the pixel? Another example is the modeling of the convective fields and the associated precipitation for which it is essential to know the distribution of rain cells.

Goldhirsh et al. summarizes a statistical study developed at Wallops Island-Virginia (USA), which shows that the size of the rain cells is practically invariable for the rain rate interval of 3 to 88 mm h^{-1}[1]. For the low rainfall rates an important number of very small cells was observed.

At tropical latitudes and in particular in the Sudano-Sahelian zone between 10N and 20N, 80% of the rain is produced by squall lines. The remaining 20% is due to isolated convective cells. The distribution of cell size in squall lines, has never been quantitatively and statistically described. The main objective of this paper is to contribute to fill this gap.

The raingage measurements allow the detection of punctual time variations and, under various hypotheses, enable the inferring of some information about the spatial properties of the rain fields[2, 3]. However, a spatial sample from a raingage network is not sufficient to describe the distribution of the rain cell size. Radar observation is the only way to collect a dataset with a sufficient resolution in space and time, to analyze the cell size distribution of the rain fields[4].

II. EXPERIMENTAL AREA AND DATABASE DESCRIPTION

The radar and rainfall dataset used in the present work was collected in cooperation with ORSTOM during the EPSAT Program (*Etude des Precipitations par SATellile*), which has been developed since 1988, on an experimental area located near Niamey, Niger [5, 6]. The dataset consists of radar data obtained from a C-band radar (λ=5.2), of which the main characteristics are given in Table 1, and from a raingage network composed of approximately 100 raingages over a 10,000 km^2 area. The radar is situated at the Niamey Airport (2 10' 32" E; 13 28' 38" N) which is located on a flat country of about 200 m of altitude. Above this region, because of the ground flatness, the structure of the rain fields is pure, and the radar observation at a larger range is easy.

The raingage network is composed of tipping-bucket sensor with static memory which allow the processing of the rainfall data by a central workstation. Table 2 gives the size of the dataset used in this work. The dataset in

Table 1. Main characteristics of the EEC Radar WR-100-5 SN11 at Niamey, Niger.

Parameters	Values
Frequency	5.6 GHz
Power	250 kW
Recurrence	250 Hz
Pulse width	2 μs
Receptor sensitivity	-102 dBm
Noise factor	9 dB
Beamwidth at 3 dB	1.5°

Table 2. Used dataset for the rainy season in 1992.

Parameters	Numbers
Number of squall line events	7
Number of images	25
Total number of cells	24700

made up of the whole squall line events that occurred during the rainy season of 1992.

III. DATA PROCESSING

Before each squall line episode processing, the radar data were calibrated. The calibration method is based on comparison between the radar data and the precipitation field over a predefined surface and time interval. The individual calibration factors are defined by the relation:

$$f = \frac{H_P}{H_R} \quad \cdots\cdots (1)$$

where H_P and H_R are the cumulated rainfall measured by the raingage network and that measured by the radar respectively. After the calibration, the radar reflectivity is converted into rain rate by the relation:

$$Z = 411 R^{1.33} \quad \cdots\cdots (2)$$

where Z is the radar reflectivity factor in $mm^6\ m^{-3}$, and R the rain rate in mm h^{-1}. This relation was established for the Niger area[7].

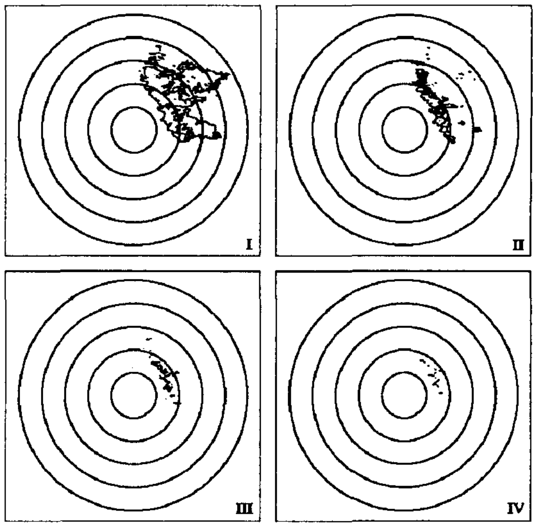

Figure 1. Cell contours for the 2(I), 11(II), 60(III) and 160(IV) mm h^{-1} thresholds for the event of 22/July/1992 at 14h 38 UT at Niamey, Niger.

To construct the cell contours, for each PPI (Plan Position Indicator) image, a contouring software computing the area with a rain rate (R) greater than or equal to the contour thresholds (τ) of 2; 3; 5; 7; 11; 17; 25; 40; 60; 100 and 160 mm h^{-1} ($R \geq \tau$), was employed. The number of cells was calculated for each value of τ. Figure 1 shows, as an example, a series of PPI images after the contouring program, for the 2, 11, 60 and 160 mm h^{-1} thresholds. For each of the 24700 cells, the mean equivalent radius (Req.), that is the radius of a circle having the same area as the contour, was calculated. The statistical analysis was done for all the PPI images available.

IV. RESULTS AND DISCUSSION

Figure 2 shows an histogram of the total number of cells, as a function of the rain rate. It can be observed that the mode of the distribution is located at 3 mm h^{-1}. It also appears that, for the weak rain rates, a great number of cells is found. For rain rates greater than 3 mm h^{-1}, the number of cells drops dramatically for

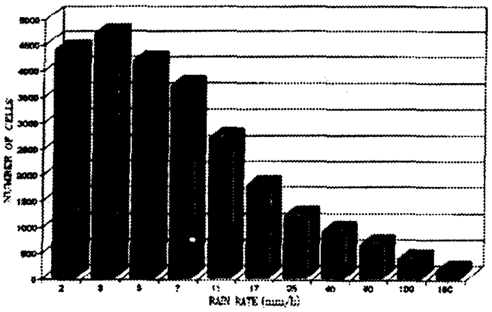

Figure 2. Number of cells as a function of the rain rate threshold for Niamey, Niger - rainy season 1992.

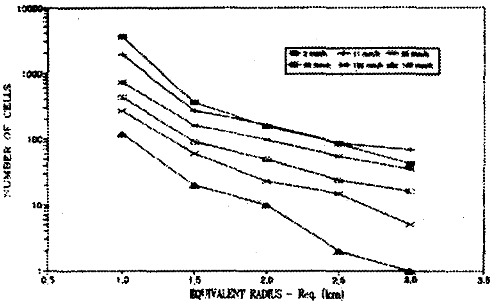

Figure 3. Number of cells as a function of the equivalent radii for different thresholds for Niamey, Niger - rainy season 1992.

increasing threshold values.

The number of cells as a function of the mean equivalent radius (Req.) for different thresholds (2, 5, 11 and 25 mm h^{-1}) is represented in Figure 3. What can be seen is that an increase in the number of cells corresponds to a decrease of the rain rate. For all the thresholds the maximum number of cells corresponds to the smaller surfaces. Also, the number of cells is approximately an inverse exponential function of the equivalent radius.

The percentage of cells as a function of the equivalent radius intervals for different thresholds, is given in Figure 4. About 10% of the cells present an equivalent radius of the order of 1.5 km. This combination of values can be represented by an exponential relation of the form:

$$P = A\exp(b\,Req.) \quad (3)$$

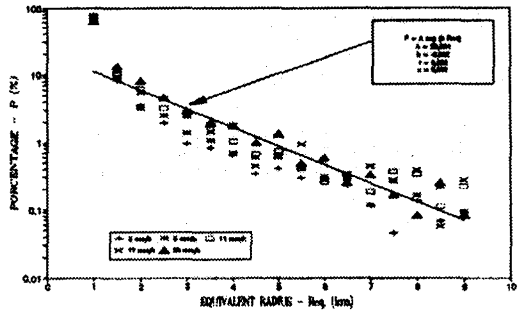

Figure 4. Percentage of the number of cells as a function of the equivalent radius intervals for the 2, 5, 11, 17 and 25 mm h^{-1} thresholds, "r" is the correlation coefficient and "s" the standard deviation.

Figure 4 also shows the values of the coefficients "A" and "b" for the thresholds 2, 5, 11 and 25 mm h^{-1} and for Req. greater than or equal to 1 km and smaller than 9 km. If a threshold greater than 30 mm h"[1] is considered, the values of the coefficients "A" and "b" are different.

In the same way the percentage of the number of cells as a function of the equivalent radius intervals is presented in Figure 5. In this figure the thresholds are 40, 60, 100 and 160 mm h^{-1}, and the interval variation of Req. is between 1 and 3 km. Coefficients "A" and "b" are also shown in Figure 5. It can be observed when the dispersion of the points is larger for an equivalent radius greater than 2 km.

The variations of the equivalent radius, in terms of its median and average values, as a function of rain rates class are given in Figure 6. The points in Figure 6 correspond to the rain rate threshold used for Figures 4 and 5. The mean equivalent radius can be seen to remains constant at a bout 1.4 km until the rainfall of 60 mm h^{-1}. The median radius is constant and equal to 0.56 km, that is a surface of 1 km^2, until a rainfall rate of 11 mm h^{-1}. Beyond this value the median radius increases and reaches 0.8 km, which corresponds to a surface of 2 km^2.

The behavior of the median radius for thresholds greater than 11 mm h^{-1} can be explained by the drastic

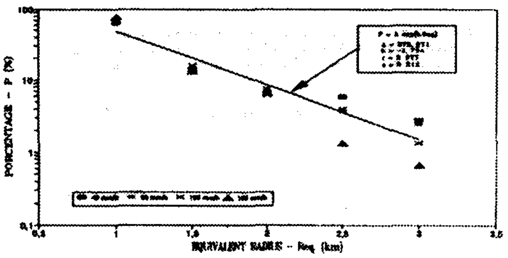

Figure 5. Percentage of the number of cells as a function of the equivalent radiui intervals for the 40, 60, 100 and 160 mm h^{-1} thresholds, "r" is the correlation coefficient and "f" the standard deviation.

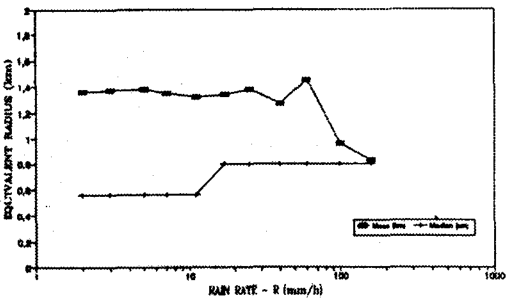

Figure 6. Average and median of the Equivalent Radius as a function of rain rates.

decrease of the number of cells having small equivalent radii. The accentuated reduction of the mean radius for the thresholds greater than 60 mm h^{-1} is probably due to the small number of cells having small equivalent radii.

V. SUMMARY AND CONCLUSION

From a radar and raingage network dataset collected in the Sudano-Sahelian zone of West Africa, statistics on the number, the equivalent radius and the areas of the rain cells for several rain rate intervals were calculated. The results show that in the tropical zone, 80% of the rain cells are associated to sizes (equivalent diameter) smaller than 3 km. This result is important because most of the methods and techniques of rain field observation has a spatial resolution worse than 3 km. Another example is the radars to be used from space [e.g. TRMM [8]].

To overcome this difficulty, a promising way is to use threshold methods, particularly the fractional area method[9, 10, 11, 12].

The statistical results about rain cell sizes presented in this work, can be very useful to understand and to set up the statistics of attenuation from rain, for the ground-ground and ground-satellite link.

REFERENCE

[1] Goldhirsh, J. and B. Musiani, "Rain Cell Size Statistics Derived from Radar Observation at Wallops Island, Virginia", *IEEE Trans. Geosci. and Remote Sensing,* vol. GE 24, No. 6, pp. 947-954, 1986.

[2] Drufiica, G. I. and I. Zawadzki, "Statistics of Raingage Data", *J. Appl. Meteo.,* vol. 14, pp. 1419-1429, 1975.

[3] Sauvageot, H., "The probability density function of rain rate and estimation of rainfall by area integrals", *J. Appl. Meteor,* vol 33., pp. 1255-1262, 1994.

[4] Sauvageot, H., "Radar Meteorology". *Artech House,* 366 p, 1992.

[5] Guillot, B. and D. Cadet, "EPSAT: Estimation des pluies par Satellites", *ORSTOM.* in French, 1991.

[6] Lebel, T., H. Sauvageot, M. Hoepffher, M. Desbois, B. Guillot and R. Hubert, "Rainfall estimation in the Sahel: the EPSAT-Niger experiment", *Hydrological Science Journal.* 37, pp. 201-215, 1992.

[7] Sauvageot, H. and G. Despaux., "SANAGA: Un systeme d'acquisition numerique et visualisation des donnees radar pour validation des estimations satellitaires de precipitations", *Veille Climatique Satellitaire,* bull. No. 30-31, 51-55. in French, 1990.

[8] Simpson, J., R. F. Adler and G. R. North, "A proposal Tropical Rainfall Measuring Mission (TRMM) Satellite", *Bull. Amer. Meteo. Soc.* vol 69, No.3, pp. 278-295, 1988.

[9] Atlas d., D. Rosenfeld and D. A. Short, "The Estimation of Convective Rainfall by Areas Integrals, 1. The Theoretical and Empirical Basis", *J. Geophys. Res.* vol. 95, D3, pp. 2153-2160, 1990.

[10] Ramos Buarque S., "Estimation des precipitations en region tropicale par la methode des aires fractionnelles: application ou programme EPSAT", *Publication de l'AIC*, vol. 5, pp. 105-112. in French, 1992.

[11] Ramos Buarque S., "Estimation de l'intensite de la pluie par radar dans les lignes de grains Soudano-Saheliennes par integrates spatio-temporelles", *These de l'Universite Paul Sabatier (Toulouse III)*, No. 1782, 126 p. in French, 1994.

[12] Sauvageot, H., S. Ramos Buarque, L. Bourrel, P. Bationo, M. S. Diop and R. S. Tenorio, "L'estunation des precipitations par radar et infrarouge satellitaire a partir d'integrales d'aires", *Acte desJoumees Hydrologiques de l'ORSTOM* 12 p. in French, 1994.

Ricardo Sarmento TENÓRIO
(히까르도 사르멘또 떼노리오)
1993. 8 - 1996. 9 프랑스 Paul Sabatier University (뽈사바티에 대학교) 원격 기상학 박사
1987. 3 - 1989. 8 영국 University of Reaging (리딩대학교) 기상학 석사
1981. 3 - 1985. 12 브라질 Federal University of Alagoas (알라고아스 주립대학교) 농업기상학 학사
현재 브라질 알라고아스 주립대학교 기상학과 조교수
기상학과 대학원 학과장
브라질 북동부 지역 레이더와 위성을 이용한 강수 연구의 책임자

권 병 혁(Byung-Hyuk Kwon)
1982~1986 연세대학교 기상학
1993~1994 그르노블대학원 지구유체역학
1998~1999 경북대학교 Post-Doc. 연구
2000~2001 알라고아스 대학교 방문교수

이 동 인(Dong-In Lee)
1980. 2부산수산대학교 환경공학과 - 공학사
1984. 2부산수산대학교 환경공학과 (대기오염) - 공학석사
1989. 3일본 북해도대학 대학원 - 이학박사
1983.10 - 1985. 3부산수산대학교 환경공학과 조교
1989. 4 - 1990. 2부산수산대학교 대기과학과 조교
1990. 3 - 1992. 2부경대학교 대기과학과 전임강사
1992. 3 - 1996. 3부경대학교 대기과학과 조 교수
1996. 4 - 현 재부경대학교 환경대기과학과 부 교수
1999. 2 - 2000. 2 미국 North Dakota 대학 교환교수
1997. 7 - 1997. 8 중국 천진 남개대학 파견
1996. 7 - 1996. 8 프랑스 Center of Research Atmosphere 파견 연구
관심분야 : 레이더 기상학, 대기열역학, 환경대기분석