AREAL VERSUS POINT RAINFALL FOR THE CALIBRATION OF TIR METEOSAT DATA.

A SAHELIAN APPLICATION.

Y. Arnaud, V. Thauvin
UR 1B, Hydrologie ORSTOM
BP 5045
34032 Montpellier cedex
France

ABSTRACT. Areal rainfall computed from data measured with a dense raingauge network are used to calibrate a satellite rainfall algorithm over the Sahel using Thermal Infra-Red Meteosat data. Areal rainfall estimates improve significantly calibration compared to estimates using point data. The kriging technique has been used to compute areal values and the estimate error standard deviations. Selecting areal ground estimates according to their standard deviation improves the correlation between rainfall and satellite signals. The methodology was tested over small areas (225 km^2), and for a short time step (a few hours).

1. INTRODUCTION

Rainfall estimation methods using remote sensing require calibration with ground data. Usually satellite rainfall estimations are based on sparse and punctual rainfall data provided by raingauges or recording raingauges. However areal rainfall data are more appropriate for remote sensing calibration. Data records obtained from the dense network of the EPSAT-Niger experiment (Estimation des Précipitations par SATellite), presented in Hoepffner et al. (1989), and the use of a statistical method give us the opportunity to test the improvement due to areal rainfall estimates. A new method aims at evaluating rainfall evaluation for a single shower and over a small Sahelian zone (9 Meteosat pixels eg. 225 km^2). In this region, rainfall estimates using meteorological satellite radiometry were, until now, limited to periods greater than 10 days (Flitcroft et al., 1987 ; Carn et al., 1989).

2. CONTEXT OF THE STUDY

2.1. Study area

The study area is a 110 km x 110 km square located in the republic of Niger (13/14°N-2/3°E) (see figure 1). The so-called square degree is representative of a part of the Sahelian belt (western Africa), because it receives an average of 547 mm of rain per year (Niamey City, 1905-1989), and it exhibits a smooth relief. During the rain season (June to September), the major rainbearing system is the squall line : a convective system moving westwards with a typical speed of 15 m.s-1 (Desbois et al. 1988).

2.2. Raingauge network description

The 1990 network will be composed of 100 static memory recording raingauges. Two pre-campaigns were carried out in 1988 and 1989 with a smaller number of gauges (respectively 37 and 79). The existing network at the end of the 1989 rain season is presented on figure 1.

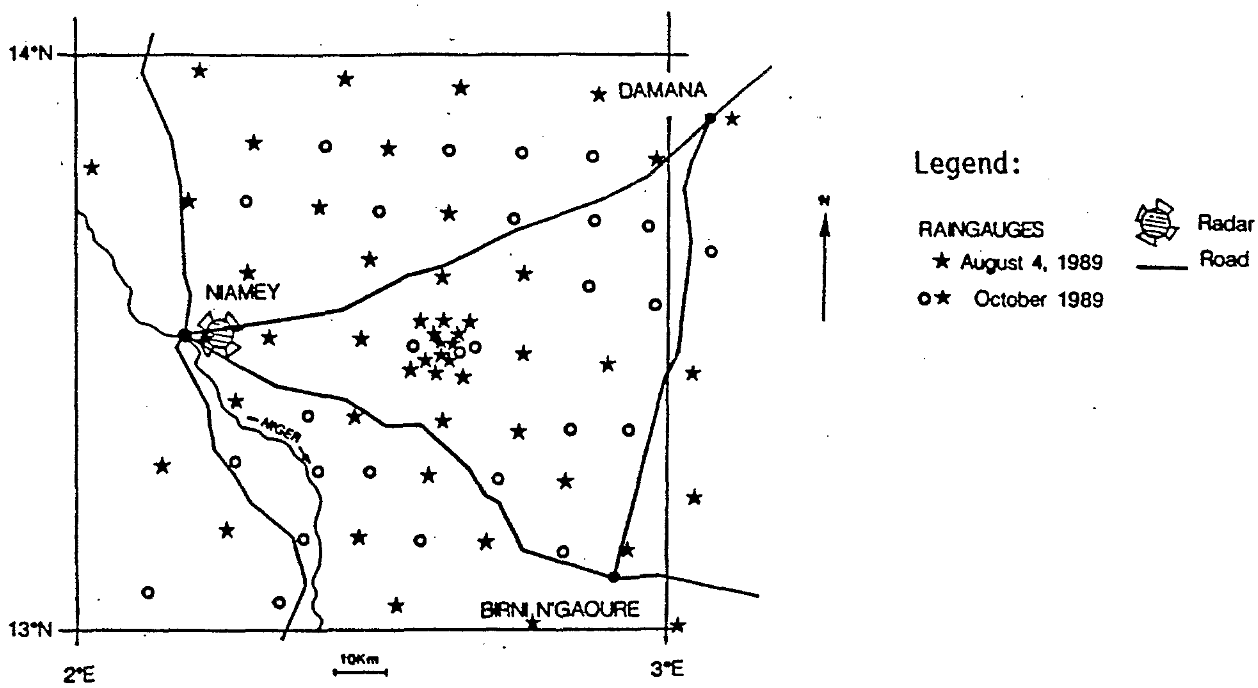


Figure 1 : The recording raingauge network of the EPSAT-Niger experiment.

The quasi-regular pattern is noteworthy, with a basic mesh of 13 km x 13 km, which is roughly the dimension of 9 Meteosat pixels (15 km x 15 km). The network centre is more densely equipped : 16 raingauges are concentrated over a 10 km x 10 km target area, with a variable mesh going from 1 to 5 km. This target area allows :(1) better estimates of areal rainfall (2) the study of network density influence on rainfall estimate (see Thauvin & Lebel, 1989).

2.3. Meteosat data

Real time window rectified image data is utilized, but more specifically the Thermal Infra-Red (TIR) "window" channel (wave-lenght 10.5-12.5 μm) at full space and time resolution. The nominal TIR channel resolution is 5 km, involving a 25 km^2 pixel area. The navigation is not very accurate. A point could be located anywhere within an area of 9 pixels (225 km^2) whose centre is the theoretical corresponding pixel given by the conversion of the geographical coordinates into image coordinates. The TIR image periodicity is 0.5 hour providing useful data 24 hours a day. Quasi-continuous recording is essential for the survey of meteorological events in the Sahel, because precipitation usually occurs at night.

A Meteosat image is considered as a "snapshot" of the field area. Data acquisition duration lasts only 12 seconds. TIR digital counts were reversed in order to process colour composition with two channels : Visible and TIR spectrum. Hence, the lowest temperatures are represented by the Maximal Digital Counts (MDC).

3. SATELLITE RAINFALL ESTIMATE

3.1. Principle and assumptions

In a recent paper (Arnaud et al., 1990), we explained the method to obtain an algorithm of rainfall estimation using MDC on a pixel for single rain events.

The higher the cloud, the colder it is ; a high digital count is then recorded. If cloud thickness and opacity is sufficient (case of tropical cumulo-nimbus), detected signals emitted from the cloud top give an indication of the cloud-top elevation. It is assume that cloud elevation is linked to convection, and that convection is related to rainfall. For an operational purpose it seems difficult to relate each TIR digital count to a distinct rainfall intensity, in order to obtain a cumulated rainfall estimate for a single rain event. However, we can assume that the maximal altitude of clouds on a pixel is an important parameter, representing cloud activity as well as rainfall generation. Thus, the satellite TIR channel gives an indication of convection, and serves as an indirect rainfall index.

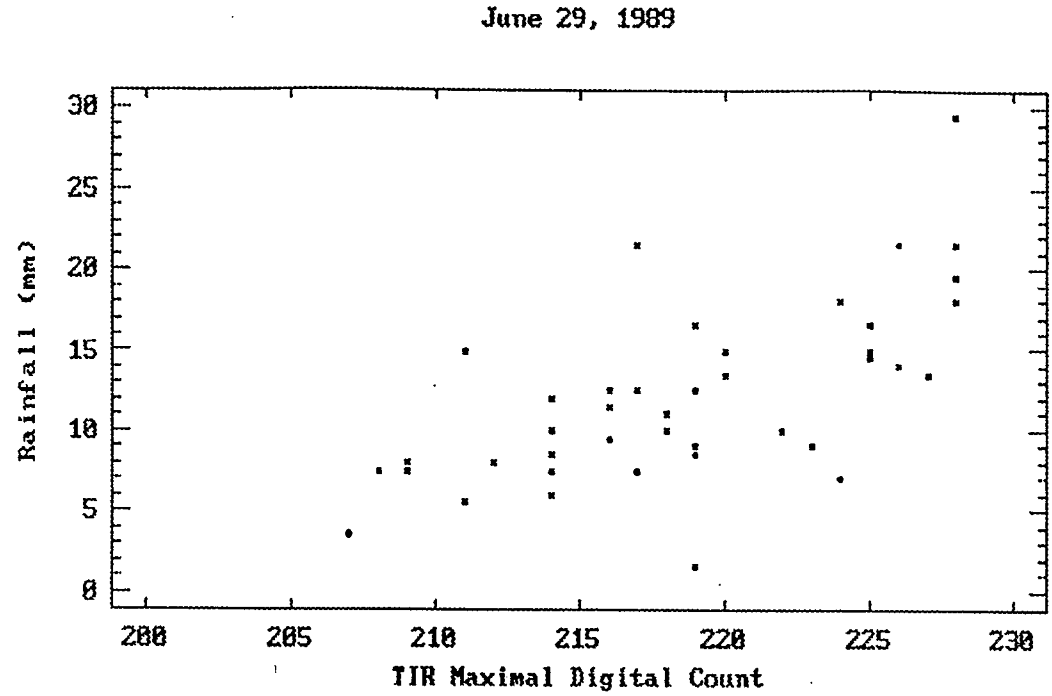
3.2. Data processing

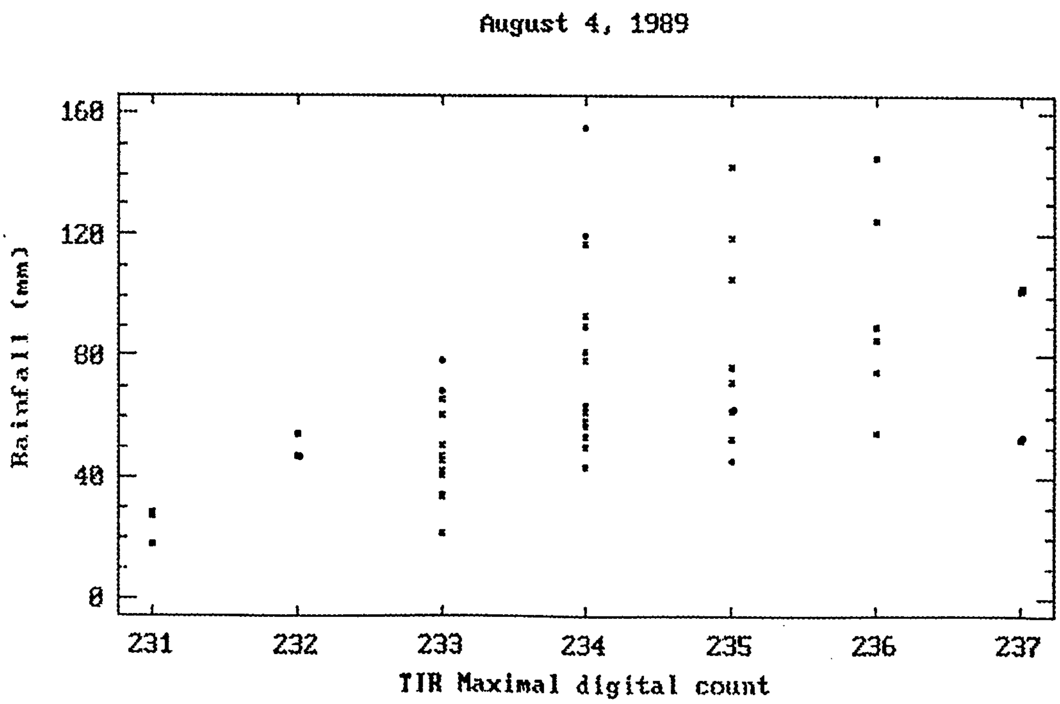
We have compared systematically rainfall to MDCs. The following method was applied:
(1) The beginning and the end of rainfall for a single event is detected.
(2) Image sequences corresponding to the rain period over the square degree is selected.
(3) The MDC is extracted from each pixel. A new image is produced using all of these MDCs.
(4) Cumulated rainfall for each available station is calculated.
(5) These stations are located on the MDC image.
(6) The MDC pixel over a station and the corresponding cumulated rainfall are compared in order to find a relationship.

4. USING POINT RAINFALL TO CALIBRATE RAINFALL ESTIMATE METHOD

4.1. Results

Results of the method are presented for two squall lines : June 29, 1989, and August 4, 1989 (figures 2 & 3). Total rainfall recorded on August 4 is exceptional ; the 119 mm recorded at Niamey City has a return period of nearly one hundred years.





Figures 2 & 3: Rainfall/TIR Maximal Digital Counts relationship.
(※) : point rainfall and associated pixel value.

Two events provide the data that proves the existence of a relationship between rainfall and MDC, thus confirming the hypothesis that cloud elevation is linked to rainfall. In the Sahel, periods of high intensities contribute to more than 50% of total rainfall. These periods correspond to shower bodies which last between 15 min and 80 min. High intensities are provoked by strong convection processes involving high cloud tops. The method chosen is particularly well adapted to perform under these conditions.

Scatter in plotted data increases with rainfall and with the MDCs ; this may be explained by the increase of rainfall spatial variability. An important part of the scatter is due to the lack of representativeness of point rainfall values. These point values cannot be directly compared to a signal measured over the pixel area (25 km^2). Moreover, Flitcroft et al.(1989) point out that the greater the area and the distance between points and the center of area, the greater the error involved. The error increases with a second major factor : the localization imprecision of Meteosat images. Indeed, by joining a raingauge with its theoretical corresponding pixel, one can find this point out of the corresponding pixel, due to satellite localization error.

4.2. Comparison of two types of data with their own resolution and their own sampling features

On the one hand, we have a collector of small size (400 cm^2), the recording raingauge, which is punctual and is a nearly continuous acquisition instrument (time resolution : 1 second). On the other hand, we have the satellite which gives an "instantaneous" value over an area of 25 km^2 with a sampling frequency of 48 images/day (periodicity 0.5 hour). In our method, we compared cumulative rainfall at a station to the MDC value of a single pixel selected in the corresponding image sequence. We assumed that an instantaneous areal value (MDC) was representative of a point cumulative value (accumulated rainfall). To overcome this spatial inadequacy, areal rainfall values are used to calibrate satellite rainfall estimates.

5. AREAL RAINFALL ESTIMATION

5.1. Background

To test the improvement provided by areal ground data we had to compute areal rainfall with an accurate estimate method. Previous studies (Creutin & Obled, 1982 ; Lebel et al., 1987) have shown that optimum linear interpolation techniques give better results than techniques which do not take into account the statistical structure of values in 2D.

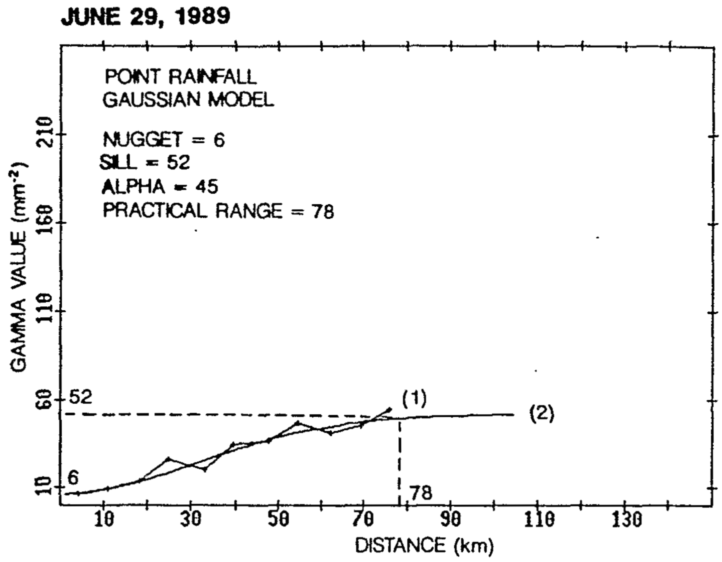
Two main reasons led us to choose the kriging as an estimation technique : first, it computes the variance associated with each estimation ; second, it can be used for a single rain event. Furthermore, the EPSAT-Niger network, with its great number of gauges and its meshes of variable size, let us benefit from all advantages of kriging.

Kriging, developed by Matheron (1965), belongs to the B.L.U.E. family (Best Linear Unbiased Estimator), "Best" referring to the ability to minimize the estimates variance.

The underlying hypothesis considers the phenomenon under study as a realization of a random process (in 2D for the case of rain fields). The method is based on the identification of the variogram, or spatial structure function, which indicates the correlation between the data. The experimental variogram is computed from the data to which a theoretical model is fitted. The model is then used to fill in the variance-covariance matrix of the interpolation system.

5.2. Examples

On figure 4 is presented the variogram for June 29, 1989. The data represent rainfall depths at each available gauge for a whole rain event (the duration of an event is between 1 to 10 hours). The shape and the parameters of the theoretical variogram are retained to compute areal rainfall estimate.



Theoretical variogram formulation :

$\gamma(h)=p+(P-p)*(1-\exp(-h^2/\alpha^2))$

p : nugget (mm^{-2})

P : sill (mm^{-2})

h : distance between two measurement points (km)

$a'=\alpha\sqrt{3}$ (km) represents the practical range eg. the distance beyond which no more correlation between data points exists.

Figure 4 : Experimental (1) and fitted (2) variograms of point rainfall for a rain event.

In the present study, we determined the kriging parameters for each studied rain event and, subsequently, areal rainfall was computed over squares of 15 km X 15 km, representing 9 Meteosat pixels.

Following the work of Lacomba (1986), we calculated the variogram of areal rainfall over a 25 km^2 area, and the variogram of the MDC (area 25 km^2), in order to compare the two spatial structures for the same rain event (figure 5).

We see that the variogram of areal rainfall is smoother than the one for point rainfall. Furthermore, the shape of the areal rainfall variogram is very close to the MDC one, indicating that the spatial structure of these two data set are related. This characteristic is necessary to compare rainfall and MDC values. Particularly, the two practical ranges have the same values, meaning that there is no more correlation between the data at the same distance.

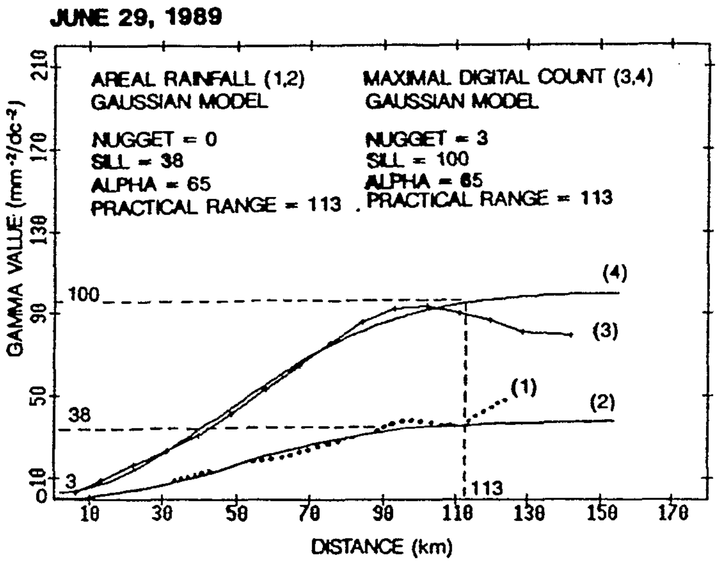


Figure 5 : Experimental (1,3) and fitted (2,4) variograms of areal rainfall and the Maximal Digital Counts for a rain event.
dc means digital count.

6. CALIBRATION WITH AREAL RAINFALL

We applied linear regressions between areal rainfall and MDC, where areal rainfall and MDC are respectively kriged estimates and a 9 MDC pixels arithmetic mean computed over the same area (15 km x 15 km).

We sorted the computed areal rainfall and divided the series into three groups, according to their standard deviation :

Min Std ≤ GROUP 1 ≤ Min Std+(Max Std-Min Std)/3

Min Std+(Max Std-Min Std)/3 < GROUP 2 ≤ Max Std-(Max Std-Min Std)/3

Max Std-(Max Std-Min Std)/3 < GROUP 3 ≤ Max Std.

Linear regressions have been computed for different combinations of these groups. We obtained better results when selecting the areal values according to their standard deviation. Although the group 1 alone (smallest standard deviation) gives greater R^2, groups 1 and 2 present better Fisher-test coefficients (F) because of the greater number of points, indicating a more significant relationship. The R^2 and F improvement during two events (June 29 and August 4, 1989) are shown on table 1. On figures 6 & 7 are shown the regressions for group 1 and 2 for these two events.

Table 1 : R-squared (%) and Fisher-test coefficients for different groups of rainfall values.
Fisher test coefficients are enclosed within brackets.
The number of data points is shown between quotes.

	June 29, 1989			August 4, 1989		
Point values	53.1	(50.9)	'47'	30.0	(19.7)	'48'
Groups 1, 2, 3	61.8	(87.2)	'56'	65.0	(100.4)	'56'
Groups 1 and 2	69.4	(97.6)	'45'	70.2	(120.3)	'53'
Group 1	82.5	(56.7)	'14'	79.4	(111.8)	'31'

The squared correlation coefficient (R^2) increases when using areal rainfall values instead of punctual values (see table 1). For the June 29 example, the R^2 computed with punctual values is 53.1% compared to 61.8% obtained with areal values. For the August 4 example the R^2 computed with ponctual values is 30% compared to 65% obtained with areal values. This R^2 improvement is due both to the comparison of two data sets at the same space scale instead of comparing punctual and areal values, and to the reduction in localization errors. The second reason is less important because the spatial variability of the MDC image is low (see figure 5).

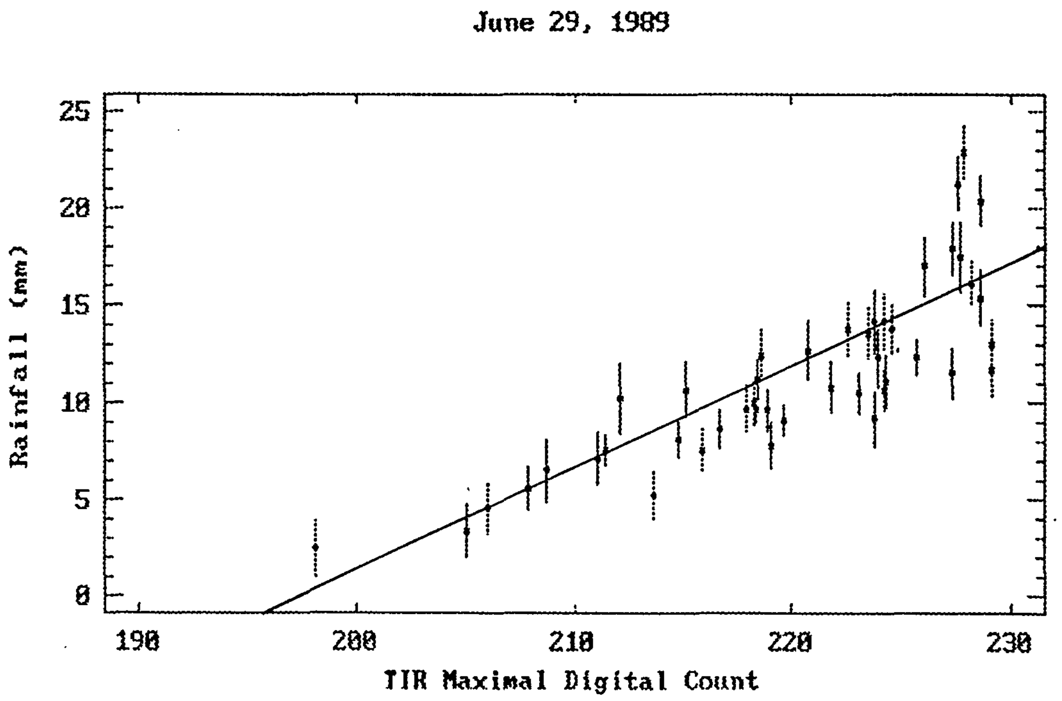


Figure 6: Rainfall/TIR Maximal Digital Counts relationship.
(*) : areal rainfall and associated 9 MDC pixels value.
(|) : rainfall estimation standard deviation (x 2).

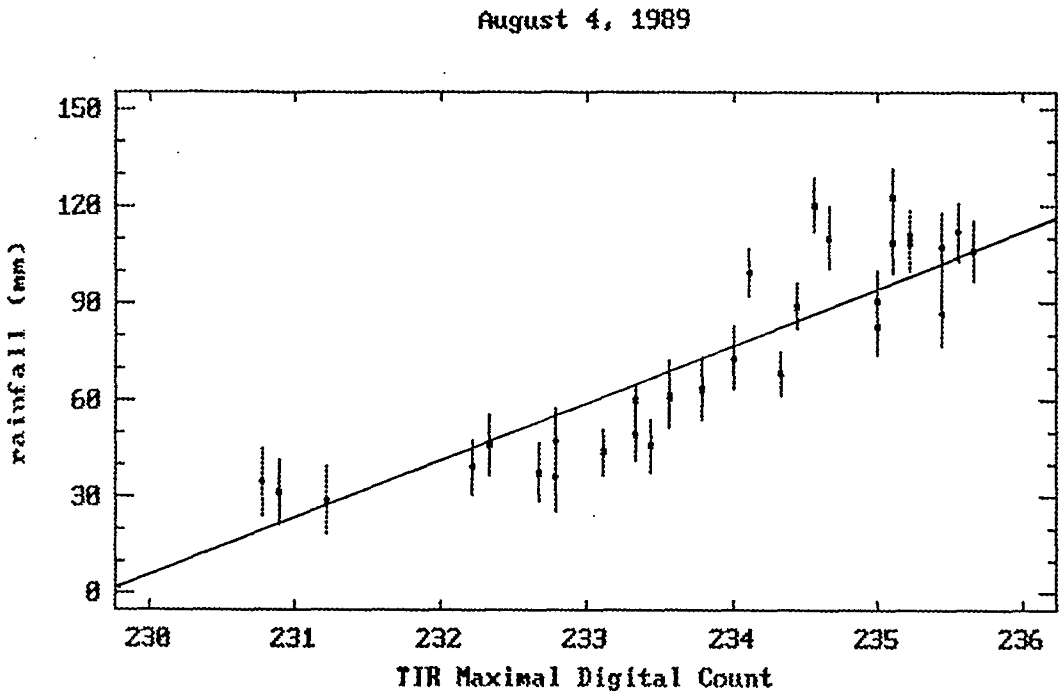


Figure 7: Rainfall/TIR Maximal Digital Counts relationship.
(*) : areal rainfall and associated 9 MDC pixel value.
(|) : rainfall estimation standard deviation (x 2).

Dividing rainfall data into three groups according to their standard deviation has rendered the possibility to find a group better suited to calibrate remote sensing data. Following previous observations, we can say that the standard deviation is an important parameter to select objectively the rainfall values suite to calibration. This is a benefit compared to the use of point values on which no objective partitioning is possible.

Moreover, standard deviation bars on graphics allow us to judge the importance of rainfall tolerance according to the spread of the relationship (see figures 6 & 7). Knowing the quality and the scarcity of rainfall stations in the Sahel, it is of prime importance to work with accurate data acquired from a dense raingage network to develop small scale and short time step rainfall estimation algorithms.

6. CONCLUSION

Through the described method based on the minimal temperature of cloud tops, we have established the interest of areal rainfall values to elaborate a rainfall estimation algorithm at short time and small space scale. Areal values computed with a statistical estimation technique are interesting, giving both a mean rainfall over an area and an associated standard deviation. These values provide a criteria to select objectively ground data and allow a better comparison of rainfall and satellite data. Indeed the two kinds of data computed over the same area have similar spatial structure. A significant improvement in the squared correlation coefficient was obtained using areal instead of point rainfall values, pointing out the suitability of areal rainfall to calibrate satellite data.

We have to test the method with more data and with different algorithms in order to assess the improvement brought by areal rainfall. However the use of areal rainfall have to be taken into account for the calibration of all satellite rainfall estimates. Thus, the need of a dense validation network is evident to enhance such a method. Among the usefullness of such a network is the verification of rainfall algorithms over a study field.

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