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Towards a Rainfall Estimation Using Meteosat over Africa

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Abstract

The scope of the research is to develop a method of rainfall estimation at both small space and time scales (9 pixels -225 km^2-, and single shower duration -several hours-) using Thermal Infra-Red Meteosat data. The method is based on the cloud-top radiometry. The study area is located between 13°-14°N and 2°-3°E (Niamey area). A dense recording raingauge network implanted in Niger provides the data to calibrate satellite estimations. A relationship was found to link the maximum digital count to the squall line rainfall amount. The use of area average rainfall estimates increases the relationship's reliability.

Introduction

The interest of satellite study in hydrology is important especially in areas like the Sahel where raingauge networks are sparse. Nowadays, satellite rainfall estimations over western Africa are used for time periods longer than ten days (Carn et al. 1989). Methods change according to the time and space resolution chosen for the application (Barrett and Martin 1981). The EPSAT-Niger (Estimation des Précipitations par SATellite) experiment has the specific objectives of both improving our knowledge of precipitation processes and deriving operational algorithms to estimate rainfall over the study area (Hoepffner et al. 1989). The study area is a square of about 110x110 km^2 (13-14°N/2-3°E) located in the Niamey outskirts. The so-called "square degree" is representative of the large Sahelian belt situated between annual isohyets 400 and 800 mm from N'Djamena (Chad) to Kayes (Mali). The study area has a smooth relief (maximum elevation difference of 100 m). Hence orographic effects can only be moderate. The Sahelian precipitation regime is characterized by two seasons: a

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dry season (October to May) and a rain season (June to September). The maximum monthly rainfall occurs generally in August. The major rain-bearing cloud system is the squall line : a convective system moving westward with a typical velocity of 15 $m.s^{-1}$. Mean annual rainfall is 546 mm at Niamey City (1905-1987). In 1988, 558 mm was recorded and 600 mm in 1989.

Raingauge Network and Meteosat Data

The high density static memory raingauge network (rainfall accuracy of 0.5 mm for a minimum of one second time interval) is presented by Hoepffner et al. (1989). The basic pattern of raingauge distribution is a regular 13x13 km^2 mesh, and a target area located at the center of the square degree receives 16 raingauges. In 1988, 37 raingauges were set up and the network was completed until October 1989 with a total of 79 raingauges installed on the square degree.

The study is based on real time window rectified image data for the 1988 and 1989 rain seasons. The Thermal Infra-Red (TIR) "window" channel (10.5-12.5 μm wavelength) is used at full space resolution (25 km^2 pixel area). The frequency of these images is 48/day (periodicity 0.5 h). We can consider Meteosat images as a snapshot of the field area because data acquisition durations last only 12 seconds. The image quality and the navigation algorithm allow a localization accuracy of ± 1 TIR pixel. In the paper the Maximum Digital Count (MDC) stands for the lowest temperature reached by a pixel, which is usually represented by the minimum digital count.

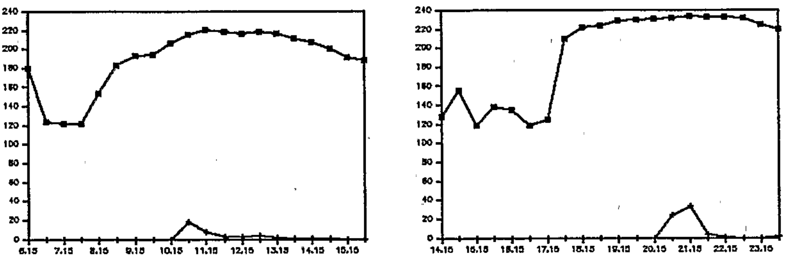
1988 Preliminary Study

The first step consisted of finding significant parameters from images for estimating rainfall at a time scale adapted to the squall line (several hours). To obtain this information we compared half hourly time series of rainfall at one raingauge station and parallel modification of the digital counts at the corresponding pixel (figures 1/2).

On July 17 (see figure 1), the cloud's coldest part (< -40°C) climbs progressively for 3 h and stays 5 h on the same pixel. Rainfall intensities are high at the beginning (shower body) corresponding with the MDC arrival. After the shower body, rainfall intensities become moderate (shower train) with no notable modification of the digital count. The typical areal shape of the cloud (well defined convex western edge and badly defined eastern edge), as well as the rainfall intensity pattern correspond to Sahelian squall lines (Desbois et al. 1988).

On August 10 (see figure 2), the cloud's coldest part climbs quickly (0.5 h) and stays 7 h on the same pixel. The precipitation occurs when the coldest part is established over the station. The shower intensity pattern does not present an organized structure. It is likely that this event is not a squall line, but rather a diurnal convective event.

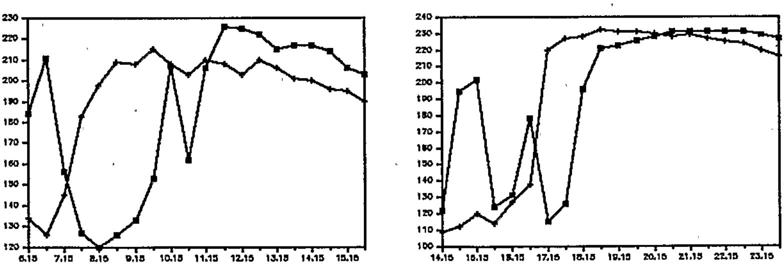
July 17, 1988 August 10, 1988



Time (GMT)

Figures 1/2: Evolution of the rain depth (+) in mm and the satellite digital count (▪). An example: Gassanamari station.

July 17, 1988 August 10, 1988



Time (GMT)

Figures 3/4: Comparison of the digital count evolution at two stations. Examples: (▪) Niamey and (+) Gamonzon

An investigation was then undertaken to find a rainfall indicator from Meteosat images for single showers. On July 17 (see figure 3) we have two stations (Niamey and Gamonzon) corresponding to two different pixels. The Niamey MDC is higher than the Gamonzon one.

On August 10 (see figure 4), no significant MDC difference exists between the two stations. On the squall line of July 17 the MDCs differ, and we could suppose that this difference is linked to the rainfall depth at the station.

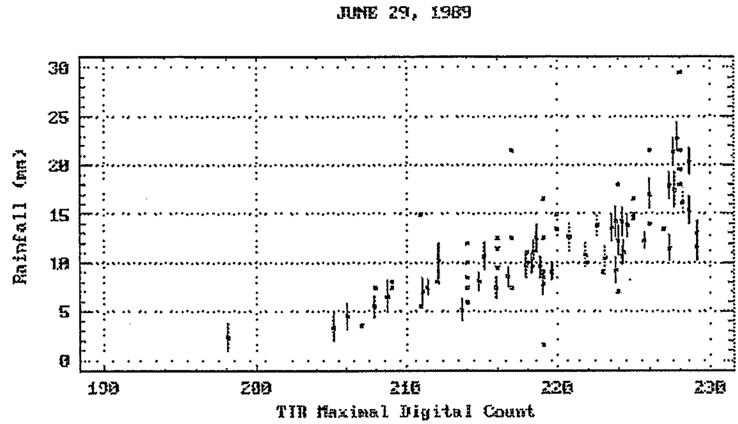
1989 Elaborate Study

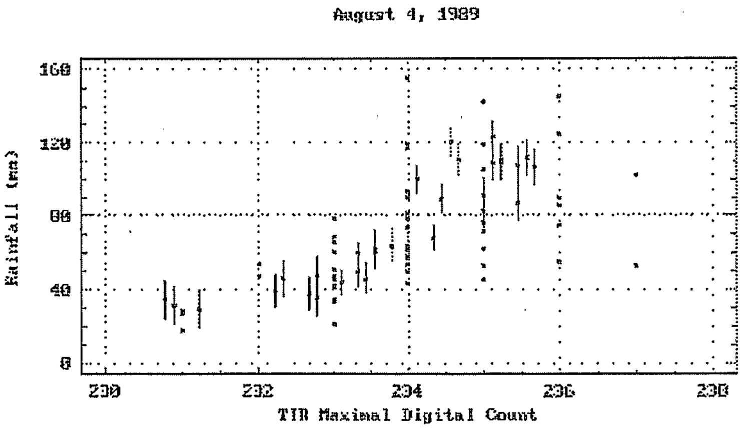
To verify the preliminary results, we compared systematically the rainfall and the MDCs. The following method was applied:
(1) The beginning and the end of the rainfall for a single event is detected. The image sequence corresponding with the rain period over the square degree is then selected.
(2) On each pixel the MDC is extracted
(3) A new image representing this MDC where the coldest part represents the active zone is produced.
(4) Cumulated rainfall for each station is computed and these stations are located on the MDC image.
(5) The MDC pixel and the corresponding cumulated rainfall are compared, looking for a statistical relationship.

The application of this method is presented for two squall lines : June 29 and August 4, 1989 (figures 5/6). Note that the return period of the August 4 shower (119 mm) at Niamey is about one hundred years.

Analysis

We find a relationship between one MDC pixel and the cumulated point rainfall (squares in figures 5/6) at a station for an individual event. The scatter of the points increases with the amount of rainfall as well as with the MDC value. A great part of the scatter is due to the lack of representativeness of a point value as the mean of the pixel area. The greater the area and the distance between a point and the area's center, the greater is the error involved (Flitcroft et al. 1989). Another source of error is the localization accuracy : since a point can be located anywhere within an area of 9 pixels (225 km^2) whose center is the theoretical corresponding pixel given by the conversion of the geographical coordinates into image coordinates. To overcome these observational errors we have considered an area's average rainfall and we have compared it to the corresponding satellite signal of the 9 pixels area. Following different works (Lacomba (1986), Lebel et al.(1987), Thauvin and Lebel (1989)) we have thus computed areal rainfall values using kriging. These values (squares with vertical bars in figures 5/6) were used to replace the point values formely used for studying the relationship between the MDC and the ground rainfall (vertical bars represent one standard deviation interval). As can be observed this improves the relationship.





Figures 5/6 : Rainfall / TIR Maximal Digital Count relationships.(▪) point rainfall and associated single pixel value, (ǂ) area average rainfall and associated 9 pixels value where the vertical bar is the standard deviation of the areal average.

Conclusion

The relationship shows the existence of a link between a simple variable (MDC) and rainfall, and gives a rough estimate of rainfall depth over an area. The improvement due to the use of areal rainfall is derived from the utilization of appropriate ground based data for the calibration of satellite rainfall estimate algorithms. Thus more attention must be payed to the validation of satellite rainfall estimates. However more events must be analyzed to assess the relationship between rainfall and satellite MDC during rain seasons over a given area. This paper is the first step of a larger study which aims to assess the rainfall estimation capabilities of our method. A dense raingauge network such as the EPSAT-Niger network is of prime importance for the improvement of satellite rainfall estimation over the Sahel.

References

BARRETT, E. C., and MARTIN, D. W. (1981). The use of satellite data in rainfall monitoring. Academic Press, London, U.K.

CARN, M., DAGORNE, D., GUILLOT, B., LAHUEC, J.P. (1989). "Estimation des pluies par satellite en temps réel en Afrique sahélo-soudanienne. Essai d'utilisation d'une calibration du champ de température maximum de surface." Veille Climatique Satellitaire, 28 ,47-54.

DESBOIS, M., KAYIRANGA, T., GNAMIEN, B., GUESSOUS, S., and PICON, L. (1988). "Characterization of some elements of the Sahelian climate and their interannual variations for July 1983, 1984 and 1985 from the analysis of METEOSAT ISCCP data." J. Climate, 1 (9), 867-904.

FLITCROFT, I. D., MILFORD, J. R., and DUGDALE, G. (1989). "Relating point to area average rainfall in semiarid West Africa and the implications for rainfall estimates derived from satellite data." J. Appl. Meteor., 28, 252-266.

HOEPFFNER, M., LEBEL, T., and SAUVAGEOT, H. (1989). "EPSAT-Niger : a pilot experiment for rainfall estimation over West Africa." Proc. WMO/IAHS/ETH Workshop on Precipitation Measurement, St Moritz, Switzerland, 251-258.

LACOMBA, P. (1986). "Evaluation des précipitations par combinaison d'images satellitaires V.I.S. et I.R. et de réseaux de pluviomètres. Application à la péninsule arabique et au sud de la France." Thèse de Docteur-Ingénieur, INPG-Université Grenoble ,France.

LEBEL, T., BASTIN, G., OBLED, C., and CREUTIN, J. D. (1987). "On the accuracy of areal rainfall estimation : a case study." Water Resour. Res. , 23 (11), 2123-2134.

THAUVIN, V. and LEBEL, T. (1989). "EPSAT : study of rainfall over the Sahel at small time steps using a dense network of recording raingauges." Proc. WMO/IAHS/ETH Workshop on Precipitation Measurement, St Moritz, Switzerland, 259-266.