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Rainfall estimation over South America using the Precipitation RADAR product of the TRMM satellite, IR-VIS cloud classification and properties of convective systems

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1 Introduction

Due to the low spatial sampling of the ground-based radars, an accurate rainfall estimation using geosynchronous satellite data becomes an important tool in meteorology and hydrology applications. Vicente et al. (1998); Adler and Negri (1988) and Scofield (1987) focus on this topics using the GOES infrared (IR) window (11µm). In this work the GOES visible channel (VIS) (0.65 µm) is also used in order to obtain a cloud classification, allowing us a specific rainfall rate estimation for each cloud type. TRMM precipitation radar data is used in the analysis and validation phases. The model classifies first the pixels associated with rain and then estimates a value of rainfall rate for these pixels. The final rainfall estimation uses some radiatve and evolution parameters (Machado et al. (1998)) of the convective systems, the brightness temperature of the GOES IR channel and IR-VIS cloud classification.

2 Data

In this study we use two months of Tropical Rainfall Measuring Mission (TRMM) precipitation radar satellite data over South America during November (analyzed period) and December (validation period) of 2004. An IR-VIS cloud classification is carried out using a cluster analysis. Four parameters are used: the IR brightness temperature (Tb), the visible reflectivity and two texture indexes computed as the Standard Deviation between the first neighbors of each pixel in both channels. From the IR GOES channel we also extract the following parameters: cloud top temperature (11µm brightness temperature) and some parameters derived from the convective systems tracking system described in Machado et al. (1998) (see chapter 3).

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Figure 1 shows the domain chosen for this study and the TRMM swath over South America with the rain area in grey superimposed over the IR image.

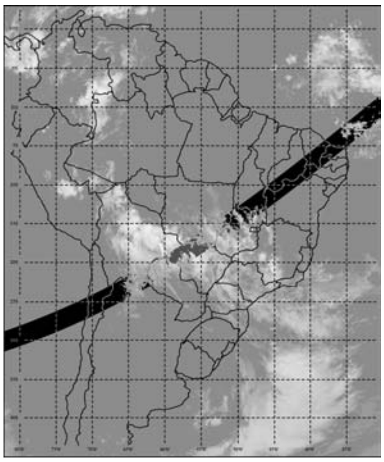

Fig. 1. Area selected for this study. In black the TRMM swath and in dark grey the precipitation area.

3 Rainfall rate estimation

The rainfall rate estimation technique presented is based on the correlation between radiative and evolution parameters of the convective systems and its mean rainfall rate. Therefore only pixels colder 250 K are considered. A deep convective cloud system is identified by adjacent satellite image pixels with infrared brightness temperature colder than a given threshold. The following parameters associated with the structure and evolution of each convective systems are computed for five different thresholds (250 K, 240 K, 230 K, 220 K and 210 K): Mean and Minimum Temperature (MT and MINT), Mean Temperature difference between two consecutive images (MTD), Minimum temperature difference between two consecutive images (TMIND) and the expansion computed as the normalized difference between areas divided by time (30 min.) in two consecutive images (DSIZE).

More than 95% of the rain pixels of the selected cases in November are classified in five cloud types: 4 types as convective clouds and one as cold stratiform. One of the four convective types is flagged as a Deep Convective Cloud (DCC) and the others can be interpreted as the coldest part of the anvil of the DCC in different temperature ranges. The reflectivity in the VIS channel of GOES is similar for all 3 cases. We differentiate between Rain / no Rain due to the following selection criteria:

a) The % of pixels for each class in every cluster and for each Tb threshold is computed.

b) For each threshold, every cluster is associated with the class containing more pixels.

c) Only clusters associated with the cloud types mentioned above are classified as rain clusters.

d) Only pixels belonging to the five cloud types mentioned above in each cluster classified as a rain cluster, is classified as a possible rain pixel.

e) Finally, for every threshold, only the pixels with an IR brightness temperature lower than the mean temperature in the cluster will be classified as a rain pixel.

The final rainfall rate estimation of the pixels classified as rain pixels consist of three steps. In the first step the mean rainfall rates from the radar data are computed for each cluster and each threshold. This means that every cluster are associated with 5 different values of mean radar rainfall rate corresponding to the following intervals: 250 K-240 K, 240 K-230 K, 230 K-220 K, 220 K-210 K and below 210 K). A multiple linear regression is computed between MT, MINT, TMD, TMIND, DSIZE and the mean radar rainfall rate for every threshold in every cluster. Thus, each pixel from the same cluster and the same Tb interval are associated with the same estimated value of rainfall rate (Rm) given by the following expression:

$$Rm = a_i MT + b_i MINT + c_i TMD + d_i TMIND + e_i DSIZE, \quad (1)$$

Where i is the Tb interval and a, b, c, d and e are the correlation coefficients.

Figure 2 shows the mean radar rainfall rate versus the multiple linear regression computed rainfall rate for a 230 K threshold.

In the second step of the rainfall rate estimation the difference between the brightness temperature of each pixel and the mean temperature of the cluster for each threshold (Temperature Difference, TD) is used in order to assign a more accurate value of rainfall rate to each pixel.

The following rainfall rate will be assigned to each pixel belonging to a cloud type:

$$r = Rm + Rc ,$$

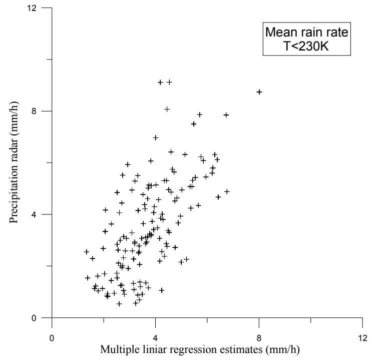

Fig. 2. Scatter plot between the mean radar rainfall rate for each cluster versus multiple regression estimate for each cluster. In this case the threshold to select the clusters is 230 K.

where r is the value of rainfall rate assigned to the pixel, Rm is the multiple linear regression computed rainfall rate and Rc is the pixel correction due to the Temperature Difference and the cloud type. Rc is therefore a function of TD and the cloud type. Rc is the result of the comparison between the mean value of the difference between the radar value and Rm for each 1 K interval of TD from -10 to 20 K. A similar methodology is used in Vicente et al. (1998). Figure 3 shows this relation for the DCC. The points were fitted to a three degree polynomial curve.

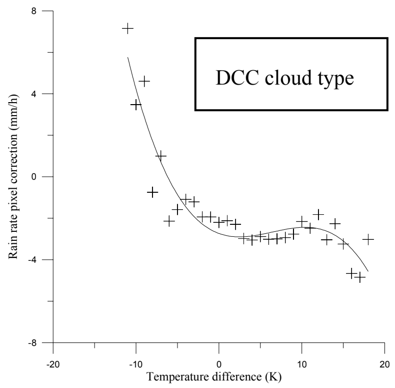

Fig. 3. Mean value of the difference between the radar data and the multiple linear regression value computed for each 1 K interval of the Temperature difference for DCC clouds. The curve is fitted with a 3rd degree polynomial function. Different curve are also fitted, depending on the cloud type.

Both Rm and Rc contribute to the value of r. Rm is the cluster contribution and its value depends on the radiative and evolution parameters that characterize each cluster. Rc is the pixel contribution to the total rainfall rate and is a function of TD, which gives an idea of the value of the spatial temperature gradient within the pixel. However, both contributions are derived as functions of the mean value of the radar data. As a consequence, the range of r is smaller than the range of the radar data (figure 4), but both radar and r frequency distributions fit to an exponential distribution.

In the third step of the rainfall rate estimation both radar and r distributions will be approximated to an exponential distribution. The final value of the estimated rainfall rate R will be given by fitting the r distribution to the radar distribution.

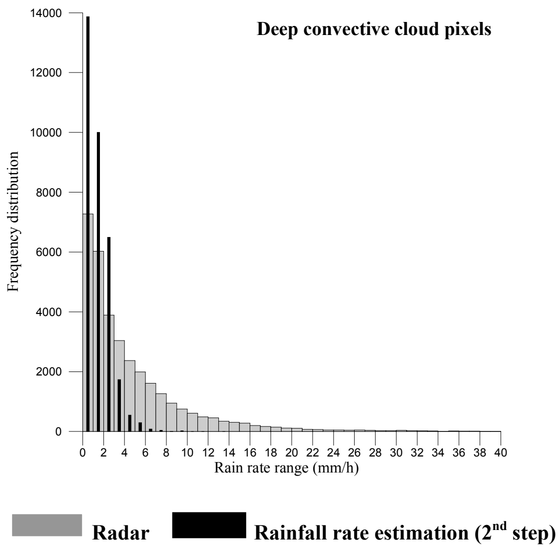

Fig. 4. Frequency distribution of rainfall from radar and rainfall rate estimation during the second step of the method for DCC pixels

4 Results and conclusions

Both Rain / no Rain discrimination and rainfall rate estimation are carried out, taking into account the different cloud types. Preliminary results show that the method performs reasonably well not only for heavy precipitation estimation, but also for stratiform precipitation of the cold stratiform and the warmer convective cloud pixels.

Several statistical measures are used to compare the rainfall rate estimation with the radar data. This includes the correlation coefficient, the RMSE, the BIAS, the False Alarm Ratio (FAR), the Probability of Detection (POD) and the Error (ERR).

Preliminary results for both the analyzed and validation period are shown in table 1. Other results show that the statistical parameters for the Rain / no Rain discrimination are better for DCC pixels (which represent more than 50% of the total rain).

Table 1. False Alarm Ratio, Probability of Detection and Error for both analyzed and validation period.

	Analyzed period	Validation period
FAR	0,43	0,32
POD	0,61	0,55
ERR	0,26	0,32

The rainfall rate estimation technique was tested for a case study, a deep convective storm on November 12 of 2004 (1115 UTC) in the north-eastern region of the Amazonia state of Brazil. Figure 5 shows the radar data (figure 5a) and the rainfall rate (figure 5b).

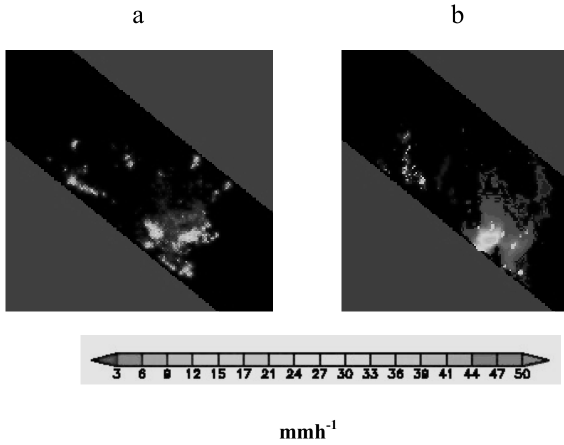

Fig. 5. Rainfall rate on November 12 of 2004 (1115 UTC). (a) Radar (b) Estimated.

Preliminary results show that the estimation tends to overestimate low values of rainfall rate and underestimate high values. Although the result show modest skills at 1x1 pixel resolution (4 km x 4 km), an improvement is observed for a higher grid size.

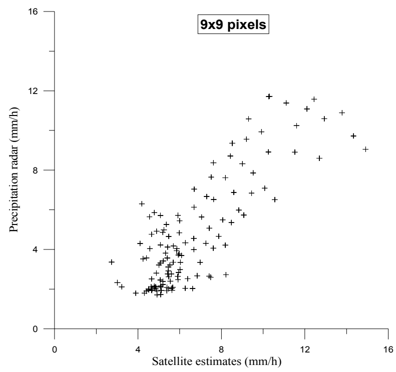

Fig. 6. Scatter plot of the satellite estimates versus radar data for a grid size of 9x9 pixels.

Figure 6 show the scatter plot of the satellite estimation versus the radar values for a grid area of 9x9 pixels. These are the computed statistical parameters:

$$RMSE=1.41 \qquad BIAS=1.99 \qquad r^2=0.68$$

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