RAINFALL ESTIMATION USING SATELLITE DATA FOR PARAÍBA DO SUL BASIN (BRAZIL)

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ABSTRACT:

This work presents a self-consistent algorithm for near real-time rainfall estimation via infrared Geostationary Operational Environmental Satellite (GOES) (each ½ hour) data based on a validation simultaneous dataset from Precipitation Radar (PR) onboard the Tropical Rainfall Measuring Mission (TRMM) satellite, GOES and lightning data, for the basin of Paraíba do Sul river. The dataset corresponds the period from September of 1998 to March of 2000. The rainfall estimation methodology was developed by Morales and Anagnostou (2003) and has been adapted for the proposed of this work and it is based on following assumptions: (1) lightning is correlated with the presence of precipitation and ice particles that are associated with deep convective nucleus; (2) the precipitation area and its convective portion are related to the cloud and lightning areas of a precipitating system; and (3) lightning and no-lightning clouds exhibit different precipitation characteristics. The aforementioned database was used to analyse and understand the main physical characteristics of the different types of raining systems which act in the study area. Results are presented and discussed.

1. INTRODUCTION

Information on the spatial and temporal variability of global precipitation is of fundamental importance to applications ranging from hydrologic engineering to climate change research. This paper presents an algorithm developed for near real-time retrieval of instantaneous surface rainfall over a region of Brazil using information from an geo-stationary satellite infrared observations, and adjacent rainfall measurements from the first space-borne precipitation radar (PR) onboard the Tropical Rainfall Measuring Mission (TRMM) satellite (Theon, 1994), and lightning data. This study is formulated under the hypotheses that: (1) lightning is correlated with the presence of precipitation sized ice particles that are associated with deep convective cores: this observation can improve the identification of convective rain area; (2) the precipitation area and its convective portion are related to the cloud and lightning areas of a precipitating system; and (3) lightning and lightning free clouds exhibit different precipitation characteristics.

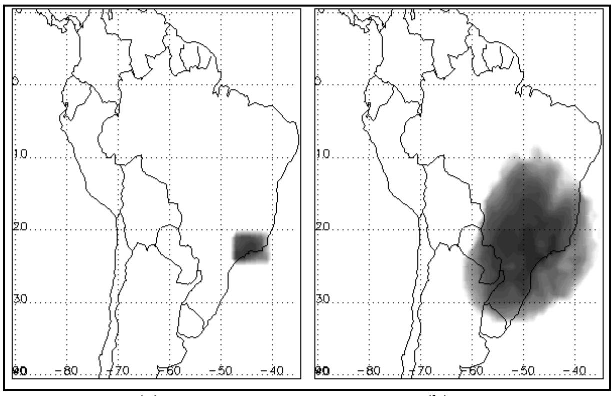
The relation of lightning to precipitation has been the subject of various precipitation remote sensing and climatology studies. Workman and Reynold (1949) related flash rates to convective rain fluxes, and suggested that the frequency of lightning may be a measure of convective activity. Goodman (1990) developed a relationship between lightning frequency and rainfall intensity for systems in Florida. Similarly, Buechler et al. (1994) demonstrated a linear relationship between rainfall and lightning activity for Florida thunderstorms and Tappia et al. (1998) estimated convective rainfall rate from rainfall-lightning ratios using the Melbourne, Florida, WSR-88D radar.

Satellite infrared (IR) images have been used to retrieve rainfall at large spatial and temporal scales, and for delineation of rain areas in cloud systems (Arkin and Meisner, 1987). Adler and Negri (1988) developed a technique to distinguish convective and stratiform precipitating systems based on the temperature gradients evaluated around the minimum temperature in the cloud clusters. Recently, Vicente et al. (1998) presented an auto-estimator IR technique that uses additional information of precipitable water and relative humidity from a numerical weather prediction model. These IR rainfall estimation methods have deficiencies associated with the presence of thin non-precipitating cirrus clouds and non-raining cold Mesoscale Convective System (MCS) cloud shields. Anagnostou et al. (1999) in an effort to minimize this uncertainty used a statistically adjusted IR technique with microwave sensors and showed that the area within a cloud cluster whose temperature is at or below the most frequent temperature in that cluster is well-correlated with rain area. They were also able to improve the convective and stratiform rain area delineation in those precipitating systems. Despite those efforts on improving IR algorithms, there is considerable uncertainty in the estimates since the relation between cloud-top longwave IR brightness temperature and the underlying surface rainfall is complex and is based on indirect physical relationships. Morales et al. (1997), and Morales and Angnostou, (2003) have shown that lightning measurements associated with active convection in the clouds can provide reliable delineation of the convective cores, which would lead to improvements in the convective rain estimation.

This paper presents a lightning-IR-rainfall algorithm that consists of procedures for estimating rain area and its convective/stratiform portions for clouds with lightning (LTG) and lightning free (NLTG). Convective and stratiform rainfall rates are related to lightning rates and IR brightness temperatures through relationships determined using the TRMM PR precipitation products as reference. Evaluation of the algorithm (defined as the Sferics Infrared Rainfall Technique, SIRT) performance based on daily rainfall rate from Global Precipitation Climatology Project (GPCP) is done in a qualitative way.

2. DATA PROCESSING AND EXPLANATION ALGORITHM

The initial idea was to use simultaneous infrared GOES data, lightning data and rainfall measured by meteorological RADAR onboard on TRMM over Paraíba do Sul basin area (figure 1a), for the period from September of 1999 to March of 2000. However it was not possible due to amount of data to establish a consistent statistics curves for rainfall estimation for the study area. The latter has been solved by extend the training area as shown in figure1b.



(a) (b)

Figure 1. Lightning space distribution represented by the dark areas: (a) Paraíba do sul river area (b) extended area.

The GOES brightness temperature, lightning data and rain (TRMM) were project and interpolated in equidistant projection of 0.1 x 0.1 degrees (~ 10 km x 10 km).

For evaluation of the effectiveness of the methodology for rainfall estimation via infrared GOES data in this work, a set of 4738 infrared GOES data and 1621 rainfall from TRMM-PR data were used. The table 2 shows the amount of lightning and lightning free cloud simultaneously used to establish the curves

Table 2. Cloud number with lightning (LTG) and lightning free (NLTG) simultaneously collected with GOES infrared data and rainfall from TRMM-PR.

Type of Clouds	Number of Clouds
Lightning (LTG)	71
Lightning free (NLTG)	693

The algorithm is based on the following hypotheses: (1) lightning information can advance our ability to discriminate convective rain areas within a cloud system, given that current IR algorithms face limitations in dealing with the presence of cirrus clouds and non-raining cloud shields like those in Mesoscale Convective System (MCS); and (2) the development of a combined lightning and satellite IR algorithm based on the newly available PR rain products can lead to improvements in the definition of rain area, precipitation classification, and quantitative rain estimation from these sensors. The algorithm is designed to produce maps of instantaneous surface rainfall fluxes and rain type classification based on a combination of lightning, IR brightness temperature (10.2-11.2 μm) observations, and precipitation profile measurements from PR.

Besides the algorithms classify clouds with lightning (LTG) and lightning free (LTG), this classifies the clouds system on the land or ocean, and if is a stratiform or convective one. This way the following calibration curves are generated: Brightness temperature distribution and rainfall rate, rain area and convective fraction, and assignment of rainfall rate.

2.1. Brightness Temperature and Rainfall Rate

The figure 3 presents the temperature distributions for the rain clouds with LTG and NLTG over the land and ocean. It can be noticed that the clouds that possess LTG present a larger frequency of colder tops, in other words, larger vertical development. The convective area also presents colder temperatures.

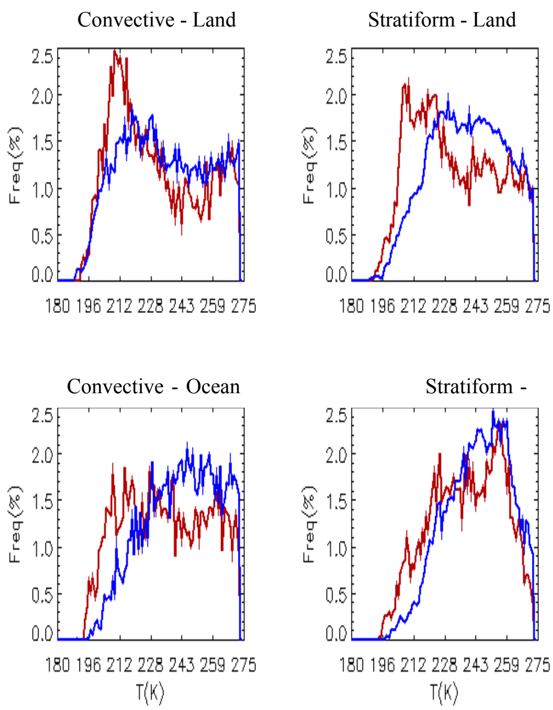


Figure 3. Distribution of frequencies of brightness temperature for rain clouds with lightning (red) and lightning free (blue) for convective (left) and stratiform areas (right) over the land (top) and ocean (below).

The figure 4 illustrates the distribution of rainfall rate for the rain clouds with LTG and NLTG. Differently of the temperature distribution, it doesn't happen a significant difference for the rainfall rate for the clouds with LTG and NLTG, as presented by Morales and Anagnostou (2003).

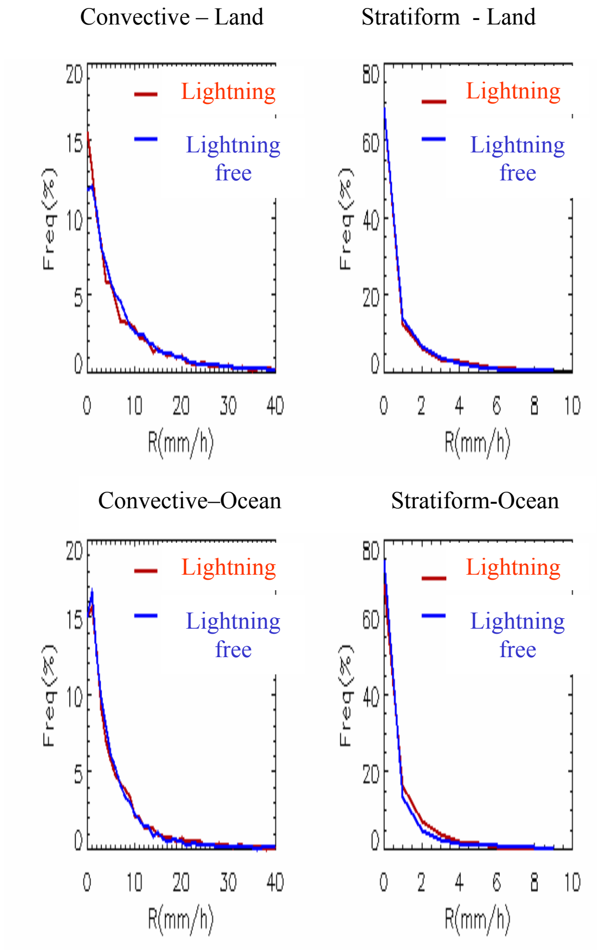


Figure 4. Percentage of convective (left) and stratiform (right) cases versus rainfall rate for rain clouds with lightning (red) and lightning free (blue) on the land (top) and ocean (below).

2.2. Rain Area and Convective Fraction

Following Morales and Anagnostou (2003), the cloud fraction with rain is defined using a brightness temperature less than 273 K whose there are corresponding rain areas accused by TRMM-PR. This way is determined the more frequent temperature for each cloud or Tmode and its area.

Following Morales and Anagnostou (2003) and based on the data statistical analyses, it was initially obtained for the clouds lightning free, the following intervals of Tmode which represent the best relation: Tmode ≤ 210; 210 < Tmode ≤ 220; 220 < Tmode ≤ 230; 230 < Tmode ≤ 240; 240 < Tmode ≤ 250; 250 < Tmode ≤ 260; 260 < Tmode ≤ 270; and Tmode > 270. The other hands, for the clouds with lightning were obtained the following intervals: Tmode ≤ 220; 220 < Tmode ≤ 240; 240 < Tmode ≤ 260; and Tmode > 260.

The figures 5 and 6 present the relations of rain fraction for the NLTG and LTG clouds, respectively, taken into account all classified Tmode (or intervals). It is noted as long as that Tmode reduce the rain fraction areas increase that could be connected to the intensification of convective.

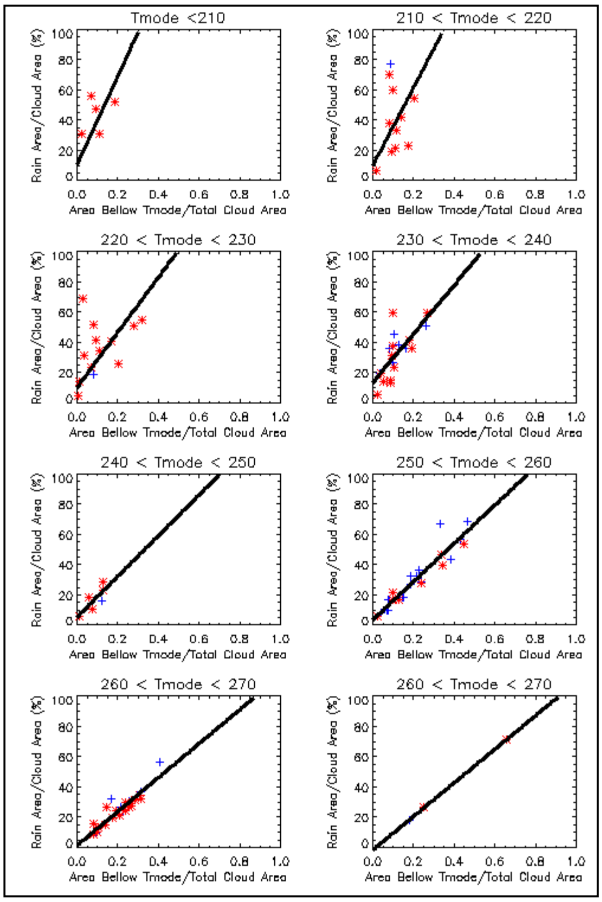


Figure 5. Rain fraction of the clouds lightning free for different Tmode (or classes).

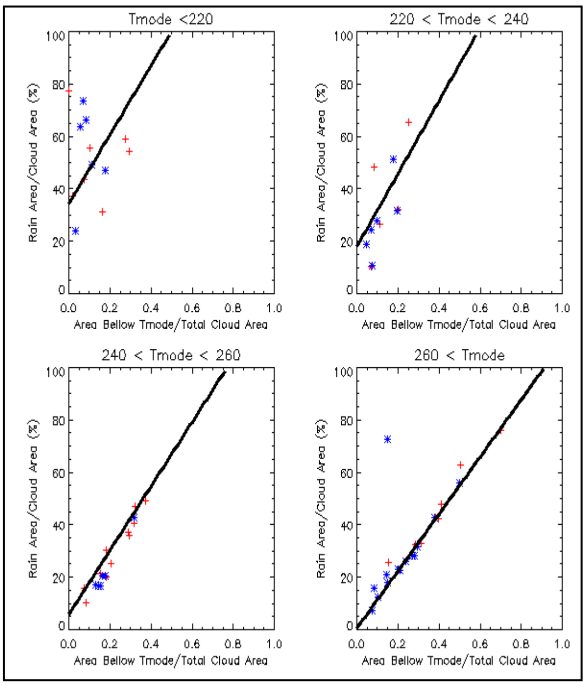


Figure 6. Rain fraction of the clouds lightning for different Tmode (or classes).

2.3. Assignment of Rainfall Rate

The relationships between rainfall rate and brightness temperature and or frequency of lightning are derived starting from the Probability Matching Method (PMM). In this method, the distribution of cumulative probability of each distribution is made calculations (rainfall rate, brightness temperature and frequency of lightning), and it is assumed that the two distributions are correlated by the same interval of probability. In other words, suppose that two distributions X and Y exist, as described in the figures 3 and 4. Supposes that the variable X_{50} represents the value of the distribution X with a cumulative probability of 50%, Y_{50} represents the value of the distribution Y with a cumulative probability of 50%, and therefore it links the variable X_{50} with Y_{50}, and so on. In the calculated relationships, it is assumed although the hottest temperature is associated with rainfall rate same 0 and the coldest temperature is associated with the rainfall rate more intense, this way it is guaranteed that the hottest areas have smaller precipitation and the coldest possess the most intense precipitation.

This way, the distributions of cumulative probability of temperature, rainfall rate and frequency of lightning are calculated for the different classes, or be: Tmode, land, ocean, with LTG or NLTG, convective and stratiform.

In the figures 7 and 8 the relationships of rainfall rate are presented in function of the temperature for clouds with lightning on the land and ocean respectively.

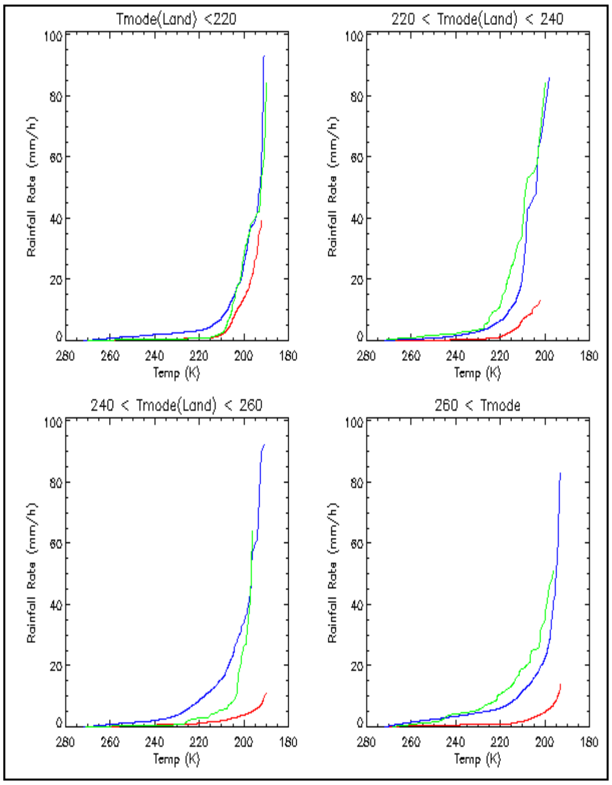
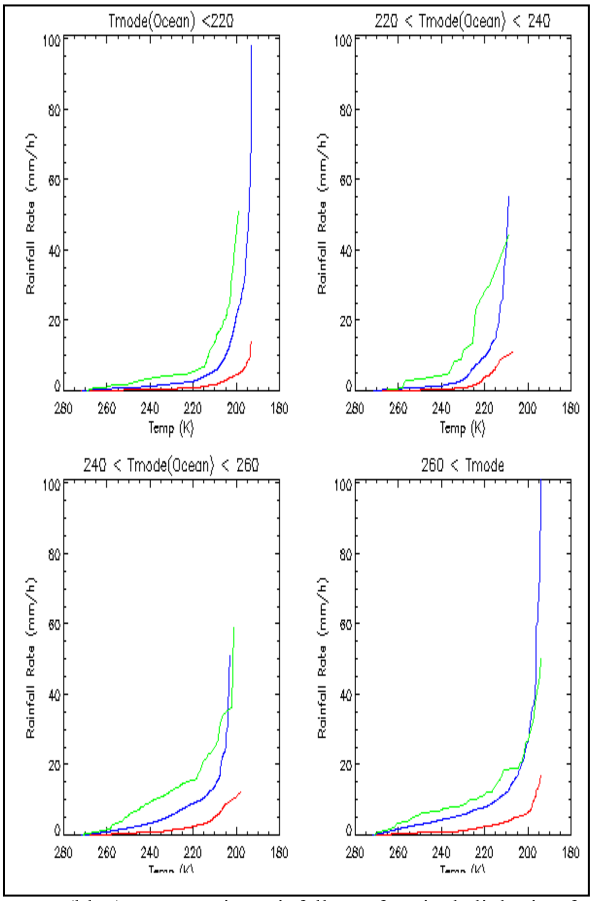


Figure 7. Rainfall rate curves for clouds with lightning over land. (blue) – convective rainfall rate for pixels lightning free; (green) – convective rainfall rate for pixels lightning; (red) stratiform rainfall rate.

It is noticed that the rainfall rate are more intense on the land for the coldest areas of the cloud, while on the ocean it concentrates on hotter areas. In fact, the marine clouds concentrate more content of liquid water in the first kilometres of the cloud, soon developing larger drops than implicate in precipitation. Already the land clouds due to great amount of aerosols need a larger vertical development for the drops to win mass and precipitate like this. Therefore, this vertical development implicates in a larger amount of mass, because it increases the volume. Finally these results allow obtain the different properties among the land and oceanic clouds.

Figure 8. Rainfall rate curves for clouds with lightning over



ocean. (blue) – convective rainfall rate for pixels lightning free; (green) – convective rainfall rate for pixels lightning; (red) stratiform rainfall rate.

3. RESULTS AND DISCUSSION

3.1. Instantaneous Rainfall Rate

A figure 9 shows simultaneously the infrared GOES image with lightning data represented by white cross (top figure), rain fraction for convective (red – middle figure) and stratiform (blue – middle figure) and instantaneous rainfall rate (button figure) at 16:39 UTC and 20:09 UTC on 13 of January of 2000. The methodology shows a quite good performance to capture active rainy convective areas.

Figure 9 presents a good example of very intense convective system including a significant number of lightning (or atmospheric discharges).

16:39 UTC on 13 January of 2000 (a)	20:09 UTC on 13 January of 2000 (b)

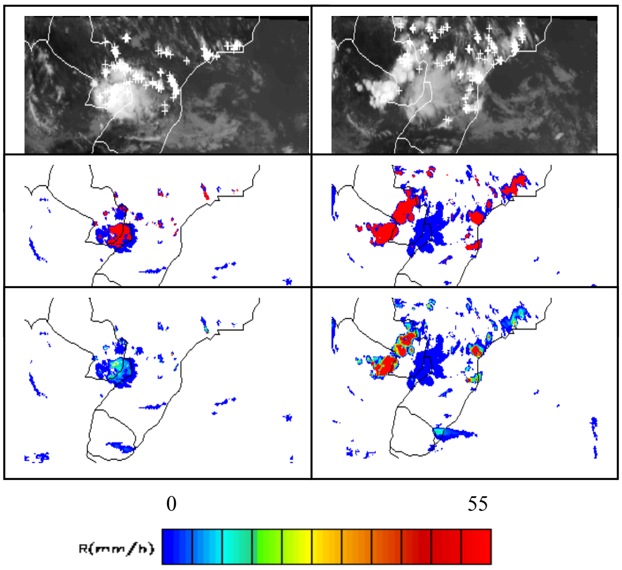
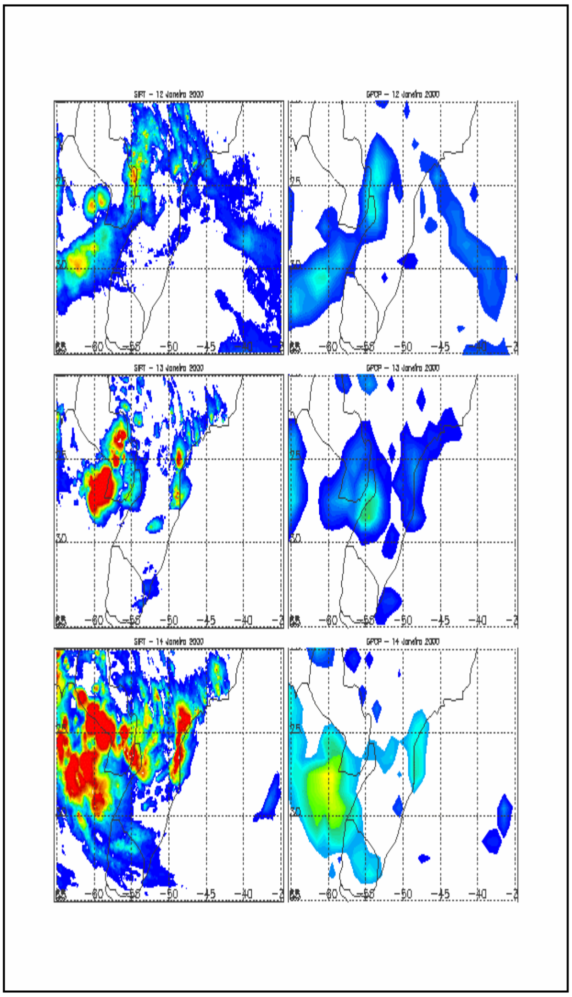


Figure 9. The illustration shows infrared GOES image with lightning data represented by white cross (top figure); rain fraction for convective (red – middle figure) and stratiform (blue – middle figure) and instantaneous rainfall rate (button figure) at 16:39 UTC and 20:09 UTC on 13 of January of 2000.

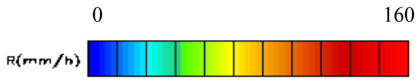
3.2. Daily Rainfall Rate

Following Huffman (1997) and in order to make a comparison between the results from rainfall estimation algorithm proposed in this work and values from the Global Precipitation Climatology Project (GPCP) in a daily basis, it was taken GOES data from the period of 12 to 14 of January 2000 (figure 10). There is a spatial scale difference between the two used data since the GCP one were obtained at resolution of 1º x 1º.



The comparison idea is to present, as shown in figure 10, the spatial rainfall distribution estimated by the proposed algorithm SIRT and GPCP. The results show a quite good coherence regarding to spatial distribution point of view. Since the GCCP spatial resolution is 10 times poorer, loosing information, the SIRT. And the reason why the SIRT is able to observe higher variability of the precipitation the heavy precipitation intensity estimated by SIRT is observed in the same areas given by GPCP.

Figure 10. Daily rainfall estimation for the method SIRT (left) and GPCP (right), for the period12-14 of January 2000.



It has well the precipitation field over study area. The methodology shows a quite good performance to capture active rainy convective areas. The adjusted curves of cloud fraction area and their respective convective and stratiform part were inferred, and finally the different curves of rainfall rates base on the temperature and frequency of lightning were obtained.

The results illustrate the potential of the rainfall estimation on areas the where a great variability in space and time of the rain exist, and especially with great frequency of Lightning (atmospherics discharges).

As future perspectives, efforts will be made in order to use a larger data set aiming to reach better fitting curves.

5. ACKNOWLEDGEMENTS

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