

RAIN CLIMATOLOGY IN THE CENTRAL REGION OF THE STATE OF SÃO PAULO USING RADAR ECHOES DURING THE WET PERIOD

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Jose Carlos Figueiredo*

Instituto de Pesquisas Meteorológicas, Universidade Estadual Paulista, Bauru, S.P., Brazil

1. INTRODUCTION

Information from meteorological radars is utilized relatively little in Brazil, except by the agricultural sector, and mostly related to the sugar plantations in the State of São Paulo. Detailed information on the variability of rainfall with a spatial resolution of 1km^2 is very important, considering the agricultural development in the State of São Paulo and taking into consideration new technologies becoming available in the agricultural sector. A climatology of precipitation, together with other information collected in the agricultural field, using GPS technology, will improve the analysis and treatment of the resulting data, which in turn, will result in better planning for the use and applications of the agricultural operations. Obviously the farmer will score economically, but the impact of his activities on the environment could also be minimized.

To comply with that, an old dilemma has to be faced, which is: How best to compare rainfall measured by radar and rainfall measured by pluviometers? Several ways have been proposed as solution, but the problem seems to be far from having been resolved, once several authors have shown that pluviometers are vulnerable to the local climatology, e.g., considering the effects of wind (Groisman 1994).

Perhaps, the problem is inherent in the data collection adopted! This is certainly the main difference between both instruments used for monitoring rainfall. Although the variable would be the same (viz., precipitation), differences have been found in most of the comparative studies of radar versus pluviometers, such as by Calheiros (1982) and Antonio (1991), and more recently by Calvetti *et al.* (2003), who used an objective statistical analysis, which took into consideration the influence of the distance between a collection point and the matching radar pixel, resulting in better estimates of rain.

Saltikoff *et al.* (2000) did not find any significant values for the bias, when comparing rainfall measured by an S-band radar and a traditional pluviometer. To normalize the precipitation data they have used equation (1), where G is measured by the pluviometer and R_a is measured by the radar.

$$F=10*\log(G/R_a) \quad (1)$$

Tokay and Short (1996), using 100 days of intense rainfall in the west of the equatorial Pacific, and trying to separate the different types of rainfall (stratiform and convective), have found that convective type of rain is better represented by radar reflectivities above 43 dBZ.

Gandú (1984) has presented a statistical study of radar echoes for the eastern region of State of São Paulo, using an S-band radar to describe the rainfall regime associated with large-scale circulation. The author found, that storm cells have movements from west to east with an average speed of 7m/s, using 2705 observations from January 1979 to March 1980.

Chaudhry *et al.* (1996), have presented a statistical study on convective rainfall observed by the Bauru C-band radar, for the period of October 1981 to March 1982 and October 1984 to March 1985, considering two areas 28×28 km, located 82.2 km and 113.4 km from the radar, respectively, one being a hilly area and the other one close to the Tietê river. They found that the speed of the rainfall cells observed in these areas was varying between 20 and 50 km/h, with an average speed of 42 km/h. The preferential time for the occurrence of convective rainfall was between 17:00 and 20:00 LT (Local Time).

1. DATA AND METHODOLOGY

The data used in the study are from the Bauru S-band Doppler radar (Altitude 620 msl, Latitude $22^{\circ}35'S$ and Longitude $49^{\circ}03'W$, Figure 1). This radar forms part of IPMet's (Instituto de Pesquisas Meteorológicas) network of two S-band Doppler radars, being operated continuously with volume scans every 7.5 – 15min, if rain occurs within the 240km range, comprising 11 PPIs between 0.3° and

*Corresponding author address:

Jose Carlos Figueiredo, Instituto de Pesquisas Meteorológicas, UNESP, CX-281, 17001-970 Bauru, S.P., Brazil; email:Figueiredo@ipmet.unesp.Br

34.9° elevation. The beam width is 2° and the resolution is 1km² in range and 1° in azimuth. The study period was from 1994 to 2004, with 27.072 CAPPis collected during January and 24.942 CAPPis during February.

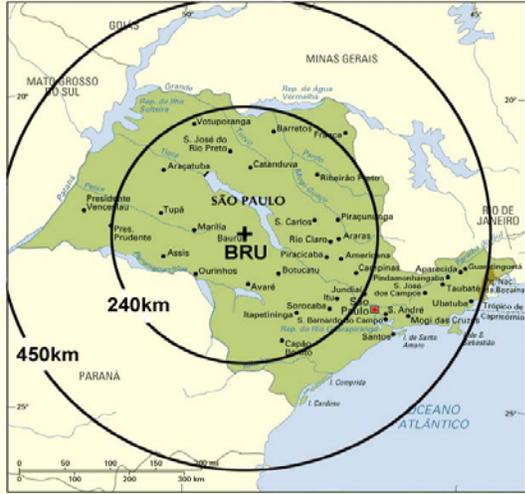


Figure 1. Map of the State of São Paulo, showing the main cities, rivers and the position of the Bauru radar (BRU) with 240 and 450 km range rings (Source: <http://www.guianet.com.br/sp/mapasp.htm>)

The radar data were copied from the magnetic tape to CDs, transformed into ASCII format and thereafter converted to the universal format NetCDF. The data collection is done every 7.5 or 15 minutes to generate CAPPis. For one hour of accumulated rainfall, one can have up to 8 CAPPis. Each CAPPi was recorded as a matrix of 480x480 pixel, where each pixel represents an area of 1km² as shown in Figure 2.

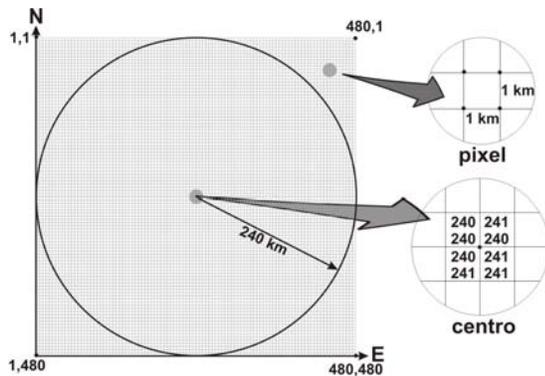


Figure 2. Study area, segmented into a matrix of 480x480 points, where each point represents 1km² (pixel). The center corresponds to the radar location. The black circle indicates the 240 km range of the CAPPi.

To select the most suitable Z-R equation, some tests were performed using data from the automatic weather station located at Botucatu (Lat. -22°55'S, Lon. -48°27'W). The analysis was done using the Z-R relationships of Marshall and Palmer (1948), Jones (1956), Sekhon and Srivastava (1971), Tokay and Short (1996) [Tokay_1] for all types of rainfall and Antonio (1998), Tokay and Short (1996) [Tokay_2] for convective rainfall, Tokay and Short (1996) [Tokay_3] for stratiform rainfall. The values for the constants A and b of above mentioned Z-R relationships are presented in Table 1. A threshold of ≤45 dBZ has been considered in the equations for the Z-R relationships, in agreement with the data collected by Tokay and Short (1996), who found the majority of rainfall, including stratiform and convective types, was between 23 and 43 dBZ (95%). Considering that a low reflectivity represents very light rain, all values below 15 dBZ, were not considered in the calculations of the rainfall fields.

Table 1. Values for the constants of the Z-R relationships.

Equation	Constants (Z-R)	
	A	b
Marshall/Palmer	200	1.60
Antonio	236	1.26
Jones	486	1.37
Sekhon & Srivastava	300	1.35
Tokay_1	315	1.20
Tokay_2	139	1.43
Tokay_3	367	1.30

The equations (2), (3) and (4) were used to quantify the errors between the various Z-R relationships shown in Table 1 and the automatic weather station data, always considering the same time slot for both measuring systems.

$$F_{bias} = 10 \times \log \left(\frac{P_{luv}}{R_{ad}} \right) \quad (2)$$

$$EQM = \left[\frac{1}{N} \sum_{i=1}^N (R_{ad} - Pluv_i)^2 \right]^{1/2} \quad (3)$$

$$ERM = \frac{EQM}{Pluv} \times 100 (\%) \quad (4)$$

where R_{ad} is the estimated rainfall, G_{au} the gage estimated rainfall and EQM = quadratic mean error and ERM = mean relative error.

Equation (2) normalizes the bias error F_{bias} , indicating the differences between the radar estimated rainfall (R_{ad}) and the rainfall (G_{au}) observed by the pluviometer for the same grid point. A value for R_{ad} was adopted, equal to the average

between the closest point in the matrix and the coordinates for the pluviometer including four neighboring points spaced every 1 km.

Table 2 shows the results for the errors using the selected Z-R equations. The smallest errors (1.8%) for the daily accumulation of rainfall were found by using Jones (1956) and Tok_1 (Tokay and Short, 1996), while for monthly values from the 11 years, using constants from Marshall and Palmer (1948), Antonio (1998), Sekhon and Srivastava (1971) and Tok_3 (Tokay and Short, 1996), all presented basically the same values for the average errors. Taking this into account, it was decided to adopt the Tok_1 relationship for the daily accumulation of rainfall and Marshall and Palmer (1948) for the monthly accumulation of rainfall.

Tabela 2. Calculated errors from selected Z-R relations

	Daily		Monthly	
	EQM (mm)	ERM (%)	EQM (mm)	ERM (%)
Palmer	2.9	3.6	8.7	3.8
Antonio	3.5	4.2	8.6	3.7
Jones	1.8	2.2	11.7	5.1
Sekhon	2.5	3.0	8.3	3.6
Tok_1	1.8	2.2	12.4	5.3
Tok_2	3.7	4.5	9.7	4.2
Tok_3	2.6	3.1	8.8	3.9

The average for the analysis period considering the entire grid domain, from November 1994 to March 2003, will be tagged as the climatological mean (mC) for each month and for each pixel within the 240 km range from the radar. To calculate the echo anomaly, using equation (5), the monthly data for the rainy period for 2004 was accumulated, named here as reference month (mB).

$$Anomalia_eco = \sum_{i=1}^n (mB - mC) \quad (5)$$

2. DATA AND METHODOLOGY

Table 3 shows the daily frequency of the Maximum dBZ Values (MdV) for the months of January and February during the period from 1994 to 2004, which presents very little variation between both months. Only February had more occurrences in the reflectivity intervals of 41-45dBZ and 51-55dBZ, when compared to

January, while in January the interval of reflectivities from 46 to 50dBZ showed higher frequencies than February. The absolute maximum values for reflectivity found in the analyzed domain were 76.7 dBZ and 71.4 dBZ, for January and February, respectively.

Table 3. Daily frequency of Maximum Values dBZ (MdV) for the months of January and February (1994-2004).

Reflectivity (dBZ)	Frequency (%)	
	January	February
<15	0.3	0.3
15-20	0.3	0.3
21-25	0.7	0.4
26-30	1.3	1.0
31-35	3.0	2.5
36-40	8.7	9.3
41-45	15.1	22.8
46-50	37.2	24.0
51-55	17.8	24.4
56-60	13.1	13.8
>60 (absolute maximum)	2.5	1.2

By trying to relate echo intensity to stormy weather (producing intense rainfall), was considered between 46 to 50 dBZ corresponding to VIP 4 - Video Integrator and Processor, resulting in rainfall rates of up to 24 mm/hr, considered as strong rain according to the classification by Falconer (1984).

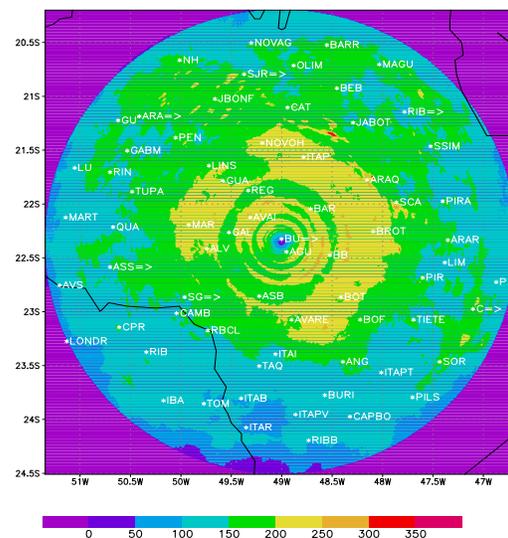


Figure 3a. Mean accumulated rainfall for January 1994 to 2004

The Figures 3a and 3b show the average accumulated rainfall for January and February from 1994-2003. It can be seen that for January and February, the rainfall distribution shows some maxima located in the 100 km range from the radar, with the mean rainfall for January varying between 200 and 250 mm (Figure 3a) and between 250 and 300 mm for February (Figure 3b).

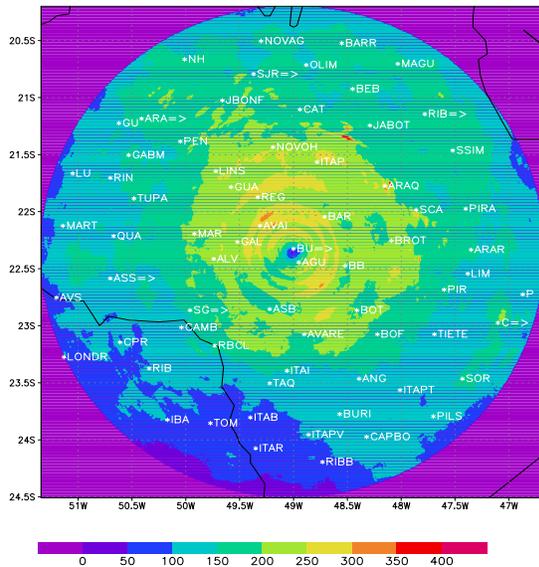


Figure 3b. Mean accumulated rainfall for February 1994 to 2004

Figures 4a and 4b show the occurrences of reflectivity exceeding 45 dBZ, for each pixel within the 240 km range, during January for the period of 1994 to 2004.

These Figures show the distribution for the majority of the observed echoes, as well as how the rainfall was distributed within the area. Between 40 to 60 times more echoes occurred in January, and between 15 and 25 times more echoes in February. The area showing the highest occurrence in the entire domain is located close to the Campinas (C) region for the months of January (>90) and February (>50).

Through the rainfall anomaly fields for January (Figure 5a) and February (Figure 5b) 2004, it can be seen that close to the areas of Morro Agudo (MAGU) and Ribeirão Preto (RIB) the occurrence of positive anomaly, with 150 mm above the mean for January and almost a twofold value during February is observed. The southern region presents a smaller value for the climatological mean and has registered January well below the average rainfall. For February

rainfall above the average climatological value was observed in the north, south and west regions, while the central and eastern areas have shown a negative anomaly, except for the Botucatu region, where the anomaly was positive.

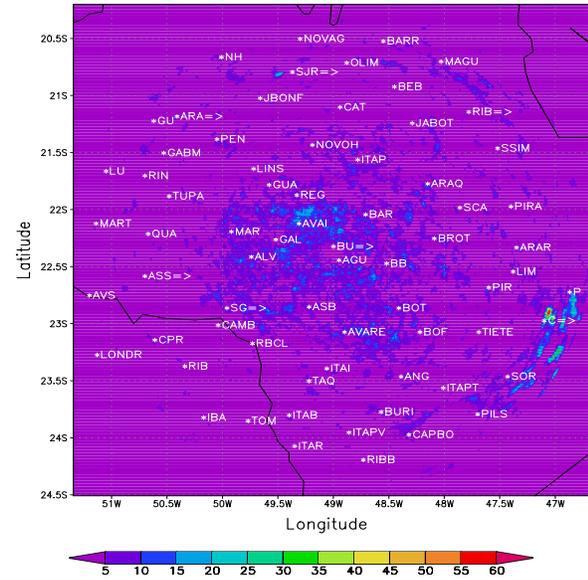


Figure 4a. Number of occurrences of echoes >45dBZ during January 1994 to 2004

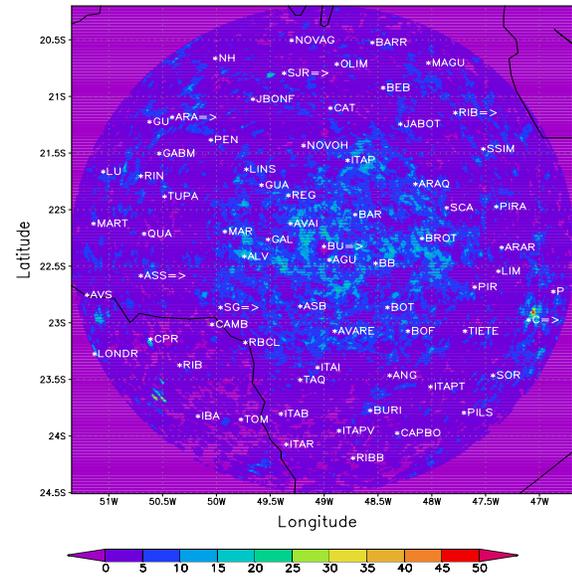


Figure 4b. Number of occurrences for echoes >45dBZ during February 1994 to 2004

4. CONCLUSIONS

In contrast, the information given by the rainfall field obtained with a pluviometer network, the rainfall

field resulting from radar has shown that February is the wetter month when compared to January.

The major rainfall concentration is located around the 100 km range from the radar, maybe as a result of greater accuracy as a function of the distance related to the radar. The southern region of the State of São Paulo shows the smallest accumulation of rainfall for both months, but being slightly greater for the month of February.

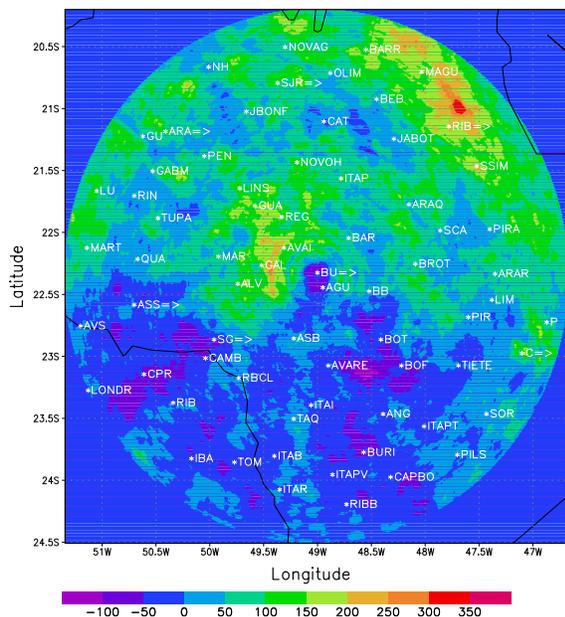


Figure 5a. Rainfall anomaly for January 2004

The echoes exceeding 45 dBZ, although not considered in the accumulated rainfall field, represent the storm mapping and show a distribution more concentrated around the 100 km range, with greater occurrence over the Campinas region, for both months of January and February.

The daily frequency of MdV for echoes varying between 46 and 60dBZ, represents a contribution of around 68% in January (1994-2004) and 62% in February (1994-2004).

5. ACKNOWLEDGEMENTS

Ana Maria Gomes and Gerhard Held are thanked for helping with the preparation of the English text of this paper. Hermes A. Godoy, is thanked for retrieving all the radar data for this study and Adelmo A. Correia, and Paulo S.

Borges, for helping with the scripts and computer programs.

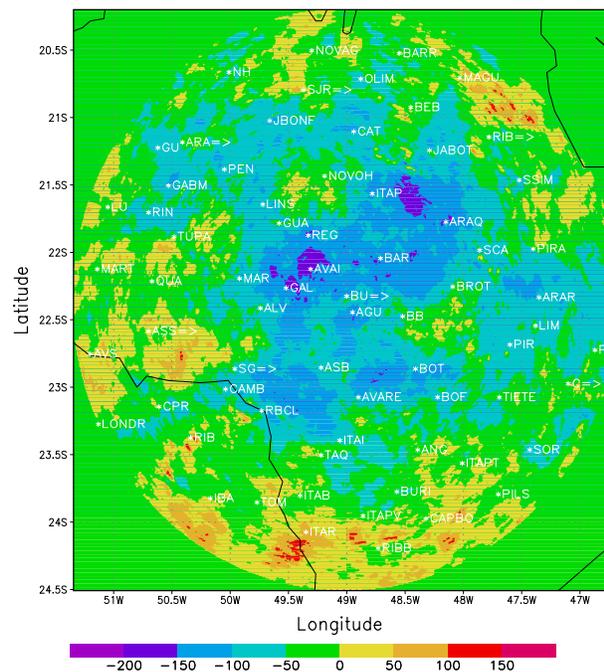


Figure 5b. Rainfall anomaly for February 2004

6. REFERENCES

Antonio, M. A., 1988: Técnica de ajuste em tempo real de medida de chuva com radar. 156p. *Tese (Doutorado em Agronomia)* – Universidade Estadual Paulista Júlio de Mesquita Filho – UNESP – Botucatu/SP.

Calheiros, R. V., 1982: Resolução espacial de estimativas de precipitação com radar hidrometeorológico. 229p. *Tese (Doutorado em Hidráulica e Saneamento)* – Universidade de São Paulo – São Carlos/SP.

Calvetti, L., Beneti, C. A. A. and Filho, A. J. P., 2003: Integração do radar meteorológico Doppler do SIMEPAR e uma rede de pluviômetros para estimativa da precipitação. In: *XI SBSR*, Belo Horizonte, Brasil, 05-10 abril 2003. Anais. INPE, p. 1137-1144.

Chaudhry, F.H., Filho, A. G. and Calheiros, R. V., 1996: Statistics on tropical convective storms observed by radar. *Atmospheric Res.*, **42**, 217-227.

Falconer, P. D., 1984: A radar-based climatology of thunderstorm days across New York State. *J. Clim. Appl. Meteor.*, **23**, 1115-1120.

Gandú, A. W., 1984: Análise estatística de ecos de radar associados a precipitação na região leste do

Estado de São Paulo, 161pp. *Dissertação (Mestrado em Meteorologia)* – Universidade de São Paulo.

Groisman, P. Y. and David R. L., 1994: The Accuracy of United States Precipitation Data. *BAMS*, **75**.

Saltikoff, E., Koistinen, J. and Hohti, H., 2000: Experience of real time spatial adjustment of the Z-R Relation according to water phase of hydrometeors. *Phys. Chem. Earth (B)*, **25**,1017-20.

Sekhon, R.S., and Srivastava, R.C., 1971: Doppler radar observations of drop-size distributions in the thunderstorm. *J. Atmos. Sci.*, **28**, 983-994.

Tokay, A. and Short, D. A., 1996: Evidence from Tropical Raindrop Spectra of the Origin of Rain from Stratiform versus Convective Clouds. *J. Appl. Meteor.*, **35**, 355-371.