P3R.7 STORM-TRACKING AND THUNDERSTORM NOWCASTING FOR SAO PAULO STATE, BRAZIL

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1. INTRODUCTION

This effort aims to monitor several meteorological phenomena that affect the State of Sao Paulo, in special the principal storms which cause floods, destruction of properties and that culminate in the incident of several deaths.

The identification of the convective systems associated to the atmospheric discharges can be an indicator of severe storms, since they are tied to intense vertical movements and to the presence of ice in the form of hail. Within these systems, the volume of water is one order of magnitude bigger than in the precipitant systems without flashes of lightning (Morales and Anagnostou, 2003).

From observations with satellites and other sensors, it was noticed that there are approximately 100 atmospheric electrical discharges on the globe every second, being associated on average to 1800 storms.

Concerned to predict the storms that might affect the launch of space rockets in Florida, USA, the Kennedy Space Center (KSC) of the NASA and the Massachusetts Institute of Technology (MIT) have developed a system of lightning flashes detection (Williams et al., 1999).

This system, which is called LISDAD (Lightning Imaging Sensor Demonstration and Display), disposes a meteorological radar and two atmospheric discharge detectors network. It was noted that the peak of atmospheric discharges was preceding in 5 to 20 minutes the appearance of severe weather such as strong winds, hail, microbursts and tornadoes.

Several local, tropical and even extratropical systems are developed or simply they cross the State of Sao Paulo:

a) Mesoscale Convective Systems (MCS's) with origin in Paraguay (Houze,1995), very often associated to low level jets in that region (Duquia and Silva Dias, 1994);

b) Squall lines originating from the Mato Grosso do Sul State (Sales e Pereira Filho, 2000);

c) Cyclonic vortices associated to the cyclogenic convective activities in the South America (Gan and Rao, 1991).

Besides the synoptic systems that are propagated over the State of Sao Paulo, other systems associated to the local circulation also contribute to the formation of convective systems such as:

d) Sea breeze fronts (Pereira Filho, 2000);

e) Differential heating of the surface due to the "urbane island of heat effect" (Vicente et al., 2002);

f) Shallow cold fronts blocking (Pereira Filho et al., 2002);

g) Severe convective systems with strong gust fronts such as microbursts or tornadoes (Massambani et al., 1992; Menezes and Silva Dias, 1998; Amorim et al., 1999).

Due to his great territorial extension, Brazil has the biggest incidence of lightning flashes in the globe (report of the Group of Atmospheric Electricity – ELAT of the National Institute for Space Research – INPE). During the January and February of 2001, more than 20 persons were stroke straightly by lightning in the Sao Paulo Metropolitan Area (Gin and Benetti, 2002).

In Brazil there is still not an integrated system such as developed in the LISDAD. On the other hand, the State of Sao Paulo has three operational meteorological radars. Two of them have Doppler capabilities, allowing the observation of the radial speed of the precipitant systems - Presidente Prudente and Bauru that are operated by the Institute of Meteorological Researches (IPMET).

The third one is non-Doppler radar and it is located in Salesopolis. This radar is operated by the Hydraulic Technological Center Foundation (FCTH) as shown in figure 1.

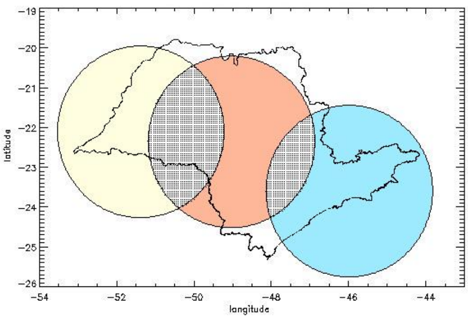

Figure 1. The Sao Paulo radars (Presidente Prudente in yellow, Bauru in red and Salesopolis in blue. The black dotted areas represent the radars intersection.

They are all inside the Integrated Network of Atmospheric Discharges Detection (RINDAT) as shown in the figure 2.

Figure 2. The RINDAT Network (symbols represent different companies from the network).

This network was built from the agreement between two power companies from the State of Minas Gerais and one from the Parana State (CEMIG,

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FURNAS and COPEL respectively), the Weather Service from the Parana State (SIMEPAR) and the National Institute for Spatial Research (INPE). This network uses Impact, Lpats III and Lpats IV sensors.

To strengthen this effort, this Ph.D. research intends to develop a storm tracking and nowcasting system to be implemented operationally in the already existent meteorological radars in the State of Sao Paulo. Through this principal objective, the project also will allow the development of three detailed points:

a) The spatial and time variability of the storms observed in the State of Sao Paulo;

b) The life cycle of the storms;

c) The intrinsic properties between radar reflectivity factor, Doppler velocities, vertically integrated liquid water and lightning in function of the storm life cycle.

2. REMOTE SENSORING DATASET

The RINDAT sensors Lpat III and Lpat IV use the TOA (time of arrival) algorithm. It is recommended a minimum of three sensors and the network counts on seventeen in order to get better accuracy. It also uses 8 IMPACT sensors that combine TOA and MDF (magnetic detection finding) algorithms, getting the magnetic directions.

The radars from IPMET have a 1.0km x 1.0km spatial resolution up to 240-km range. The radar from FCTH has 3 different settings: 0.5km x 0.5km up to 60-km range, 1.0km x 1.0km from 60-km to 120-km range and finally 2.0km x 2.0km from 120-km to 240-km range. Their geographical coordinates and characteristics are shown in the table 1 below.

Table 1: radars characteristics.

Characteristics	Radar		
	Prudente	Bauru	Salesopolis
Latitude (º)	-22 07 12	-22 21 36	-23 36 00
Longitude (º)	-51 22 48	-49 01 48	-45 58 20
Altitude (m)	460	624	925
Beam width (º)	2	2	2.1
Antenna diameter (m)	9	9	3.6
Antenna elevations	10	11	20
Scanning cycle (minutes)	10 to 15	10 to 15	5

Despite the Salesopolis radar being the only still working just on reflectivity, it also shows very good results in nowcasting (Amorim, 2000).

3. METHODOLOGY

This work has two distinct goals; the first one consists of the integration of the weather radars. This integration allows the real time monitoring of the rainy systems over the State of Sao Paulo. Beyond the surveillance by itself, the transformation of the information, from 3 polar coordinates to one Cartesian will allow the elaboration of common algorithms to the entire state.

The second goal is the classification of the systems for the interest region in order to compare them to the atmospheric discharge dataset. This classification follows the methodology proposed by Machado et. al (1998).

3.1 Radar network integration

A 3D box was built over the State of Sao Paulo, herein named 3D-PPT, where the radars information were integrated. This grid has the following vertical resolution:

- 0.5 km spacing from 1.5 km up to 7.0 km height;
- 1.0 km spacing from 7.0 up to 20.0 km height.

The horizontal resolution is 2km x 2km.

Each radar information is transformed from polar to Cartesian systems into the tridimensional grid.

Every volumetric unity of the 3D-PPT, herein called as pixel, has different portions of each single bin from one or two radars, depending on its position. The weight each bin contributes to each pixel can vary between zero and one depending on the beam width and the distance from the radar to the pixel as shown in the figure 3.

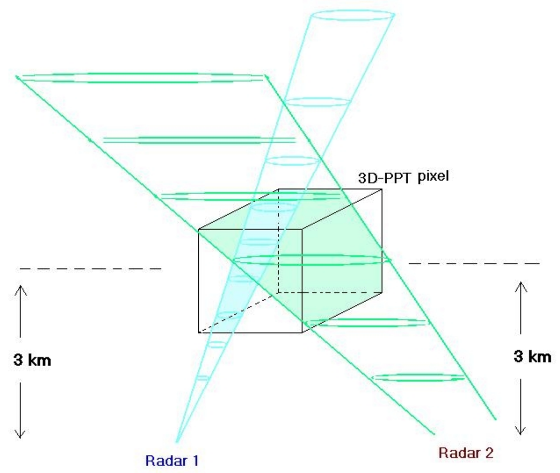

Figure 3. The Schematic representation from the contribution of individual bins to one 3D-PPT pixel final reflectivity.

The resultant reflectivity within the pixel is the sum from n-bins reflectivity (Zi) versus their distinct weight (Wi), over the total weight (Wt) as shown in the equation 1 below:

$$Z = \sum_{i=1}^{n} \frac{Z_i . w_i}{w_T} \quad (1).$$

After running this 3D-PPT, nowcasting algorithms will be incorporated. These algorithms will purpose the prevention against intense systems. However, the main benefit is the joint performance of the two responsible agencies for the radars of the state, bringing advantages in the short-term forecast of the systems that in separate way would be observed only later.

3.2 The storm-tracking algorithm

For the satellite analysis the authors classify convective systems through the infrared brightness temperatures. Thus, the thresholds that will determine when a system is convective (CS) and which clusters within each system that can be considered as maximum convection (CC) are established. These temperatures are respectively 245 K and 218 K. After isolating the CS and the CC in each image the algorithm does the recognition and identification in every integrated image. All the CC locations are compared to the CS locations to identify and count the number of CC embedded within each CS.

Similarly, when applying that satellite tracking strategy to the radar reflectivity factor we are using the thresholds of 20 and 30 dBZ, to identify the precipitating system (PS) and the precipitating cluster (PC) as recommended for so many previous works such as Cotton and Anthes (1989).

The tracking method determine the matches from one image to the next by examining all or a subset of 23 parameters (28 for the satellite because the reflectance factor which is not included for the radar algorithm) for each possible pair of PS as shown below in the table 2.

Table 2: Parameters determined for each pair of PS.

Parameter	Unity
Date and Time	(MM,dd,hh,mm)
PS center of mass	(latitude, longitude)
Radius of PS	(km)
Average Z of PS	(dBZ)
Maximum Z of PS	(dBZ)
Variance of Z of PS	(dBZ)
Gradient of Z of PS	(dBZ km^{-1})
Eccentricity of PS	
Inclination of PS major axis	(degrees from east)
Convective fraction	(%)
Number of PC	
Average radius of PC	(km)
Average Z of PC	(dBZ)
Location of largest PC	(latitude, longitude)
Propagation speed of PS	(m s^{-1})
Propagation direction of largest PC	(degrees from east)
Area overlap fraction with possible antecedent	(%)
Average (weighted) difference of all parameters	(%)

4. PRELIMINARY RESULTS

From 15th to 21st of January 2003, 210 volume scans were collected from the three radars, when several thunderstorms developed over the State of Sao Paulo. The integration and the tracking algorithm were tested for that week, when more then one cold front and other local and mesoscale systems as mentioned in the introduction affected the State of Sao Paulo (inside the black square) as shown in the figure 4 below.

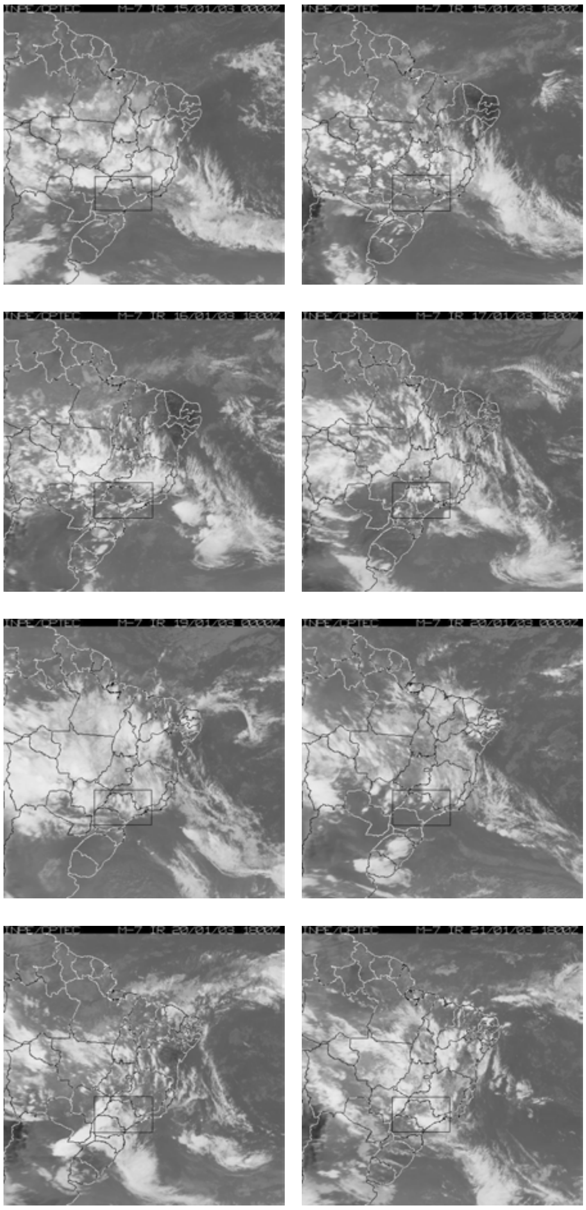

Figure 4. Sequence of infrared satellite images from 15th to 21st of January 2003.

4.1 Integration

An example of this technique can be viewed for the storms that occurred on 4th of February 2003.

Several isolated storms developed over western and eastern Sao Paulo State as well as a minor MCS that had initiated more convective storms at the north of the state as shown below in the figure 5.

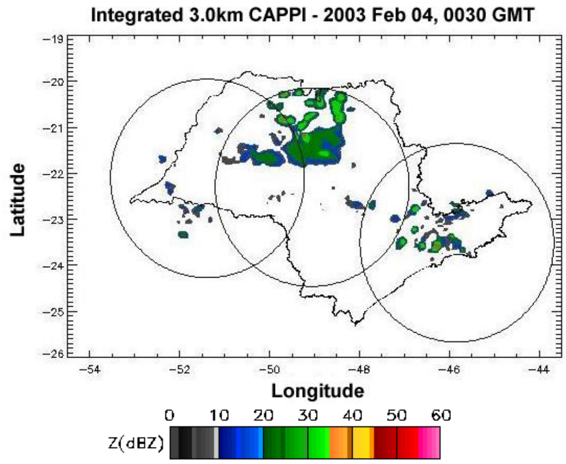

Figure 5. The integrated 3km CAPPI (above) and the reflectivity scale (below).

In those pixels from the intersection areas, the frequencies of the reflectivity from all the radars were compared to the frequencies of reflectivity obtained from the integration method.

Besides the reasonable agreement between the data from the radars (black line) and the results from the integration (red line), there is still a difference about 5% in frequency for some reflectivity intervals as shown below in the figure 6.

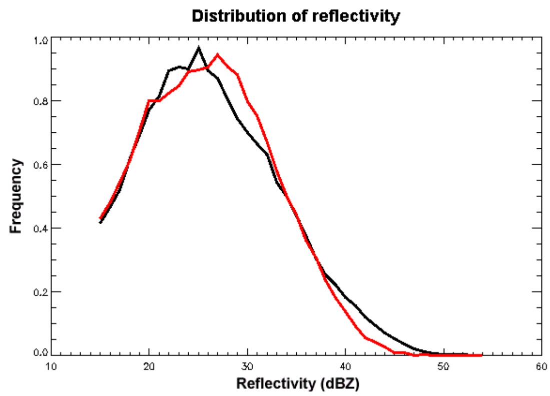

Figure 6. Results from the integration method.

Basically it can be explained in terms of bin size. Unless for some few pixels which are equidistant from two radars, the other pixels inside the intersection area are intercepted by bins of different sizes, implying in distinct volumes and finally in different backscattered signals.

Naturally, the integration will differ from each bin, since the method is adjusting the value from one bin which is too far from its radar by another one which is closest to its own radar.

4.2 Tracking algorithm

The figure 7 below shows the size dependence to the duration of the life cycle for the precipitating systems using the 20 dBZ threshold (7a) and 30 dBZ threshold (7b) and the maximum reflectivity of the precipitating systems (7c).

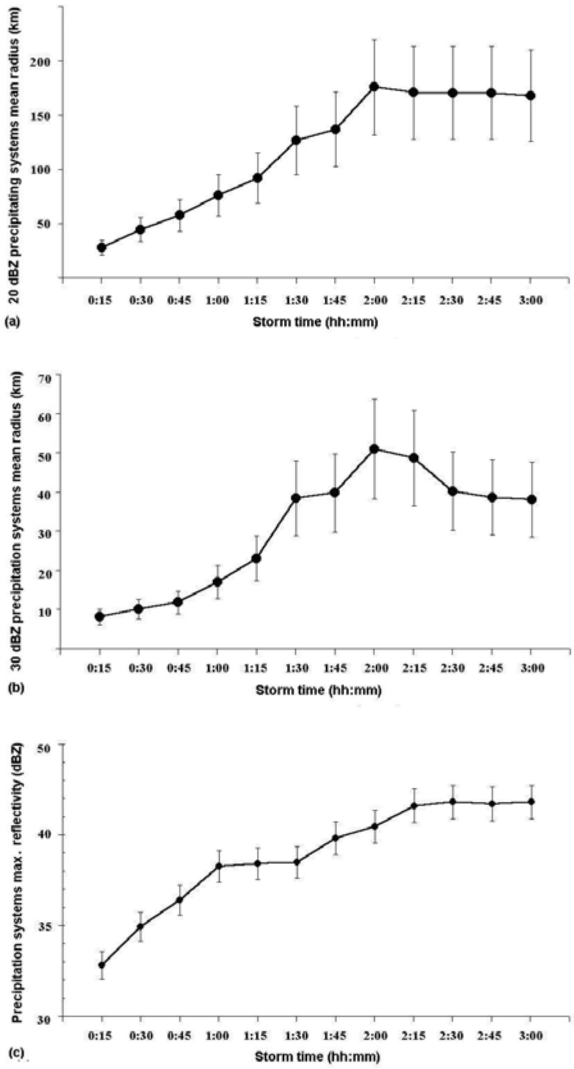

Figure 7. Initial analysis for identifying and tracking the storms over the State of Sao Paulo.

The differential early growing from the 20 to the 30 dBZ precipitating systems might indicate with more precision, the time when the storms change from the developing to the mature stages, possibly confirmed by the maximum reflectivity.

5. SUMMARY

The radar integration has been made successfully for the State of Sao Paulo. It turns possible the accomplishment of the storms over the state. From lookup tables with distance and azimutal and elevation angles, the radar coordinates are transformed into the 3D-PPT matrix.

As well as in the case of the satellite images, that were transformed from satellite projection into rectangular projection, the radar images are transformed from PPI or, inclined plans, into CAPPI, or horizontal plans, in order to calculate advection and the growth or reduction of the systems.

Besides using a few sample of the dataset, the identifying and tracking processes have been also successfully. It must be improved analyzing the entire dataset as well as the prediction tools. The next step is the coupling to the atmospheric discharge dataset. The figure 8 below shows the TRMM data for the storms that occurred on 4th of February 2003.

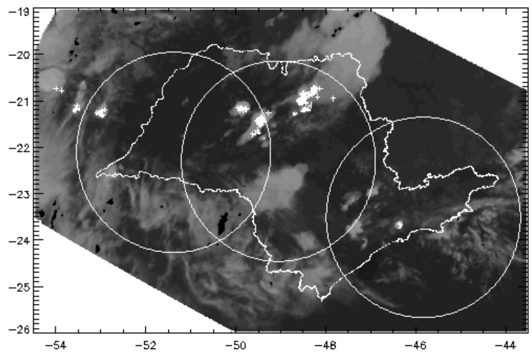

Figure 8. Atmospheric discharges (white spots) for the 3D-PPT grid.

The 3D-PPT grid will receive the lightning data from RINDAT that will be compared to the radar data and applied to the tracking algorithm as well as it was done for the reflectivity. Other thresholds will be tested in order to identify the essential parameters of the initiation of the most violent storms.

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