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ABSTRACT

A WR-110-5/EEC C-band meteorological radar was installed and has been in operation in the Eastern Coast of Northeastern Brazil at about 10°S and 36°W since the beginning of 2003. Technical specifications of the radar were given. The dynamic mechanisms that produce rain over the Eastern Coast were reviewed. The disturbances in the easterlies, and associated rainfall, is one of the main mechanisms and are difficult to be predicted because they are mesoscale weather events and forecast models do not have high enough resolution to capture them. These disturbances grow very fast and can produce severe weather with rainfall total over 300 mm day⁻¹ if the coastal sea surface temperature were above 28°C. The radar is an invaluable tool for nowcasting these events. A case study of February 19th 2003 was reported.

1. INTRODUCTION

Rainfall is the most important variable in the tropics. Apparently, rainfall seems to be simple of being observed. However, due to the random nature of the growth and development of convective cells, the classical method - the rain gage - is subject to errors that may exceed 100% in particular occasions. In addition, rain gage measurements are punctual, what makes difficult, or almost impossible, to determine the rainfall totals areal distribution with accuracy. So, whenever possible, a weather radar is the preferable instrument for observing rainfall despite the calibration problems involved. The Northeastern Brazil (NEB) is a semi-arid region, with rainfall regimes subject to a great interannual variability due to global scale phenomena such as El Niño-Southern Oscillation events. The region had a well-distributed rain gage network basically from the 1960's to 1985. However, the network was greatly degraded during the 1990's due to economic and personnel restrictions, so rainfall sampling and water management became critical issues in the region. In January 2003, a C band weather radar was installed, and has been in operation since then, in the Campus of the *Universidade Federal de Alagoas* (UFAL), city of Maceió (AL), located approximately at 10°S and 36°W, in the eastern coast of NEB. The cooperation

between *Universidade Estadual Paulista* (UNESP), Bauru (SP), *Laboratoire d'Aerologie*, Université Paul Sabatier (UPS), Toulouse, France, and the *Sindicato da Indústria do Açúcar e do Alcool do Estado de Alagoas* (Sugar and Alcohol Industries Union of the State of Alagoas) was vital to accomplish this goal. The benefits for the region include the alert of severe weather for Civil Defense, road transportation, port and airport operations, tourism and water resources management among others. The benefits for the agrarian activities, particularly sugar cane cultivation, that is the main economic activity in the coastal zones in the region, may be enormous. Calheiros and Antonio (1990) and Antonio (1996) estimated an additional gain of about US\$40 million resulting from radar information use for the State of São Paulo sugar cane cultivation, in southeastern Brazil. This article aims at divulgation of the Meteorological Radar System of Alagoas (SIRMAL) within the scientific community. The rainfall dynamic mechanisms, that produce rain in the region, and the radar system were described followed by the presentation of results of the first case study, the February 19 2003 thunderstorm.

2. A REVIEW OF RAINFALL PRODUCING MECHANISMS

Rainfall is a product of the local convection, that is, ascending motion of warm and humid air producing deep rain cells. The local convection, in turn, is controlled - intensified or inhibited - by the variability of larger scale circulation patterns resulting from a complex interaction between the atmosphere and the Earth's surface. The variability of rainfall in NEB is related to the general circulation of the atmosphere (GCA) shifts and to the air-sea interaction in the Pacific and Atlantic oceans. The El Niño-Southern Oscillation (ENSO) events are examples of planetary scale climate perturbation that modify the rainfall totals and distribution. In general, strong warm phase events (El Niño) may cause severe droughts whereas cold phase events (La Niña) are responsible for rainfall above normal. The main large scale mechanisms are the Intertropical Convergence Zone (ITCZ) and the frontal systems that are responsible for 60% to 70% of the observed rainfall in the average. Wavy disturbances in the trade wind field, convective cloud complexes and sea-land breezes are part of mesoscale systems whereas orography-induced and small convective cells are examples of microscale phenomena (Molion and Bernardo, 2002).

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Presently, it is thought that the semi-aridity of NEB is provoked by the descending branch of the Hadley-Walker cell and the associated psychrothermic inversion over the region (Molion and Bernardo, 2002). In the annual cycle, the inversion is broken by the incursion of the ITCZ in the northern part of NEB (NNE) and the penetration of southern hemisphere frontal systems over the southern part of NEB (SNE) and over the eastern coast (ENE). Wavy disturbances within the Trade wind field (WDT) are produced by the penetration of frontals systems in lower latitudes of both hemispheres over the Atlantic and Tropical Africa and occur anytime of the year. In the period December to April, the WDTs propagate within the ITCZ and, as they reach the NNE, large rain-cells are produced associated with the low level moisture flux convergence. An example is the event of April 2001 when the city of Fortaleza (3.8°S; 38.5°W) in NNE coast recorded over 800 mm due to a sequence of WDTs during that month (Cavalcanti, 2002). During May to August, the WDTs, associated with local sea-land breeze circulation, seem to be the most important mesoscale rain producing mechanism in ENE, responsible for 30 to 40% of the observed totals. An example is the event of August 2000 when parts of eastern coast recorded over 300 mm in one single day (Silva and Molion, 2002). In principle, the genesis and the structure of the WDTs could be studied with space born radar such as the TRMM except for the temporal coverage, since these systems grow and decay quite rapidly. On the other hand, a daily rain data analysis showed that 75% of the rainy days in the region had rain totals smaller than 10 mm/day, suggesting that, in general, rain cells are smaller than the TRMM highest resolution which is 4 km at the sensor's sub-point. For tropical Africa for example, Tenório (1995 and 1996), using surface radar data, concluded that rain cells had equivalent diameter smaller than 3 km. In these circumstances, a sparse, not-evenly distributed gage network tends to underestimate regional rainfall. One concludes that the weather radar seems to be the most appropriate observing instrument for NEB.

Table 1 – Main technical characteristics of the Radar WR-110-5/EEC

Wavelength (λ)	5,3 cm
Frequency	5,64 GHz
Peak Power	250 kW
Pulse repetition frequency (PRF)	250 Hz
Pulse width	2 μ s
Antenna diameter	2,4 m
Beam width	2°

3. THE METEOROLOGICAL RADAR

The radar is installed in a 25m (80ft) concrete tower built in the Campus of the Universidade Federal de Alagoas, in the City of Maceió (9°33'03"S; 35°46'13"W), a flat plateau at 104 m (340ft) above sea level. The nearest horizon obstacles are small hills of about 400 m (1300ft) altitude, located 40 km

(25 st mi) in northwestern direction. The first five floors of the tower are used as facilities for research and training.

3.1 RADAR SPECIFICATION

The equipment is a C-band WR-110-5/EEC implemented with a SASSANDRA signal-digitizing unit and computer codes. Table 1 shows the main technical specs of the radar.

A no-break and a power generator system were installed for providing continuous operation in case of power failure.



Figure 1. Area covered by the radar

3.2 RADAR DATA DIGITIZING SYSTEM

The SASSANDRA was developed at *Laboratoire d'Aerologie*, LA/UPS, Toulouse, France, led by Dr. Henri Sauvageot (Lebel et al., 1992) within the Program EPSAT (*Etude des Précipitation par SATellite*) which consists of electronic circuitry for interface the radar and PC: an analogue-to-digital signal converter, a signal integrator, an interface for antenna position (azimuth and elevation) and radar trigger synchronization to run the system appropriately. Table 2 shows the specs of SASSANDRA system.

The signal acquisition and conditioning software include distance and attenuation corrections and change of coordinates. The radar data are viewed as color images in PPI and RHI modes.

Table 2 – Main characteristics of the radar data digitizing system-SASSANDRA

Resolution	8 (eight) bits
Step value	0,33 db
Rotation Speed	1 turn per 72 s
Pulse Rate Frequency	250 Hz
Beam Range	512 – first at 1.2 km
Beam Range Resolution	250, 500 or 750 m
Ranges (3)	128km, 256 km, 383 km
Image presentation	PPI e RHI, [dBz].
Thresholds	Programmable

3.3 RADAR DATA DISSEMINATION

The radar data will be used for short range weather forecast (“nowcasting”), research purposes and for supporting human activities of the Civil

Defense, agriculture, water management, tourism and transportation segments. Figure 1 shows the area covered by the radar with 4 different coverage radii 50 km, 100 km, 250 km and 350 km, indicating that a good portion of the Atlantic Ocean will now be observed. Remind the reader that the most severe storms come from the Atlantic sector, over which they intensify through air-sea interaction processes and were practically impossible to be identified with a decision-making leading time.

The modes of operation are PPI (Plan Position Indicator) and RHI. (Range Height Indicator). In the PPI mode, the antenna sweeps 360° at low angles and provides a horizontal or plane digital image of the rainfall events that are occurring in the radar range at 1 rpm rate. The image is coded with rainfall rates and is transferred and stored sequentially in IBM personal computers containing software for image animation. Simple advection model is used to estimate the displacement time of rain-cell and storms for nowcasting purposes. The operation may be switched to the RHI whenever a vertical cross-section of the approaching storm is necessary. In case of severe storm, a warning message will be passed onto Civil Defense Headquarter for the applicable measures at this time. The warning may be followed emergency message if the storm develops further and reaches severe weather condition. It is important to mention that Brazil has fast computer numerical weather forecast operationally available. The *Centro de Previsão de Tempo e Estudos Climáticos* (CPTEC/INPE/MCT) issues 7 days in advance medium range weather forecasts, with spatial resolution of 100km and 200km grid resolution, and 72 h in advance regional short range forecasts, with spatial resolution of 40 km. The 10 km resolution scale short range forecasts are being implemented locally.

Another product is the areal distribution of daily rainfall totals, issued every 24 h which is very useful for agricultural and water management purposes. The products will be transferred to users through the web at set time intervals depending on the type of product and class of user, either free or restricted access. For example, a normal user will have a new PPI image available every 30 min in the radar web site as opposed to the Civil Defense Headquarter that will receive real-time when necessary.

4. CASE STUDY: THE THUNDERSTORM OF FEBRUARY 19th

The following ZR relationship was determined for the radar using a Joss-Waldvogel Disdrometer RD-69, Disdromet LTD, using a 10 month observed data period (Moraes, 2003).

$$Z = 176,5 R^{1.29}$$

The radar started operating at the beginning of December 2003, climatically one of the driest months. On February 19, a thunderstorm was within the range of the radar. Figure 2 shows the PPI for 15:47 local time (LT) with the rain-cells spatial distribution. Several RHI images of the raining convective complex

(RCC), located to the SW (235°) at a distance of 20 km, were made. Figures 3 and 4 show the 15:01LT the 15:45LT RHI, respectively. Comparing the two figures, one can see that the RCC grew in rain area quite fast, in 45 min approximately, cloud tops developed from 10km to 15 km height and the rain-rates, using the above ZR relationship, were estimated up to 136 mm hr⁻¹.

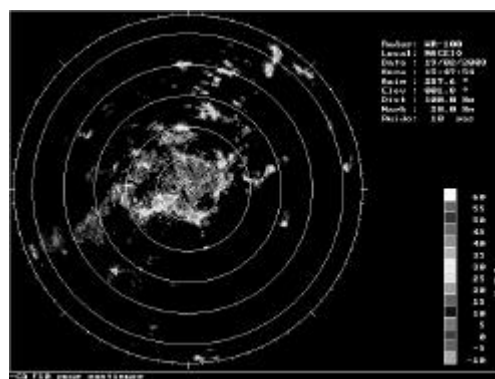


Figure 2. PPI image of February 19, 2003 at 15:47LT

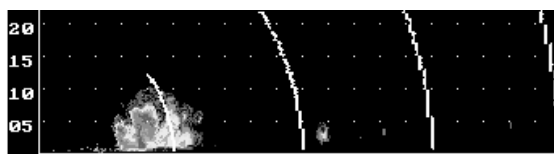


Figure 3. RHI image of February 19, 2003 at 15:01LT

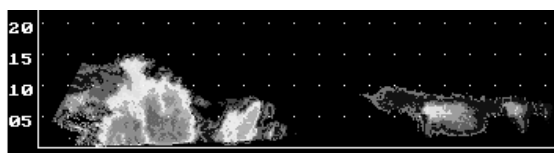


Figure 4. RHI image of February 19, 2003 at 15:45LT

The 18Z (15LT) weather analysis charts were made using NCEP ReAnalysis data with the help of the software GrADS (Grid Analysis and Display System, version 2.8SL). A cyclonic vortex, centered at 15°S and 30°W over the Atlantic, and an anticyclonic circulation, located at 15°S and 55°W over Central Brazil, generated a diffluent flow in the high troposphere over NEB, enhancing the upward motion. Figure 5 is a cross-section of vertical velocity (ω) from 10°N to 20°S, centered at longitude 35°W near the radar longitude. A strong vertical ascending motion region is seen, centered at 9°S, with a maximum of 0.12 hPa s⁻¹ about 900 hPa level and extending through the hole troposphere, indicating favorable conditions for RCC development.

The relative humidity flux divergence showed a large area with negative values along the East Coast, that is, a moisture flux convergence of about $-1.5 \times 10^{-3} \text{ kg m}^{-2} \text{ s}^{-1}$. This convergence supplied moisture for the RCC to develop and produce the high rainfall rates observed. The outgoing longwave radiation (OLR) chart, at the top of the atmosphere, showed flux

values between 140 Wm^{-2} and 160 Wm^{-2} over the NEB East Coast indicating that the area was covered with cold high cloud tops, estimated to be around 12 to 15km high in the average and consistent with radar estimates. Overall, the troposphere above the NEB East Coast was unstable and moist, favoring thunders torm development.

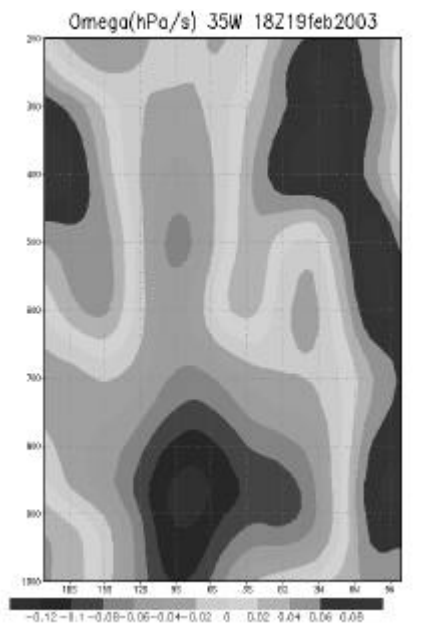


Figure 5. Latitudinal cross-section of the vertical velocity (ω) given in hPa s^{-1} from 10°N to 20°S , centered at 35°W for February 19th 2003 15LT

5. CONCLUDING REMARKS

The weather radar seems to be the most appropriate instrument for observing rainfall in the tropics, especially along coastal regions. In the case of Eastern Coast of Northeast Brazil, both TRMM and satellite images have not high enough temporal and spatial resolutions to detect most of rain cells since their equivalent diameters and life-time are below the threshold of these monitoring systems. Traveling weather disturbances within the Trade wind field, originated from the African continent and the Atlantic Ocean, may develop very quickly as they reach the continent if coastal sea surface temperatures were above 28°C and moisture flux convergence is intense. One example is the storm of August 1st, 2000, that produced over 300 mm of rain in less than 12 hours, flash floods and, as a consequence, caused the loss of 58 lives, left 80 thousand people homeless and damages exceeding US\$ 700 million in the State of Alagoas and Pernambuco. The WR-110-5/EEC C Band radar, installed in the Campus of the *Universidade Federal de Alagoas* (UFAL), has been in around-clock operation since the beginning of 2003 and has proved already to be a valuable instrument for detecting these disturbances with a sufficient leading time for Civil Defense officials to take appropriate safety measures. The case study of

February 19th 2003 storm was reported here as a first example. One foresees that this radar will be invaluable for the sustainable development and for the safety of the people living along the Eastern Cost of Northeastern Brazil.

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