THE UPPER LEVEL WINDS AND THEIR RELATIONSHIP WITH CONVECTIVE SYSTEMS – A CASE STUDY

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ABSTRACT

January 2004 was one of the rainiest transition season from dry to wet in the last 30 years in Northeast Region of Brazil, with rainfall anomalies of more than 300% in some places. A complex interaction of meteorological systems such as Intertropical Convergence Zone (ITCZ), Upper Level Cyclonic Vortex (ULCV) and South Atlantic Convergence Zone (SACZ) guaranteed almost 10 days of continuous rain, with severe convective events that caused dramatic floods. In this work we test the ability of GOES satellite derived tools generated at CPTEC/INPE, such as high-level divergence fields, cloud cluster area expansion and cloud tracking to identify and follow these convective systems. Rain gage data are used to verify the observed rain. Also it is showed a comparison between these fields and METEOSAT winds made at FUNCEME, and presented the statistics of the satellite winds quality calculated operationally at CPTEC for GOES data.

1. INTRODUCTION

Convective systems have an important role in tropical atmospheric circulation. They affect the energy changes and also are responsible by the most of the observed rain (Machado and Rossow, 1993). In Northeast Region of Brazil (NEB), the rainfall is concentrated in a short period (February to May), being mainly dependent of the ITCZ (Intertropical Convergence Zone) position. Even during this period, the convective activity presents high space and temporal variability. This variability is related to different surface conditions such as ocean-continent contrast and topography, and also to the diurnal cycle or even intraseazonal modulation, like Madden-Julian oscillation. Consequently, during NEB rainy season, a great variety of conditions can happen, from severe convective thunderstorms up to clear sky condition.

Convective systems are characterized by strong rainfall, usually with lightning and thunderstorms. Cumulu Nimbus clouds are predominant in these events. Such clouds are associated with warm, moist and unstable air and present deep vertical development with high level divergence, by the mass continuity (Holton, 1979).
The study of these systems is prejudiced by the scarcity of conventional observations. Considering yet that most of tropical areas is covered by ocean, meteorological satellites naturally appear as an alternative and

important source of information. With the improvement of the cloud-drift winds (CDW) methodologies that produce more numerous and consistent fields, some studies pointed the potential applications of such data (Schmetz et al (1995), Velden et al (1997)). Using another approach than that described by from Schmetz et al. (1995) that showed used CDW to climatic scale studies, Laurent and Sakamoto (1998) used high-level divergence fields calculated from water vapor winds to identify convective systems. They showed that areas with low brightness temperature, corresponding to convective systems are correlated with large divergence values. Sakamoto and Laurent (2003) tested briefly the use of divergence fields to identify convective systems in Northeast Region of Brazil. More recently, Machado and Laurent (2004) analyzed Amazonia convective systems based on convective area expansion, system life duration and upper levels wind divergence.

In this study we analyze January 2004 convective systems observed in the Northeast Region of Brazil, mainly in Ceara state. GOES and METEOSAT water vapor upper level winds are used, both to evaluate the upper level flow and also to calculate divergence fields. GOES images were also used to track convective clouds and evaluate the convective system area expansion. Data Collection Platform (DCP) and conventional rain gage data from Ceara state are used to verify the rainfall intensity.

2. DATA AND METHODOLOGY

2.1 Wind Derivation

Atmospheric motions are computed from semi-hourly images from METEOSAT 7 (WV channel) and GOES (channel 3), both at full resolution. The WV wind extraction procedure is basically described in Laurent (1993) . The vector computation is similar to that used in operational centers to derive cloud motion winds from IR or WV images (Schmetz et al., 1993, Velden et al., 1997). There is no distinction between clouds and pure water vapor structures. The processing is automatic, based on cross correlation scheme with similar patterns determined in a sequence of three successive images. In the windowing procedure, a target window with 16 pixels has its position shifted by the maximum gradient calculated bi-dimensionally. The level assignment is performed by comparison with numerical model results from CPTEC/INPE. Basic quality control procedures are applied: correlation coefficient, temporal and spatial consistency check (Laurent et al. (2002)).

2.2 High Level Divergence

The divergence fields presented in this study follow the procedures of Laurent and Sakamoto (1998), where the estimated wind field is firstly interpolated on a regular mesh, and the divergence is derived by finite difference. To impose time continuity, the interpolation is applied simultaneously in space and time (Doswell, 1977). For this study, we considered the vectors in the layer from 150 to 250 hPa as representative to high level, and used the vectors in this layer to calculate divergence. We adopted a grid size of 1° to interpolate the estimated wind vectors from both GOES and METEOSAT images. Averages and divergence fields were analyzed.

2.3 Cloud Tracking and Area Expansion of Convective Systems

Cloud clusters are tracked by Mathon and Laurent (2001) methodology. The procedure has a capability to detect whether a system initiates spontaneously or from a split, and whether it ends by dissipation or by merging into another system. Cloud tracking is performed routinely at CPTEC/INPE for GOES images, and these results are analyzed to January cases. Area expansion processing was made following Machado et al (1998) procedure. The methodology consists in the identification of convective system based on its brightness temperature. The quantity of pixels with temperatures bellow a threshold (we adopted 235 K) is associated to the convective system area. Only the systems with more than 200 pixels (~3500 km^2) are considered in this study. To obtain the area expansion rate we calculated the normalized difference of the system area between two successive images. Negative (positive) rates correspond to contraction or decaying (expansion or growing) phase of the system. Area expansion is calculated for GOES satellite images operationally by CPTEC/INPE, and its processing for January 2004 was used in this study.

2.4 Precipitation

The data from Ceara State rain gauge DCP (Data Collection Platform) network are used to analyze in more details the relationship between satellite derived parameters and the observed rainfall. Although very dense, the rain gauge network data provide only 24 hours accumulated rainfall. By the other hand the DCP´s network are still in installation phase, for this reason no more than 4 stations hourly accumulated rainfall data could be analyzed in the period (Fortaleza, Aquiraz, Maranguape and Sao Goncalo do Amarante stations). In Figure 2, we can see Ceara State location, and the DCP area coverage.

3. RESULTS

3.1 GOES WV Winds Quality

The GOES wind vectors fields used in the study were processed by CPTEC/INPE. WV and IR wind vectors are processed over Latin America area (60°S 100°W – 30°N 10°W). Since January 2004, these vectors are evaluated compared with collocated radiosondes. BIAS, RMSE for both, speed and vector and also the mean vector differences are calculated. The results for high-level WV winds (layer from 400 to 100 hPa) in Tropical area (20°S to 20°N) are showed in Table 1.

Month	***BIAS-VT***	***RMS-VT***	***BIAS-VL***	***RMS-VL***	***VT_M_DF***	***NUM***
January	-0.16	7.17	-0.43	4.19	2.78	210
February	0.76	8.72	0.61	5.87	3.69	217
March	0.49	7.52	0.35	4.73	3.47	206
April	0.59	7.86	0.44	4.80	3.90	194

Table 1 – Quality statistics for high-level WV winds processed at CPTEC/INPE in 2004. VT refers to vector, VL means speed, VT_M_DF is the mean vector difference and NUM is the number of analyzed wind vectors.

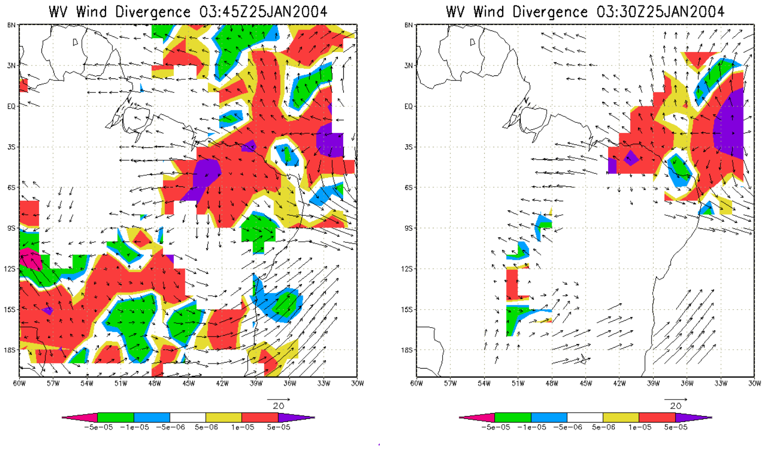
The statistics show us that the high level wind vectors processed by CPTEC/INPE present good quality. The errors are comparable to that observed in other meteorological center´s processing like NOAA and JMA. Small BIAS values both in vector and speed comparison means that satellite derived winds and collocated radiosondes have, in general, similar tendencies. RMSE and BIAS values are small for speed than for vector statistics. This can be explained by the fact that cloud drift winds reflect larger scales than radiosonde winds. In this sense the high level flow depicted for these two wind sources can be slightly variable, what reflect more in the RMSE.

3.2 GOES and METEOSAT WV Winds

Based on similar methodologies, GOES and METEOSAT WV winds were analyzed comparatively. In this study, METEOSAT wind vectors level was still defined using a climatological profile. However even considering this difference, both upper level wind fields depict the general flow (see Figure 1). To verify the variability we calculated the BIAS and RMSE comparing GOES and METEOSAT vectors over Fortaleza area, where the analysis is concentrated. For BIAS we obtained –0,34 and 5,03 for RMSE. Considering that beyond the difference related to level definition, time difference (15 minutes), and also the differences of WV channel sensors, the results can be considered satisfactory. Based on this and in the quality of GOES winds, and furthermore the data availability, GOES WV wind vectors are used more extensively in this study.

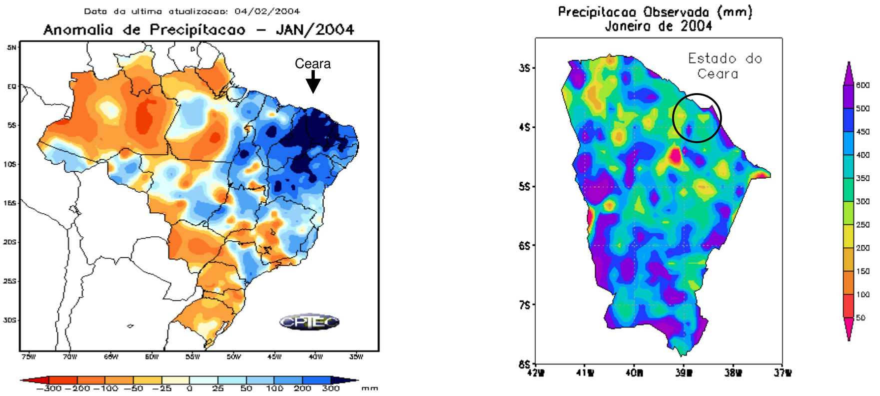
3.3 High Level Divergence

Although January is considered as the transition season from dry to wet season, in 2004, the observed rainfall was superior to any expectation. A singular interaction of three meteorological systems: Intertropical Convergence Zone (ITCZ), Upper Level Cyclonic Vortex (ULCV) and South Atlantic Convergence Zone (SACZ) caused almost 10 days of continuous rain in the second half of the month, this wet period impacted with positive anomalies with values more than 300% in almost all Brazilian Northeast regions (Figure 2a). In Ceara State, the average rainfall observed during January was 407 mm, nearly 4 times above the monthly climatology that is only 91 mm. The rain was concentrated in the second half of the month and largest values were observed mainly in the southwest, with some areas in north, including Fortaleza, the capital of the state (Figure 2b). The large amount of rainfall in the south part reflects the influence of cold frontal systems that sometimes developed in the SACZ. The others regions showing heavy rain areas were mostly related to convective systems associated with ULCV and ITCZ. Kousky and Gan (1981) described the influencec of such systems during the ULCV situation.



(a) (b)

Figure 1 – High level WV wind vector to: (a) GOES at 3:45Z and (b) METEOSAT at 3:30Z, January 25.

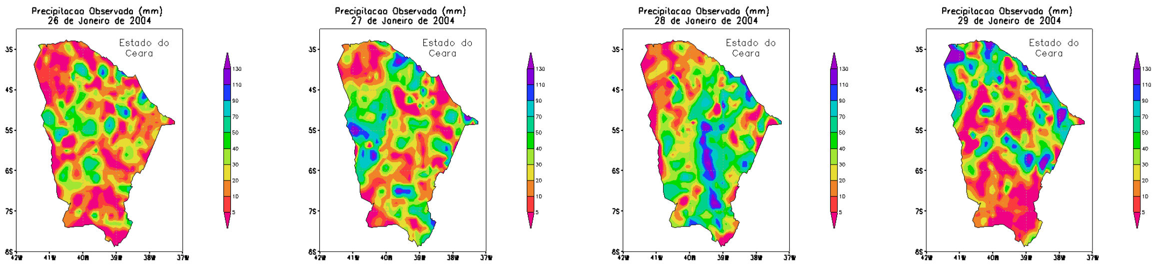


(a) (b)

Figure 2 – Rainfall for January 2004: (a) anomaly in Brazil (from CPTEC/INPE) and (b) observation in Ceara State (from FUNCEME)

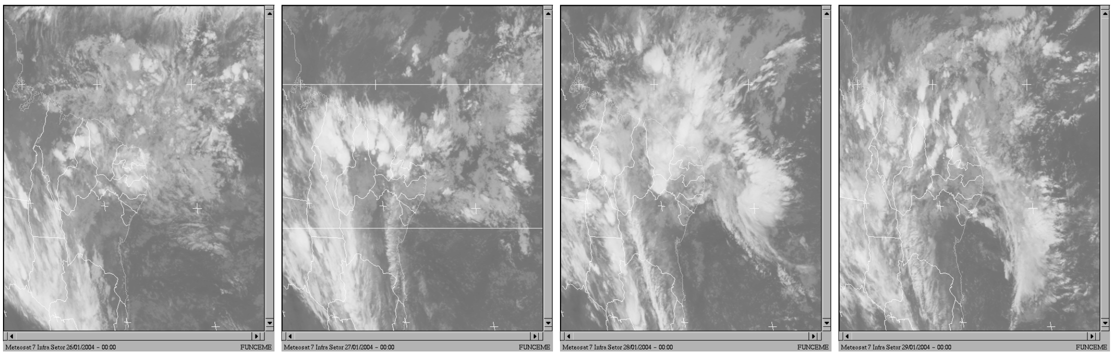
The period from January 26 to 29 were selected to analyze high level divergence fields. During this period the total amount (percent of significance in relation to monthly amount) observed in the Fortaleza, Aquiraz, Maranguape and São Goncalo do Amarante DCP´s are, 419 mm (81%), 242,2 mm (50,3%), 138,8 mm (34%) and 259,4 mm (56,7%). In several other Ceara state areas the daily rainfall amount was more than 100 mm (Figure 3). During these days, convective systems associated to ULCV were the responsible for the observed rain. As showed in the METEOSAT IR images in Figure 4, this ULCV presented typical characteristics: clear atmosphere in the center, without clouds, occasioned by the subsidence, and a cloudy boundary with convective systems. The GOES divergence fields (Figure 5), confirm high level convergence area in the center, and the large divergence areas in the boundaries. The interpolated wind vectors shows the cyclonic vortex in the ocean near the east cost and a anti-cyclonic circulation in the continent related to Bolivian High (mainly in January 29 picture). In METEOSAT divergence fields the same high level flow and divergence areas are observed (figure not shown). The values of divergence fields calculated for GOES and METEOSAT wind vectors are comparable, in both cases, in positive areas and negative value areas.

Taking into account the DCP data set, analysis to Fortaleza station showed that the upper level atmosphere is essentially divergent during all the period before precipitation. However, as we can see in Figure 6, close few hours before and during the heavy rain period, it is observed a remarkable elevation of the divergent values. This characteristic is similar to other studies like Machado and Laurent (2004) in Amazonia cases. The analysis for other DCP station data showed quite similar results.



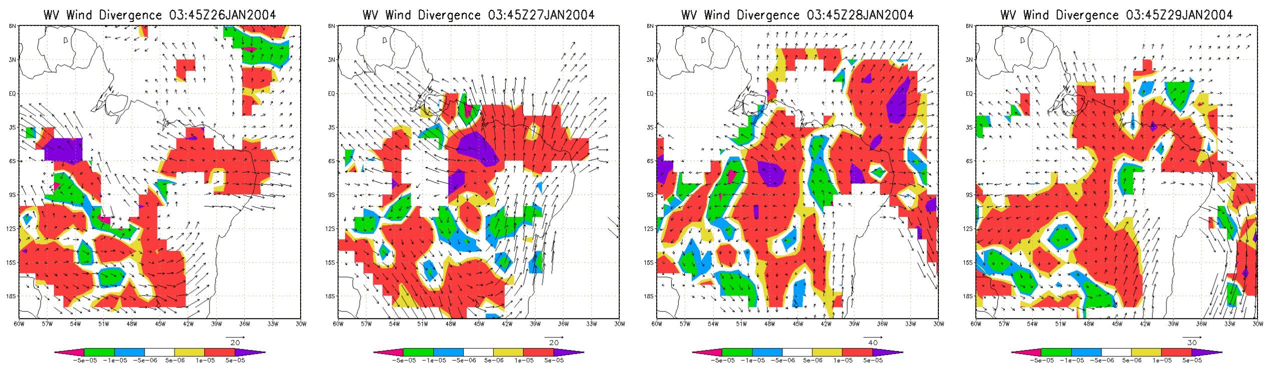
(a) (b) (c) (d)

Figura 3 – 24 hour accumulated rainfall observed in Ceara state in January: (a) 26, (b) 27, (c) 28 e (d) 29



(a) (b) (c) (d)

Figure 4 – METEOSAT 7 IR images for January: (a) 26, (b) 27, (c) 28 e (d) 29 at 03:00Z



(a) (b) (c) (d)

Figure 5 – High level divergence fields (250 to 150hPa) at 03:45Z, calculated from GOES WV wind vector to January: (a) 26, (b) 27, (c) 28 and (d) 29.

The average divergence in Fortaleza area, during rainy and not rainy period (Figure 7a) shows that during the rainy time, in general, the high level divergence was superior compared to no rainy days. In Figure 7a, we can also see a sign of the diurnal cycle, with maximum during early morning (near 8:45Z or 5:45 local time), and a minimum in the afternoon (near 18:00Z or 15:00 local time). During the period from January 26 to 29, this diurnal cycle sign was evident (Figure 8b). In Ceara State coastal areas rainfall is normally observed during night and early morning as showed by Fortaleza DCP data set for January 2004. So, this maximum of high-level divergence could reflect the daily distribution of the rainfall in the area.

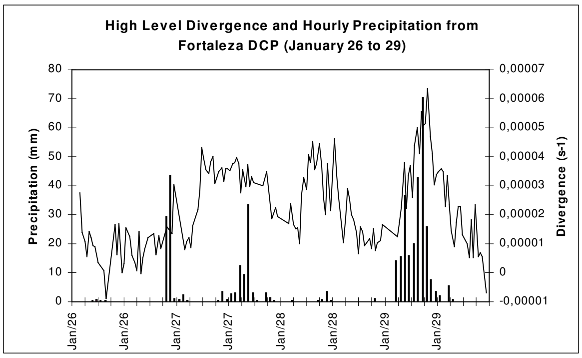
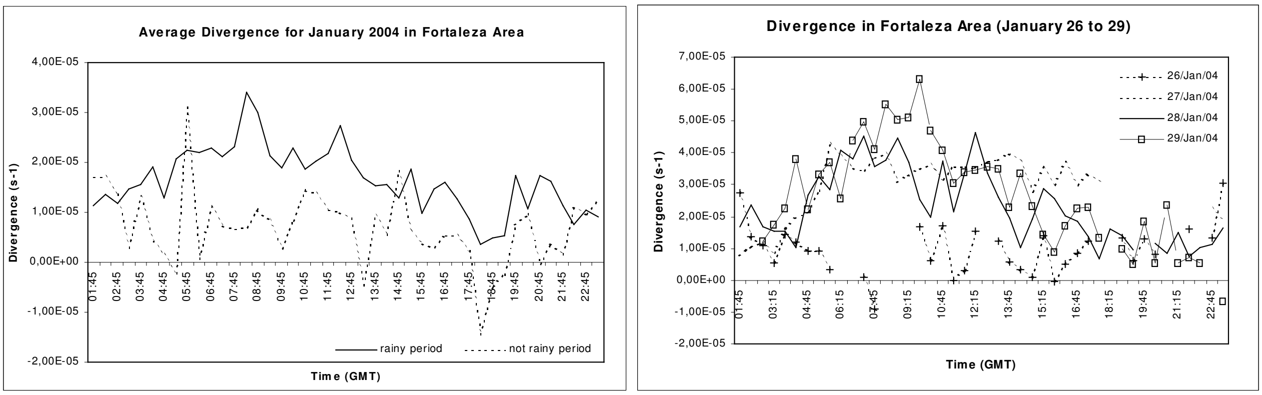


Figure 6 – High level GOES wind divergence and hourly precipitation observed by Fortaleza´s DCP for January 26 to 29

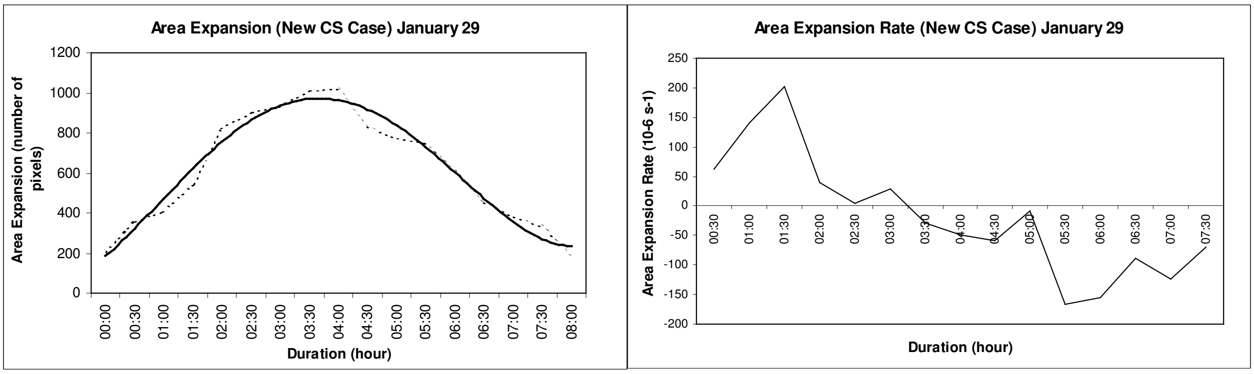


(a) (b)

Figure 7 – High-level GOES wind divergence over Fortaleza area: (a) average for January 2004 during rainy and not rainy period and (b) daily variation for January 26 to 29.

3.4 Cloud Tracking and Convective System Area Expansion

During January 29 convective systems (CS) were observed in the Northeast region. In these days more than 290 CS were observed in the area from 20°S 60°W and 6°N 30°W. Most of then had short life (less than 1,5 hour). Those having long life CS with more than 12 hours were normally the result of many merges and splits from several others convective systems. As a convective system (CS) can initiate by a split or dissipated by a merge, we decided to select only those CS that grow up spontaneously without any merge or split, and with more than 5 hours duration. In this way we can capture the characteristic of the CS from natural initiation up to natural dissipation. The life cycle of these systems is showed in Figure 8a. In average, the convective system area reaches its maximum near the middle of its life cycle. The shape of the adjusted curve (continuous line) is very similar to that obtained by Machado and Laurent (2004). In Figure 8b, we see that for these events the maximum area expansion rate happened before convective systems reaches its largest form. At the time in which CS reaches its largest area coverage, the brightness temperature is also very reduced. This is evident, mainly, in the dashed line in Figure 9 that represents the average of the minimum temperatures observed in the analyzed CS cases. By the other hand, at the period of maximum area expansion rate (nearly 1,5 hour after the beginning of the system), the CS temperature undergoes deeper decrease. In Fortaleza rainfall began during the night before the 29 and persisted up to near 16Z, with highest accumulated amount at 9Z, of 70,4 mm in one hour. Instead of a single CS this rainy event was caused by many short-lived systems. The analysis of this case is not straightforward because the observed systems were initiated by the split of a large convective system observed over the ocean, near the coast in the day before. Figure 10 shows the average curves based on only two systems that could be identified. These systems were tracked for less than 5 hour and have both a very cold minimum temperature. One of these systems was tracked at 1:15Z near the coast, and the other initiated from a split at 15:45Z. One of the systems was identified 5 hours after inside the continent, in decaying process.



(a) (b)

Figure 8 – Average of convective systems: (a) area expansion life cycle (continuous line: adjusted curve; dashed line: area expansion) (b) area expansion rate during the life cycle.

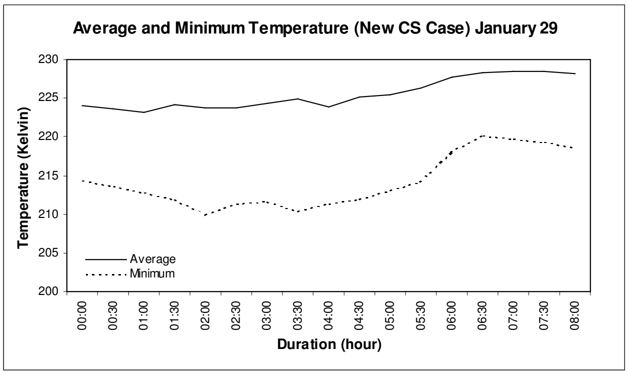
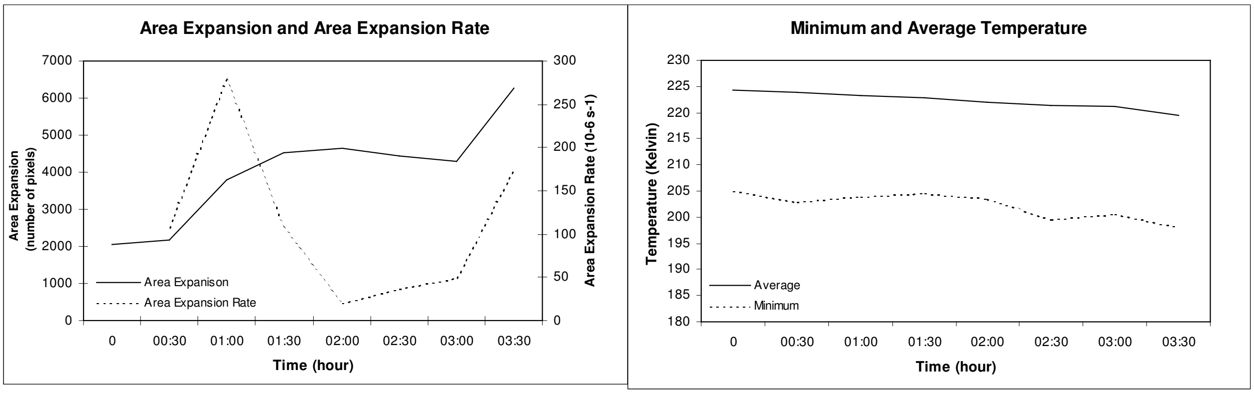


Figure 9 – Average and minimum temperature observed in the CS case studied.



(a) (b)

Figure 10 – Average of convective systems: (a) area expansion rate during the life cycle and (b) average temperature.

4. FINAL CONSIDERATIONS

This work shows the application of CDW and CS tracking, to understand and diagnostic extreme rainy events happen over Ceara state during January 2004. The results depicted the good performance of CPTEC/INPE WV winds processing. The quality statistics with collocated radiosondes present values with same magnitudes as obtained by others center. By the other hand, collocated GOES and METEOSAT WV winds presented good correlation, as showed by the BIAS and RMSE. Probably many of the possible errors were reduced because we considered a layer (250 to 150 hPa) in the two satellites comparison. Upper level atmosphere over Fortaleza area were divergent during almost all January. However during the rainy periods the high-level wind divergence was reinforced presenting values superior of that observed during not rainy time. Also, mainly during rainy days, a diurnal cycle of the upper level wind divergence could be clearly detected, with maximum during early morning at the time of maximum precipitation and the minimum in the afternoon. The performance of cloud tracking procedure was good in the detection of convective systems. The area expansion analysis permitted to see some life cycle characteristics that reinforce Machado and Laurent (2004) results. Although the data set did not permitted a deep joint analysis with divergence and area expansion, and even considering that this is a case study, the results suggest that upper level winds can be used to monitor convective systems and even to predict them.

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