7.2

A TECHNIQUE FOR FORECASTING AND TRACKING ACTIVE CONVECTIVE CELLS : AN APPLICATION TO MESOSCALE CONVECTIVE SYSTEMS OVER DEL PLATA BASIN

D. A. Vila[1,2], L.A.T. Machado[2]

[1] Instituto Nacional del Agua, INA / SIAH, Argentina
[2] Divisao de Satelites Ambientais, CPTEC/INPE, Brasil

1. INTRODUCTION

Mesoscale Convective Systems (hereafter MCSs) are responsible for most of the warm-season rainfall over tropical South America (Velasco and Fritsch, 1987; Vila, 2005), Sahelian region (Mathon and Laurent, 2001) and various regions of the earth. They are also responsible for some extreme weather conditions; the frequency of convective systems is the principal factor determining inter-annual climate variability.

Nevertheless, in spite of their substantial contribution to the production of significant weather, these systems are not forecast accurately (Corfidi et al, 1996). Knowledge of convective systems evolution is important for understanding weather and climate, particularly in the tropics; it is essential to improve forecasting in order to reduce the vulnerability of extreme weather damage The identification of predictive parameters for the evolution of a convective system, based on their previous stage, could make a significant contribution to a nowcasting scheme and provide important information for mesoscale model initialization. (Machado and Laurent, 2004).

The purpose of this study is to develop and validate an algorithm for tracking and forecast the physical characteristics of MCSs through their entire life cycle using the thermal channel information (10.8 μm) of geostationary satellites.

2. THE FORTRACC TECHNIQUE

The ForTrACC technique (Forecasting and Tracking of Active Convective Cells) is a group of programs that allows the automatic construction of Mesoscale Convective Systems physical properties database (in particular we will work with this kind of cloud systems in agreement with the definitions that will be given in the next section) using GOES 8 infrared satellite imagery (10.8 μm).

The main elements that compose this system are the following: (1) the cloud cluster detection method is based on a threshold temperature (T_{ir}<235 K); (2) the evaluation of morphological and radiative parameters of each MCSs detected in the previous step including cold tops information (T_{ir}<235 K); (3) the tracking technique based on overlapping areas between successive images with a minimum size of 150 pixels; (4) the construction of the life cycle of each MCS and (5) the virtual-image generation based on the evolution of the MCS in previous steps.

To identify in a satellite image the regions that fulfill the cold tops brightness temperature and minimum size requirements, a process of identification of connex spaces ("clusters") defined as the region of contiguous pixels was carried out. Morphological and radiative parameters of each MCS detected in the first process as size, position, mean temperature, etc. are extensively described in Machado et al (1998) and Vila y Machado (2004).

The tracking methodology is based on the tracking algorithm presented in Mathon and Laurent (2001). Tracking of convective clouds is performed with an areal overlap method. This technique simply assumes that a cloud at a later time correspond to those at an earlier time when their position overlap. When several MCSs overlap, larger surface overlapping pair of MCSs is chosen to continue the MCS life cycle.

The comparison of successive satellite images is carried out "forward" and "backward" in time (Williams and Houze 1987; Mathon and Laurent 2001), so that there are five types of possible situations to consider with this tracking algorithm: Spontaneous generation, natural dissipation (NOR), continuity (C), Split (S) and Merge (M).

The virtual image generation is carried out considering fundamentally two parameters: (1) the possible displacement of the center of mass of the MCS and (2) the life cycle phase (growth / decay) of the MCS in that moment.

(1) ***MCS Center of mass displacement estimation***: starting from the identification and tracking of a given MCS in the three successive intervals "t-2Dt", "t - Dt" and "t" along the life cycle, the displacement of the center of mass of the MCS is performed applying the following procedure: The estimated speed in the previous time step (in km/h) is calculated considering the displacement of the center of mass between "t-2Dt" and "t - Dt." Appliying this procedure, V(t-1) is obtained. Assuming constant that velocity (in intensity and direction), a predicted velocity VP(t) is generated. Simultaneously, the real displacement, V(t), is

* *Corresponding author address:* Daniel A. Vila, Instituto Nacional del Agua, Buenos Aires, Argentina; e-mail: dvila@cptec.inpe.br.

calculated considering “t - Dt” and “t” time interval. The estimation of MCS center of mass displacement VE(t+1) now is calculated as V(t) plus the difference between the real displacement and the predicted velocity (DV(t) = V(t)-VP(t)) in the last time step. This procedure can be visualized in Figure 1.

If the life cycle of an MCS is short enough (only two life stages of a given MCS are available), the center of mass displacement is estimated considering only the displacement of the center of mass between “t - Dt” and “t.” Through this procedure, a velocity V(t) is obtained. Assuming constant that velocity (in intensity and direction), a forecast position of the MCS center of mass displacement VP(t) is obtained.

This procedure is applicable only if continuity condition (C) is fulfilled, since splitting and merging of MCSs introduce non-realistic displacement of MCS center of mass. In these cases, and spontaneous generation (N), the displacement is performed as a distance weighted average displacement of the neighbor MCSs.

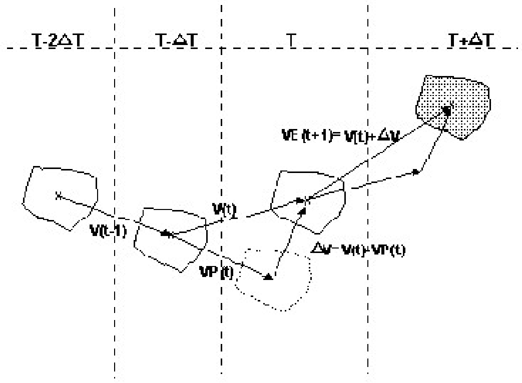

Figure 1: Schematic representation of the displacement forecast for the MCS center of mass. Each vertical dotted line represents different time steps. Dashed MCS indicates the position of the forecasted cloud system.

(2) ***MCS Tendency of growth/decay***: The tendency of growth/decay is evaluated through the Normalized Area Expansion, expressed as DE = 1/A*(dA/dt) (see Machado et al 1998, Machado and Laurent 2004). This parameter, indicates the growth (or decay) of a given MCS. Positive values indicate an expansion process whereas MCSs decays are expressed as negative values.

The objective of this section is the determination of the statistical parameters, based on the families generated in the Wet-Season Atmospheric Mesoscale Campaign (WETAMC) of the Large-Scale Biospher-Atmosphere Experiment (LBA) (Silva Días et al, 2000), of a general model that represents the MCS life cycle that will be used for the extrapolation process. The basic idea is expressed in Machado et al. (1998) and Machado and Laurent (2004). MCS life cycle can be estimated using the following equation:

$$A(t) = \alpha * e^{at^2+bt+c} \quad (1)$$

where A(t) is the MCS area and “a”, “b” and “c” are parameters to be defined according to the total life cycle of a given MCS. Therefore, ΔE are typically straight lines

$$1/A*(\partial A/\partial t) = at + b \quad (2)$$

where “a” and “b” depend on MCS total life cycle. The statistical study on the families of LBA WETAMC experiment was focused on the determination of the values of “a” and “b” (slope and ordinate to the origin) according to the total life cycle of a given MCS: smaller than 2 hours, between 2 and 4 hours, 4 to 8 hours and larger than 8 hours performing the following methodology:

For each one of these four groups, it was evaluated: (a) the mean value of ΔE in the first instant of life of each MCS, (b) the mean value of ΔE in the middle of the MCS life time (when maximum size is reached) and (c) the mean value of the ΔE in the instant of the MCS dissipation.

The result of this study is a group of three points: the mean value of ΔE at initiation, maturation and dissipation of MCSs for each one of the considered groups was computed. These points (connected by lines) can be observed in the Figure 2. These points also can be fitted with a straight line (r> 0.90 in all cases), so that “a” and “b” can be obtained with this methodology for each group.

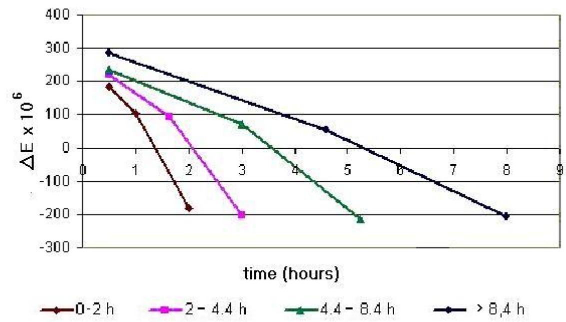

Figure 2: Mean value of ΔE x 10 6 at initiation, maturation and dissipation of MCSs for different life cycle durations: 0 – 2 hours, 2 – 2.4 hours, 4.4 – 8.4 hours and more than 8.4 hours. These points for each group are connected by straight lines.

This methodology is only a first approach to this problem, since the families selected for the statistical study have some bias (no splitting, no merging during the whole life cycle). Nevertheless, the obtained results (validation methodology will be presented in the next section) are quite reasonable and they encourage us to continue the research work in order to find new relationships for more complex MCS behavior (regenerations, external forcing, etc.).

3. VALIDATION TECHNIQUE: GENERATION OF EXTRAPOLATED IMAGES AND THE USE FORTRACC AS A NOWCASTING TOOL

As it was mentioned in the previous section, the extrapolation process for the generation of “virtual” images is carried out considering fundamentally two parameters: (a) the MCS displacement estimation, as a function of previous time positions; and (b) the expansion phase (growth/decay) based on the model presented by Machado (1998) and Machado and Laurent (2004).

The validation process is performed using contingency tables and categorical statistics for whole image.

This nowcasting tool was applied to evaluate the displacement and life cycle evolution of MCS over Del Plata basin up to 120 minutes with 30-minute intervals along December 2002-January 2003. This choice was supported by the fact that the use of an independent set of images, would be suitable to obtain more robust validation results

Figure 3 shows a subset of an image corresponding to 24th December, 2002 - 22:45 UTC (Image 1) of southeastern Brazil. A colored palette was used to indicate all pixels with brightness temperature below 273 K. Small MCSs (below 150 pixels) and warmer pixels were excluded for visualization purposes in the region of interest. In the other three panels, the result of forecast images for different lead times (30, 90 and 120 minutes) are shown. Only for comparison purposes, all MCSs (and their families) having a spontaneous generation in the observed images during the forecast time were also excluded in the verification process, since the forecast methodology cannot generate new systems. The other four situations (dissipation, continuity, split and merge) are possible

For 30-minutes forecast lead time (Image 2), the predicted image was obtained from 24th December, 2002 - 22:15 UTC. In the case of 60 minutes (not shown) the initial image is observed at 21:45 UTC of the same day; and so on for the other forecast lead times.

This situation shows the presence of a great MCS with three very well defined cold tops and a smaller group of convective systems located to the northeast of the mentioned MCS. Clearly, the forecasting technique can rescue, with enough fidelity, the main characteristics of the observed image, especially up to 90 minutes. In the last image whose forecast lead time is 120 minutes, a larger disparity is observed among the position, size and intensity between observed MCSs and predicted ones, although the main cloudy conglomerate has a similar structure.

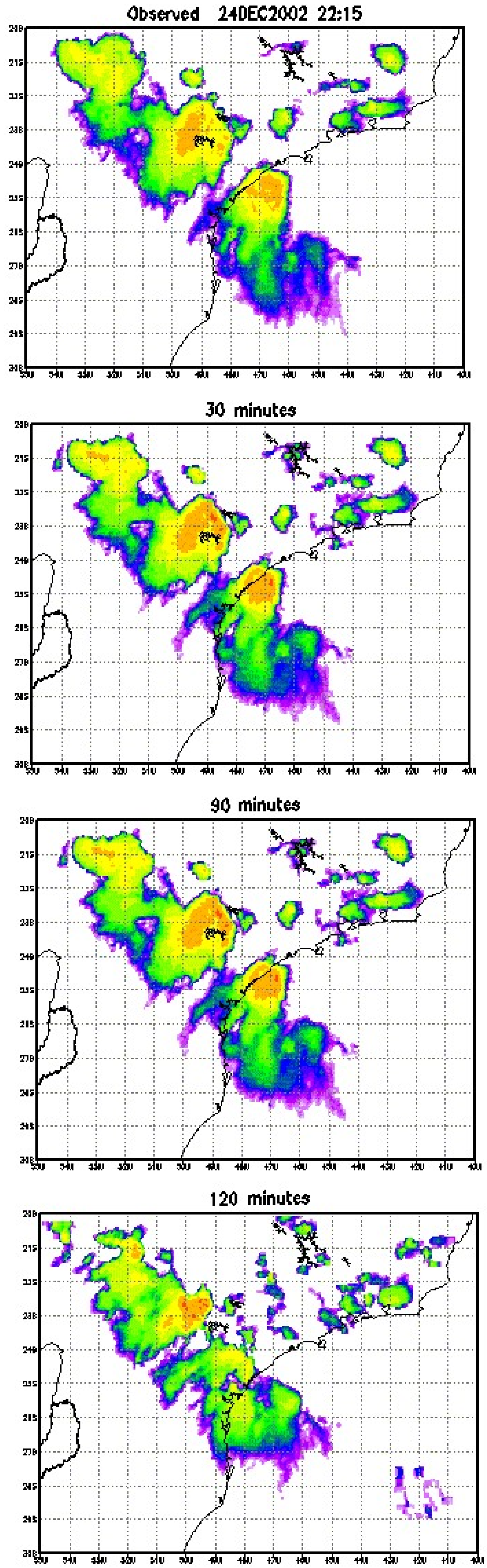

Figure 3: Validation process for 24th December 2002 – 22:45 UTC. Image 1: observed image subset of southeastern Brazil; Image 2: 30-minutes forecast lead time initiated on 24th December 2002 – 22:15

UTC. Image 3 is the 90-minute forecast image while 120-minutes forecast lead time case is presented in the lower panel.

To verify this type of forecast, we start with a contingency table that shows the frequency of "yes" and "no" forecasts and occurrences (pixels below 235 K, in this case). The four combinations of forecasts (yes or no) and observations (yes or no), called the joint distribution, are: HIT- event forecast to occur, and did occur. MISS - event forecast not to occur, but did occur. FALSE ALARM - event forecast to occur, but did not occur and CORRECT NEGATIVE - event forecast not to occur, and did not occur. The contingency table is a useful way to assess what types of errors are being made. A perfect forecast system would produce only hits and correct negatives, and no misses or false alarms.

		Observed		
		yes	no	Total
Forecast	yes	Hits (q_1)	false alarms (q_2)	forecast yes
	no	Misses (q_3)	correct negatives (q_4)	forecast no
	Total	observed yes	observed no	total

Table 1: Contingency table

A large variety of categorical statistics are computed from the elements in the contingency table to describe particular aspects of the forecast performance. For this case, only four categorical statistics were calculated: Accuracy (ACU), Bias Score (BIAS), Probability of Detection (POD) and False Alarms Rate (FAR) (Jolliffe and Stephenson, 2003).

Figure 4 shows the number of observed and predicted pixels (Tir < 235 K) for the entire image, for 30- minute forecast lead time for the period 6th -11th January 2003. It can be observed that the diurnal cycle is correctly predicted, whereas a light underestimation in the number of predicted pixels (on average) is observed.

The accuracy (ACU) shows larger values for this forecast lead time (30 minutes). The mean value is around 0.98. In other words, 98% of the pixels has been correctly predicted. However, this value is high since most of pixels corresponds to correct negative pixels.

When it comes to Probability of Detection (POD), this parameter arises approximately 0.77 and false alarms rate is around 0.20. In other words, while 77% of observed pixels corresponding to Tir < 235 K were correctly predicted, 20% of the predicted pixels were not observed.

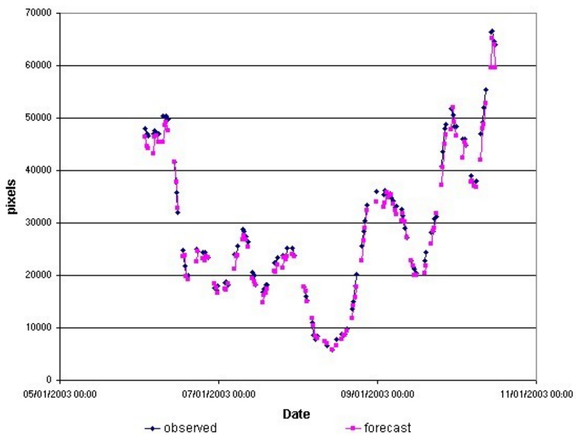

Figure 4: Number of observed and forecast pixels per image during the period 6th – 11th January 2003 for 30-minute forecast lead time. Spaces between solid lines correspond to lack of information (Southern Scan GOES 8 routine).

The less favorable situation is obtained for the case of 120-minute forecast lead time. Figure 5 shows that the number of predicted pixels is smaller than that of observed pixels. This result suggests that the proposed model tends to dissipate the MCSs more quickly than it does in reality. This situation can be explained by the fact that while in the proposed model of MCS evolution exists a beginning, a maturation and a dissipation phase. In the real world, the behavior of MCSs are more complex with frequent regenerations, splits and merges that are not considered in the proposed model. Nevertheless, the forecast reflects the same diurnal cycle structure of the convection. Figure 6 shows the lost of forecast quality with increasing of forecast lead times.

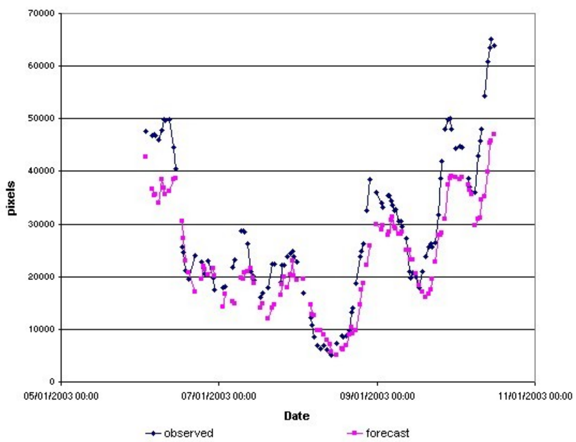

Figure 5: Idem Figure 4 for 120-minute forecast lead time.

4. SUMMARY AND CONCLUSIONS

The ForTrACC technique for detection, tracking and short term forecasting of MCSs using satellite images has been presented. This technique, fully automated, is composed of four independent modules: (a) Cloud detection defined by a threshold temperature; (b) calculation of statistical parameters; (c) the tracking algorithm based on overlapping images and (d) the forecast module.

Considering the hypotheses outlined in the extrapolated images generation methodology, a statistical verification was carried out among real images and forecast images generated with the proposed model. The main results can be summarized as follows:

(a) Considering the forecast and observed pixels with brightness temperatures below 235 K (independently of their position), it is observed that, on the average, the model tends to underestimate the number of pixels, this underestimation, on average, is larger with longer forecast lead times. Overestimations take place, in general, during the MCS dissipation phase because, based on statistical mean values, this algorithm tends to smoothen these processes

(b) The proposed methodology represents the diurnal cycle of MCS with acceptable accuracy both in amplitude and phase.

(c) The accuracy (ACU) obtained with this technique is, in mean terms, 95%. This high value is due to the inclusion of correct negatives pixels. In the case of POD and FAR (that do not consider the inclusion of these correct negatives) a gradual lost of quality is observed. POD decreases and FAR grows with longer forecast lead times.

In the future, it should be deepened the study of merging, splitting and regenerations processes on the evolution of MCS life cycle.

5. REFERENCES

Corfidi S.F., J.H. Meritt and J.M. Fritsch. 1996: Predicting the Movement of Mesoscale Convective Complexes. Weather and Forecasting: Vol. 11, No. 1, pp. 41–46.

Jolliffe, I.T., and D.B. Stephenson, 2003: Forecast Verification. A Practitioner's Guide in Atmospheric Science. Wiley and Sons Ltd, 240 pp.

Machado L. A., W. B. Rossow, R. L. Guedes y A. W. Walker, 1998: Life cycle variations of mesoscale convective systems over the Americas. *Mon. Wea. Re*v., **126**, 1630-1654.

Machado L. A., Laurent, H.. 2004: The Convective System Area Expansion over Amazonia and its Relationships with Convective System Life Duration and High-Level Wind Divergence. *Mon. Wea. Rev.*, **132**, 714-725.

Mathon V. and H. Laurent, 2001. Life cycle of the Sahelian mesoscale convective cloud systems. *Quart. J. Roy. Meteo. Soc.*, **127**, 377-406.

Silva Dias M.A. F., S. Rutledge, P. Kabat, P.L. Silva Dias, C. Nobre, G. Fish, A. J. Dolman, E. Zipser, M. Garstang, A. Manzi, J. D. Fuentes, H. Rocha, J. Marengo, A. Plana-Fattori, L. Sá, R. Alvalá, M.O. Andreae, P. Artaxo, R. Gielow, L. Gatti, 2001 - Clound and rain processes in a biophere atmosphere interaction context in the Amazon Region, *Journal of Geophysical Research – Atmospheres - LBA special issue.*

Velasco, I. y J.M. Fritsch, 1987: Mesoscale convective complexes in the America*s. J. Geoph. Re*s., **92**, 9591-9613.

Vila D. A. , Machado L.A.T., 2004: Shape and Radiative Properties of Convective Systems Observed from Infrared Satellite Images, *International Journal of Remote Sensing*, Vol 25, Nro 21, 4441-4456.

Vila D., 2005: Sistemas Convectivos Precipitantes de Mesoescala sobre Sudamerica: Ciclos de Vida y Circulación en Gran Escala Asociada. *Tesis de doctorado*, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires (in spanish).

Williams, M., R. A. Houze, Jr., 1987: Satellite-Observed Characteristics of Winter Monsoon Cloud Clusters, *Mon. Wea. Rev.,* **115**, 505–519.