2.19 CONVECTIVE SYSTEM AREA EXPANSION, HIGH-LEVEL WIND DIVERGENCE AND VERTICAL VELOCITY: A TOOL FOR NOWCASTING

Luiz A. T. Machado[1], C. Morales[2], Henri Laurent[3], Daniel Vila[4], Suzana R. Macedo[1], Carlos F. Angelis[1] and Wagner F. Araujo[1]

1 Centro de Previsão de Tempo e Estudos Climáticos CPTEC/INPE – Brazil
2 Universidade de São Paulo/IAG – Brazil
3 Institut de Recherche pour le Développement –IRD - France
4 Instituto Nacional del Agua – INA - Argentina.

1. INTRODUCTION

Knowledge of convective system evolution is of fundamental importance for understanding weather and climate, particularly in the tropics, and it is essential to improve forecasting of these systems to reduce vulnerability to extreme weather damage. The identification of predictor parameters for the evolution of a convective system, based on its previous evolution, could make a significative contribution to a nowcasting schemes and provide valuable information for mesoscale model initialization.

Machado and Laurent (2004) showed that it is possible to estimate the probable lifetime duration of a convective system, within certain error bar, considering only its initial area expansion. They also have shown that the area increase in the initial stage is mainly due to the condensation process then afterwards, in the mature stage, the upper air wind divergence increases.

The full resolution geostationary satellite images can be used to detect and track the convective systems during their life cycle. Machado et al. (2003) and Vila et al. (2005) introduced the FORTRACC, a methodology to follow and forecast the mesoscale convective systems. This methodology was tested and developed using a dataset from two experiments: The WETAMC/LBA experiment (see Silva Dias et al, 2002 for details) held over tropical South America, during the wet season, and the RACCI/LBA, another experiment in the Amazon region, covering the pre wet season (see Morales et al., 2004 for details). The data collected by a weather radar were used to study the cloud top time rate increase to forecast the convection intensity and duration.

This study presents the use of the area expansion and upper level wind divergence to estimate the rate of condensation and analyse the use of the cloud top rate as a nowcasting tool.[1]

2. AREA EXPANSION OF THE CONVECTIVE SYSTEMS

The convective system area is calculated from the number of pixel with a brightness temperature lower than the given threshold (235 K or 210 K). The area expansion rate is defined as the normalized system area difference between two successive images. The area expansion is closely linked to the phase of the convective system life. At the beginning of its life cycle the convective system presents a large positive area expansion. The area expansion is close to zero during the mature phase of the system and negative during the dissipative phase. The magnitude of the area expansion could be a good indicator to monitor the convective activity of the convective system, acting as a proxy to quantify the mass flux or the condensation rate inside the convective systems.

Machado et al. (1998) suggested that the magnitude of the area expansion at the initial time could be related to the total duration of the convective system. They found that the area expansion is systematically larger at the initiation stage for long-lived convective systems. There are two possible reasons for this: (i) the environmental conditions that are needed for vigorous development of convection, such as low level moisture convergence and vertical conditional instability, are likely to persist during the following hours; (ii) A strong area expansion indicates a strong internal dynamic (strong mass flux) of the convective system which will transport energy to the middle to high troposphere, modifying the atmospheric circulation and favoring the low level moisture convergence that will in turn increase the lifetime of the convective system.

3. AREA EXPANSION AND HIGH-LEVEL WIND DIVERGENCE

The area expansion depends not only on the divergence but also on the cloud growing due to the condensation process. The area expansion reaches its maximum value in the initiation stage whereas the upper level wind divergence reaches its maximum later, at or just before the mature stage. The rate of increase of the total liquid water of the convective system cannot be neglected during the initiation stage, when the maximum area expansion occurs. The temporal evolution of the convective system area is a function of wind divergence and condensation/ evaporation process as described by the equation in Figure 1.

Considering this Equation, the relative variation of the condensation term can be deduced from the difference between area expansion and horizontal wind divergence, using only the normalized terms. The following behavior can be seen in Fig. 2: at the initiation of the convective system the area expansion is very large, due mainly to a very strong condensation rate. Then the divergence increases during the growing phase. At the mature phase (maximum size) all terms are close to their mean

[1] * *Corresponding author address:* LUIZ MACHADO. Centro de Previsão de Tempo e Estudos Climáticos. Rodovia Pres. Dutra, km 40. Cachoeira Paulista/SP - 12630-000. Brasil. e-mail: machado@cptec.inpe.br

value. During the dissipation stage the negative area expansion is associated with small divergence and evaporation.

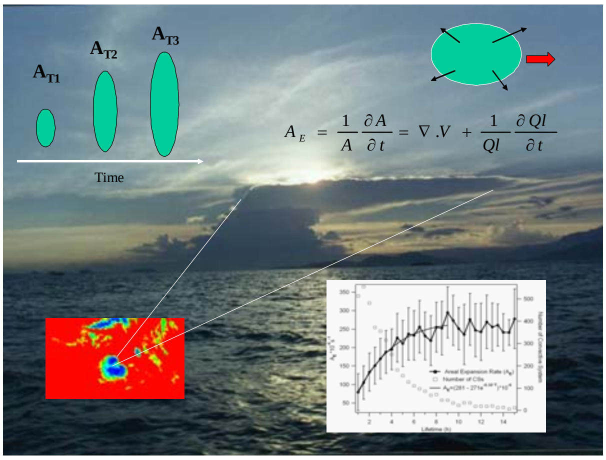

Figure 1: Schematic diagram of the convective system detection and size evolution. Figure also shows the equation relating A_e, the normalized area time rate of expansion, with the upper level wind divergence and the condensation/evaporation rate (Ql is the liquid water content). On the right side figure shows Ae, at the initiation stage, as a function of the convective system lifetime.

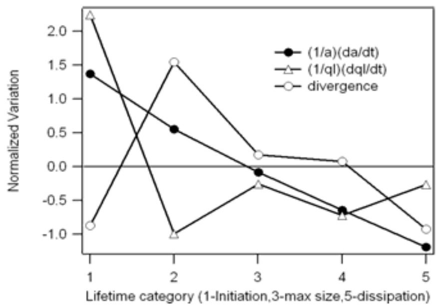

Figure 2: Average variation of the normalized area fraction for convective systems having duration between 3.5 h and 10 h, associated normalized anomalies of wind divergence and calculated condensation/evaporation rate, as function of the lifetime categories: 1 – initiation; 2 - intermediary stage between initiation and mature stage; 3 - maximum area stage (mature stage); 4- intermediary stage between the mature and the dissipation stage; 5 – dissipation stage. Values are normalized by their

4. RAINING CLOUD TOP RATE AS A TOOL FOR NOWCASTING

To deduce the equation presented in Figure 1, linking the area expansion, the wind divergence and the rate of condensation/evaporation , Machado and Laurent (2004) discarded the term describing the ascend/descend rate of the top of clouds. They considered that the top of the convective system, detected using a cold threshold, is close to the tropopause and therefore its variations are relatively small and can be neglected. It is reasonable when satellite data and cold threshold are used. In that case, satellite data commonly show a nearly stable height of the cloud deck and does not give any information about the evolution of cloud dynamic. When radar high time resolution data is employed, the importance of the term describing ascend/descend rate of the top of clouds should be of first order. For instance, when convection is developing this term can describe the dynamic of the cloud droplets inside the convective cores. To analyze this feature we have used radar data, every ten minutes, to compute the time rate increase/ decrease of the raining cloud top, hereafter called as cloud top variation or average vertical motion inside the cloud (W), defined as:

W=dH/dt (1)

where ***H*** is a reflectivity threshold height and ***dt*** is the time interval between successive measurements.

The dataset employed in this analysis was collected during LBA/RACCI (Radiation Cloud and Climate Interaction in LBA Amazon dry to wet season – see Morales et al., 2004 for details). A Brazilian weather radar manufactured by the TECTELCOM was used in this campaign. This radar is a Doppler S-Band (2.7-3 GHz), with 2 degrees antenna aperture, with a maximum power of 750 kW. During the experiment, 10 minutes interval volume scans with 24 elevations were realized to describe the horizontal and vertical distribution of the precipitating systems. The measurements concentrated in the period from 16 September to 7 November 2002. As this was the first time that this radar was used in research, we performed several electronic calibrations to detect the stability of the measurements. Additionally, we performed an intercomparison with the Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) [Kummerow et al. 1998] to depict an existence of a bias offset. The final and adjusted data were used to compute the Constant Altitude Plan Position Indicator (CAPPI) retrieved at 5x5 km horizontal with 1km height resolution, from 2 to 19 km altitude, for all the experiment based on weighted volume beams (Anagnostou et al., 1999).

To depict the cloud top variations observed with the weather radar, we have applied the FORTRACC technique over the 2 km CAPPI and set the threshold as 20 dBZ. As a result we have tracked all the raining cells along their lifecycle. Using equation (1) we have computed, for each time step, the average vertical motion inside the raining cells (W). Combining these information we were able to calculate the typical W value for each phase of the raining cells lifetime. The lifecycle stages were separated as initiation (INIT - first time detected), mature (MAT - maximum size), dissipation (DIS - last time detected) and the intermediate time between initiation and mature (INIT-MAT) and mature and dissipation (MAT-DIS). Figure 3 shows the variation of W along the lifetime of the typical raining systems having more than 50 minutes lifetime. We can note a nearly linear variation of W along the lifecycle; the largest value is found in the initiation stage, around the mature stage W is nearly zero and at the dissipation stage we found the smallest value.

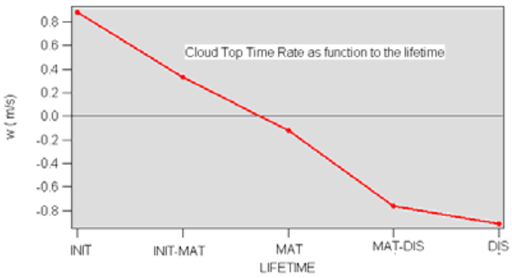

Figure 3 – Time rate of cloud top as function of the lifetime (top is defined as 20 dBZ)

As discussed in section 2, the area expansion of the convective system is larger in the initiation stage and the absolute value of the area expansion in the initiation stage can be used as a proxy of the lifetime duration. One physical explanation for this result can be based on the principle that this parameter measures the vigor of the convective forcing. Thus, the area expansion can be used as a proxy to quantify the mass flux or the condensation rate inside the convective system and consequently the W. To test this assumption we computed the value of W, at the initiation stage, as function of the lifetime duration of the raining cells. Figure 4, shows this calculation for all raining cells having no split or merge during their lifecycle. We can note that the larger W in the initiation stage, the longer the raining system duration. Therefore, W, at the initiation stage, can also be employed to forecast the lifecycle duration of the raining cell.

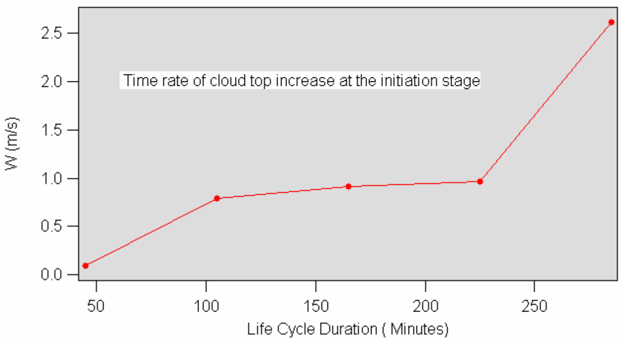

Figure 4 – Time rate of the raining cloud top at the initiation stage as function of the lifecycle duration

Figure 5, shows the average radar reflectivity profiles for the different lifecycle stages. The radar reflectivity profile, at the initiation stage, presents strong activity at lower levels and low reflectivity in higher levels. This behavior explains the larger W value found in the initiation associated with intense convection and still reduced ice phase development. At the mature stage the ice phase is well developed as well in the lower levels, having a maxima radar reflectivity around 5 km. The decay phase has a radar reflectivity value reduced in all levels.

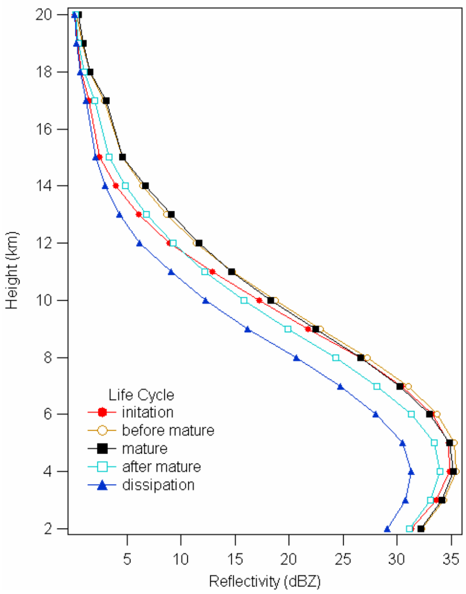

Figure 5 – Average reflectivity profiles for different lifecycle stages of the raining cells.

The results obtained in the W analysis demonstrate the potential of this parameter as a tool for nowcasting. To verify this approach the following analysis was performed: W, computed for 20 dBZ, was separated in 5 classes as following -20 m/s < W < -10 m/s, -10 m/s< W < 0 m/s, 0 m/s< W < 5 m/s, 5 m/s < W < 12 m/s and 12 m/s < W < 24 m/s. For each of these five classes, we have computed the change in the radar reflectivity profile after 10, 20 and 30 minutes (Figure 6). After 10 minutes, the average variation in the reflectivity profile, for the class of largest W, shows an increase in the radar reflectivity for all levels, this behavior being prominent near the surface (precipitation increase) and at the high levels (ice particles aloft). The same behavior is observed after 20 and 30 minutes, except in the middle levels. For the W class between 12 and 5 m/s, we observe that reflectivity increases in the lower levels, after 10, 20 and 30 minutes, but a clear decrease is observed in the higher levels indicating the beginning of the decaying stage. For the classes 5 to 0 m/s and 0 to-10 m/, we observe a process of convection decaying in all levels. One interesting feature is observed for the class describing the strongest rate of raining top decrease, showing a decrease in the reflectivity near the ground (precipitation) and a considerable increase in the ice phase in the upper levels. This class seems to describe the collapse of the ice phase to form the bright band, in association with the collapse of the convective activity and the development of stratiform clouds.

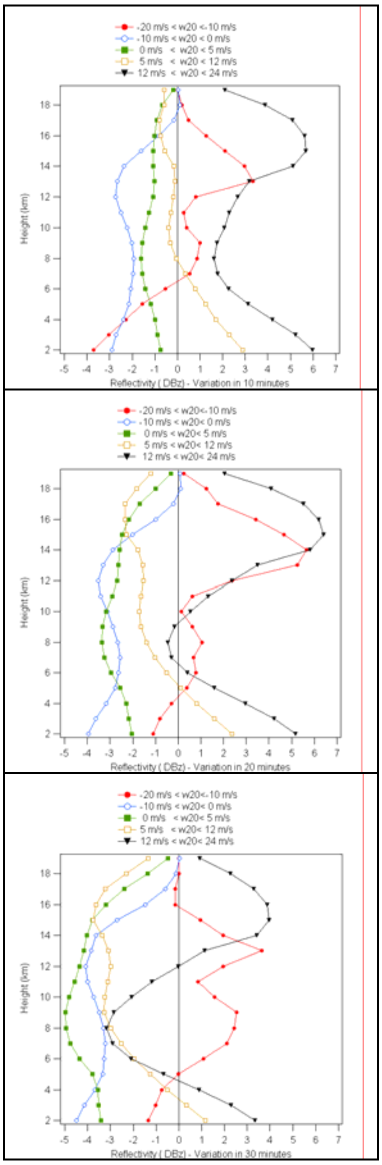

Figure 6 – Reflectivity profiles variations as function of the W value after 10 (top), 20 (middle) and 30 minutes (bottom).

5. Conclusions

This study summarizes the main results obtained using the FOTRACC technique applied to satellite data for nowcasting and presents preliminaries results of the application of raining cloud top variations, using weather radar, to forecast the convection intensity and duration.

The analysis of the area expansion showed that this parameter could be very useful for short-range forecasts and convection diagnostics. Also, the area expansion can be used to determine the convective system life stage and to supply information about the condensation processes and the upper level divergence.

Using radar data, the results present a typical time evolution of the vertical reflectivity profiles for different range of the raining cloud top variations. Large values of cloud top increase are associated with a clear increase of ice phase (ice particles aloft) and surface precipitation in the next 30 minutes. For the situation when the cloud top rapidly decreases, the reflectivity profile, in the next half hour, presents the collapse of the ice phase and a significant decrease of the precipitation. The rate of cloud top increase can be approximately related to the average vertical velocity of the convective core. The time variations of this variable can also be used as a proxy for the stage, intensity and lifetime duration of the convective activity.

Combining this result with the one obtained for the convective system area expansion we can have a complete description of the lifecycle of the convective system. Although the use of satellite does not allow for a detailed description of the ascend/descend of the cloud top, the use of area expansion showed to be a very useful tool for nowcasting, allowing to forecast the lifetime duration, the stage of the lifecycle, and giving an idea about the convective system size changes. On the other side, the nearly stable height of the cloud deck does not give any information about the evolution of the convective system. But when radar data are available, the use of the raining top variations can help to describe the dynamic of the cloud/ice droplets. W value seems to be a useful parameter to describe the lifetime of the raining cells and to forecast their evolutions.

6. ACKNOWLEDGMENTS

This work has received financial support from the Fundação de Amparo a Pesquisa do Estado de São Paulo (FAPESP) grant 01/13816-1 and 01/06908-7, and grant from CNPq project grant 910153/98-1.

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