# Convective System Area Expansion and its Relationship with precipitation Intensity

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## 1. Introduction

Convective systems are responsible for most of the rainfall in tropical regions as well as in temperate latitudes during the warm season and they are also responsible for some extreme weather conditions in various regions of the earth. 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 significant contribution to a nowcasting scheme and provide important information for mesoscale model initialization.
The growth rate of the convective systems can be deduced from their area expansion, which is easily observed from successive satellite images. This area expansion is expected to be associated with the high-level wind divergence and with the rate of condensation/evaporation that is directly related to the mass flux inside the convective system. The objective of this study is to investigate these hypotheses, to examine if the rate of change of area of a convective system can be associated with its lifetime and if this rate can indicate the level of convective activity

## 2. Data

The WETAMC/LBA allows us to study the three-dimensional structure of convective systems and their associated precipitation using a combination of raingauge network, satellite images and radiosonde data. The GOES-8 satellite images were pre-processed by NASA-GSFC for the entire duration of the experiment at full resolution (every 30 min; pixel size of ~4 km for the infrared channels). The convective systems are detected using the thermal infrared channel (~11 µm) assuming that the convective clouds that are high and thick are those with a small brightness temperature. A convective system is here defined as an area of at least 200 pixels (i. e., area larger than about 3500 km$^2$) that falls below the temperature threshold. Two thresholds were used: 235 K to identify the whole convective system including the thick cirrus shield, and 210 K to identify the areas of very intense convection that may exist embedded in the convective system. The systems are tracked during their life cycle using the method described by Mathon and Laurent (2001) which determines whether the system initiates spontaneously or from a split, and whether it ends by dissipation or by merging into another system. This objective tracking was performed for the period 11 January-27 February over a window covering tropical South America approximately from 7.5 N to 20 S and from 80 W to 30 W. The total number of systems tracked was 13409 at 235 K and 3867 at 210 K. For comparison with the WETAMC/LBA observations we use a window defined by 12 S-8 S and 64 W-60 W. A more detailed description of the methodology is given in Laurent et al. (2002).

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## 3. Area expansion of the convective systems

The convective system area is calculated from the number of pixel with a brightness temperature smaller than the given threshold (235 K or 210 K). The area expansion rate is simply the normalized difference of the system area between two successive images (Machado et al., 1998). The area expansion is closely linked to the phase of the convective system life. At the beginning of its life the convective system presents a large positive area expansion. The area expansion is close to 0 during the mature phase of the system and negative during the dissipative phase. The magnitude of the area expansion may 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 system.
Machado et al. (1998) discuss the possibility of associating the area expansion of the convective systems with the high-level wind divergence, if condensation and evaporation are neglected, with the

$$A_e = \frac{1}{A}\frac{\partial A}{\partial t} \approx \nabla . V \qquad (1)$$

following equation:

Where A is the convective system area and $V$ is the horizontal wind vector. $A_e$ is the normalized area time rate of expansion called area expansion hereafter. A negative area expansion corresponds to contraction.

Rapid area expansion would correspond to large upper levels wind divergence.

Machado et al. (1998) suggest that the magnitude of the area expansion at the initial time may 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 favouring the low level moisture convergence that will in turn prolong the life of the convective system. This feedback is likely to be activated if the convective system has a strong internal mass flux, in the initial stage. Note that as the convective systems have a size larger than 3500 $km^2$, they include various convective towers and the satellite analysis is an integration of all small-scale features.

## 4. Results

### 4.1 Relationship between area expansion and lifetime

The work of Machado et al. (1998) was based on a low resolution dataset and did not consider the different situations of splitting and merging of convective system. This study aims to test the hypotheses mentioned using high resolution data from various sources. In order to analyze the relationship between the area expansion of a convective system and its lifetime, we only consider here the systems that initiate spontaneously (i.e., not as a result of a split of a former system) and end by dissipation (i.e., not by merging into another system). This ensures that the initial growth of the system is due to its internal dynamics, and that the lifetime is representative of a complete life cycle. The tracking method allows for such a selection; the number of systems is thus reduced to 4240 at 235 K and 2569 at 210 K.

The average relationship between area expansion at the initial time (between t0 and t0 + 30 min) and total lifetime is shown in Figure 1. The plot gives the mean area expansion observed for each life duration and the associated standard deviation. The number of observed convective systems is also indicated. On average, the convective systems with a weak area expansion during the initial phase have a short lifetime. The convective system duration increases as its initial area expansion increases. The fitted curve shows that there is a nearly exponential relationship. For life duration larger than 8 h the function could be asymptotic, however the small number of cases leads to a very noisy and inconclusive relationship. For most cases (lifetime smaller than 8 h) the results show that the area expansion is a good indicator of the lifetime, within error bars, and that the relationship can be approximated by an exponential function.

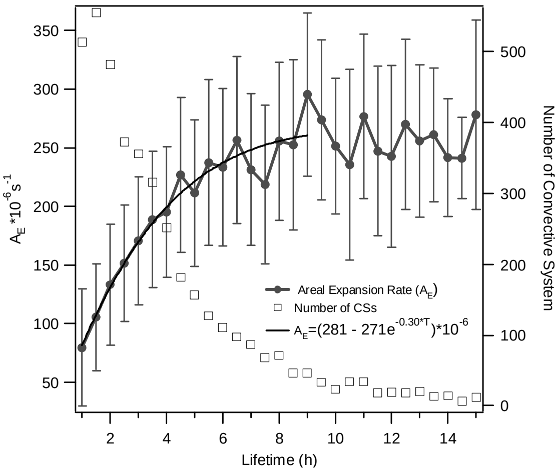


Figure 1. Area expansion (Ae, $10^{-6}s^{-1}$) and associated standard deviation as a function of the convective system lifetime (h). The number of cases is also plotted (right axis).

### 4.2 Relationship between area expansion and precipitation and cloud cover.

Figure 2 shows the average diurnal cycle of the area expansion, rainfall and 235K area fraction. It can be seen that the maximum area expansion occurs close to the time of maximum precipitation and around 4 hours before the maximum cold cloud fraction defined with the same threshold (235K). This means that, for this region, the area expansion captures the moment of maximum precipitation whereas a traditional approach to estimate the rainfall using brightness temperature would be biased by about 4 hours. As discussed by Machado et al. (2002), precipitation occurs very rapidly in the beginning of the afternoon close to the time of minimum total cloud cover. It is also the time when high and convective clouds have the maximum area fraction increase rate and when the initiation of convective systems and rain cells are the most numerous. These are the characteristics of the convection in the WETAMC/LBA region. However other investigations are needed to determine whether the nearly simultaneous time of maximum precipitation, wind divergence and area expansion could be verified in others regions of Amazonia.

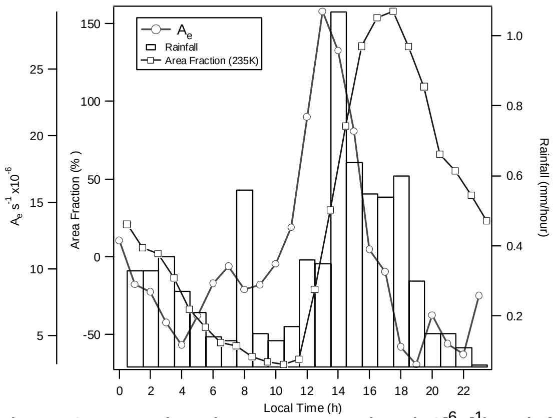


Figure 2: Mean hourly area expansion ($10^{-6}s^{-1}$), rainfall ($mmh^{-1}$) and 235 K area fraction (%) for the WETAMC/LBA region.

## 5 Conclusion

The convective system area is calculated from the number of pixel with a brightness temperature smaller than the threshold considered (235 K or 210 K). The area expansion is defined as the system area difference between two successive images, normalized by the mean area. The area expansion is closely linked to the phase of the convective system's life. At the beginning of its life the convective system presents a large positive area expansion. The area expansion becomes close to zero during the mature stage of the convective system and negative in the dissipation stage.
The results demonstrate the ability to predict the probable lifetime of a convective system from its initial area expansion. The physical explanation for this result is founded on the principle that this parameter measures the vigor of the convective forcing indicating the time/space scale of the convective cloud organization. The area of the cloud shield of the convective system changes in association with the upper level wind divergence and with the condensation/evaporation process.
The maximum area expansion occurs close to the time of maximum precipitation and about 4 hours before the maximum cold cloud fraction at the same threshold (235K). It can be concluded that the area expansion could be used to determine the time of maximum precipitation. This approach led to some more results that are described in Machado and Laurent (2004).
The analysis of the area expansion showed that this parameter could be very useful for short-range forecasts, convection diagnostics, and maybe to help improve precipitation estimation from geostationary meteorological satellites.

## 6 Acknowledgements

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## 7 References

Laurent H., L. A. T. Machado, C. A. Morales and L. Durieux, 2002. Characteristics of the Amazonian mesoscale convective systems observed from satellite and radar during the WETAMC/LBA experiment. *J. Geophys. Res*. VOL. 107, NO. D20, 8054, doi:10.1029/2001JD000337.

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

Machado L. A. T., H. Laurent and A. A. Lima, 2002. The diurnal march of the convection observed during TRMM-WET AMC/LBA. *J. Geophys. Res*., VOL. 107, NO. D20, 8064, doi:10.1029/2001JD000338.

Machado L. A. T. and H. Laurent, 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.