FURTHER INVESTIGATION ON THE TOOCAN ALGORITHM TO DETECT AND TRACK CONVECTIVE SYSTEMS IN THE TROPICS

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I. Introduction

The study of the life cycle and the characteristics of convective clouds is an important way to understand the tropical hydrological cycle and heat budget. Deep convective systems consist in organized cloud clusters spanning a wide range of spatial scale and degree of organization. They are the major provider of rainfall at the ground, of atmospheric heating through latent heat release, and the main source of cloudiness that drives the radiation budget in the tropics. In this context, a new automatic tracking algorithm called TOOCAN (Tracking Of Organized Convection Algorithm through 3D segmentatioN), based on an IR image segmentation with no or little dependence on any given threshold, has been developed to detect and follow convective systems using geostationary infrared images (Fiolleau and Roca 2009). A previous study has introduced the TOOCAN methodology and has shown the improvements it brings to the characterisation the convective systems life cycle, in particular by avoiding problems of splitting and merging. Moreover, the detection of the convective systems is performed earlier in their initiation stages and later in their dissipation stages.
The present study aims to further detail the tracking methodology. First the distribution of the cold cloudiness clusters is investigated at different brightness temperature thresholds to describe the cloud population and the functioning of the TOOCAN approach. The sensitivity of the algorithm to the detection step parameter is then evaluated by running the algorithm at three different detection steps on a case study which occurred in September 2006 over Niamey. Finally, Statistical analyses of the TOOCAN segmentation are discussed for the period of July 2006.

II. Data

The data used in this study are the 10.8 µm METEOSAT Second Generation images with a 3km spatial resolution at the satellite subpoint and a 15 minutes temporal resolution. The study area covers the West African region from 25°W to 25°E and from 0°N to 20°N and computation is performed for the period July and September 2006.

III. The TOOCAN algorithm

1. Clusters distribution in the IR imagery

In order to have a better understanding of the convective clusters detection performed by the TOOCAN algorithm, the relation between the brightness temperature thresholds and the area and lifetime of segmented clusters is analyzed. Infrared images are segmented using 5 different temperature thresholds (190K, 200K, 210K, 220K, and 235K) for the period of July 2006. Convective seeds are then identified and defined as a contiguous area of pixels with a brightness temperature lower than the threshold. Figure 1-a shows the normalized cumulated distribution of the convective seeds population segmented at these five temperature thresholds. The closeness of the distributions of population segmented by thresholds within the range [200K-235K] shows that there is a little dependency of the cluster sizes to the temperature thresholds, in terms of population. 50% of their occurrence is due to clusters exhibiting an area lower than 10 pixels. For a brightness temperature threshold set at 190K, 50% of the population is explained by convective seeds smaller than 3 pixels.

Besides, it is to be noticed that no clusters segmented by the 190K threshold reach an area larger than 500 pixels.
Figure 1-b illustrates the normalized cumulated contribution to the cloudiness as a function of the cluster area for the same temperature thresholds. Contrary to the CDF of the populations, the contribution of the cold cloudiness appears sensitive to the temperature thresholds. Hence, 50% of the cold cloudiness is due to clusters larger than 350 pixels for a 200K threshold, whereas half of the total clusters coverage defined at 235K is explained by clusters larger than 2100 pixels.

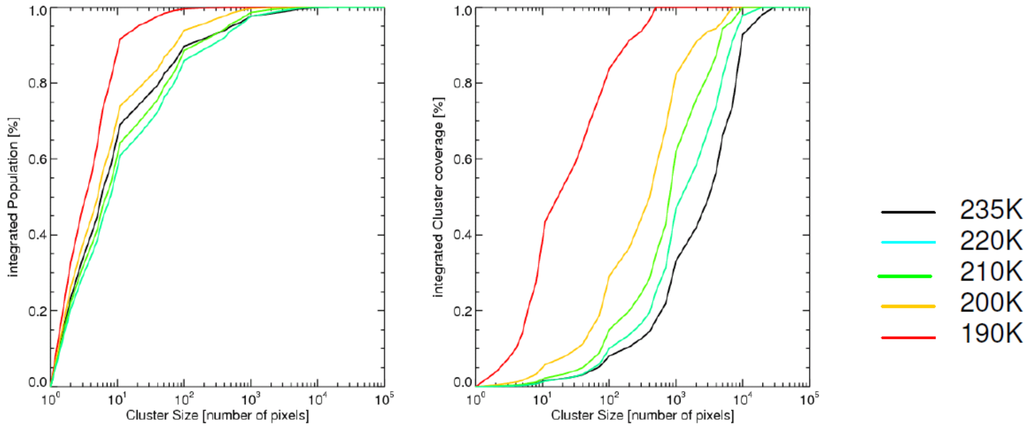

Fig 1-a - Normalized cumulated distribution function of the clusters occurrence as a function of the Cluster area (in pixels) b- Normalized cumulated contribution to the clusters occurrence weighted by cold cloudiness as a function of the Cluster area (in pixels). Statistics are computed for the period of July 2006 over West Africa and the imagery is segmented with different brightness temperature thresholds indicated by colors.

In order to evaluate the sensitivity of the convective seed lifetimes to the brightness temperature thresholds, spatiotemporal images have been segmented for the July 2006 period. Figure 2 shows the normalized cumulated distribution function of the convective seeds population segmented with the 5 temperature thresholds, according to their lifetime. The distributions indicate that 50% of the clusters segmented by thresholds within the range [200K-235K] are due to lifetime shorter than 5 frames. Within this range, the cluster lifetimes seem to be insensitive to the temperature threshold. However, for a threshold set at 190K, clusters shorter than 3 frames explain 50% of the population. Besides, we can observe that no clusters segmented by a 190K threshold last more than 12 frames.

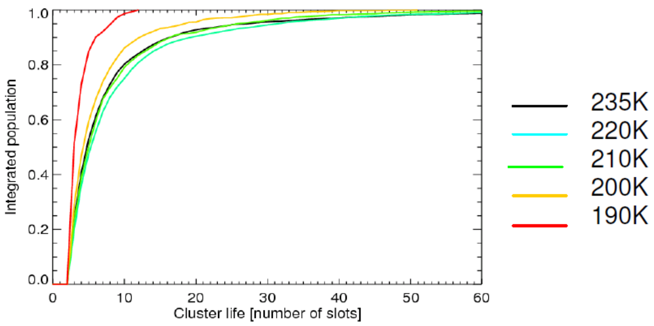

Fig 2 Normalized cumulated distribution function of the clusters occurrence as a function of the system duration (in slot). Statistics are computed for the period of July 2006 over West Africa and the imagery is segmented with different brightness temperature thresholds indicated by colors.

Therefore, we will in the following run our multiple detection steps, starting at 190K with a 3 frames minimum duration.

2. Functioning of the TOOCAN 3D segmentation

The TOOCAN algorithm, based on an IR image segmentation with no or little dependence on any given threshold, to detect and follow convective systems through their life cycle is now described. The goal of the algorithm is to split the cold cloud shield defined at a brightness temperature threshold between convective clusters, in order to have a better representation of the organized convection. The Detect and Spread (DAS) technique was introduced by Boer and Ramanathan to detect and follow cloud systems provides us a sound basis for the algorithm. This methodology was tuned to the tropical deep cloud detection using INSAT (Roca and Ramanathan, 2000; Roca et al., 2005) and METEOSAT data (Roca et al., 2002). The DAS results were used in conjunction with a simple overlap tracking technique to analyse the life cycle of the systems. However, this technique gives rise to split and merge artefacts, and then prevent a better characterization of convective systems life cycle. In order to go further these problems we have introduced a method for tracking the tropical MCS based on 3D segmentation. The DAS technique is here restricted to high cold clouds and is extended in time to form a 3D segmentation technique (2D+time). A spatiotemporal image, whose spatial axes are longitude and latitude, is then generated by the 96 daily MSG images (Figure 3).

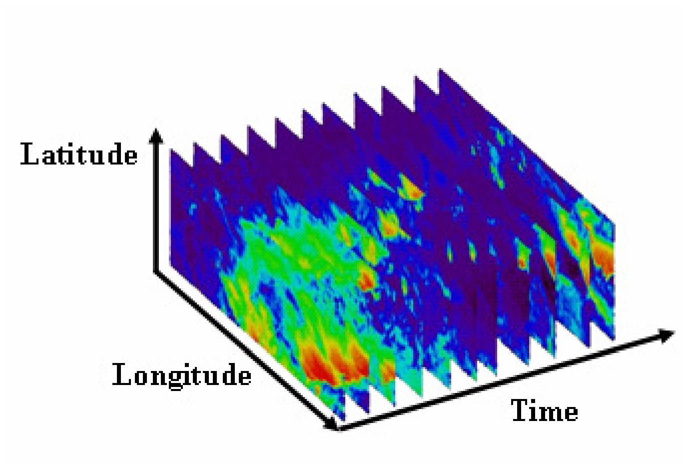

Figure 3: example of a 3-dimensional spatiotemporal image

The algorithm can be thought of as generalized clustering technique which progress from the convective core to the cloud edges in multiple steps. It relies on the idea that adjacent pixels in the satellite image belongs to the same physical system and that the optical depth of the cloudiness decreases away from the convective core (thick) towards the cloud edges (thin cirrus) (Boer and Ramanathan, 1997; Roca et al., 2005). This algorithm is a multi-stage, multi-threshold method to extract individual cloud systems in the volume image. The two principal stages are described below:
1 - A 3D segmentation of individual convective cores, in the spatiotemporal domain is performed. It involves finding consecutive set of pixels whose temperature does not exceed a certain threshold and which have not been assigned to other already identified clouds. Each newly detected cloud receives a unique label.
2 – A Spread of the convective core, in the spatio-temporal domain, to the cold cloud shield edges, here defined using a BT threshold. It involves adding edge pixels colder than this threshold to all already identified clouds until no more edge pixels can be assigned to clouds. Thus, all pixels in the feature domain are labelled by determining to which cluster they belong. The idea is to associate the anvil cloud with the convective activity. Region growing is performed by using to a 10-connected spatiotemporal neighbourhood (figure 4): 8-connected spatial neighbourhood and 2-connected temporal neighbourhood (past and future), in order to emphasize the region spread in the spatial axis.

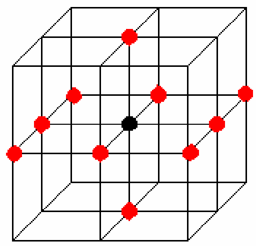

figure 4 : 10-connectivity directions

A first set of clusters is identified at a 190K threshold in the spatiotemporal image. Once a core of a convective core is detected, the cold cloud boundaries are spread up until the cold cloud shield defined by the next threshold temperature is reached. An iterative process then starts with such a detection and spread phase. Clusters are detected in multi-steps from 190K to 235K with a 5K step.

For each detection step, every identified cluster is spread up in the spatiotemporal image to a 5K warmer threshold, from 195K to 235K. The sensitivity of the algorithm to the detection steps is shown in the next section.
The TOOCAN algorithm relies on two main parameters:
- A lifetime threshold which is the minimum lifetime that can last a convective system. The lifetime threshold has been established to 3 images (45 minutes) in order to follow convective systems trough their entire life cycle, from their initiation stages to their dissipation stages. (See previous paragraph discussion)
- An area threshold is applied in order to filter convective seeds in their first detection in the three dimensional image, before spreading them to the cold cloud shield. The value of this threshold has been set to 75 pixels in the spatio-temporal domain, that is to say 25 pixels per frames to segment convective systems exhibiting a degree of organization. Hence, according to the figure 1, between 30% and 40% of the population of convective clusters are detected for a temperature threshold within the range 200K-235K, contributing to more than 90% of the total cold cloudiness. For a brightness temperature threshold set at 190K, only 7% of the population of convective seeds can be segmented by an area threshold set at 25 pixels per frame.

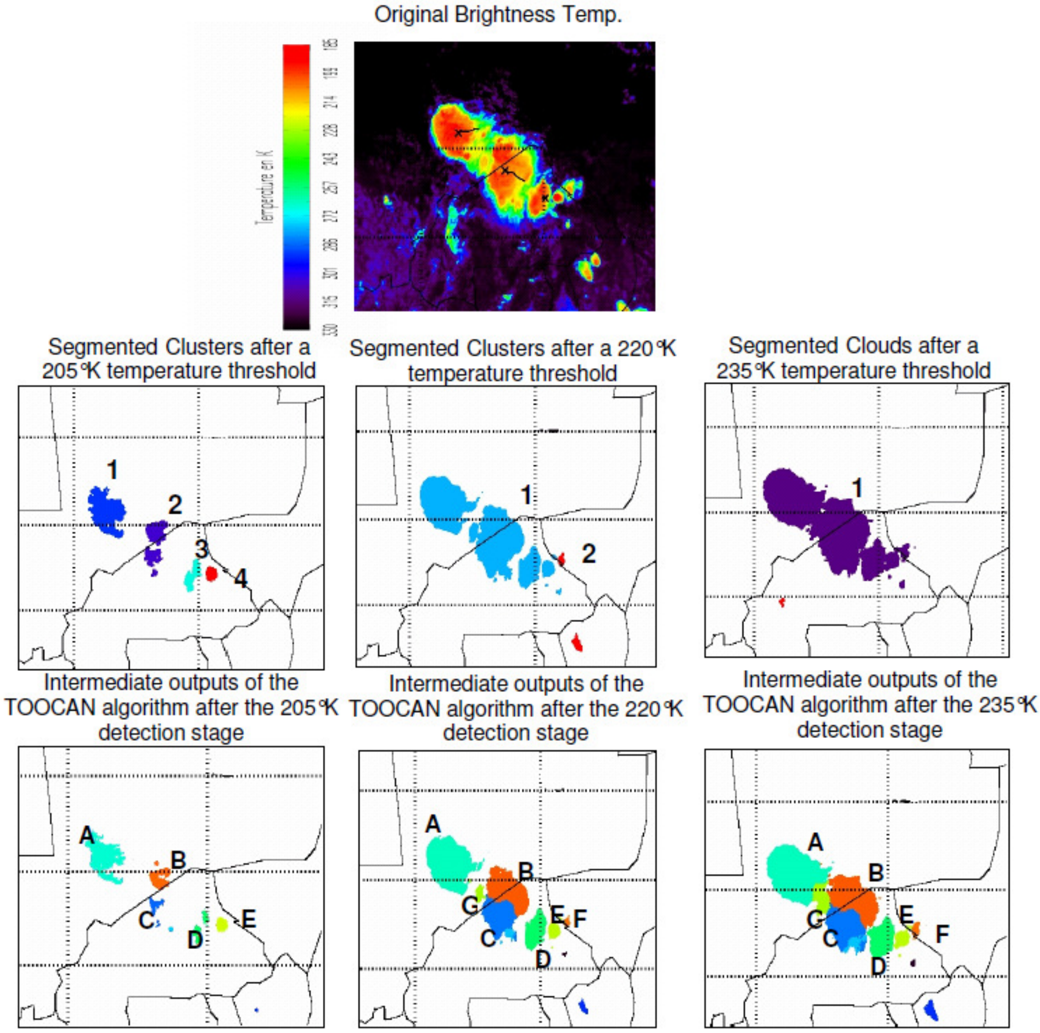

Figure 5 : ***. From top to bottom:*** **Brightness temperature image at 1600 UTC on 11 September 2006. Segmented Clusters after a 205K, 220K and 235K temperature threshold. Intermediate outputs of the TOOCAN algorithm after the 2005K, 220K and 235K detection stages**

In order to analyse the TOOCAN methodology, figure 5 compares a convective situation which occurred over Niamey in September 2006 segmented by a 205K, 220K, and 235K thresholds with the intermediate outputs of the TOOCAN algorithm after the 205K, 220K and 235K detection stages. At a 205K step, we can observe that a segmentation by a single threshold delineates four convective seeds. According to the TOOCAN intermediate outputs, for a detection stage at the same temperature threshold, five convective systems have been segmented. For a 220K detection step, a segmentation by a single threshold gives rise to only two convective clusters, whereas the TOOCAN algorithm splits the convective cold cloud shield defined at 220K in six convective clusters. Finally, at a 235K threshold, only one cluster is segmented by a single threshold split in seven convective systems by the TOOCAN algorithm. Hence, figure 5 shows the segmentation of the IR image in terms of individual convective systems, including core and anvil. At a 235K, the TOOCAN results seem to be in a better agreement with human analysis than with a 3D segmentation using single thresholds.

IV. Sensitivity of TOOCAN to the detection steps: analysis of a case study

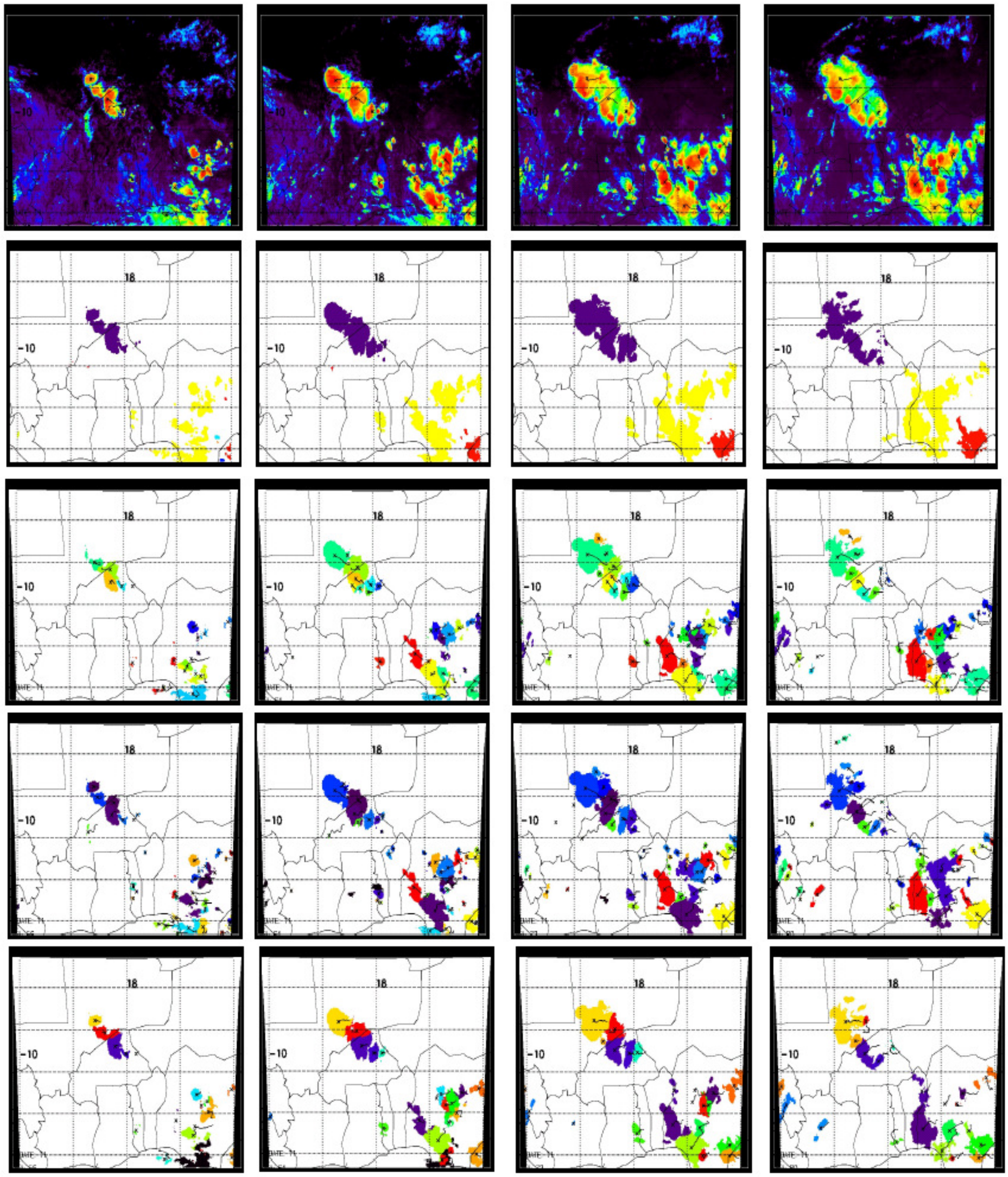

Figure 6 : Sequence of frames of satellite imagery from the 11 September 2006 convective situation over the region of Niamey. From top to bottom: METEOSAT Brightness temperature images; images segmented by using a single brightness temperature threshold set at 235K; images processed by the TOOCAN tracking algorithm for a 2K step, a 5K step, and a 10K step.

The figure 6 illustrates the tracking scheme over a selection of images at 1130UTC, 1600 UTC, 1800UTC and 2000UTC for the convective situation which occurs over the region of Niamey on 11th September 2006. The meteorological and cloud conditions are fully discussed in Bouniol et al., 2009. The second row represents the clusters segmented by a single threshold set at 235K, whereas the last three rows illustrate the outputs of the TOOCAN tracking for three different detection steps (2K, 5K, 10K) expressed in brightness temperature. The Convective Clusters are represented by different colours and a black line represents trajectory histories of the clouds centre-of-gravities followed by the TOOCAN algorithm. To illustrate the case study, convective systems exhibiting a cumulated area lower than 900 pixels through their life cycle are filtered. First, we can observe that a segmentation of the convective situation by a single temperature set at 235K gives rise to only one cluster. On the contrary, whatever the detection step used, the cold cloud shield defined at 235K is sliced up in several convective systems segmented by the TOOCAN algorithm. Hence, we can notice that the segmentation performed by the tracking algorithm is more representative of the organized convection.

The sensitivity of the TOOCAN outputs to the detection steps is now evaluated. The segmentation of the cold cloud shield defined at 235K by the new algorithm seems to be insensitive to the detection steps. Indeed, large clusters seem to be segmented similarly whatever the magnitude of the detection step used. However, we can observe that greater the detection step, smaller the number of segmented convective seeds is. Thus, the variation of the number of detected convective seeds involves a different aggregate of the pixels to already segmented convective cores during the spreading stages.

V. Statistical analysis of the TOOCAN results

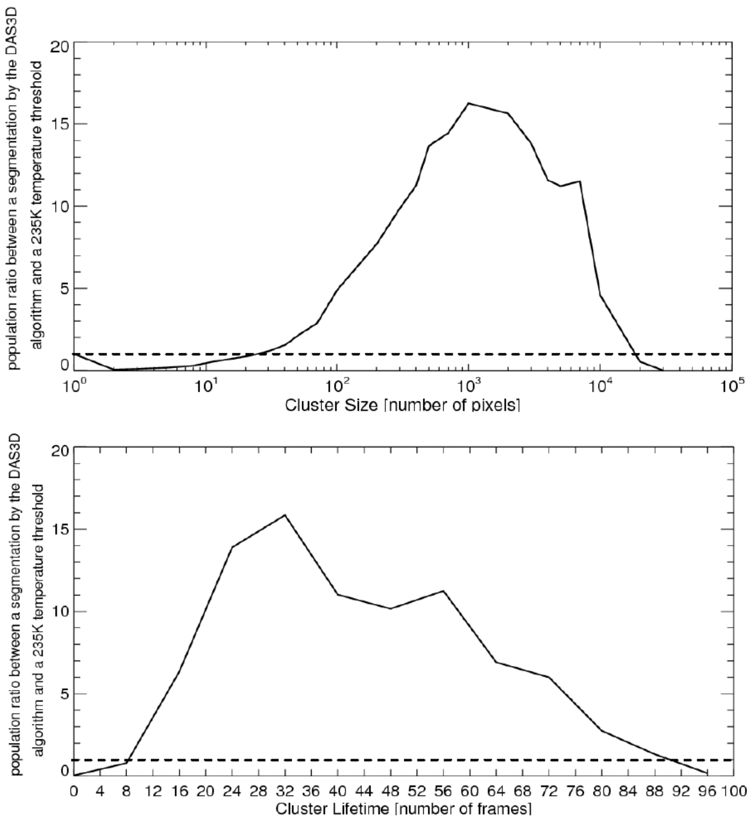

Figure 7 :a - Population ratio between clusters segmented by the TOOCAN algorithm and by a single threshold set at 235K for the July 2006 period , as a function of the cluster areas. b- as a function of their durations.

A statistical analysis is performed for the period of July 2006 over the West African Region to evaluate the behaviour of the TOOCAN segmentation. Figure 7-a illustrates the ratio of population of clusters performed by the TOOCAN algorithm to the population of clusters segmented by a single threshold set at 235K, as a function of the cluster sizes and binned into classes. For clusters smaller than 30 pixels, the number of convective seeds segmented by the 235K threshold is more important than with the TOOCAN algorithm. Then, for cluster size within the range 30 pixels-10000 pixels, the distribution shows a more number of clusters segmented by the TOOCAN methodology. The maximum of the ratio is reached for the class 1000 pixels-2000pixels with up to 16 times more clusters segmented by the TOOCAN algorithm than with the 235K threshold. For clusters larger than 20000 pixels, the ratio of population indicates a larger number of clusters segmented by the 235K threshold. If we consider the ratio of convective clusters population according to the lifetime and binned into 8 frames classes (figure III.7-b), we can observe a more important number of clusters segmented by a 235K than with the TOOCAN algorithm. However, for lifetime within the range 8 pixels-88 pixels, we can notice a more important number of clusters segmented by the TOOCAN algorithm. The maximum of population is reached for the lifetime class 32 frames-40 frames.

VI. Conclusions

A new tracking methodology, called TOOCAN, using 10.8 µm IR satellite images, to detect and track convective systems through their life cycle in a 3 dimensional spatio-temporal image has been described. The goal of the algorithm is to divide the cold cloud shield defined at a defined brightness temperature threshold between segmented convective clusters. A case study, which occurred over West Africa on 11 September 2006 has been analysed and the outputs of the tracking algorithm have been compared with a segmentation based on a single temperature threshold. Results show that the TOOCAN algorithm improves the representation of the organized convection and that the segmentation seems to be in better agreement with human analysis.

A previous study has introduced the contributions of the TOOCAN algorithm to the characterization of the convective systems life cycle. Convective systems are detected earlier in their initiation stages and later in their dissipation stages. Moreover, the split and merge artefacts have been suppressed. Hence, the characterization of the main morphological aspects of the convective systems life cycle has been improved.

VII. References

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