

# A NEW APPROACH TO THE DETECTION AND TRACKING OF MESOSCALE 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. In this context, automatic tracking of convective systems on geostationary images has been the subject of several studies over the past decades. Using infrared imagery, threshold based clustering techniques have been put forth to delineate the cold cloud shield associated with the convective systems and tracked in time using simple overlapping assumptions (e.g., Williams and Houze, 1987; Arnaud et al, 1992, Mathon and Laurent, 2000). These approaches rely upon selecting the minimum size of the object to be tracked, the overlap fraction needed to account for continuity in time and give rise to the so –called splitters and mergers, whereby complex cloudy scenes are segmented into individual mesoscale convective systems. These techniques also rely on a given IR threshold although recent efforts implemented adaptative thresholding version of the cluster detection and overlap approach (Morel and Senesi, 2002). These techniques have been shown very useful to document and study the convection from satellite (Srinivasan and Joshi, 2007).

With respect to the detection of clusters associated with mesoscale convective systems, generalized clustering techniques make it possible to somehow elaborate an IR image segmentation with no (or little) dependence on any given threshold. The Detect and Spread (DAS) technique (Boer and Ramanathan, 1997) provides a sound basis for such an enhanced detection of cloud systems. It was successfully 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 aim of the present study is to introduce an improved method for tracking the tropical MCS based on a 3D extension of the above mentioned generalized clustering approach.

The methodology is first detailed and then cases studies for the summer 2006 using MSG observations are presented. A systematic comparison with the results of the previous single given threshold and overlap approach is provided to highlight the behaviour of the new method compared to the original one. Season statistics are also shown to complete the new description of organized convection in West Africa obtained using the present approach and a summary of the improvement upon previous approach is finally given.

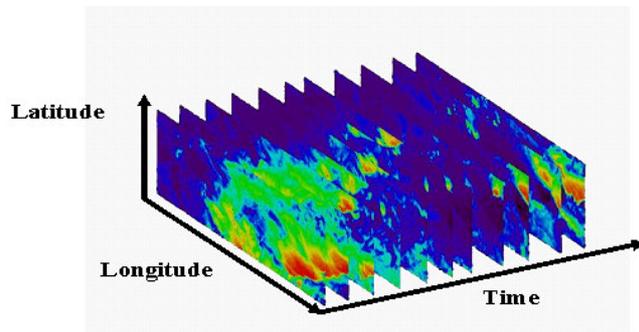
## II. DATA

The data used in this study are the 10.8  $\mu\text{m}$  Meteosat Second Generation images degraded to a 30 minute period and with a 3km spatial resolution at the satellite subpoint. The study area covers the West African region from 30°W to 30°E and from 5°S to 20°N and computation is performed for the period June to September 2006. The test uses the METEOSAT first generation characteristics to possibly reprocess the METEOSAT archive for climatological purposes (Fiolleau et al., 2009).

## III. IMAGERY SEGMENTATION IN 3D

The DAS technique is here restricted to high cold clouds and is extended in time to form a 3D segmentation technique (2D+time). To segment moving objects in an image sequence, the

homogeneity that combines the temporal and spatial information is used in this proposal tracking method. A spatiotemporal image, whose spatial axes are longitude and latitude, is then generated by the 48 daily MSG images. Figure 1 shows a sequence of images to illustrate the volumic approach.



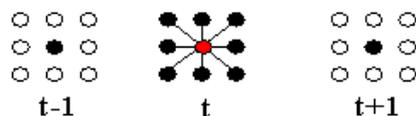
**Figure 1: example of a 3-dimensional spatiotemporal image**

A cloud identification scheme is introduced, based on the assumption that individual clouds are distinct systems as long as their cores are separated by higher effective brightness regions in the spatiotemporal image (Boer and Ramanathan, 1997; Roca et al., 2005). Individual clouds are identified by computing the evolution of cloud systems as a function of their spatiotemporal scales. This algorithm is a multi-stage, multi-threshold method to extract individual clouds in the volume image.

The two principal stages are described below:

1- A 3D detection of clouds in the spatiotemporal domain 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- Spreading of clouds, in the spatiotemporal image, to a certain Temperature threshold 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. Region growing is performed by using a 10-connected spatiotemporal neighbourhood (figure 2): 8-connected spatial neighbourhood and 2-connected temporal neighbourhood (past and future), in order to emphasize the region spread in the spatial axis.



**figure 2 : 10-connectivity directions**

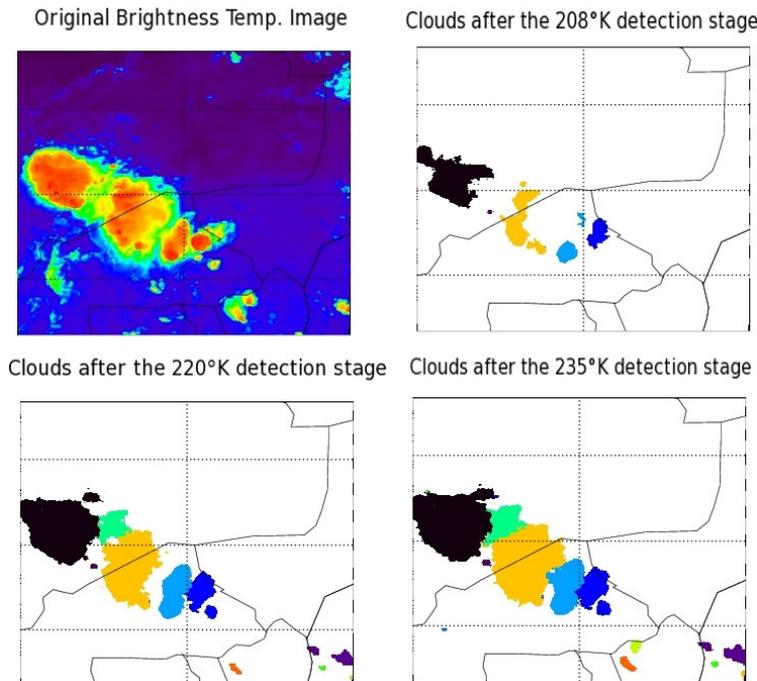
Assuming that low brightness temperatures are strongly related to deep convection, a first set of clusters is identified at a 190°K threshold in the spatiotemporal image. This low temperature threshold permits to distinguish each convective cluster from nearby clusters. Cluster volumes are then identified and labelled as cloud cores, if they exceed 600 pixels and last more than 1H30.

Once a core of a cloud is detected, the cloud boundaries are expanded thanks to the 10-connected spatiotemporal neighbourhood until the next threshold temperature set at 195°K is reached.

An iterative process then starts with such a detection and spread phase. Clusters are detected in multi-steps from 190°K to 235°K with a 5°K step (190°K, 195°K, 200°K, 215°K, ... 235°K). For each detection step, every identified cluster is spread in the spatiotemporal image to a 5°K warmer threshold, from 195°K to 235°K (195°K, 200°K, 205°K, ... 235°K) (figure 3).

The upper limit threshold of 235°K, used here, is in the range of the commonly used thresholds to characterize deep convection and to estimate rainfall in the tropics (Arkin 1979). No cluster size filtering is applied during the spread stage, so that clusters are detected earlier in their triggering phase, and in their Dissipation stage. Moreover, cases of cluster regeneration can't be missed.

With this new methodology, the morphology (spatial extension, brightness temperature distribution, ...) of mesoscale convective systems is hence characterized over their life cycle in a 3 dimensional spatiotemporal image.



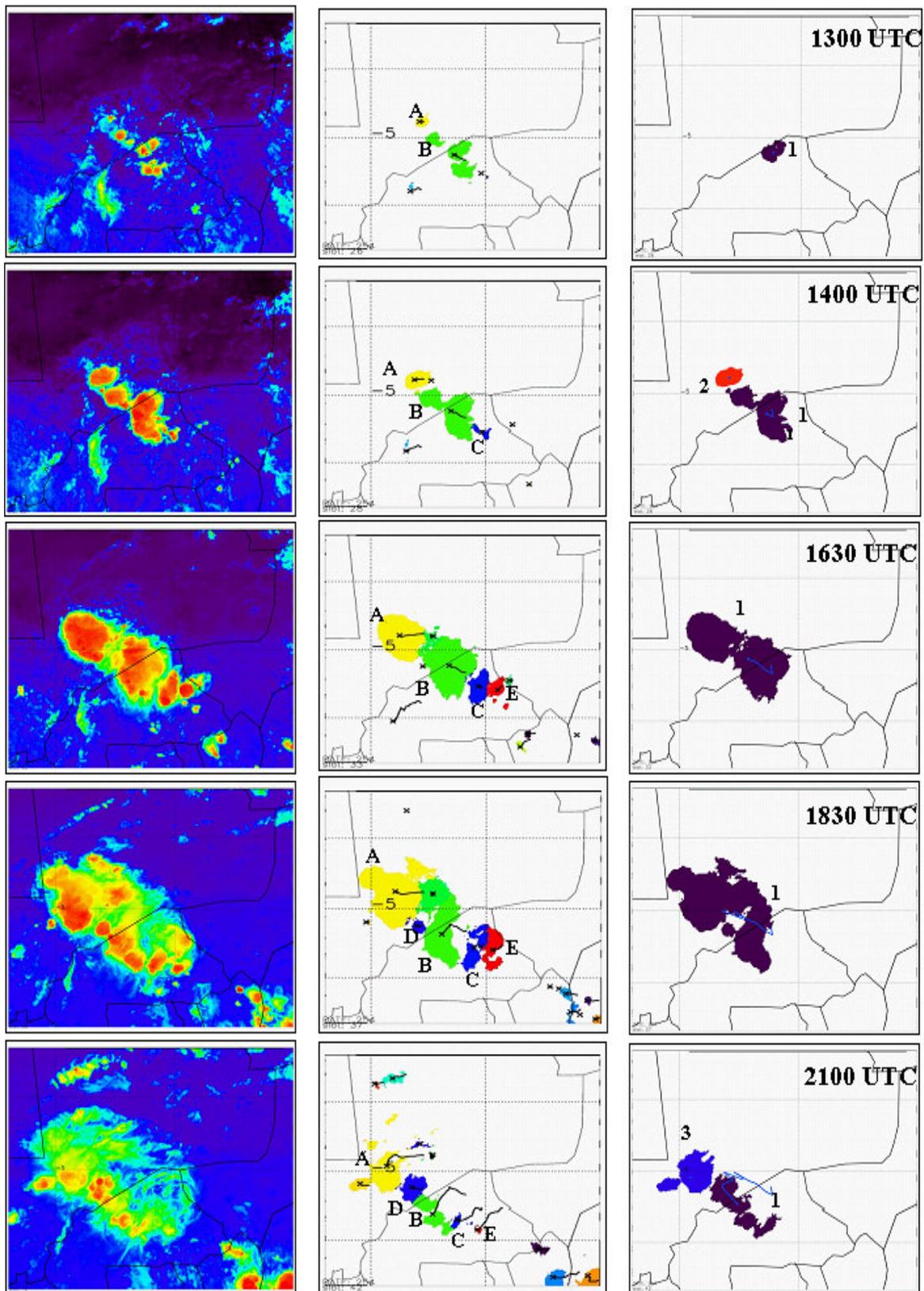
**figure 3** : Brightness temperature image at 1600 UTC on 11 September 2006, with the identified clouds after the 208°K detection, after the 220°K detection stage and after the final set of identified clouds at 235°K.

#### IV. Application of the algorithm – Performance assessment

In order to assess the effectiveness of the tracking method, we compare the accuracy of the tracking results obtained by the proposed method in this paper, with the tracking method based on area-overlapping analysis (Mathon and Laurent, 2000). The area-overlapping technique consists in delineating continuous clusters in the full resolution infrared imagery by using a single brightness temperature threshold. Using an overlap assumption, clusters are then identified from one slot to another and followed in time.

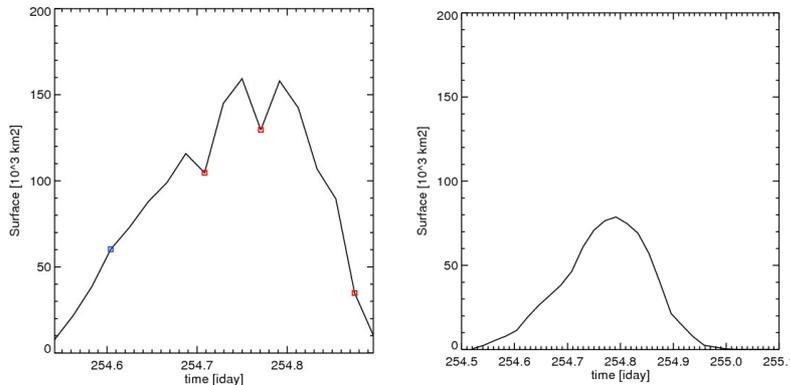
The figure 4 illustrates the tracking scheme over a selection of images at 1300 UTC, 1400 UTC, 1630 UTC 1830 UTC, and 2100 UTC for the convective situation which occurs over the region of Niamey on 11th September 2006. This figure illustrates the performance of the new tracking method compared to the results of overlapping technique. Convective Clouds, detected and followed by the two tracking algorithms, are represented by different colours. A black line represents trajectory histories of the clouds centre-of-gravities. We find that the new tracking algorithm identifies and tracks cloud clusters much as one would view pictures subjectively. The DAS3D methodology seems to delineate correctly convective systems in the sequence of images. The detection procedure detects 24 convective systems (5 for the overlapping technique) for this period, from which, no one originates by splitting or dissipates by mergers (2 splitting or merging events for the overlapping technique).

According to the area-overlapping algorithm, in the first time step, cluster n°2 is merged by cluster n°1. Cluster n°2 is then ended up by merging into the big cluster n°1. Between the fourth image and the last image, a part of cluster n°1 splits and gives rise to the new cluster n°3. Actually, cluster A processed by the new tracking algorithm is a cluster consisting in cluster 2 at 1400 UTC, a part of cluster 1 at 1630UTC and at 1830 UTC and cluster 3 at 2100 UTC. Cluster 1 is a cluster consisting in cluster B at 1300 UTC, and at 1400 UTC, A, and B at 1630 UTC, A, B, D at 1830 UTC, and B, C and D at 2100 UTC. Thereby, thanks to the design of the new algorithm, all MCS detected describe a coherent life cycle, in terms of their spatial variability. Because they don't meet the minimum size criterion (5000km<sup>2</sup>), the very small convective systems C and E followed by the algorithm are not identified by the tracking based on the overlapping-area. Yet, clusters C is of special interest because it was penetrated by research aircraft during the AMMA campaign in 2006 (Bouniol et al., 2009). Due to this independence to a minimum size criterion, the new tracking algorithm identified the triggering of convection in its earlier phase. As well, the dissipation phase of each convective system is detected in its later phase.



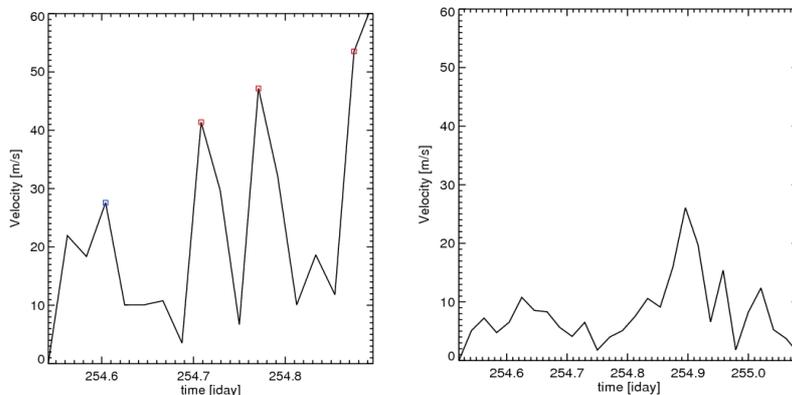
**Figure 4 :** Sequence of frames of satellite imagery from the 11 September 2006 convective situation over the region of Niamey. From left to right: Meteosat Brightness temperature images; images processed by the output of the new tracking algorithm; images processed by the area-overlapping tracking.

Cloud A processed by the DAS3D algorithm and cluster 1 processed by the area-overlapping method are chosen for a graphical representation. The temporal evolution of their cloud areas and the temporal evolution of their propagation speed are analysed and compared.



**Figure 5:** Time series of the evolution of clouds area for the Cluster A processed by the new algorithm (right) and the cluster 1 processed by the area-overlapping algorithm (left). Red points and blue points indicate respectively merges and splits.

Figure 5 illustrates that several splits and merges artefacts occur in the cluster 1 life cycle, processed by the overlapping tracking. Although its area evolution is noisy, the cluster 1 describes a growing phase from 1300 UTC to 1800 UTC, and then, reaches the area of about 160000km $^2$ . The dissipation stage which follows is marked by several splits. The evolution of the cluster A is also described by a growing phase from 1300 UTC to 1900 UTC on 11 September 2006, but the surface (79000 km $^2$ ) reached is smaller than the cluster processed by the overlapping tracking (162000km $^2$ ). The cluster A then decreases until 0200 UTC on 12 September 2006. It is to be noticed that the evolution of the cluster A area is smooth due to the lack of split or merge artefacts.



**Figure 6:** Time series of the evolution of clouds area for the Cluster A processed by the new algorithm (right) and the cluster 1 processed by the area-overlapping algorithm (left). Red points and blue points indicate respectively merges and splits.

The speed of cloud 1 (estimated by the displacement of the centre of gravity) processed by the overlapping-area technique presents abrupt variations (figure 6). Propagation speed of cluster 1 can reach 60 m/s during its lifetime. These variations are explained by successive mergers or splits artefacts which occur. On the contrary, the speed of the cluster A processed by the 'DAS3D' algorithm varies slightly, with a peak at 26m/s, and an average value of 8m/s.

## V. CONCLUSION

A new tracking methodology, using 10.8  $\mu$ m IR satellite images, to detect and track convective systems through their life cycle in a 3 dimensional spatio-temporal image has been introduced and described. This method is based on generalized clustering technique is referred to as DAS3D as it

build upon various previous implementation of the Detect and Spread technique (Boer and Ramanathan, 1997). This algorithm provides a new way to characterize the convective systems life cycle, in particular by avoiding problems of splitting and merging, which occur in the previous studies. Moreover thanks to independence to a minimum size criterion, this algorithm can detect the convective systems triggering in their earlier stage and their dissipation stages in their later stage. A case study, which occurred over West Africa on 11 September 2006, has been analysed, and tracking results have been compared with the tracking method based on area-overlapping technique. The new automated results are in better agreement with human analysis than previously developed techniques. Future improvements in the algorithm will be brought to the detection of the full upper level cloudiness associated to the convective event instead of a cut-off threshold. Multi spectral observations of SEVIRI sensor will be used to this endeavour and the MCS detection will be applied on classification of high clouds following previous investigation of the DAS2D technique (Roca et al., 2002).

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