Journal of Natural Sciences Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.8, No.16, 2018

Climatology of Satellite-Derived Mesoscale Convective Systems over West Africa

Elijah Adesanya ADEFISAN
Department of Meteorology and Climate Change, Federal University of Technology, Akure, Nigeria.

David Eche OKEWU
Central Forecasting Office, Nigerian Meteorological Agency, Abuja, Nigeria.

Abstract
This work studied the climatology of Mesoscale Convective Systems (MCSs) over West Africa. Infrared brightness temperature (BT) data was collected from Tropical Rainfall Measuring Mission (TRMM) website over the rainy season period for ten years (2006 - 2015) from 1st of June to 30th of September. The study area covers West Africa from 5ºS to 25ºN and 20ºE to 20ºW, it was divided to 5° X 5° boxes. The T-R criteria used to detect the minimum size of MCSs was a diameter of 200 km or more and a BT of 233 K (-40 ºC) or less. All the MCSs were tracked for the months of June, July, August and September and compared the wettest (2014) and the driest (2009) years as observed from the ten years annual rainfall data collected from the archives of the Nigerian Meteorological Agency (NIMET). The results indicated that for both the driest and wettest years, latitudinal row 5ºN - 10ºN is the most active zone favorable for the initiation, propagation and decay of MCSs over West Africa with 45% of MCSs found there in the month of June and row 10ºN - 15ºN as the next favorable zone (29-32% of MCSs). In the month of July, the active zone shifted to 10ºN - 15ºN while the next favorable zone also shifted to 5ºN - 10ºN, which was maintained and became more favorable through August and September. There were almost double the number of MCSs occurrence in the wettest year compared to driest year. During wettest year, MCSs were found out to be slower than their driest year counterpart. The results also gave a better insight of the behavioral patterns of West African MCSs, hence improving general forecasting method and reliability.
Keywords: active zone, initiation, propagation, DETRAWACS, tracking.

Introduction

West Africa is a vast zone where several types of mesoscale convective systems (MCSs) develop depending on the latitude, surface conditions and terrain condition. A broad definition of an MCS that most, if not all of its forms is a cumulonimbus cloud system which produces a contiguous precipitation area approximately 100 km or more in at least one direction. Different names and nomenclatures have been used to describe tropical mesoscale systems depending on their shapes, sizes and some other properties when observed. Some of these are; disturbance lines (Hamilton and Archbold, 1945); mesoscale convective complexes (MCC first defined by Maddox, 1980) of circular type; organised convective systems (OCS, Mathon, 2001) which gives the more precipitation over the Sahelian band, and superclusters described by Mapes and Houze (1993) which lasts more than two days. They move rapidly westward at around $15ms^{-1}$, faster than the ambient wind at all levels throughout the troposphere (Riehl *et al*., 1974) and produced most of the precipitation over the region. MCSs are an important link between atmospheric convection and the larger scale atmospheric circulation. For example, they are associated with various ways with large-scale wave motions (Payne and McGarry, 1977; Hodges and Thorncroft, 1977; Houze *et. al*. 2000 and Carbone *et. al*. 2002). A compilation of the different names and definitions of convective cloud clusters and squall lines was presented by Rowell and Milford (1993). For the purpose of this study, the Squall Line Systems (SLSs) represented MCSs. Often, the two may be used interchangeably. From the climatological studies of SLS (referred to a "disturbance lines", DLs) over the West Africa by Aspliden *et al.,* (1976) using the three phases of GATE data, it was discovered that majority of the SLS generated and decayed over land. The generation occurred predominantly in the afternoon over land and in the early morning over water. The number that developed over land and water are shown in Figure 1(a) while the number that generated and decayed in each 5ºx5º grid box over the continent and ocean are shown in Figure 1(b). It is clearly seen that majority of the systems initiated and dissipated within latitude 10ºN and 20ºN. By comparing the cases over land and ocean, those that occur over the ocean have a shorter lifespan, lower speed (excluding phase 1), propagated over less area and much fewer than their counterparts over the land (Aspliden *et al.*, 1976).

In the Sahel, 358 MCSs were retained by the tracking algorithm developed by Clemence *et al.* (2011) between 1st of July and 22nd of September 2006 which accounted for approximately 70% of the precipitation over the study area. Most of the MCSs initiated in the afternoon showed 3 hrs later a maximum in intense precipitation and the time at decay appeared more variable that the time it generated.

In this study, we detect and track mesoscale convective systems through their entire life cycle and also observe their behavior patterns. The aim of this research was to climatologically determine the active zone(s) of MCSs over West Africa. The specific objectives of this study were to: (i) validate an algorithm for automatic detecting and tracking of MCSs over West Africa; and (ii) identify the most active zone(s) for each of the initiation, propagation and decay of MCSs over West Africa.

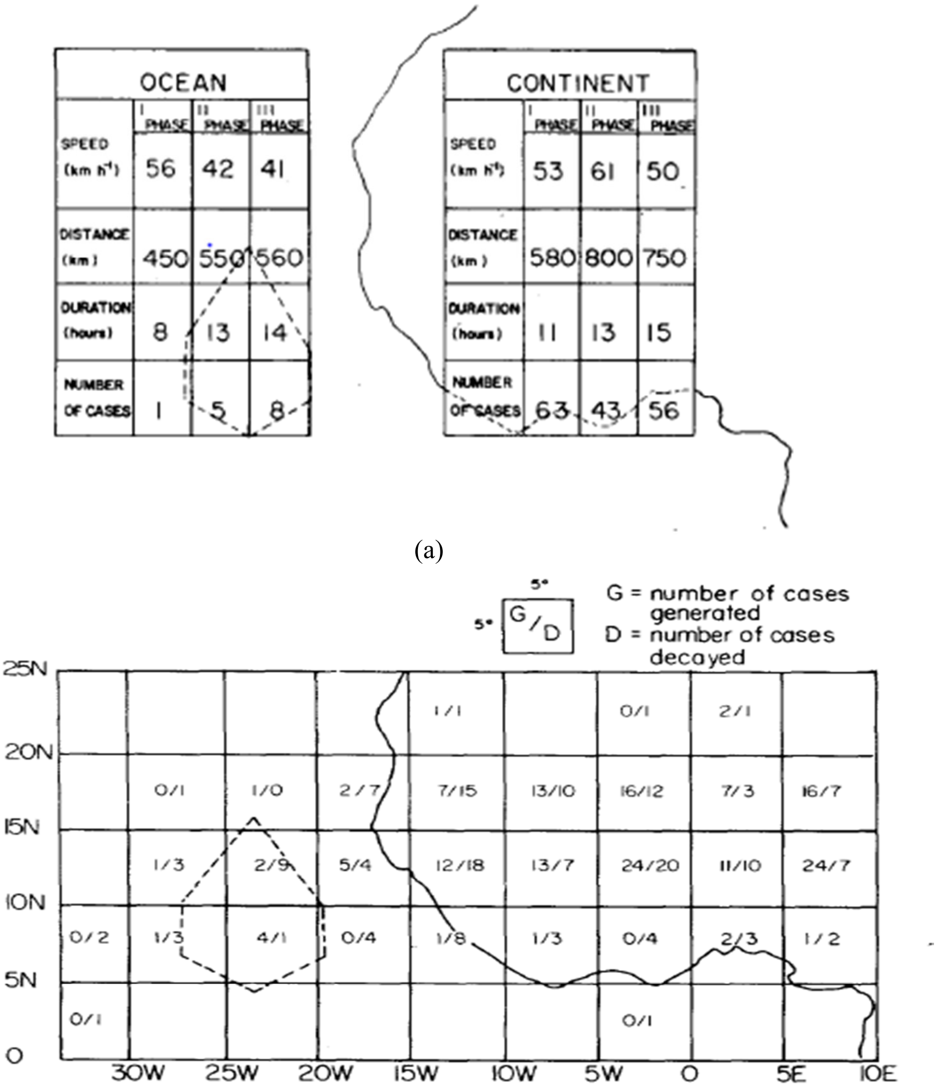

Figure 1: Properties of disturbance lines such as (a) their number, mean speed, duration and distance travelled; and (b) number that generated and decayed within each 5ºx5º grid box. All were analyzed over ocean and land for the three phases of GATE (Aspliden *et. al.,* 1976).

Study Area, Data and Methodology

This research work covers West Africa geographical domain from 5ºS to 25ºN and 20ºE to 20ºW. The study area is divided into grid boxes of 5º x 5º with labels numbering 1- 48 from East to West representing each grid box. MCSs that initiated on the boundary of each 5º x 5º grid box were counted as part of the grid box to the right. The latitudinal column comprising of grid boxes between 15ºE and 20ºE (grid boxes 1, 9,17,25,33 and 41 as labelled in Figure 2) were not considered for counting the number of MCSs that initiated. This was done to remove a spurious error of any MCS that propagated from Central Africa (further east) into this column to be captured as being initiated there. Therefore the column was not used for the entire analysis of this research, instead the grid boxes lost were used to compute the percentages for the corresponding rows**.**

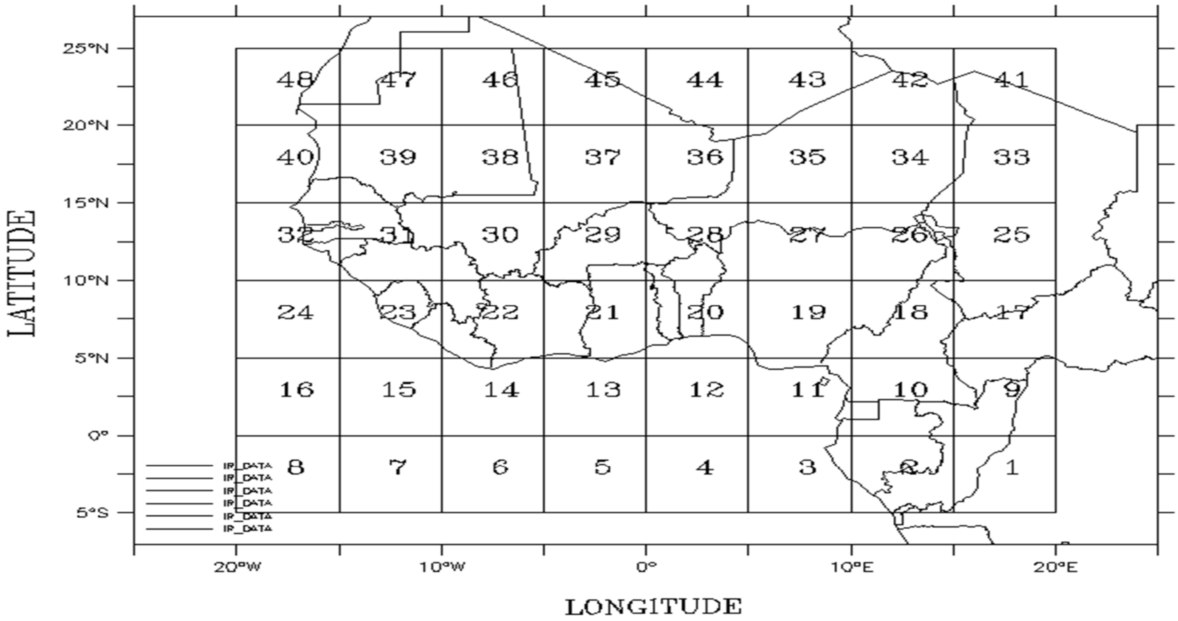

Figure 2: Map of West Africa geographical domain covering 5ºS to 25ºN and 20ºE to 20ºW divided into grid boxes of 5ºx5º.

The observed data are in three categories: (i) the Infra-Red (IR) brightness temperature (BT) from satellite imagery; (ii) annual rainfall for some selected stations spread across Nigeria; and (iii) the record for days of occurrence of squall over Ikeja NIMET station in Lagos. The Infra-Red brightness temperature (BT) data used in this work is the Climate Prediction Centre (CPC) merged dataset. This dataset has been prepared by merging pixel resolution IR brightness data from Geostationary channel 8 and 10 (GOES/8/10), METEOSAT channel 7 and 5, and GMS geostationary satellite at a spatial resolution of 4km and temporal resolutions of 30mins. The satellite data is archived and can be downloaded from this website: (Http://mirador.gsfc.nasa.gov/collections/MERG_001.shtml).

The data collected was over the rainy season for 10 years (2006 - 2015) from June 1st - September 30th. The geographical domain which covers West Africa from 5ºN to 25ºN and 20ºE to 20ºW was extracted from the global merged BT data. The annual rainfall data for a period of 10 years (2006 - 2014) over ten stations spread across Nigeria. They stations are Lagos, Ilorin, Abuja, Port-Harcourt, Ondo, Enugu, Calabar, Kano, Yola, and Abeokuta. This data was used to determine the wettest and driest years. The record of days with occurrence of squall over Ikeja NIMET station with coordinates 06º35'N, 03º20'E was collected for the year 2015 over the rainy months of June, July, August and September.

The tracking algorithm developed by Adefisan (2014) which follows Schröder *et al.,* (2009) used in this study was written in Linux-based FORTRAN language. Data analysis and visualization of the IR brightness temperature was also performed. These environments present several advantages for projects related to imaging. Indeed, scripts can be compiled and executed and subsequent results can be displayed immediately in the same environment. This is very useful when working with images. The program also presents an extensive subroutine library. Two scalars functions commonly used by climate scientists to study clouds are infrared (IR) brightness temperature and precipitation respectively. Given the IR brightness temperature distribution, the set of clouds over the corresponding geographical region is identified as the collection of sub-level set components for a given temperature threshold (T). Geostationary satellites have been proven to be appropriate for detecting and tracking MCSs (Kidder and Vonder Haar, 1995; Goyens *et al.,* 2011). These satellite images allow the observation of ever-changing large-scale weather events due to their high temporal resolution and large field view. The strong contrast between the cold cloud top and the warm background further aids in identifying and tracking MCS (Kidder and Vonder Haar, 1995). The threshold values usually depend on whether the clouds of interest are tall or short. Colder temperatures ($\leq$ 210 K) indicate tall clouds with cloud tops at 7.5 km or higher and are associated with Cumulonimbus (Cb) cells, while higher temperatures indicate short clouds that are associated with Stratus clouds (Mahani *et al.,* 2000). There are several methods and algorithms for tracking MCS and its characteristics. These include Subjective and Automated methods (Velaso and Fritsch, 1987; Williams and Houze, 1987 and Machado *et al.,* 1998).

Detecting and tracking of convective systems using satellite imageries requires some processes. The first process is to take a threshold value of the brightness temperature (BT) of cloud tops. Different BT values from 245 K to 233 K have been used over different parts of the tropics with different reasons and at times for different types of MCS (Squall Lines (SL), Organized Convective Systems (OCS) and Mesoscale Convective Complexes, (MCC)) in all of the studies cited previously. In order to conform to the African Monsoon Multidisciplinary Analysis (AMMA) and with a little modification, a diameter of 200 km or more is used for MCS. Since the present study involves tracking of convective cloud system whose thermodynamics and structural properties before they develop into full blown MCS and through propagation till they decay will be investigated, two threshold diameter of 140 - 200 km are used for any Convective Cloud Cluster (CCC). The combination of temperature and diameter (radius) criteria is hereinafter referred to as T-R criteria. Thus, the life cycle of a given (CCC). The combination of temperature and diameter (radius) criteria is first met and the life cycle of such system ends when this criteria is no longer met, so that a CCC becoming an MCS signifies development while an MCS that becomes a CCC is decaying. A fully automated detecting and tracking algorithm for West Africa CS developed by Adefisan (2014) was used for this study. The Algorithm is referred to as DEtecting and TRAcking of West African Convective Systems (DETRAWACS).

The annual rainfall data over 10 stations spread across the Nigeria as shown in Table 1 was adopted to obtain the wettest year and driest year between years 2006 and 2014. The data for the year 2015 was not readily available. The rainfall amount over these stations for each year were ranked from the highest to the lowest using numbers ❶ - ❾ for each of the stations. The remarks (RMKS) column gives a summary of the number of stations for each year that falls into wet, moderate and dry categories using the ranges ❶ - ❸ for Wet, ❹ - ❻ for Moderate and ❼ - ❾ for Dry. From the Table 1, 2014 is considered the wettest year recoding the highest amount of rainfall in five (5) stations; LAG ❶, ILR ❶, ABJ ❶, ABK ❶, and OND ❶ and also a high value over KAN ❷ station. Four (4) stations recorded moderate rainfall and no station recorded dryness. On the contrary, 2009 recorded the least amount of rainfall in four (4) stations; LAG ❾, ILR ❾, ENU ❾, CAL ❾ and also low values over KAN ❽ and OND ❼. Three (3) stations fell into the moderate category and just One (1) station recorded wetness. With this, we established year 2009 as the driest year and year 2014 as the wettest year. MCSs was detected and tracked for the years 2009 and 2014 using the IR brightness temperature data over West Africa.

	STATIONS										
YEAR	**LAG**	**ILR**	**ABJ**	**ABK**	**PH**	**OND**	**ENU**	**CAL**	**KAN**	**YOL**	**RMKS**
2006	1516 ❽	1303 ❸	1311 ❻	1142 ❽	2542 ❸	1505 ❾	2096 ❷	2607 ❽	1309 ❸	1131 ❶	5 Wet 1 Mod 4 Dry
2007	1536 ❼	1292 ❹	1388 ❺	1637 ❷	2790 ❶	1587 ❽	1859 ❺	3281 ❹	1094 ❻	1081 ❷	3 Wet 5 Mod 2 Dry
2008	1553 ❻	1401 ❷	1174 ❾	1201 ❼	1972 ❽	1901 ❸	1767 ❻	3265 ❺	1035 ❼	495 ❾	2 Wet 3 Mod 5 Dry
2009	1393 ❾	895 ❾	1444 ❹	1313 ❺	2562 ❷	1624 ❼	1427 ❾	2529 ❾	992 ❽	682 ❻	**1 Wet** **3 Mod** **6 Dry**
2010	1669 ❹	924 ❽	1682 ❷	1563 ❸	2116 ❼	1929 ❷	1709 ❽	3125 ❼	1097 ❺	814 ❹	3 Wet 3 Mod 4 Dry
2011	1748 ❷	1086 ❻	1270 ❼	1270 ❻	1749 ❾	1639 ❻	1723 ❼	3521 ❷	1220 ❹	575 ❽	2 Wet 4 Mod 4 Dry
2012	1557 ❺	1079 ❼	1638 ❸	1364 ❹	2248 ❻	1464 ❺	2139 ❶	4044 ❶	1764 ❶	930 ❸	5 Wet 4 Mod 1 Dry
2013	1731 ❸	1290 ❺	1093 ❽	1031 ❾	2487 ❺	1695 ❹	1974 ❸	3497 ❸	888 ❾	653 ❼	3 Wet 3 Mod 4 Dry
2014	2226 ❶	2500 ❶	1686 ❶	1646 ❶	2518 ❹	1947 ❶	1966 ❹	3188 ❻	1365 ❷	803 ❺	**6 Wet** **4 Mod** **0 Dry**

Table 1: Observed annual rainfall (mm) over some stations in Nigeria, ranked from the station with the highest rainfall amount to the lowest. (❶ - ❾).

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3. Results and Discussion

3.1 Validation of the Satellite Imageries and Tracking Algorithm (DETRAWACS).

To validate DETRAWACS, we compared the spatial plots of IR brightness temperature from the satellite imageries and the output of the automatic detecting and tracking algorithm with the days of occurrence of squall over Ikeja NIMET station, Lagos. NIMET Ikeja station with coordinates 06º35'N, 03º20'E observed a passage of a squall line on the 23rd of August, 2015 at about 1226 hrs, which propagated at a speed of 22.5 ms^{-1}. Figure 4.1(a-l) shows the satellite imageries of IR brightness temperature data plotted for 23rd of August, 2015 manually identifying an MCS centred around 7ºE, 7ºN which initiated at 0730 hrs and how it propagates, also satisfying the T-R criteria for the occurrence of MCSs over West Africa. Figure 4.2 shows the output file generated by DETRAWACS of the life cycle of an MCS that initiated at about 0730 hrs centred around 7ºE, 7ºN on the same 23rd of August, 2015 which propagated from East to West for 6½ hrs and later decayed around centre 5ºE, 8ºN at 1300 hrs. The output file provides the time, longitudinal and latitudinal position, area covered, BT average, minimum BT, speed of propagation, direction and remarks.

Comparing the plots of the satellite imageries in Figure 4.1 and the resultant output gotten in Figure 4.2, one can see that the MCS came over Ikeja station at about 1200 hrs with a propagation speed of 23.5 ms^{-1}. It is seen that the objective characteristics of the selected MCS (from Figure 4.2) is very close to ones (subjective) roughly estimated by merely looking the Figure 4.1(a-l). This analysis therefore establishes two things: (i) that the TRMM satellite imagery of Cloud Top Temperature (CTT) remotely captured what was observed on the earth surface; and (ii) the results of DETRAWACS (speed and time of passage over Ikeja) and the observed squall system over Ikeja are almost the same.

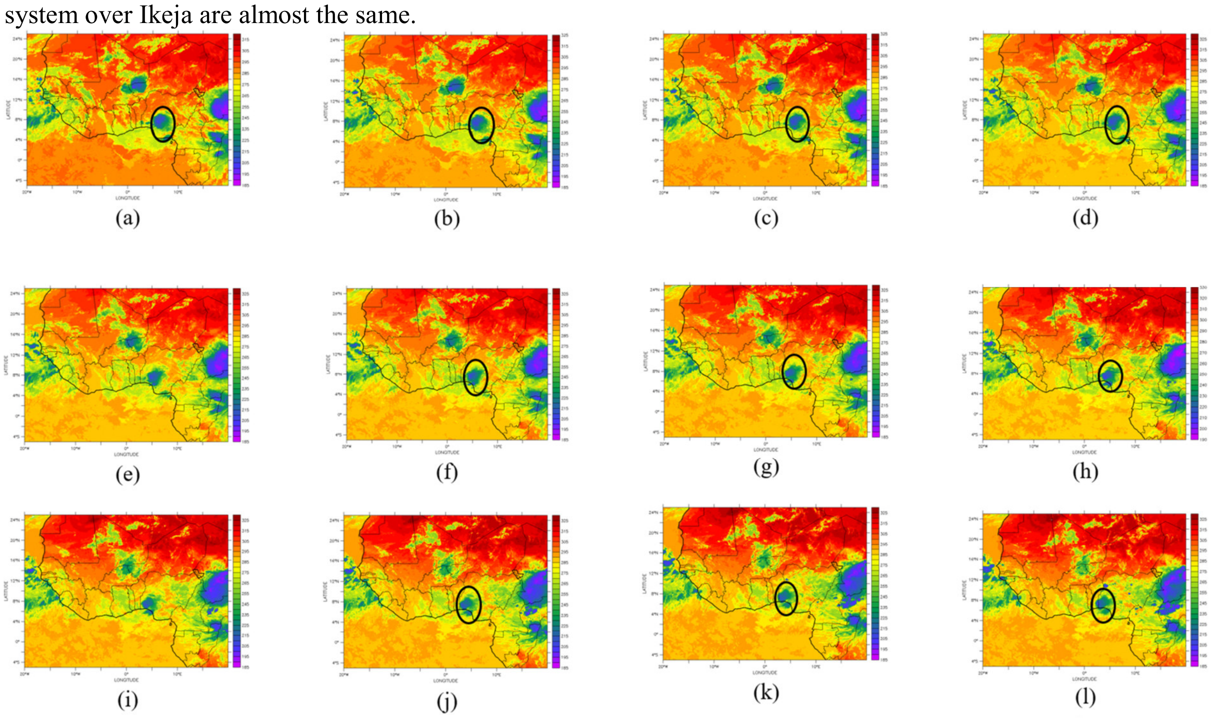
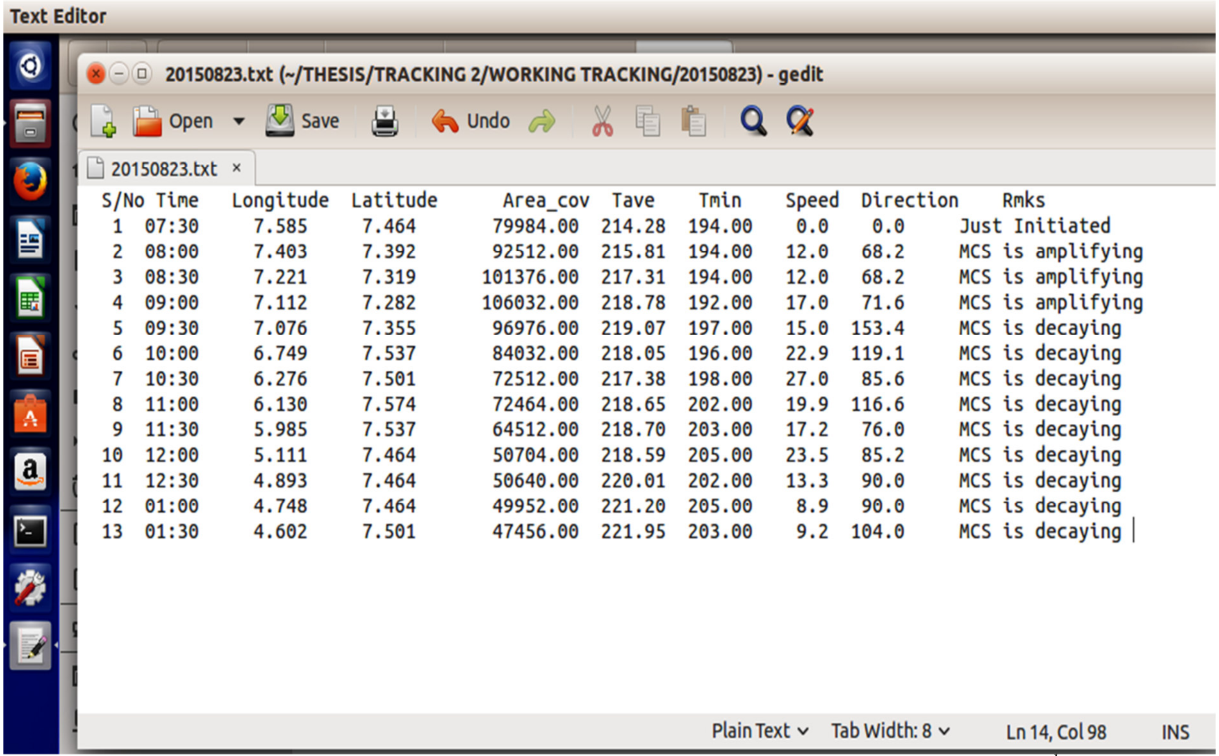


Figure 3: Satellite imageries for brightness temperature showing the propagation of an MCS that initiated around centre 7ºE, 7ºN on 23rd August, 2015 at: (a) 07:30; (b) 08:00; (c) 08:30; (d) 09:00; (e) 09:30; (f) 10:00. (g) 10:30; (h) 11:00; (i) 11:30; (j) 12:00;(k) 12:30; and (l) 13:00.



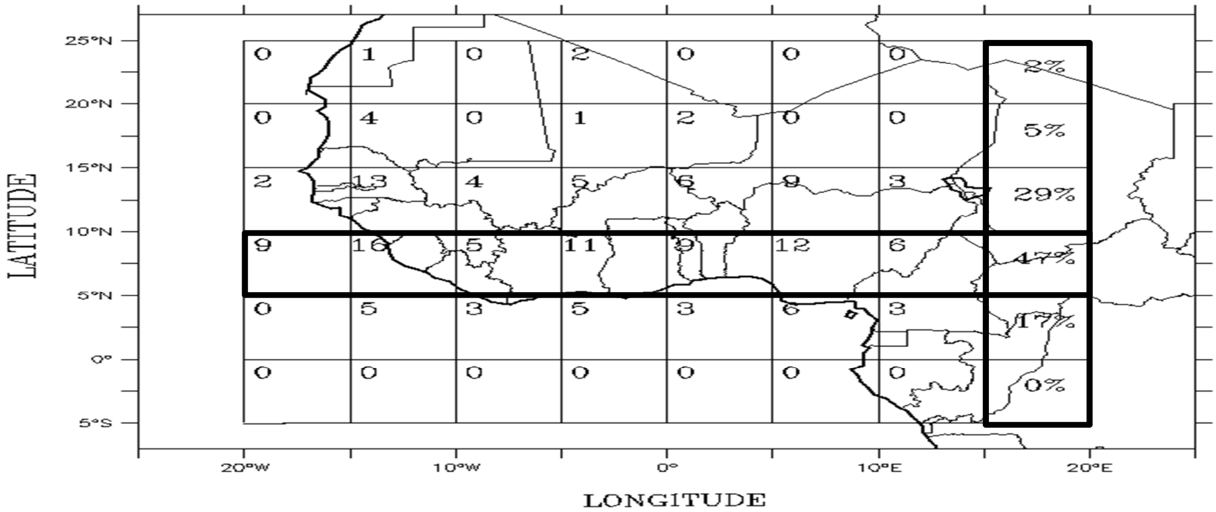
S/No	Time	Longitude	Latitude	Area_cov	Tave	Tmin	Speed	Direction	Rmks
1	07:30	7.585	7.464	79984.00	214.28	194.00	0.0	0.0	Just Initiated
2	08:00	7.403	7.392	92512.00	215.81	194.00	12.0	68.2	MCS is amplifying
3	08:30	7.221	7.319	101376.00	217.31	194.00	12.0	68.2	MCS is amplifying
4	09:00	7.112	7.282	106032.00	218.78	192.00	17.0	71.6	MCS is amplifying
5	09:30	7.076	7.355	96976.00	219.07	197.00	15.0	153.4	MCS is decaying
6	10:00	6.749	7.537	84032.00	218.05	196.00	22.9	119.1	MCS is decaying
7	10:30	6.276	7.501	72512.00	217.38	198.00	27.0	85.6	MCS is decaying
8	11:00	6.130	7.574	72464.00	218.65	202.00	19.9	116.6	MCS is decaying
9	11:30	5.985	7.537	64512.00	218.70	203.00	17.2	76.0	MCS is decaying
10	12:00	5.111	7.464	50704.00	218.59	205.00	23.5	85.2	MCS is decaying
11	12:30	4.893	7.464	50640.00	220.01	202.00	13.3	90.0	MCS is decaying
12	01:00	4.748	7.464	49952.00	221.20	205.00	8.9	90.0	MCS is decaying
13	01:30	4.602	7.501	47456.00	221.95	203.00	9.2	104.0	MCS is decaying

Figure 4: Output file generated by DETRAWACS of an MCS that initiated at 07.30 hrs on 23rd August, 2015 centred on 7ºE, 7ºN.

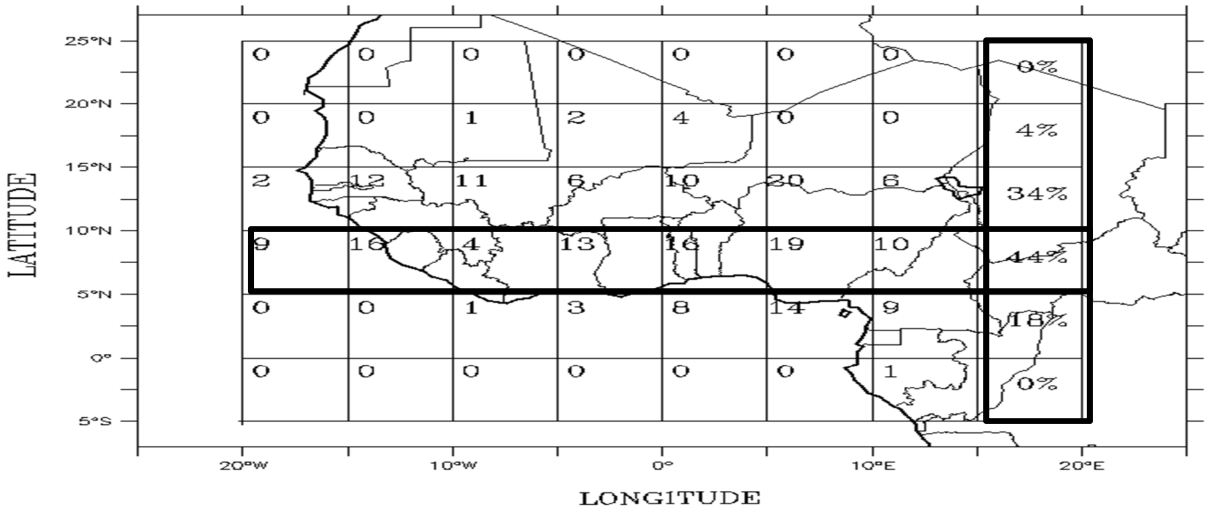
Initiation of MCSs over West Africa.

The total number of MCSs that initiated in each 5º x 5º grid box were obtained for the raining months of June, July, August and September. The number of MCSs that developed for each month in both the driest (2009) and wettest (2014) years and their averages were compared. Their behavioural patterns and trends were also discussed. The most active zones for the generation of MCSs over West Africa was obtained. Figure 5 shows the distribution of MCSs that initiated in each 5º x 5º grid box over West Africa during the month of June for (a) 2009; (b) 2014 and (c) average of the two years. A total of 67 MCSs initiated for the driest year (2009) as captured by DETRWACS, 23 (34.3%) of which generated over the ocean and the remaining 44 (65.7%) generated over land as shown in Figure 5(a). Grid boxes along row 5ºN - 15ºN recorded the most initiated MCSs indicating an area favourable for the initiation of MCSs over West Africa sub-region for the month of June. In terms of percentages, 53.7% developed between 5ºN - 10ºN, 25.4% between 10ºN - 15ºN and 14.9% between 0ºN - 5ºN. Therefore, 5ºN - 15ºN is the active zone favourable for the initiation of MCSs, with over three-quarter (79.1%) of the systems generating over this zone and row 0ºN - 5ºN fairly favourable. Row 5ºN - 10ºN is the most active zone for the initiation of MCS over West Africa for the month of June 2009, accounting for more than half (53.7%) the number of systems that initiated over the region as highlighted in Figure 5(a). Similarly, a total of 86 MCSs initiated in the wettest year (2014), 24 (27.9%) of which initiated over the ocean and the remaining 62 (72.1%) over land as shown in Figure 5(b). On row basis, the percentages of 5ºN - 10ºN, 10ºN - 15ºN, 0ºN - 5ºN and 15ºN - 20ºN are 51.2%, 31.4%, 10.5% and 7.0% respectively. In a similar manner as 2009, over three-quarter (82.6%) of the systems initiated between 5ºN - 15ºN which shows that this region is an active zone suitable for the initiation of MCSs and row 0ºN - 5ºN fairly suitable and recorded 10.5%. As highlighted in Figure 5(b), 5ºN - 10ºN is the most active zone for the initiation of MCS over West Africa for the month of June 2014, accounting for half (51.2%) the number of systems that initiated over the region.

Considering the average number of MCSs that initiated in June of 2009 and 2014 as shown in Figure 5(c), latitudinal row 5ºN - 10ºN is the most active zone for the initiation of MCSs over the West Africa sub-region for the month of June. This study therefore establish that in the month of June, either in the driest year (2009) or the wettest year (2014), the most active zone in terms of 5º latitudinal rows is the 5ºN - 10ºN, which is also the same for propagation and decay since majority of the systems that developed in a particular latitudinal row propagated and dissipated along that path. The study also found out that the number of MCSs that initiated over West Africa in a wettest year are more than those that initiated in the driest year during the month of June. This is in conformity with the active weather zone (zones C_1 and C_2 of Dhonneur, 1971 and zone C of Hamilton and Archbold, 1945) associated with the meridional movement of ITD during the Boreal Summer.



(a)



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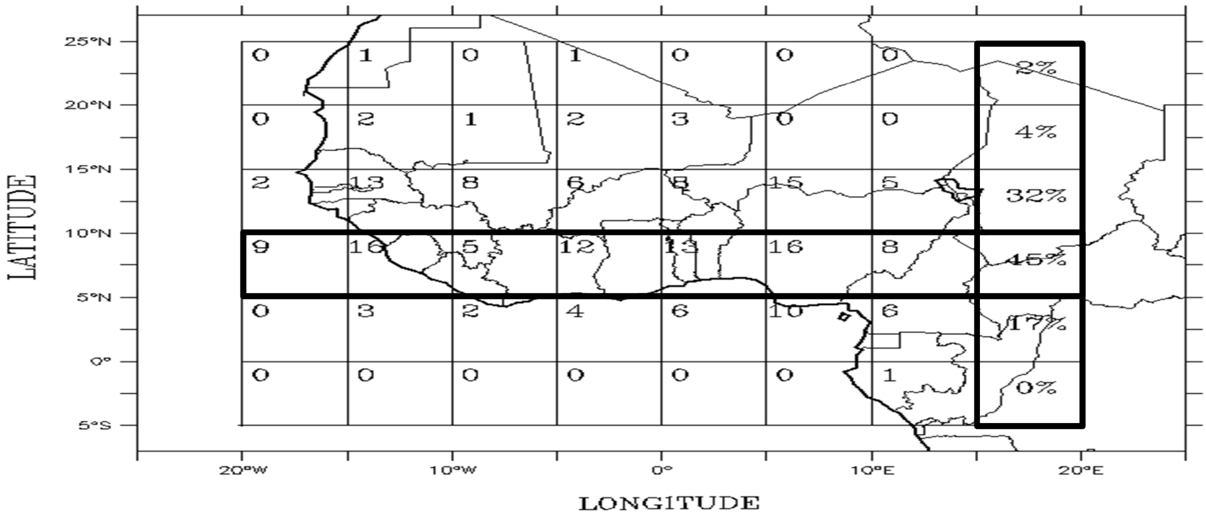
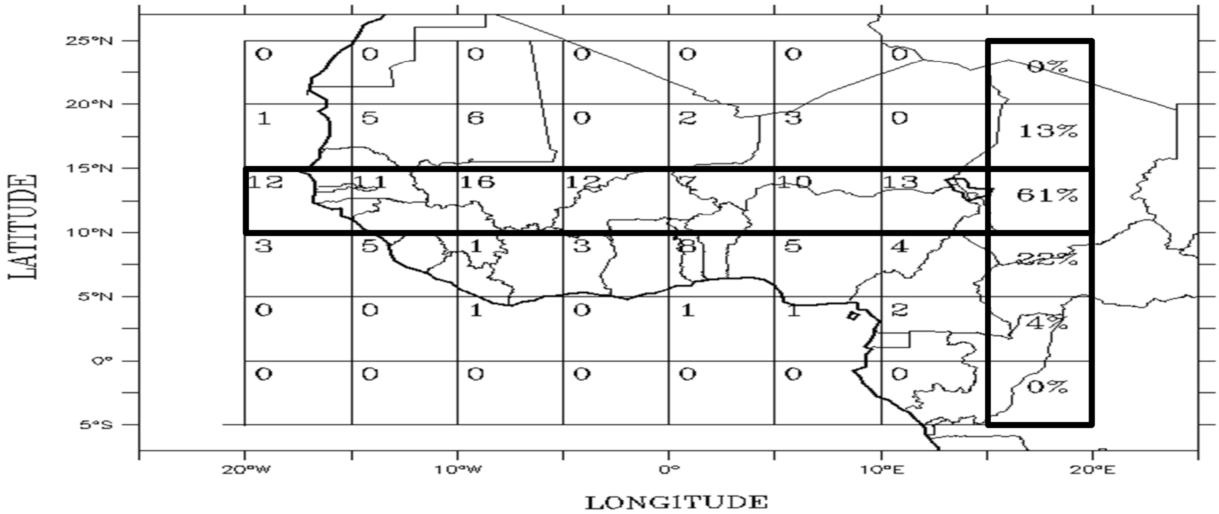


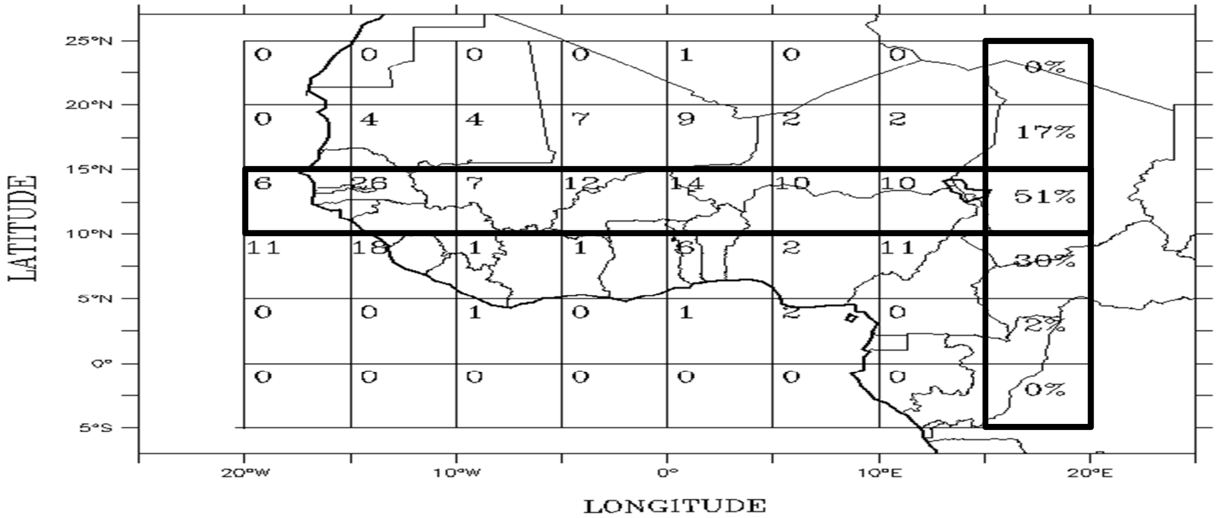
(c)

Figure 5: Map of West Africa showing the number of MCSs that initiated in each 5ºX5° box and the percentage of each row as highlighted in the right most column for (a) June 2009, (b) June 2014 and (c) their averages. The active zone for the initiation of MCSs is also highlighted.

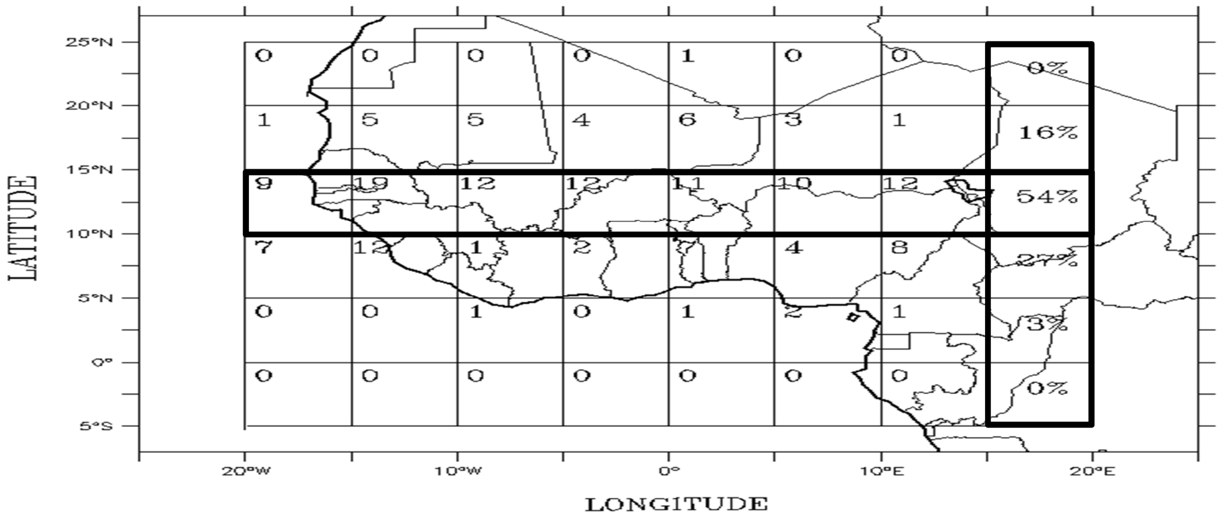
The distribution of MCSs that initiated in each 5º x 5º grid box over West Africa during the month of July for (a) 2009; (b) 2014 and (c) average of the two years as shown Figure 6. The tracking algorithm (DETRWACS) captured a total of 58 MCSs which initiated for the driest year (2009), 10 (17.2%) of which generated over the ocean and the remaining 48 (82.8%) generated over land as shown in Figure 6(a). The month of July recorded less MCSs that initiated compared to June. Grid boxes along 5ºN - 15ºN recorded the highest number of generated MCSs indicating an area favourable for the initiation of MCSs over West Africa sub-region for the month of July. In terms of percentages, 67.2% developed between 10ºN - 15ºN, 19.0% between 5ºN - 10ºN and 12.1% between 15ºN - 20ºN. Therefore, the region 5ºN - 15ºN is the active zone favourable for the initiation of MCSs, with over three-quarter (86.2%) of the systems generating over this zone and 15ºN - 20ºN fairly favourable. As highlighted in Figure 6(a), row 10ºN - 15ºN is the most active zone for the initiation of MCSs over West Africa for the month of July 2009, accounting for more than half (67.2%) the number of systems that generated over the region. Similarly, a total of 88 MCSs initiated in the wettest year (2014), 16 (18.2%) of which generated over the ocean and the remaining 72 (81.8%) developed over land as shown in Figure 6(b). On row basis, the percentages of 10ºN - 15ºN, 5ºN - 10ºN, and 15ºN - 20ºN are 55.7%, 28.4%, and 14.8% respectively. In a similar manner as 2009, over three-quarter (84.1%) of the systems initiated along row 5ºN - 15ºN which shows that this area is an active zone suitable for the generation of MCSs and row 15ºN - 20ºN fairly suitable. As highlighted in Figure 6(b), 10ºN - 15ºN is the most active zone for the initiation of MCS over West Africa for the month of July 2014, constituting over half (55.7%) the number of systems that generated over the region. Figure 6(c) displays the average number of MCSs that initiated in July of 2009 and 2014. In terms of initiated MCSs, the wettest year captured more MCSs (+20) compared to the driest year which corresponds with the findings of Omotosho, 1985 and Fink *et al.,* 2006 who established that over West Africa, MCSs produce more than 75% of the total annual rainfall south of 10ºN and more than 90% north of it. This study therefore establish that over the West Africa sub-region for the month of July, the most active zone in terms of 5º latitudinal rows for both the driest and wettest year is the row 10ºN - 15ºN and also the same for propagation and decay. The shifting of the most active zone from row 5ºN - 10ºN (in June) to row 10ºN - 15ºN (in July) further substantiates the fact that the most active area for convective activities shifts Northward following the Northward (in land) migration (penetration) of the Inter-Tropical Discontinuity ITD. Also, maximum activity of deep convection is observed between 10ºN - 15ºN over West Africa (Desbois *et al.,* 1988; Chong *et al.,* 1987; Arnaud *et al.,* 1992; Laing and Fritsch, 1993). It also showed that though the zone 5ºN - 15ºN is favourable for the initiation of MCSs in both driest and wettest years accounting for more than 80%, there is a better spread of generated MCSs on latitudinal rows in the wettest year than the driest year. We also observed a shift in the fairly favourable zone for initiation of MCS from 0ºN - 5ºN in June to 15ºN - 20ºN in July. In terms of average of the driest and wettest year, 15ºN - 20ºN recorded 13.5% in July against 5.8% in June based on latitudinal row percentages.



(a)



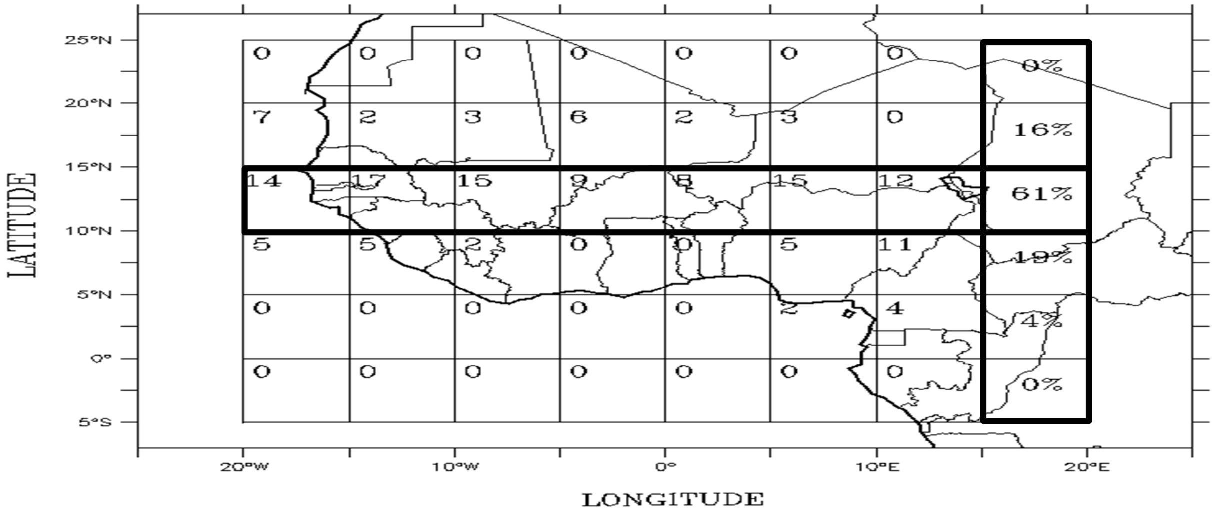
(b)



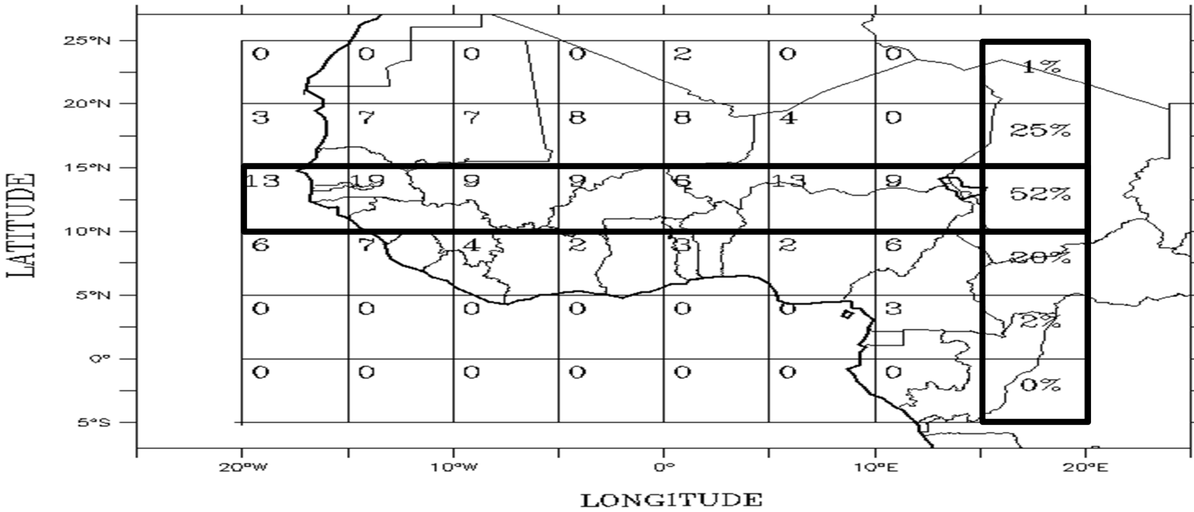
(c)

Figure 6: Map of West Africa showing the number of MCSs that initiated in each 5ºX5° box and the percentage of each row as highlighted in the right most column for (a) July 2009, (b) July 2014 and (c) their averages. The active zone for the initiation of MCSs is also highlighted.

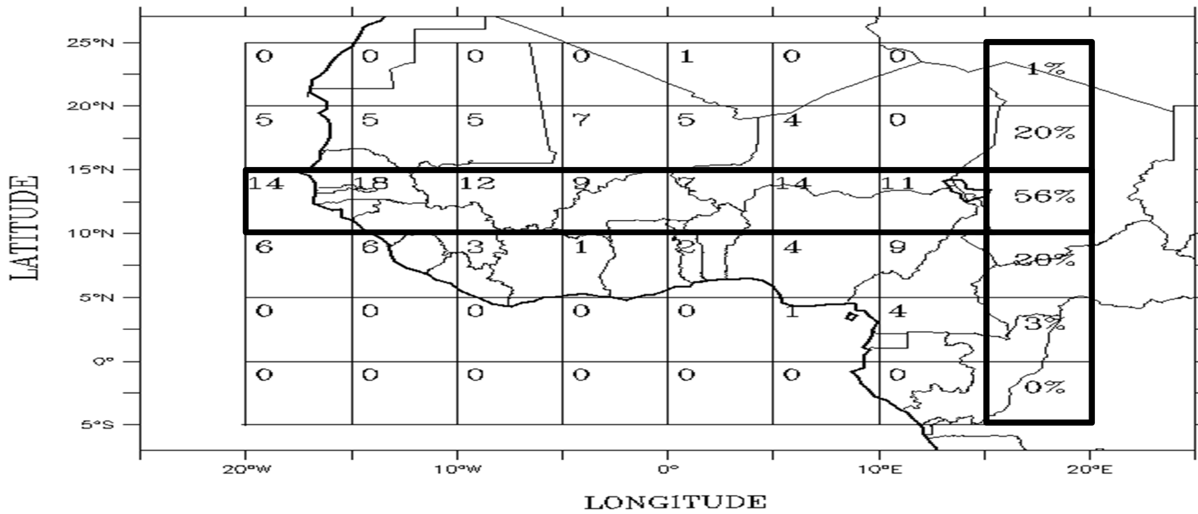
The number of MCSs that initiated in each 5º x 5º grid box over West Africa during the month of August for (a) 2009; (b) 2014 and (c) average of the two years is shown in Figure 7. Out of the 51 MCSs that initiated for the driest year (2009), 12 (23.5%) generated over the ocean and 39 (76.5%) generated over land as seen in Figure 7(a). The month of august recorded the least number of initiated MCSs (51), against those recorded in June (67) and July (58). In terms of percentages, 70.6% developed between 10ºN - 15ºN, 15.7% between 15ºN - 20ºN and 13.7% between 5ºN - 10ºN. Row 10ºN - 15ºN is the most active zone for the initiation of MCS over West Africa for the month of August (2009), accounting for nearly three-quarter (70.6%) the number of systems that initiated over the region as highlighted in Figure 7(a). Rows 15ºN - 20ºN and 5ºN - 10ºN are fairly favourable zones recording close percentages of 15.7% and 13.7% respectively. Similarly, a total of 66 MCSs initiated in the wettest year (2014), 11 (16.7%) of which initiated over the ocean and 55 (83.3%) over land as shown in Figure 7(b). Grid boxes along row 10ºN - 15ºN captured the most number of initiated MCSs indicating that the row favours the initiation of MCSs over the West Africa sub-region for the month of August. On row basis, the percentages of 10ºN - 15ºN, 5ºN - 10ºN and 15ºN - 20ºN are 57.6%, 21.2%, and 19.7% respectively. As highlighted in Figure 7(b), row 10ºN - 15ºN is the most active zone for the initiation of MCS over West Africa for the month of August 2014, accounting for more than half (57.6%) the number of systems that initiated over the region. Similarly, rows 15ºN - 20ºN and 5ºN - 10ºN are fairly favourable zones recording close percentages of 19.7% and 21.2% respectively. Figure 7(c) displays the average number of MCSs that initiated in August of 2009 and 2014. The month of August experienced a drastic reduction in initiated MCSs when compared to June and July for both the wettest and driest years which clearly was as a result of the 'little dry season' (LDS), a phenomenal that occurs in July/August over West Africa (Nigeria). As established by Omotosho (1988), LDS reveals the existence of a latitudinal belt of more pronounced dryness between 6ºN and 8.5ºN within a coastal region of a general rainfall minimum. On row basis, the percentages based on the average of the driest and wettest years of 10ºN - 15ºN, 5ºN - 10ºN and 15ºN - 20ºN are 65.0%, 16.3%, and 17.7% respectively as shown in Figure 7(c). The reduction in the number of initiated MCSs greatly affected grid boxes along row 5ºN - 10ºN which is as a result of lower rainfall within 6ºN and 8.5ºN due to the stronger subsidence associated with outflows from deep convective systems located to the north of the area during the LDS (Omotosho, 1988). This study therefore establish that in the month of August, either in the driest year (2009) or the wettest year (2014), the most active zone in terms of 5º latitudinal rows is the 10ºN - 15ºN. Also, row 5ºN - 10ºN formally an active zone in the months of June and July is a fairly favourable zone for the initiation of MCSs in August. Again, row 15ºN - 20ºN maintained its place as a fairly favourable zone.



(a)



(b)

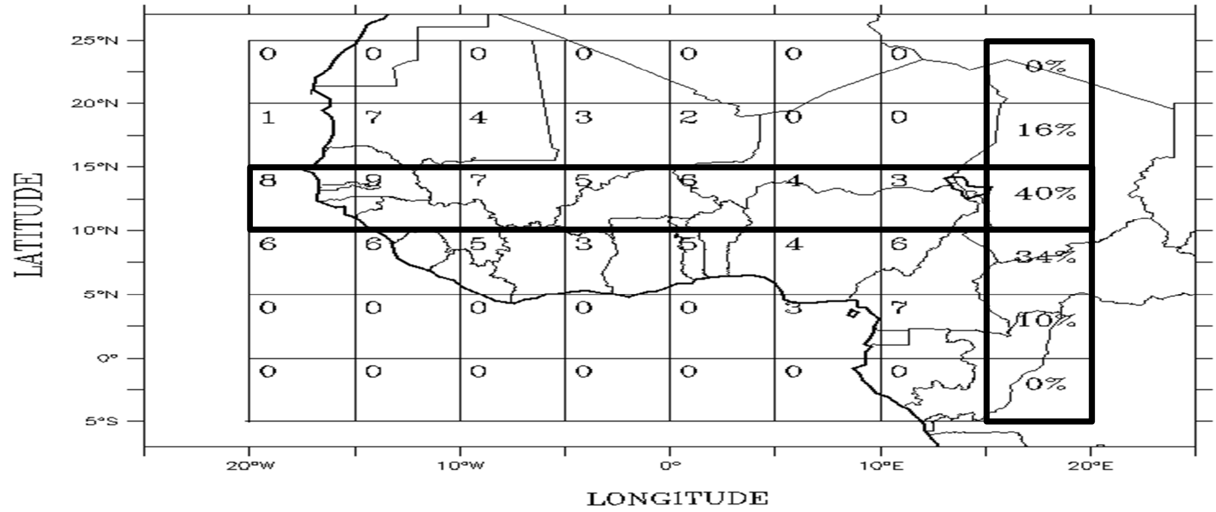


(c)

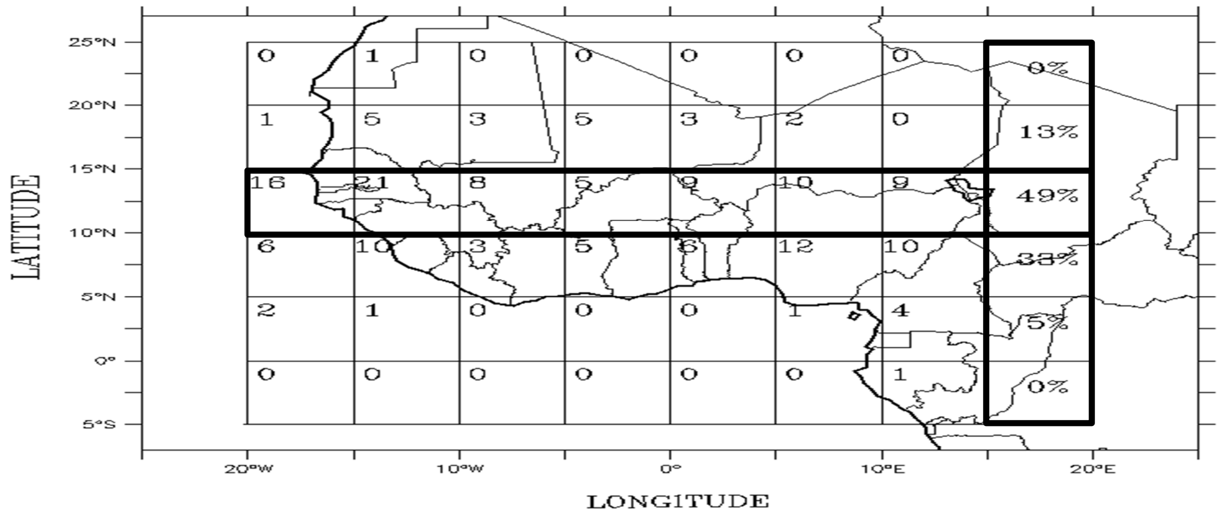
Figure 7: The number of MCSs that initiated in each 5ºX5° box and the percentage of each row as highlighted in the right most column for (a) August 2009, (b) August 2014 and (c) their averages. The active zone for the initiation of MCSs is also highlighted.

Figure 8 shows the distribution of MCSs that initiated in each 5º x 5º grid box over West Africa during the month of September for (a) 2009; (b) 2014 and (c) average of the two years. A total of 59 MCSs initiated for the dry year (2009), with over one-quarter 12 (20.3%) generated over the ocean and the remaining 44 (79.7%) generated over land as shown in Figure 8(a). In terms of percentages, 42.4% developed between 10ºN - 15ºN, 32.2% between 5ºN - 10ºN and 22.0% between 15ºN - 20ºN. Row 5ºN - 10ºN is retained as the most active zone for the initiation of MCS over West Africa for the month of September 2009, accounting for nearly half (42.4%) the number of systems that developed over the region as highlighted in Figure 8(a). September recorded the least percentage of initiated MCSs for the most active zone when compared to June, July and August. We observed that the difference in percentage between the most active zone 10ºN - 15ºN and the rows below and above it reduced drastically in September as the initiated MCSs were evenly distributed between them and as a result 5ºN - 10ºN and 15ºN - 20ºN are also active zones.

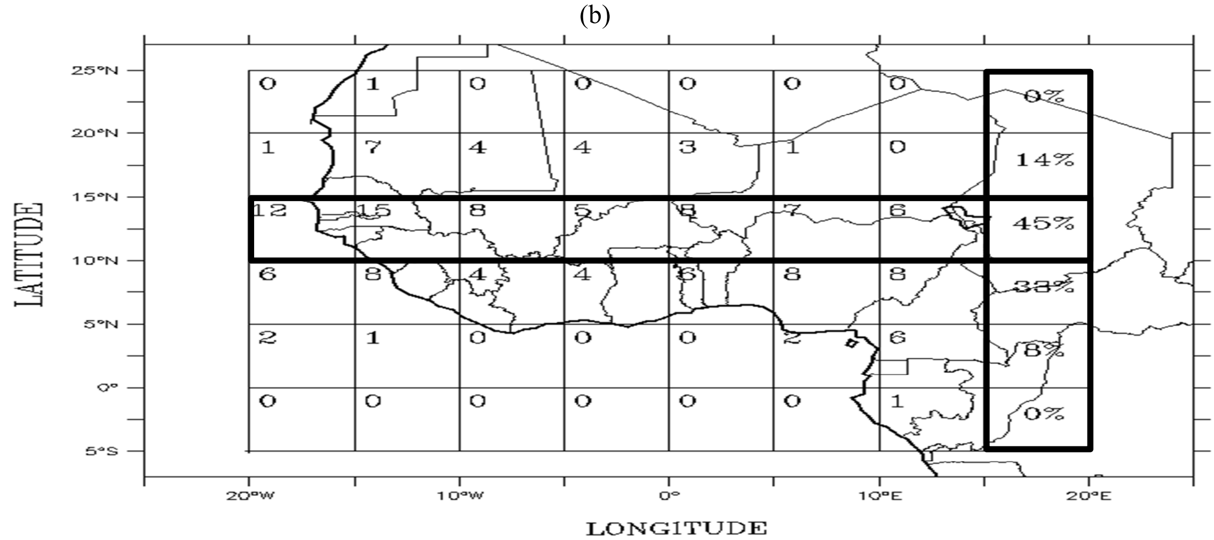
Similarly, a total of 81 MCSs initiated in the wettest year (2014), 16 (19.8%) of which initiated over the ocean and 65 (80.2%) over land as shown in Figure 8(b). On row basis, the percentages of 10ºN - 15ºN, 5ºN - 10ºN and 15ºN - 20ºN are 45.7%, 30.9% and 21.0% respectively. In a similar manner as 2009, 10ºN - 15ºN is the most active zone suitable for the initiation of MCSs over West Africa for September (2014) as highlighted in Figure 8(b). Rows 5ºN - 10ºN and 15ºN - 20ºN are next most active zones for generation of MCSs. As observed in the driest year, the difference in the most active zones and the zones below and above it were drastically reduced indicating an even distribution of the initiated MCSs along 5ºN - 20ºN. Figure 8(c) displays the average number of MCSs that initiated in September of 2009 and 2014. With the LDS phenomenon gone, we observed an increase in initiated MCSs for both the driest and wettest years in September against those that initiated in August which was as a result of the positive build-up of moister air increasing again and gradually spreading southward (Omotosho and Abiodun, 2007). Although 10ºN - 15ºN was maintained as the most active zone favourable for the initiation of MCSs over the West Africa sub-region for the month of September constituting nearly half (44.1%) the number of systems that generated, it recorded the least percentage (44.1%) compared to the months of June, July and August which recorded 52.5%, 61.5% and 65.0% respectively. Rows along 5ºN - 20ºN are the active zones suitable for the generation of MCSs, with increased initiated MCSs along 5ºN - 10ºN and with the LDS phenomenon gone.



(a)



(b)



(c)

Figure 4.10: Map of West Africa showing the number of MCSs that initiated in each 5ºX5° box and the percentage of each row as highlighted in the right most column for (a) September 2009, (b) September 2014 and (c) their averages. The active zone for the initiation of MCSs is also highlighted.

5 Conclusion

Rainfall is the most important of the weather parameters that directly affect plants and animals. Extreme of this parameter (deficit or surplus) may result in a great havoc if not properly managed. Studies of MCSs which produce between 75 - 90% of rainfall over West African and its applications are particularly important to agriculture, commercial and general transportation (land, air and sea), space launch operations and poor utilities, among many other sectors.

This research work covers West Africa geographical domain from 5ºN to 25ºN and 20ºE to 20ºW and divided into grid boxes of 5º x 5º. IR brightness temperature data was used to track MCSs for the years 2009 and 2014 as established as the driest and wettest years respectively of the 10 years (2006 - 2015) daily rainfall data. The total number of MCSs that initiated, propagated and decayed in each 5º x 5º grid box was obtained for each of the raining season months (June, July, August and September) as captured by the tracking algorithm (DETRAWACS).

In terms of the number of MCSs that generated in the research domain, the tracking algorithm captured 67, 58, 51 and 59 MCSs in the months of June, July, August and September respectively which adds up to give 235 MCSs for the driest year (2009). Similarly, in the wettest year (2014), DETRAWACS captured 86, 88, 66 and 81 MCSs for the months of June, July, August and September respectively totalling 321 MCSs. A difference of 85 systems exist between the driest and wettest years which clearly corresponds with the findings of Omotosho, 1985 and Fink *et al.,* 2006 who established that over West Africa, MCSs produce more than 75% of the total annual rainfall south of 10ºN and more than 90% north of it. Generalising, approximately 80% of the MCSs captured developed, propagated and dissipated over land for both the wettest and driest years while the remaining 20% over the ocean. Although, majority of the systems generated and decayed over land, the ocean remains the most favourable for the decay of MCSs over West Africa.

For both the driest and wettest years, latitudinal row 5ºN - 10ºN was the most active zone favourable for the initiation, propagation and decay of MCSs over West Africa for the month of June accounting for more than half the number of systems that generated, propagated and dissipated over the region, with row 10ºN - 15ºN as the next favourable zone.

The month of July observed a shift in the most active zone from 5ºN - 10ºN (in June) to 10ºN - 15ºN, which further substantiates the fact that the most active area for convective activities shifts northward following the northward (in land) migration (penetration) of the Inter-Tropical Discontinuity (ITD), with row 5ºN - 10ºN as the next favourable zone. August experienced a decline in the number of initiated MCSs, precisely along row 5ºN - 10ºN which was a result the existence of a latitudinal belt of more pronounced dryness between 6ºN and 8.5ºN within a coastal region of a general rainfall minimum caused by the “Little Dry Season” (LDS) phenomenon (Omotosho, 1988). Regardless, August maintained the most active zone as row 10ºN - 15ºN, with rows 5ºN - 10ºN and 15ºN - 20ºN as favourable zones for the initiation, propagation and dissipation of MCSs. September also maintained 10ºN - 15ºN as the most active zone with nearly half (approximately 45%) the number of systems developing, propagating and dissipating along that path. 5ºN - 10ºN and 15ºN - 20ºN were also maintained as the next favourable zone. Majority of the MCSs captured by DETRAWACS initiated, propagated and decay along the same latitudinal row.

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