Nigerian Meteorological Agency

INTERCOMPARISON OF MODELS

Verification of Moderate Rainfall over Nigeria in the Summer of 2010.

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ABSRACT

The science of weather forecasting is only as good as its ability to produce results. Models are some of the tools meteorologists have come to depend on to help them in forecasting and the dependability as well as reliability of a model is measured by its ability to track and forecast ahead of time a given event. Thus this study looked at the inter comparison of four models namely; GFS, ECMWF, UKMET and METEOFRANCE models, three of which are mostly used by the forecast offices of the Nigerian Meteorological Agency.

The months of June through October of 2010 summer was looked at. The data used is the gauge rainfall data over 47 stations provided by the Nigerian Meteorological Agency. This data was used to verify both the deterministic and probabilistic Ensemble forecast. A categorical skill analysis was carried out based on 0-5mm, 5-10mm, 10-15mm, 15-20mm, 20-25mm and >25mm thresholds. Case study event was selected based on the high amount of rainfall accumulated over the study area on the day in question (25^{th} June). Simple diagnostic methodology to provide in-depth information on the performance of the forecast models in terms of spatial distribution and intensity of precipitation was applied.

All the models looked at have their own weaknesses and strengths. While one model shows weaknesses in depicting certain features, the other model may have better representation of the feature. However, the GFS model had a better accuracy in rainfall forecast and less error magnitude during the study period. It showed better skill in forecasting rainfall event even though the UKMET model had greater skill in forecasting rainfall less than 5mm.

ACKNOWLEDGMENT

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1.0: INTRODUCTION

In an attempt to predict ahead of time the behavior of weather elements and the occurrence of weather events so as to help minimize the losses incurred from their destructive effects and also maximize their potential for sustainable development, science developed models which are simulations for short time forecasting of weather elements to help track and monitor both their movement and occurrence. Meteorologists worldwide have become dependent on these models to help forecast weather events over their respective geographical locations. Models such as UKMET, GFS, METEOFRANCE, ECMWF, JMA, CMC, BoM, etc. are relied on.

It is therefore expedient to verify the performance of the models in use so as to know how accurate they can be and to what extent they can be relied on. This study considers four models, three of which are commonly used in Nigeria; with emphasis on three.

1.1: BACKGROUND INFORMATION

Nigeria is a large country located between latitude 3 – 14 °N and longitude 2 – 15°E. It is set within 3 main vegetation zones namely; the rainforest, Guinea savanna and the Sahel savanna, with an array of rivers, streams and high grounds. It also borders the Atlantic Ocean at its southern end and is found within the Gulf of Guinea. These attributes help in modulating the weather patterns over the country. The science of Meteorology in Nigeria like any other part of the world is dependent on the use of forecast models. A better understanding of the strength and weakness of these models over Nigeria will go a long way in helping to fine tune how they are used and check their excesses and help in bettering the forecast products that get to the end users. Models such as the ECMWF, UKMET and METEOFRANCE are mostly used. A fourth model, the GFS is incorporated for the sake of this study.

The summer period starts as early as February/march in the south, but across the country it usually spans May through October and this period is focused on.

Forecast is usually user specific. It could be deterministic or probabilistic. It could be spatiotemporal or could be object/event oriented, etc. According to Murphy (1993), a good forecast is consistent (degree to which forecast corresponds with forecasters best judgment based on his knowledge base), has quality (degree to which forecast agrees with actual) and has value (degree to which forecast helps decision makers to gain incremental economic and other benefits). The quality and consistency of the forecast models will be looked at in this study as well as the deterministic, probabilistic and event oriented forecast will be verified.

2.0 DATA AND METHODOLOGY.

The study area is Nigeria located between 3 – 14°N and 2 – 15°E. Though for the sake of getting a better picture of lower and mid-tropospheric wind flow, a broader area over the Gulf of Guinea within longitude 20° E and W and latitude 0 – 25°N was considered.

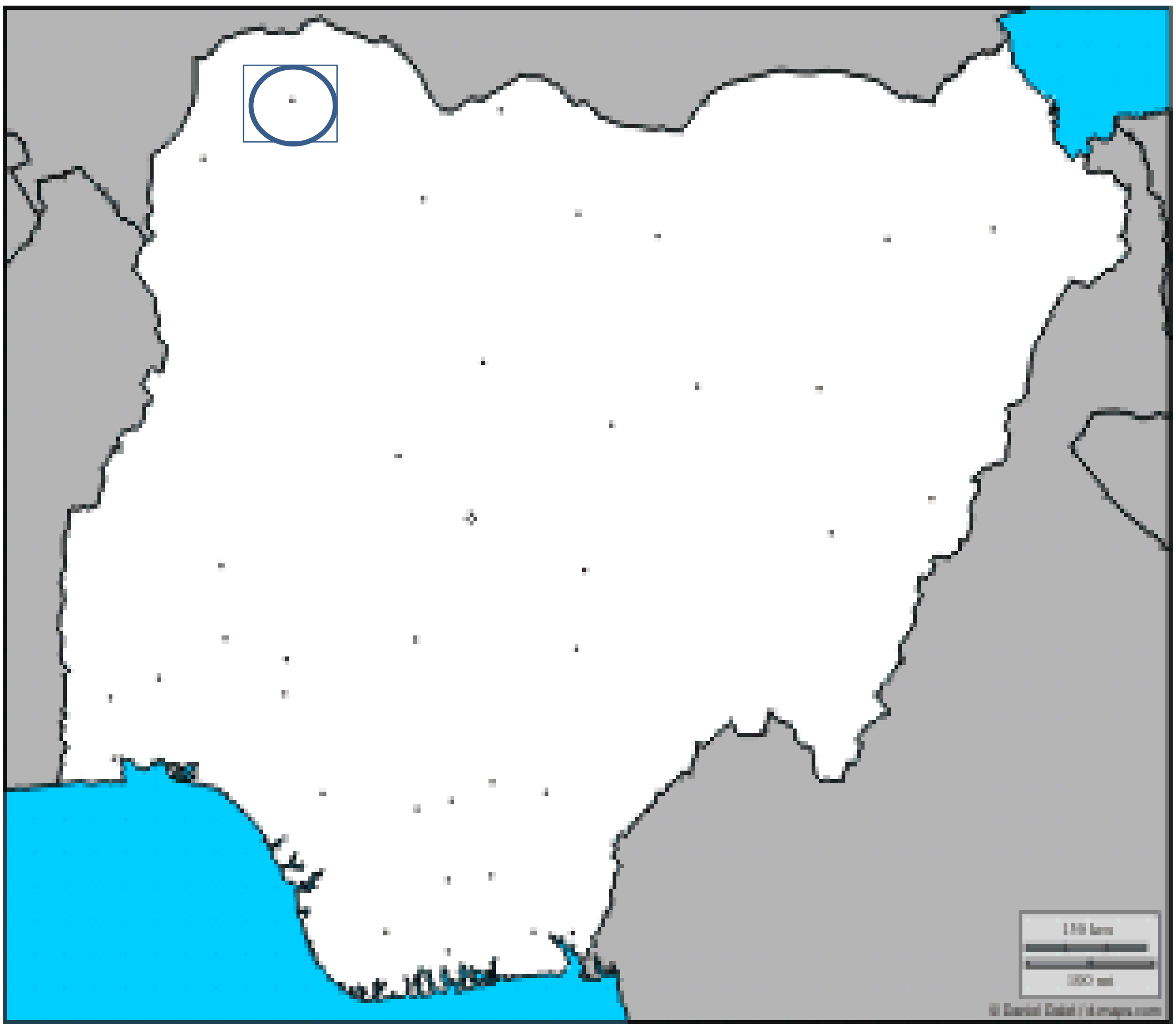

Figure 1 Map of Nigeria showing study area (Sokoto) in box.

The study uses 24hours rainfall accumulation as the primary data set for rainfall verification. The data used is the gauge rainfall data over 47 stations in the months of June - October 2010 provided by the Nigerian Meteorological Agency. Model data resolution was selected at 0.50 x 0.50 and 10 x10 using 9 grid points for verification and comparison analysis over the study area. Rainfall intensity thresholds were set at 5, 10, 15, 20 and 25mm/day based on information obtained from rainfall preliminary analysis. Rainfall Estimates derived from merging Satellite (IR and microwave) and GTS gauge rainfall were obtained from NCEP-CPC/FEWS data archive and compared with gauge data. Model data were obtained from TIGGE portal and NCEP-CPC data facility.

Case study event was selected based on the high amount of rainfall accumulated over the study area on the day in question. Rainfall verification for the event was treated categorically according to whether rainfall exceeds the specified thresholds.

Ensemble probabilistic verification of the models was conducted based on the available ensemble members for each model. In this study, ECMWF with 50 ensemble members, GFS 20 members and UKMO 23 members were involved in the inter-comparison of the forecasting systems. Probabilities were obtained based on the ensemble outputs by setting threshold values. Ensemble mean, spread and probability of exceeding for the selected thresholds were computed. The ensemble verification was done using the eye ball verification method.

Simple diagnostic methodology to provide in-depth information on the performance of the forecast models in terms of spatial distribution and intensity of precipitation was applied.

2.1 Description of Statistical Scores:

Quantitative statistical analysis of the model in predicting occurrence of the event was done using a non-parametric skill score following (wilks, 1995, Hanssen Kuiper, 1965) methodology. The analysis was decomposed categorically for a number of precipitation threshold forecasts and observations. This methodology was chosen because of its suitability for this kind of verification and often Forecasters conceptually interpret model output in a similar way. Moreover the methodology avoids penalization of the model for the forecasts that are not exact but can be considered approximately correct and useful.

$$Accuracy =$$

The skill scores are summarized using a Spatial Multi-Category Contingency Table for a range of thresholds on the forecasts resulting into multiple categories to each forecast. For a range of K thresholds on the forecasts then the frequency of forecasts and observations in the various windows can be summarized in a contingency table (See table 1). Where n(Fi,Oj) denotes the number of forecasts in category *i* that had observation in category *j*, and the total number of the forecasts in category *i* is given by N(Fi). N(Oj) denotes the total number of observations in category j and N is the total number of forecasts.

Table 1 Multi-category Contingency Table (Adopted from World climate Research Program)

		Observed Category				
	i,j	*1*	*2*	----	*K*	*Total*
	1	$n(F_1,O_1)$	$n(F_1,O_2)$	----	$n(F_1,O_K)$	$N(F_1)$
Forecast	*2*	$n(F_2,O_1)$	$n(F_2,O_2)$	----	$n(F_2,O_k)$	$N(F_2)$
Category	----	----	----	----	----	----
	K	$n(F_k,O_1)$	$n(F_k,O_1)$	----	$n(F_k,O_k)$	$N(F_k)$
	Total	$N(O_1)$	$N(O_2)$	----	$N(O_k)$	N

Using this methodology a perfect forecast system (model) would have non-zero elements along the diagonal and zero values entries elsewhere. The off diagonal entries provide some information on the specific nature of the model forecast errors (Murphy et al. 1987) and (Brooks and Doswel, 1996).

The forecast categories are 0-5mm, 5-10mm, 10-15mm, 15-20mm, 20-25mm and >25mm.

To determine the fraction of the forecast that was in the correct category the formula for accuracy was applied.

$$Accuracy = \frac{1}{N}\sum_{i=1}^{K} n(F_i, O_i)$$

The Hanssen and Kuipers skill score (HK) was adopted to determine the accuracy of the Models in predicting the correct category relative to the random chance for un-bias forecast. A perfect score will be HK=1, poor score HK=-1 and no skill will be HK=0.

$$HK = \frac{\frac{1}{N}\sum_{i=1}^{K} n(F_i,O_i) - \frac{1}{N^2}\sum_{i=1}^{K} N(F_i)N(O_i)}{1 - \frac{1}{N^2}\sum_{i=1}^{K}(N(O_i))^2}$$

To obtain some information about error in location and intensity of the spatial forecast a feature-base verification methodology by Ebert and MacBride, 2000 was used. A threshold of 60mm/day over a 1° radius was selected to isolate the area of moderate to heavy rainfall and then through intensity and shape differences matching contiguous rain area (CRA) was identified on the observation and forecast fields. Location and intensity can then be verified using a contingency table format shown (Table 2).

Table 2 Feature- based Contingency Table

		Intensity		
		Too little	Approx. correct	Too Much
Location	Close	Underestimate	Hit	Overestimate
	Far	Missed Event	Missed Location	False alarm

3.0 Analysis and Discussion

3.1 General Overview. The METEOFRANCE model is initialized form 06Z as against 00Z for the other models; this limitation restricts most of the analysis to just the GFS, UKMET and ECMWF models. Significant amount of rainfall was observed over many stations on four particular days in the month of June; 8th, 15th, 20th and 25th. The gauge rainfall was compared with both the controlled (deterministic) forecast and the perturbed (probabilistic) forecast of each model.

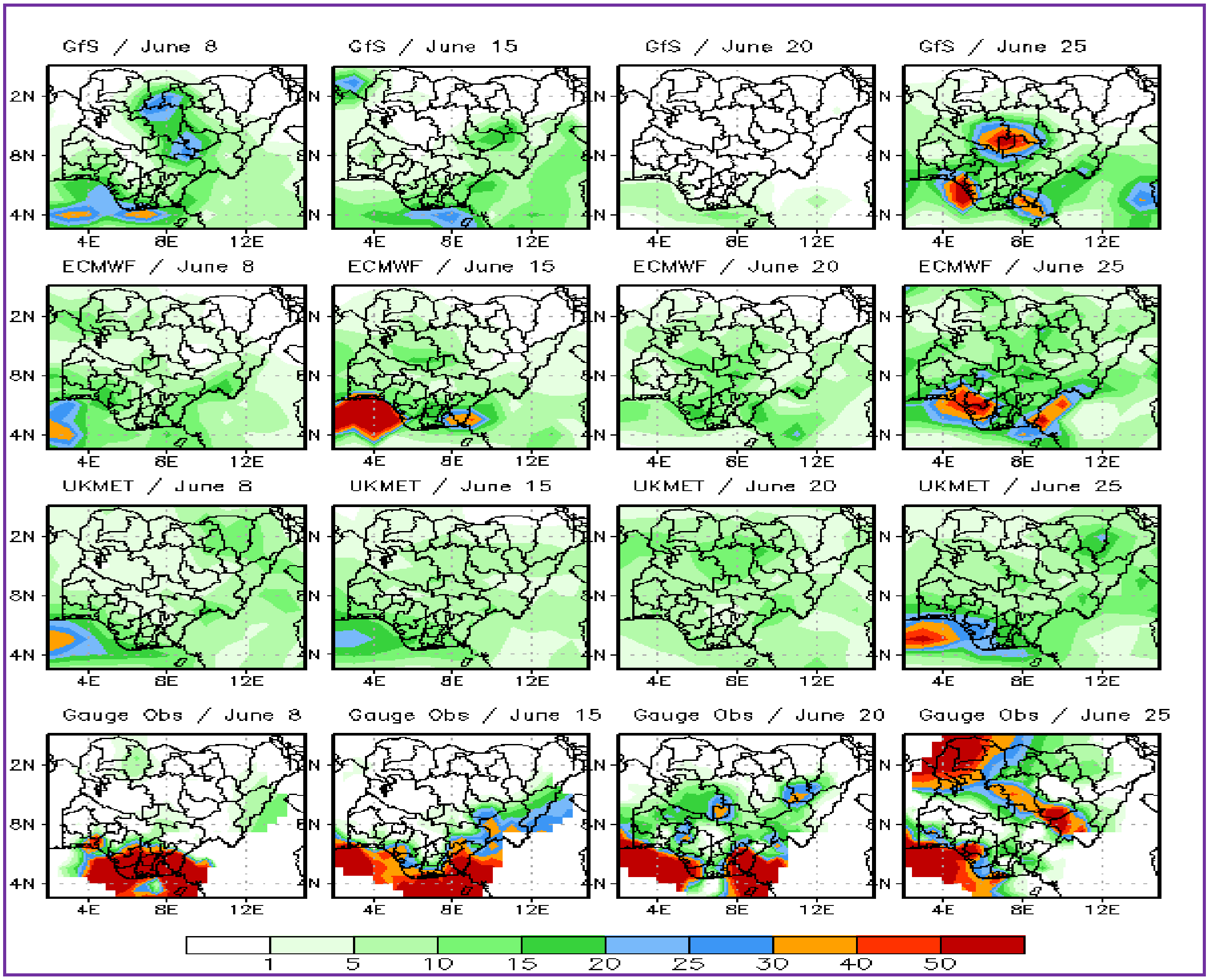

Figure 2 Rainfall Forecast for Four Days in June Paired Against the Gauge Rainfall.

Table 3 Categorical skill analysis of rainfall for June 8th 2010

June 8	MODELS	Mean Error (bias)	RMSE	Accuracy	Skill (HSS)
Controlled	GFS	-9.62	40.57	0.28	0.07
	ECMWF	-11.64	41.74	0.34	0.12
	UKMET	-12.91	41.20	0.36	0.13
	Meteo France	-15.21	42.86	0.36	0.07
Perturbed	GFS	-11.87	39.40	0.28	0.12
	ECMWF	-12.01	41.40	0.30	0.15
	UKMET	-12.81	41.74	0.30	0.04
	Meteo France	-1201	41.40	0.30	0.15

On the 8th, all the models under forecasted the rainfall event with METEOFRANCE having the highest error of about 42.86%.

Table 4 Categorical skill analysis of rainfall for June 8th 2010

June 15	MODELS	Mean Error (bias)	RMSE	Accuracy	Skill (HSS)
Controlled	GFS	-14.71	39.98	0.53	0.20
	ECMWF	-12.36	40.62	0.09	-0.03
	UKMET	-5.45	44.77	0.28	0.08
	Meteo France	-12.75	41.47	0.26	0.01
Perturbed	GFS	-14.43	39.98	0.45	0.19
	ECMWF	-11.90	40.41	0.06	-0.04
	UKMET	-2.05	51.57	0.21	0.03
	Meteo France	-12.75	41.65	0.09	-0.04

On the 15th, all models under forecasted the rainfall event with UKMET having the highest error margin of about 44.77%.

Table 5 Categorical skill analysis of rainfall for June 20th 2010

June 20	MODELS	Mean Error (bias)	RMSE	Accuracy	Skill (HSS)
Controlled	GFS	-19.93	44.00	0.57	0.08
	ECMWF	-13.95	40.97	0.30	0.08
	UKMET	-13.67	42.11	0.11	0.01
	Meteo France	-16.06	43.11	0.21	-0.15
Perturbed	GFS	-15.11	41.35	0.32	0.08
	ECMWF	-13.40	40.25	0.26	0.13
	UKMET	-13.83	42.03	0.13	0.03
	Meteo France	-15.52	42.73	0.19	-0.05

There was a higher level of under forecasting by all models on the 20th with an error margin of 44.0%, 40.97%, 42.11% and 43.11% for GFS, ECMWF, UKMET and METEOFRANCE models respectively.

Table 6 Categorical skill analysis of rainfall for June 20th 2010

June 25	MODELS	Mean Error (bias)	RMSE	Accuracy	Skill (HSS)
Controlled	GFS	-6.05	40.56	0.26	0.04
	ECMWF	-4.84	38.61	0.17	0.04
	UKMET	-6.74	39.05	0.13	0.01
	Meteo France	-8.47	34.53	0.23	0.11
Perturbed	GFS	-8.12	39.38	0.15	0.04
	ECMWF	-3.71	39.42	0.13	0.01
	UKMET	-6.50	38.76	0.09	-0.01
	Meteo France	-10.26	37.44	0.09	0.00

The under forecasting trend was maintained by all 4 models on the 25th, however METEOFRANCE had the least error margin of about 34.53%.

3.2 Bar Chart Presentation of Accuracy of Models.

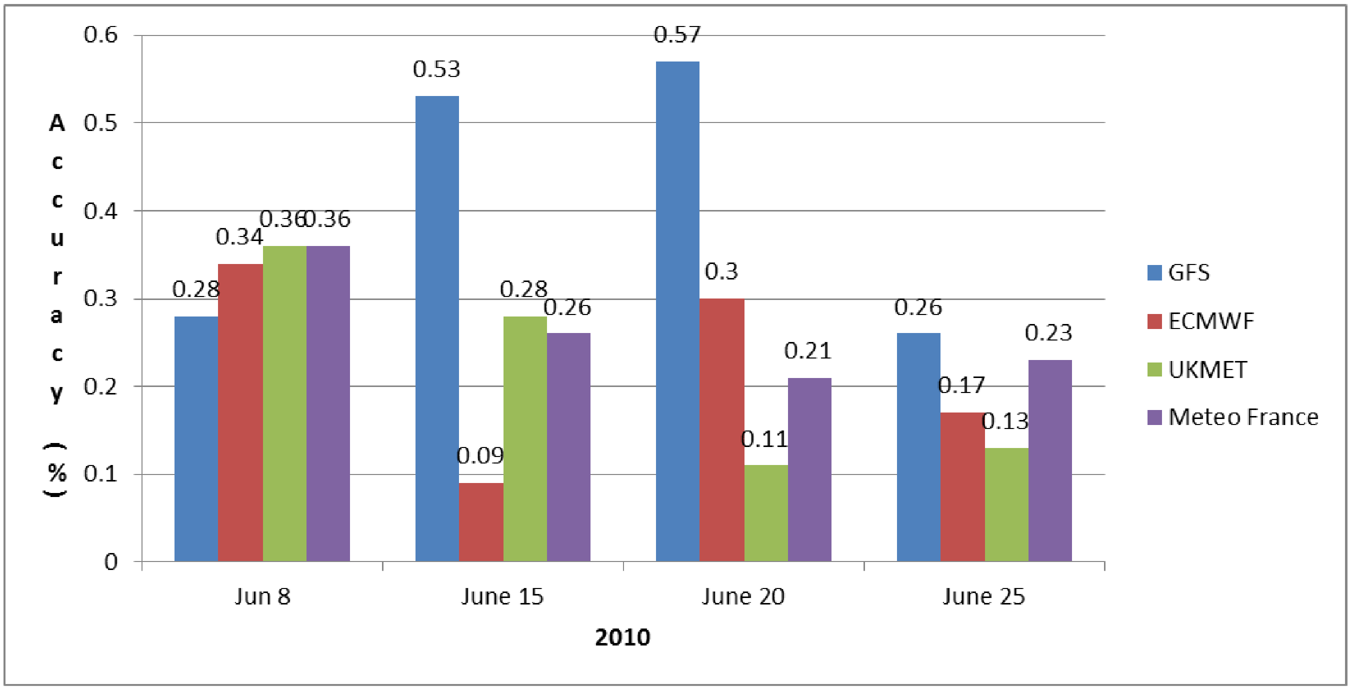

Figure 3 Categorical Model accuracy using gauge data (STN)

A categorical verification of the models using thresholds of 0-5mm, 5-10mm, 10-15mm, 15-20mm, 20-25mm and >25mm/day showed both the METEOFRANCE and the UKMET models were about 36% accurate as against ECMWF's 34% and GFS' 28% on the 8th. While on the 15th, 20th and 25th, the GFS model was most accurate with an accuracy of about 53%, 57% and 23% respectively. ECMWF was least accurate on the 15th with 9% accuracy, UKMET on the 20th and 25th with 11% and 13% accuracy.

3.3.1 A Closer Look at June 25th.

June 25th had the highest rainfall amount of the four days with significant rainfall. Strong easterly waves and the African Easterly Jet aided propagation of active systems from Chad region traversing the country.

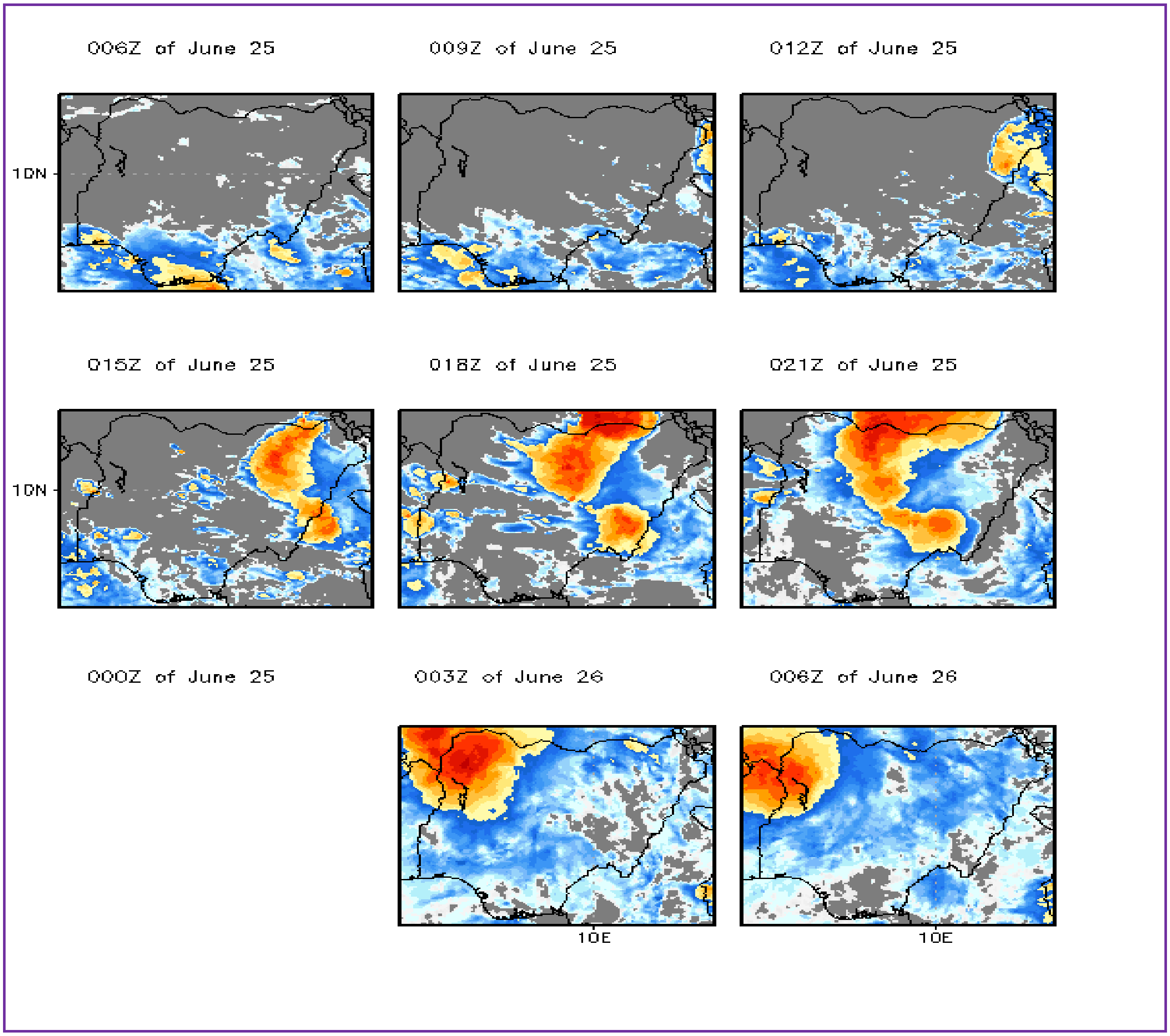

Figure 4 IR satellite imagery of 25th June event showing west ward propagation of active clouds

3.3.2 Ensemble Probabilistic Forecast

The ensemble forecast seeks to ascertain the likelihood of the outcome of an expected event, in this case, a threshold value of 20mm/day.

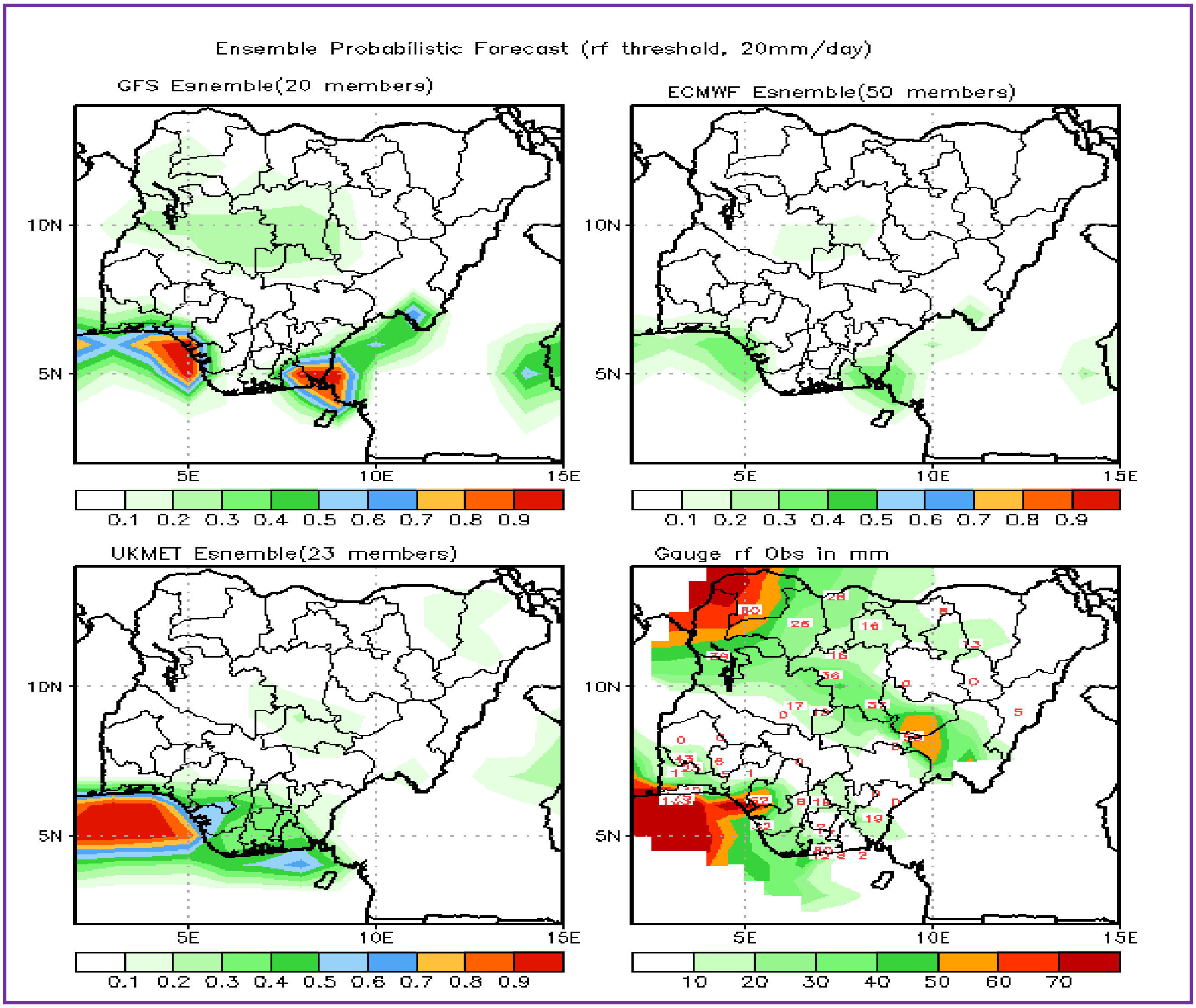

Figure 5 Ensemble Probabilistic Forecast (20mm/day) Pitched against Gauge Rainfall Value.

Using the eye-ball verification method, there is a closer correlation between the GFS and UKMET ensemble forecast and the Actual event. And a weak correlation with the ECMWF ensemble forecast.

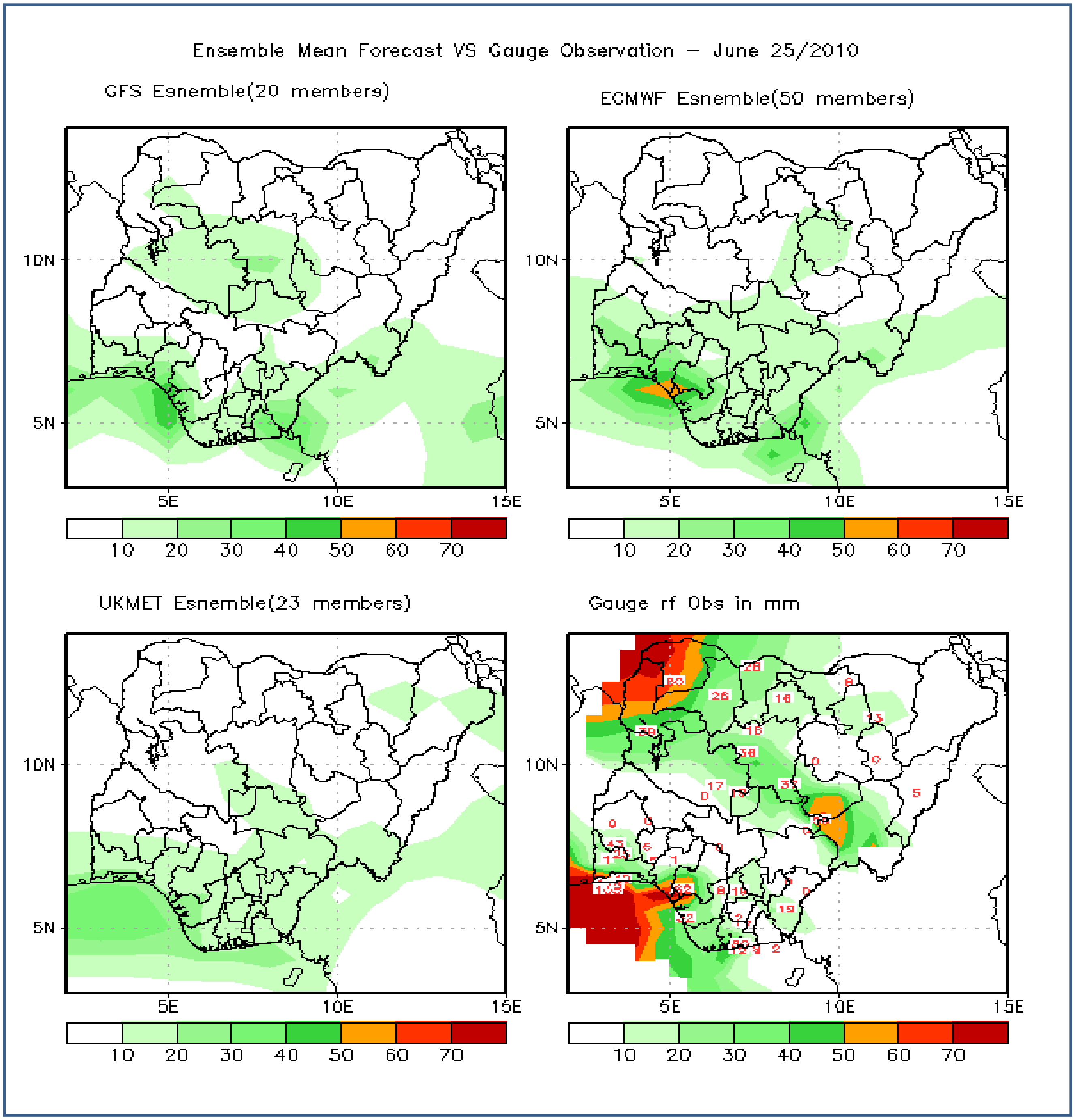

Figure 6 Ensemble Mean Rainfall Forecast

Even though the ECMWF mean ensemble forecast tends to capture the event over the south west coast, it completely misses the event over the northwestern flank, and so does the UKMET model.

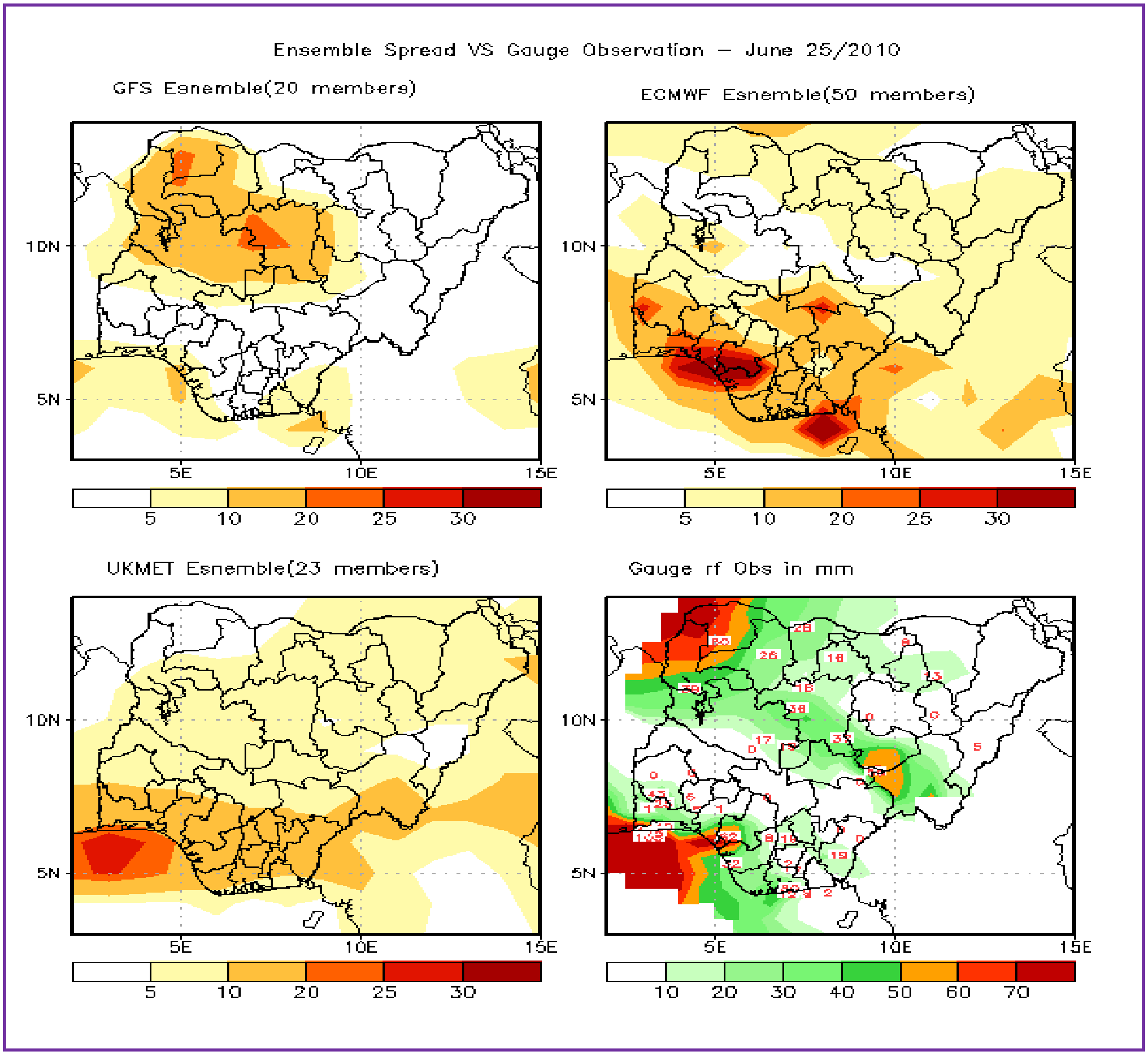

Figure 7 Ensemble Spread Forecast (standard deviation of the ensemble mean)

The gauge plot shows 3 areas of heavy rainfall; the coast of the southwest, the northwestern flank and south east central states. The GFS ensemble forecast under forecasted the activity over the northwest because there was a strong disagreement between its members with regard to that event. Even though the differences between UKMET and ECMWF members were minimal with respect to that event, they still missed it in their respective forecast.

3.4 Verification of the jumpiness/Consistency of the GFS model.

The high resolution GFS model (0.5X0.5°) has performed better than the others in the analysis carried out in this study. As such, its ability to detect and forecast a rainfall event ahead of time and remain consistent till day of event was verified.

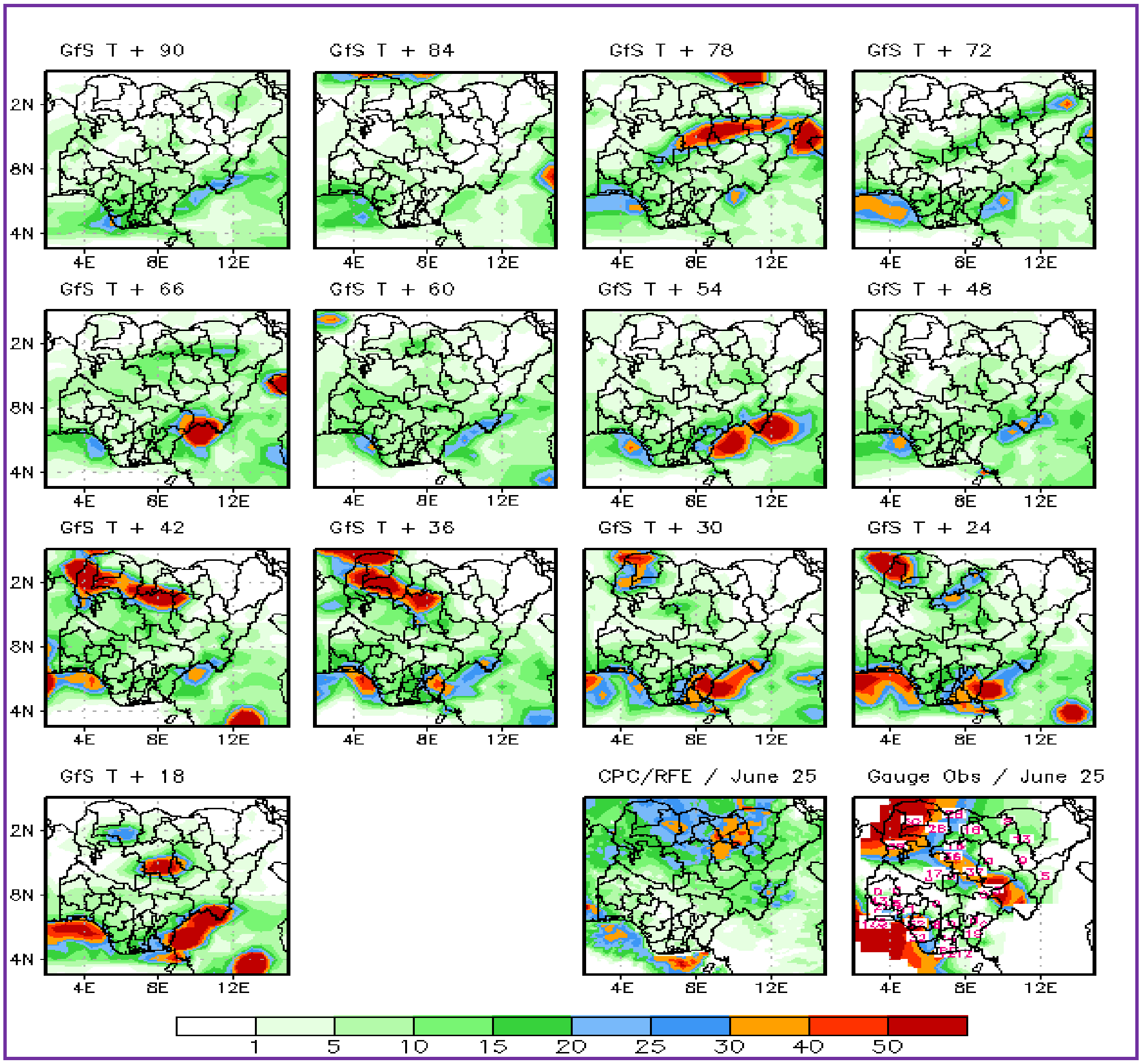

Figure 8 GFS Model Forecast from 90hr Lead Time vs. CPC/RFE and Gauge observations.

The event under consideration is the active system over the northern portions of the central states and the northwestern flank of the country. The forecast was initiated from 90hours before the actual event (fig 8); jumpiness was noticed by 78, 60, 54 and 48hours before actual event. In as much as the GFS model did get the forecast of the rainfall event, it was not consistent in detecting and forecasting the rainfall event from 48hour lead time..

3.5 CRA Verification of Rainfall Event over North West Nigeria.

The GFS model was subjected to a more objective verification methodology. By using feature-base verification methodology following Ebert and MacBride (2000), more information about the event and the possible sources of forecast error where examined.

For this case study a well predicted event was defined as the one satisfying the following criteria:

1)the location of the forecast must be within 1^0 radius from the rainfall maximum of the event 2)the intensity of the rain must be bounded within 50 and 70mm category for the approximately 60mm threshold. Based on these criteria, a contingency table was developed for the event.

Table 7 The GFS model contingency table for feature-based verification method.

Intensity (50-70mm)

		<50mm/day	50 – 70mm/day	>70mm/day	Total
Location	<1°	**22**	**3**	**0**	25
	>1°	**11**	**0**	**0**	11
	Total	33	3	0	36

The GFS model categorically predicted the event relatively better within a 1^0 radius from the center of the rainfall event area. From the contingency table it can be shown that about 30.6% of the error in forecasting the event was attributed to under-forecasting the intensity and wrong location of the event features, whereas error due to under forecasting only was about 61.1% on this event.

Accuracy of forecast with respect to rainfall intensity and placement was 8.33% in this event.

3.6 Weather Events Associated with the Heavy Rainfall Event.

The GDAS analysis data was used to verify forecasts of the three models (ECMWF, GFS and UKMET). GDAS analysis shows the deepening of the heat lows over North West Africa and parts of the Gulf of Guinea prior to the rainfall event. A 30hour forecast initialized from 12Z of 24th June shows the GFS model capturing this picture. The ECMWF and UKMET didn't do as well as the GFS.

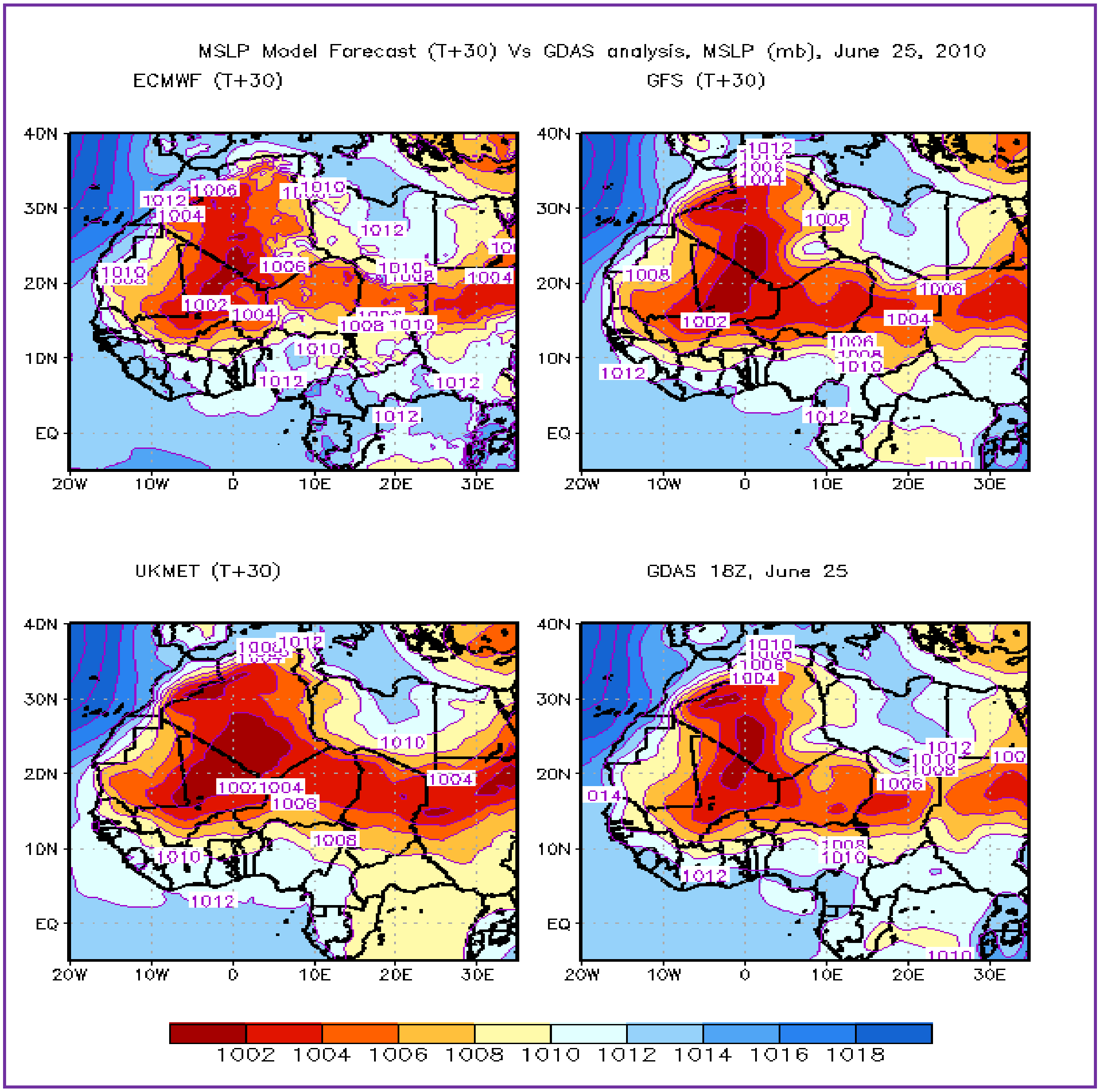

Figure 9 Mean Sea Level Pressure forecast VS GDAS Observation 18Z, 25th June 2010

The GDAS 10M wind pattern observation showed Northward pull of the ITD from about 17°N by 12Z on the 25th, reaching a North most position of about 25°N by 00Z of 26th June 2010. The UKMET and GFS models were able to capture this based on a 42hour forecast initialized from 12Z, 24th June 2010.

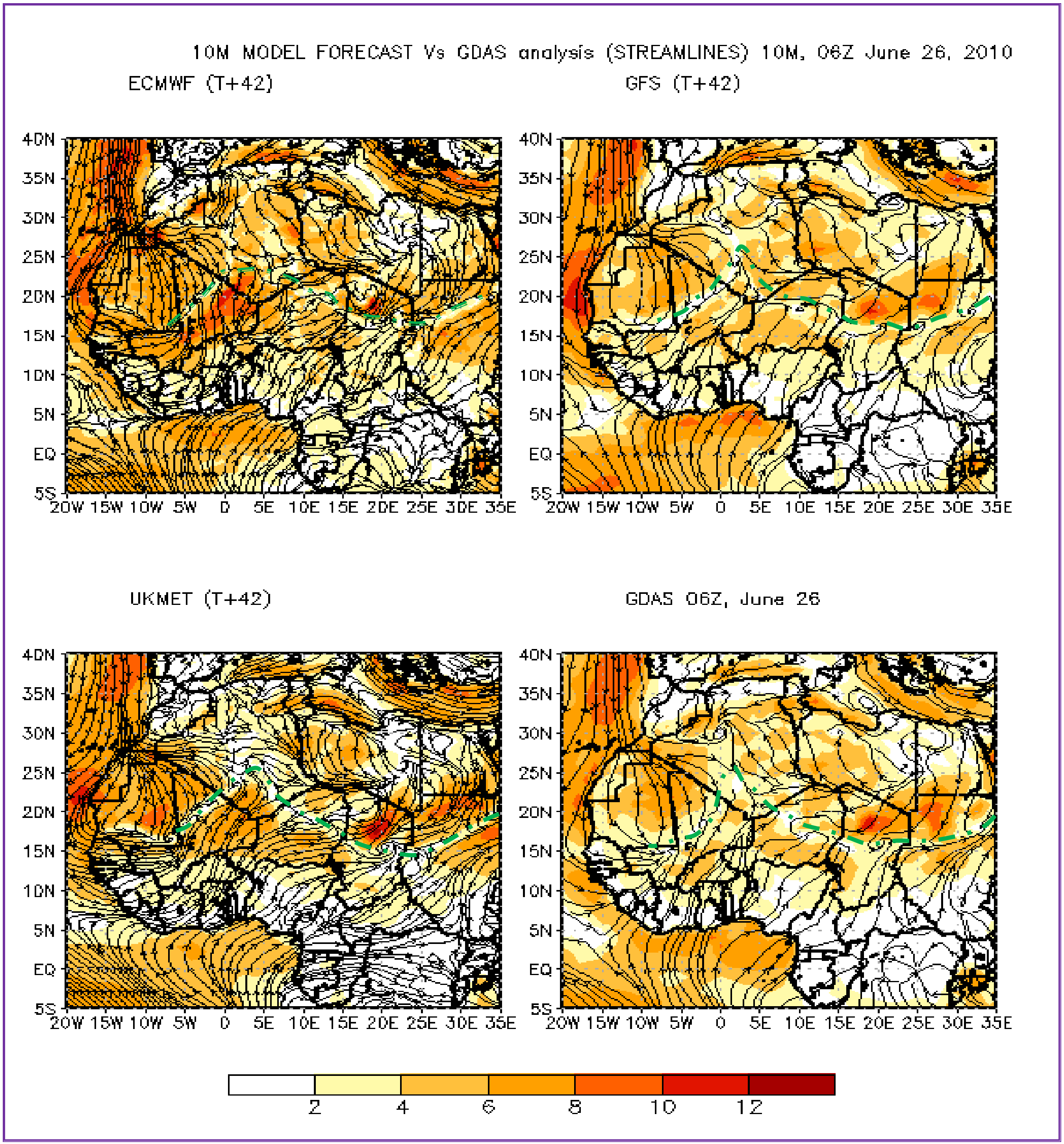

Figure 10 10M Streamline Forecast VS GDAS Observation 06Z, 26th June 2010

At the 850hpa level the Monsoon trough is well defined and is pulled northwards in a similar pattern as the ITD. Noticeable is a well-organized cyclone by 06Z of 26th June over Algeria, Mali and Cote D'Ivoire, and a good supply of Moisture. This cyclone is well captured by the GFS model based on a 30hour forecast initialized from 00Z of 25th June 2010.

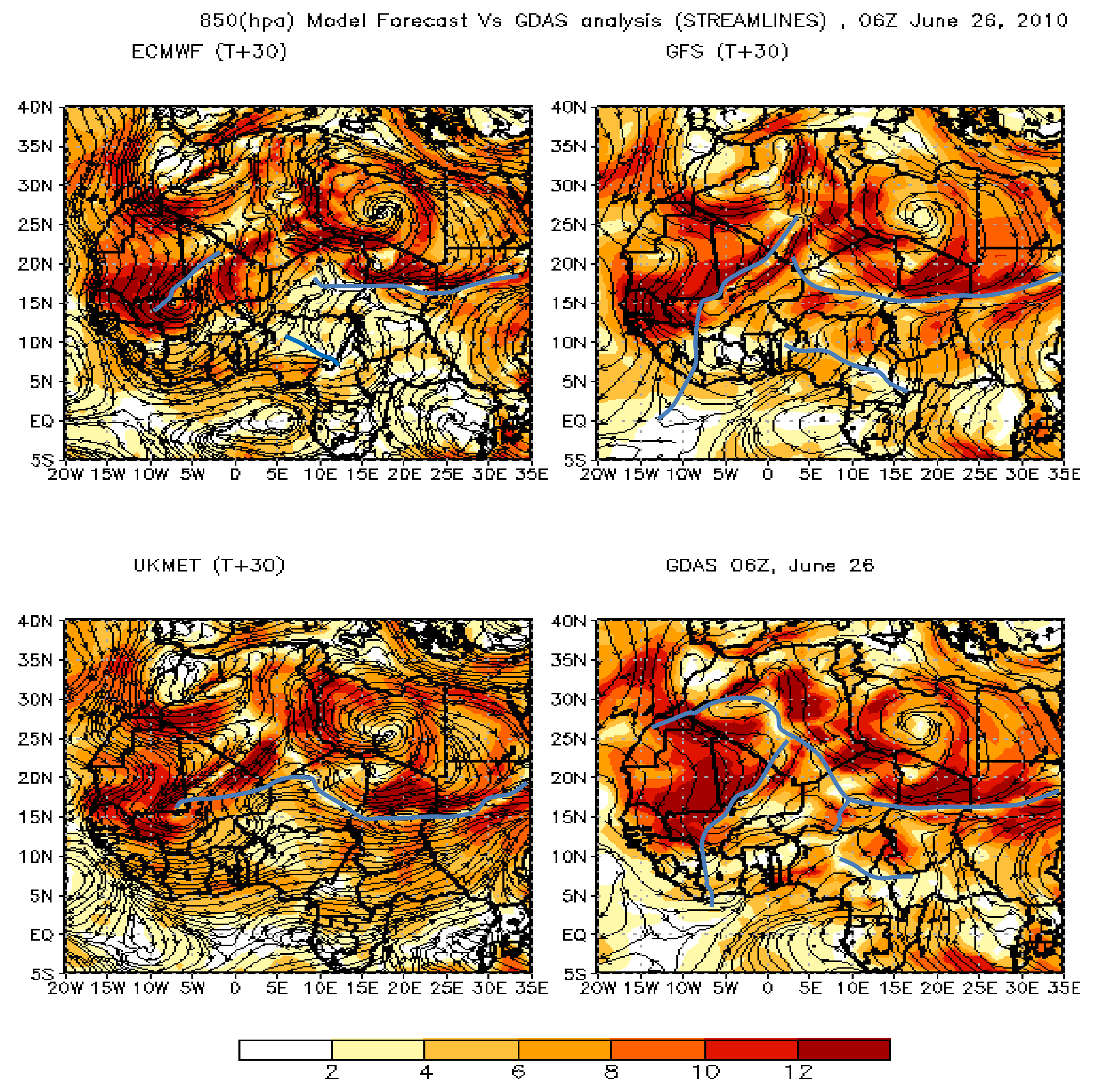

Figure 11 850hpa Streamline Forecast VS GDAS Observation 06Z, 26th June 2010

GDAS 06Z observation at 700hpa level shows strong positive vorticity over the coast of the Gulf of Guinea, the western flank of Nigeria, close to the event area and Mali. Again, the GFS 30hour forecast initialized from 00Z of 25th June 2010 shows a similar pattern with the observed. The ECMWF model forecast from same time was fair but not as good as the GFS model.

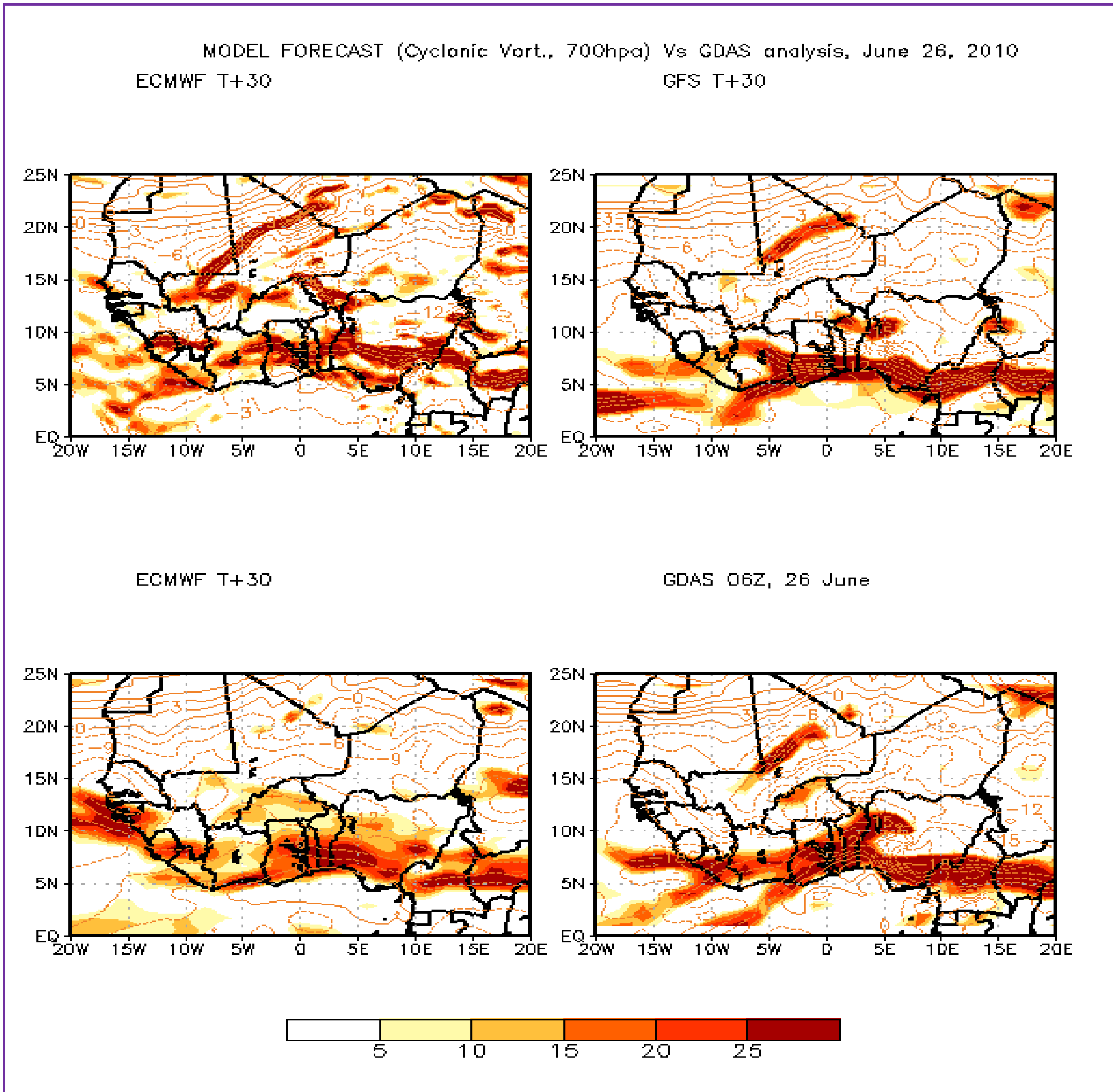

Figure 12 700hpa cyclonic Vorticity Forecast VS GDAS Observation 06Z, 26th June 2010

The zonal component of 500hpa level winds shows the African Easterly Jet was very active on the 25th with three cores and wind strength in excess of 20m/s traversing the northern fringes and parts of the central states. By 06Z of 26th June, it had 2 cores with winds in excess of 15m/s visible over the event area. The GFS model was able to better represent this from a 30hour forecast initiated form 00Z 25th June, even though it over estimated the strength of the core over the country.

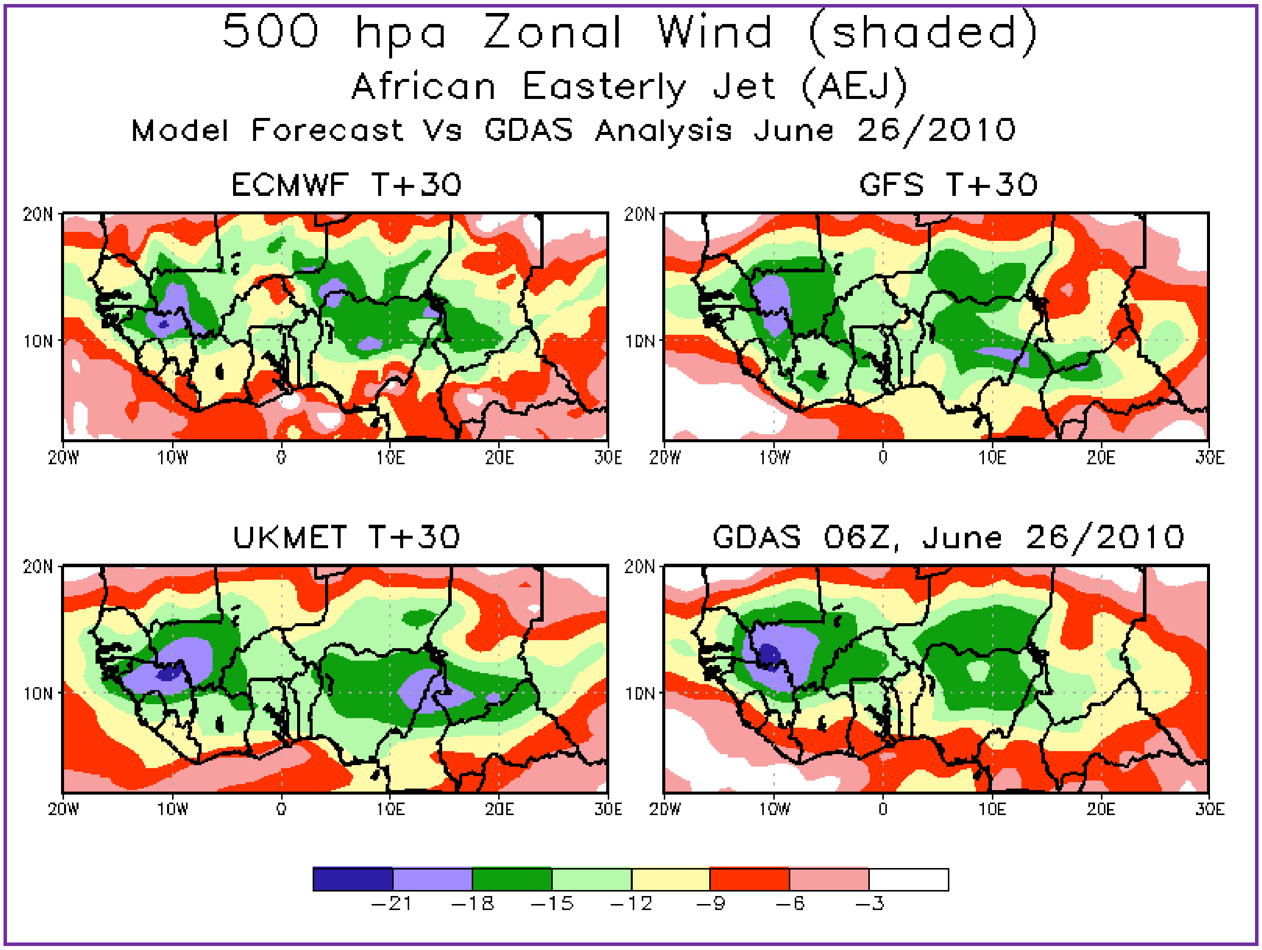

Figure 13 500hpa Level Zonal Wind Forecast VS GDAS Observation 06Z, 26th June 2010

Analysis of GDAS 200hpa zonal wind showed presence of AEJ with winds in excess of 20m/s over eastern and central Nigeria by 12 and 18Z of 25th, and over western Nigeria, Niger and central Mali between 00 and 06Z of 26th June 2010. The GFS model still appears to have a better representation of this from a 30hour forecast initiated from 00z of 25th June 2010.

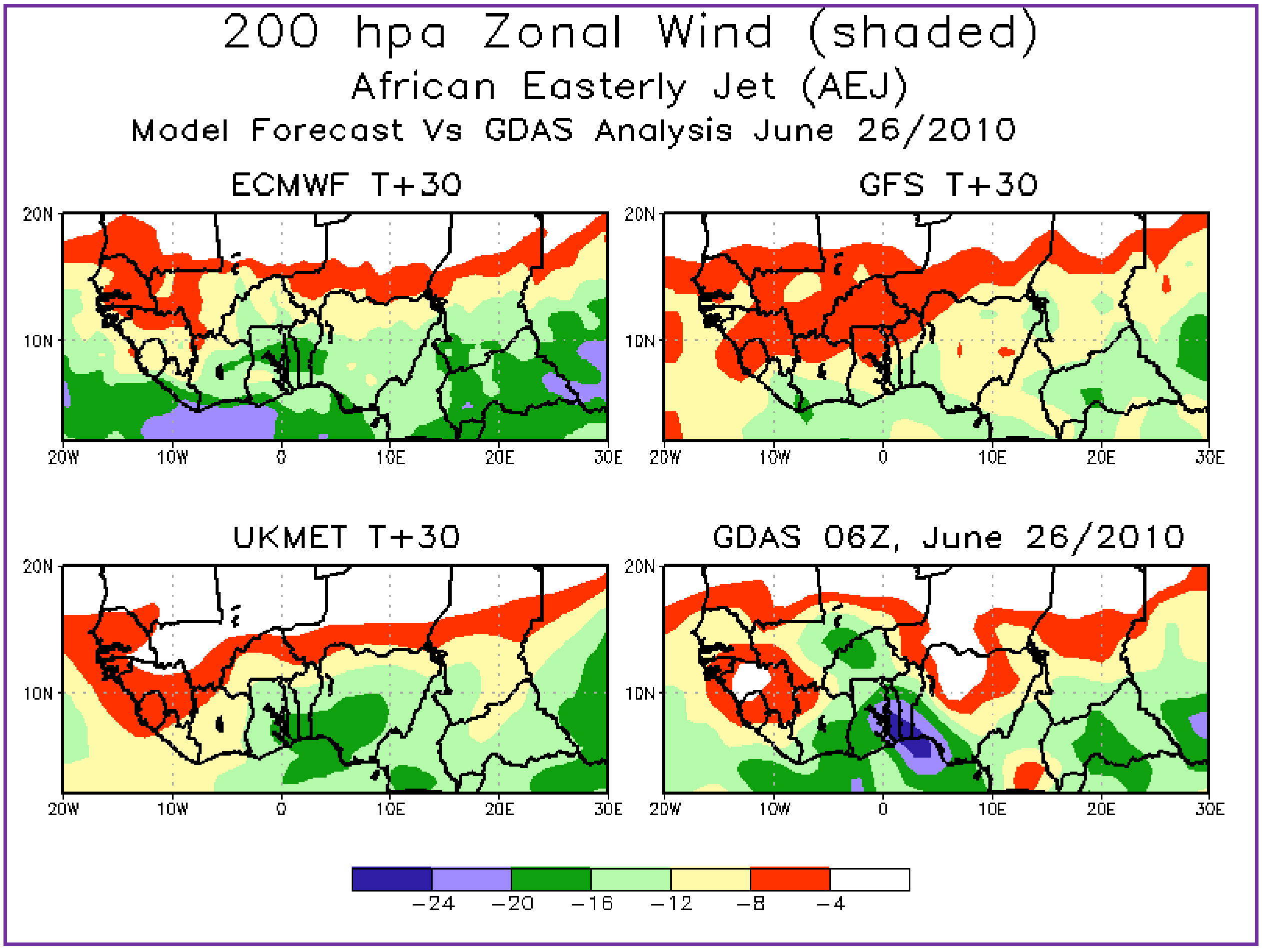

Figure 14 200hpa Zonal Wind Forecast VS GDAS Observation 06Z, 26th June 2010

4.0 Conclusion and Recommendation.

The deepening of heat lows coinciding with the pole ward pull of the ITD on the 25th aided influx of moist south westerly winds further inland. These coupled with lower tropospheric positive vorticity and active African Easterly Jet in the mid-tropospheric level provided the impetus that led to the heavy rainfall event over the North West.

The GFS model showed better skill in forecasting rainfall events even though the UKMET model had greater skill in forecasting rainfall less than 5mm. From the analysis of the four days in June, the GFS model had a better accuracy in rainfall forecast and less forecast error magnitude. The GFS model was not consistent in tracking and forecasting the event of 25th June over the North West and northern parts of the central states from a 90hour lead time but was consistent in forecasting same from 42 hours before time of event.

Even though the time span used for this study may not be adequate enough to arrive at a categorical conclusion, still, it suffices to say that of the four models considered, namely the GFS, UKMET, ECMWF and METEOFRANCE models; the GFS model had the best performance in forecasting rainfall event over Nigeria in the summer of 2010. The three models have their own weaknesses and strengths. While one model shows weaknesses in depicting certain features, the other model may have better representation of the feature. Hence, the use of multi-model approach (lazy man ensemble forecast) could be useful in this regard.

I would therefore recommend that the GFS model be inculcated into the models already being used in weather forecasting by the various forecasting offices of the Nigerian Meteorological Agency.

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