Understanding the influence of global climate drivers on monsoon onset variability in Nigeria using S2S models

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Background

The onset of the monsoon in West-Africa is considered a crucial and integral part of monsoon dynamics because it provides valuable information for decision-makers. Unfortunately, the aspect of utilizing S2S models to determine the onset dates, as well as utilizing the models to understand the roles played by atmospheric dynamics in the determination of onset dates and variability, is lacking over Nigeria

Method

The onset definitions were slightly modified in compliance with the operational practice at NiMet. Therefore, in this study, we defined conditions for determining the onset date of monsoon as follows: 1. Rainfall accumulation in the first 5 days must be at least 25mm; 2. The first day and at least 2 other days must be wet i.e. greater than 0.3mm; and, 3. There should not be 10days in the next 30 days without rainfall i.e. no 10 consecutive days with rainfall < 0.3mm.

Statistical measures, in the form of Taylor diagrams (Taylor, 2001), are utilized in order to determine the intra-seasonal and the inter-annual variability of standardized anomalies of all parameters. Quantitatively, correlation coefficients (r) and the normalized standard deviation (NSD) between all the S2S-models (their ensemble members and the ensemble mean) with reference to the observations (station rain-gauge and era-interim) are also determined. We also applied synchronization (Misra, 1991) technique to quantitatively determine how well the S2S-models capture the timing and anomaly signals. This only applies to the inter-annual variability of the onset dates. As explained by Lawal et al. (2015) and Olaniyan et al. (2018), synchronization is the percentage of periods in which the observed signs of anomalies coincide with those of simulations and or re-forecasts. Furthermore, some measures of statistical significance, such as p-value (Mason, 2008), are performed for the synchronization and correlation skills that were determined in this study. We estimated the level of significance, where p-value = 0.05, for a two-tailed experiment to decide whatever the linear association that may exist between the correlated parameters are plausible. Nigeria is divided into 3 climatological zones based on common climatology. Sea surfaces are also classified to depict Atlantic and Nino indices (Olaniyan et al. (2018)).

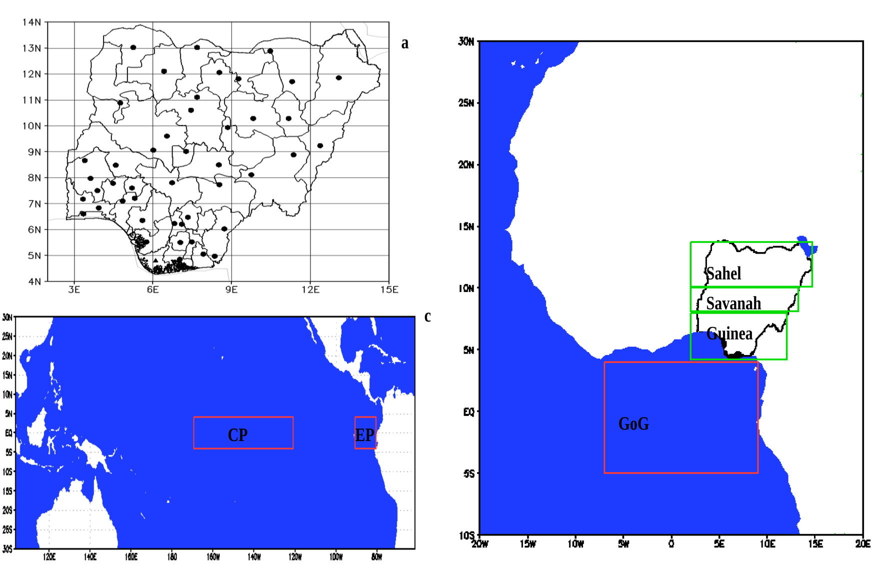

FIGURE | Maps showing **(a)** locations of synoptic stations used in this study; **(b)** three climatological zones in Nigeria in (green boxes) and defined area of the Gulf of Guinea(GoG) over the Atlantic Ocean in (red box); and, **(c)** defined Areas of the Central and Eastern Pacific ocean in red boxes. Source (Olaniyan et al., 2018).

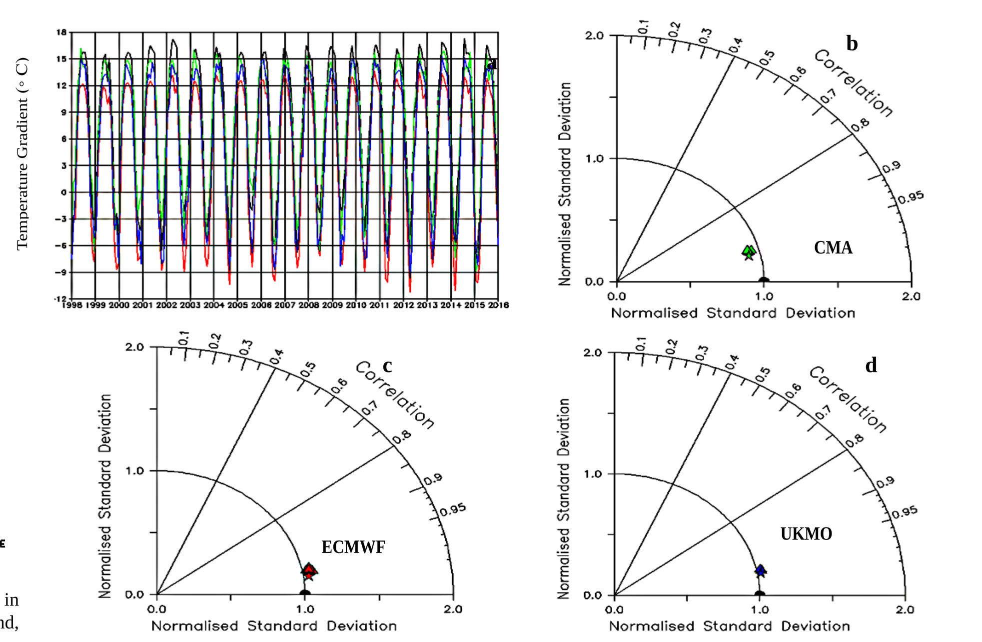

FIGURE | (a) Intra-seasonal variability of the Temperature Gradient (◦ C) over the Sahara and the coastal area of Nigeria by the CMA ensemble mean (green-lines), the ECMWF ensemble mean (red-line), and the UK-METOFFICE ensemble mean (blue-line) and observed Era-Interim (black-line); (b, c and d) Taylor diagrams showing the normalized standard deviations and the correlation coefficients of CMA(green) , ECMWF(red) and UK-METOFFICE(blue) S2S ensemble simulations with observation respectfully (triangle--ensemble members; circle for negative correlations), ensemble mean—star and Era-Interim (observation)—black semi-circle.

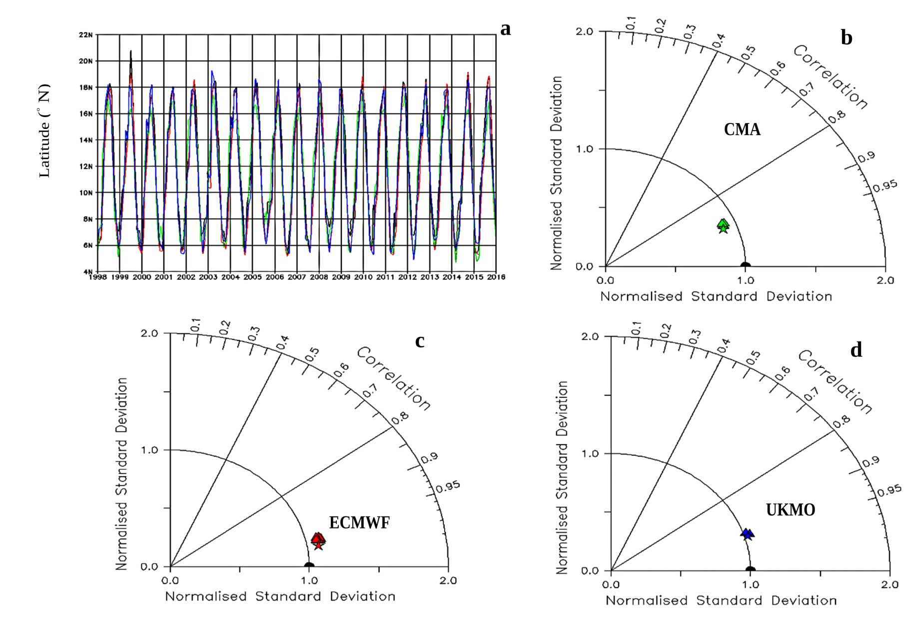

FIGURE | (A) Intra-seasonal variability of the latitudinal position of ITD (◦ N) over Nigeria by the CMA ensemble mean (green-lines), the ECMWF ensemble mean (red-line), and the UK-METOFFICE ensemble mean (blue-line) and observed Era-Interim (black-line); (B, C and D) Taylor diagrams showing the normalized standard deviations and the correlation coefficients of CMA(green) , ECMWF(red) and UK-METOFFICE(blue) S2S ensemble simulations with observation respectfully (triangle--ensemble members; circle for negative correlations), ensemble mean—star and Era-Interim (observation)—black semi-circle.

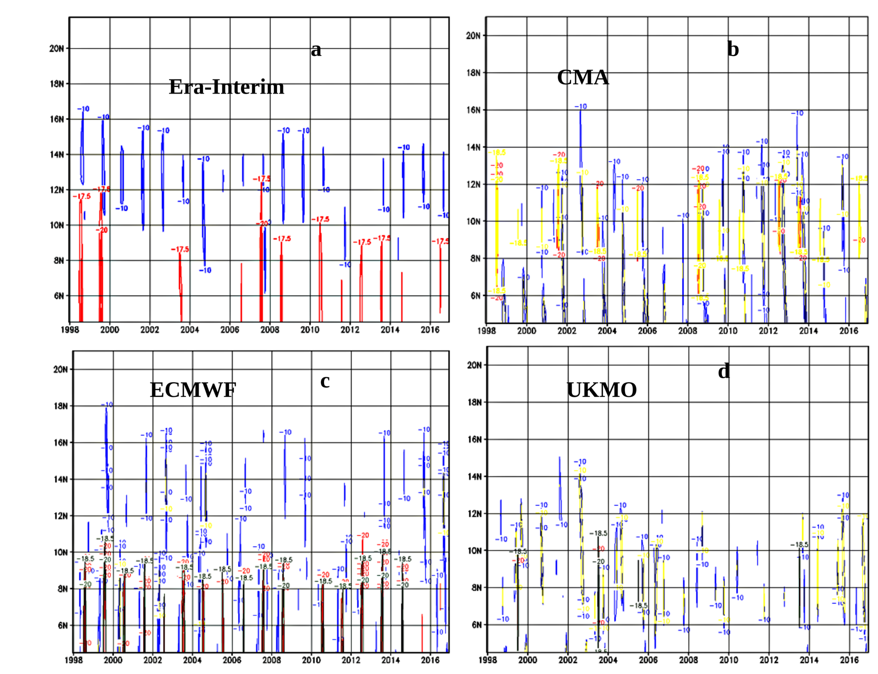

FIGURE | Intra-seasonal variability of the position of the uwind at 700mb(AEJ- blue and yellow for the ensemble mean) and 200mb(TEJ - red and green for the ensemble mean) level from the ensemble the ensemble mean of CMA(b), ECMWF (c), UKMO(d) and observed Era-Interim(a).

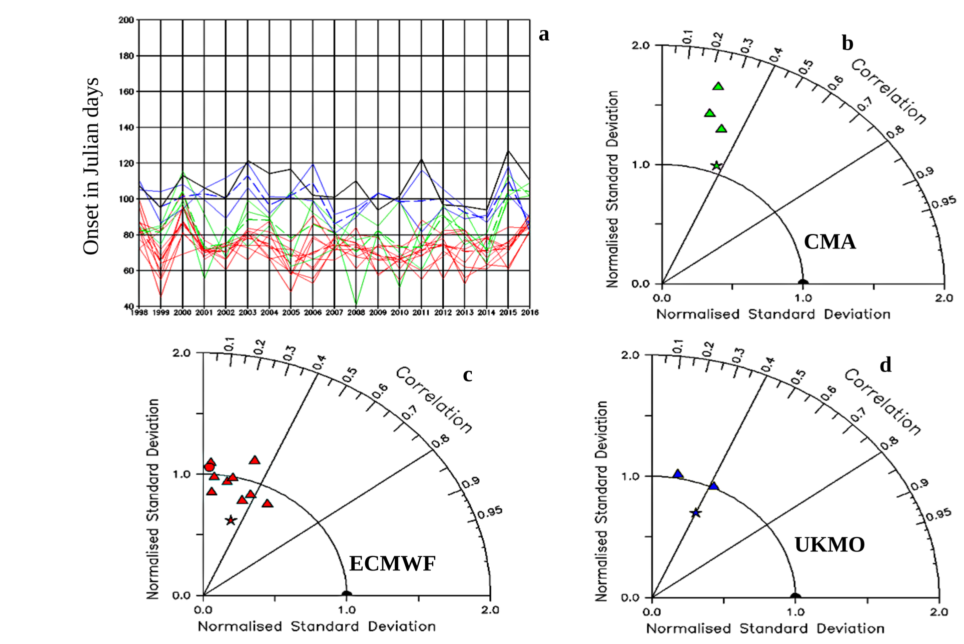

FIGURE | Inter-annual variability of rainfall onset dates (Julian dates) over (A) the Guinea Area of Nigeria from rainguage observation(blackline) the CMA ensemble members and ensemble mean(solid and broken green lines), the ECMWF ensemble members and ensemble mean(solid and broken red lines) and the UK-METOFFICE ensemble members and ensemble mean(solid and broken blue lines); (B, C and D) Taylor diagrams showing the normalized standard deviations and the correlation coefficients of CMA(green) , ECMWF(red) and UK-METOFFICE(blue) S2S ensemble simulations with observation respectfully (triangle--ensemble members; circle for negative correlations), ensemble mean—star and observation—black semi-circle.

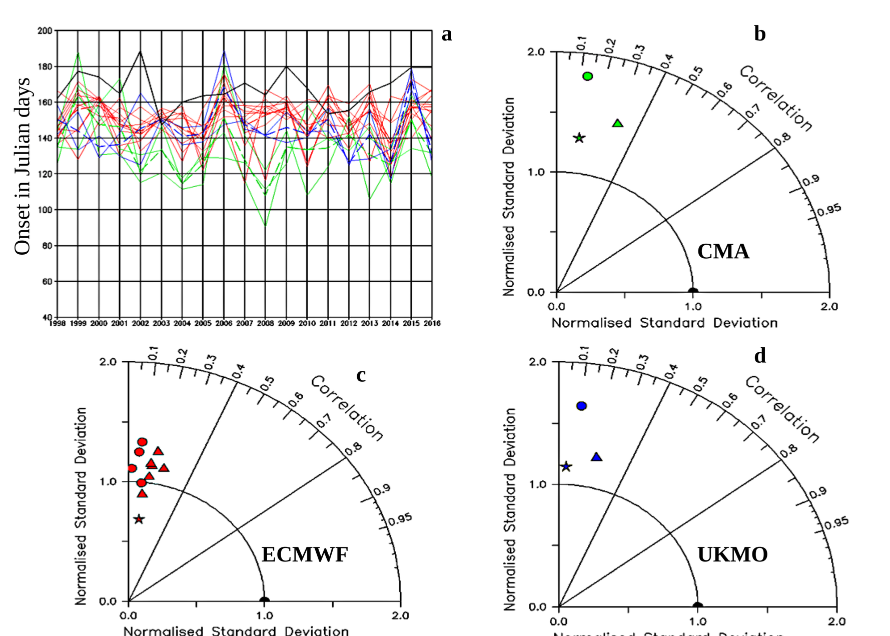

FIGURE | Inter-annual variability of rainfall onset dates (Julian dates) over (A) the Sahel Area of Nigeria from rainguage observation(blackline) the CMA ensemble members and ensemble mean(solid and broken green lines), the ECMWF ensemble members and ensemble mean(solid and broken red lines) and the UK-METOFFICE ensemble members and ensemble mean(solid and broken blue lines); (B, C and D) Taylor diagrams showing the normalized standard deviations and the correlation coefficients of CMA(green) , ECMWF(red) and UK-METOFFICE(blue) S2S ensemble simulations with observation respectfully (triangle--ensemble members; circle for negative correlations), ensemble mean—star and observation—black semi-circle.

Findings

8. only the ECMWF model was able to reproduce the strength, the spatial and temporal position of both the AEJ and the TEJ two of the crucial global drivers modulating the dynamics of the monsoon onset

9. There exists unique characteristics of the anomaly of each of the global drivers in different months, with the variability of the onset anomaly over each region.

10. While late onset (positive anomaly of the onset) over the GOG in one particular year, is linked with above normal in the position of the ITD in August of the previous year.

11. Tele-connection of the SST over the Central Pacific is direct with good correlation and synchronization skills, especially with the onset anomaly over both the Gulf of Guinea and the Sahel.

12. During the period under this study, both the AEJ and TEJ coincided eleven times. The coincidence of these jets in a particular year occurs with the onset anomaly over different region with varying degree but strongest over the Gulf of Guinea. The late onset over the Gulf of Guinea in a particular year coincides by about 70% with the coincidence of the two jets the previous year.

13 all correlation below 0.5 are statistically not significant having the evaluated P-value >>0.05.

14. The use of the multi-model ensemble is not just in size but form an important integral of decision making in a reliable probabilistic forecast.

Conclussions

Although the CMA model may have the least skill, it is, however, showed that all the S2S models despite the inherent biases are able to predict rainfall onset over Nigeria, its variability, the global drivers modulating the variability and the Tele-connections of the drivers with the variability of the onset anomaly, within the sub-seasonal time scale. Finally, the results show that improvements in multi-model ensembles are valuable added information able to significantly improve model performance.

Aim

This study accessed and evaluate the skills of CMA, ECMWF and UKMO Sub-Seasonal to Seasonal (S2S) models in predicting monsoon onset, its variability, the global drivers modulating the variability and the Tele-connections of the drivers with the variability of the onset anomaly in Nigeria.

Findings

1. Each of the models used exhibits unique and different characteristics over each classified region in Nigeria.

2. All the three models are able to simulate the Northwards migration of the Rainfall onset dates adequately with inherent biases.

3. In case of the variability of the onset anomaly, despite the poor performance of the models over the Gulf of Guinea and the Sahel, there is a considerable improvement in the correlation skill of the models over the Savannah

4. While the CMA model is shown to have the least skill in all the regions, the UKMO model shown to have the best correlation skill especially over the Savannah.

5. The probability of making a correct forecast based on onset anomaly, as suggested by the synchronization skill and as displayed by different model ensemble member, differs over each region.

6. on the average, the ECMWF model could make seven correct forecasts out of ten in over all regions; the CMA, four and seven correct forecasts over Sahel and Gulf of Guinea respectively and the UKMO, four and seven correct forecasts over Sahel and Savannah respectively.

7. all the three models reproduced the evolution and variability of the global drivers modulating the monsoon onset.

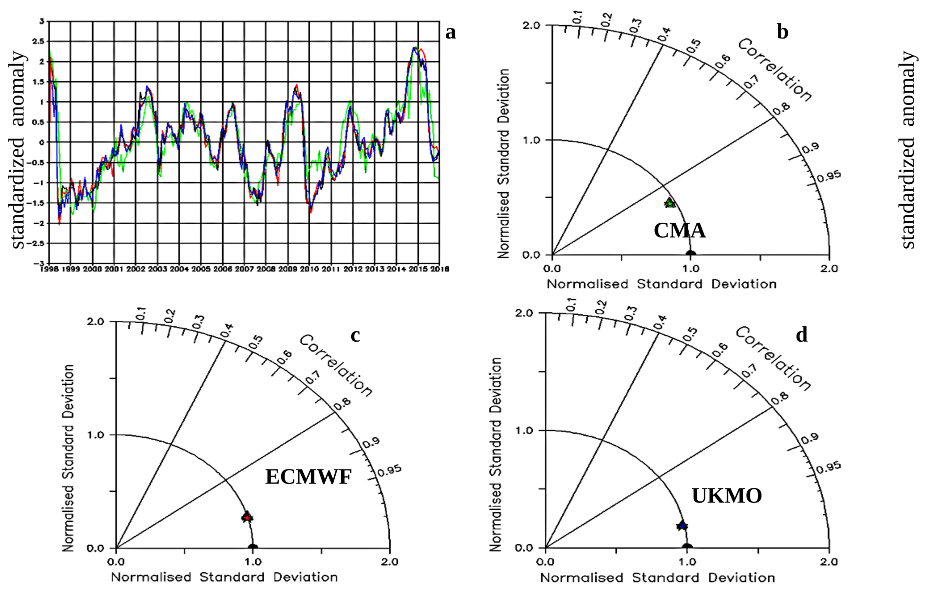

FIGURE | (A) Intra-seasonal variability of standardized SST anomaly over the Central Pacific by the CMA ensemble mean (green-lines), the ECMWF ensemble mean (red-line), and the UK-METOFFICE ensemble mean (blue-line) and observed Era-Interim (black-line); (B, C and D) Taylor diagrams showing the normalized standard deviations and the correlation coefficients of CMA(green), ECMWF(red) and UK-METOFFICE(blue) S2S ensemble simulations with observation respectfully (triangle--ensemble members; circle for negative correlations), ensemble mean—star and Era-Interim (observation)—black semi-circle.

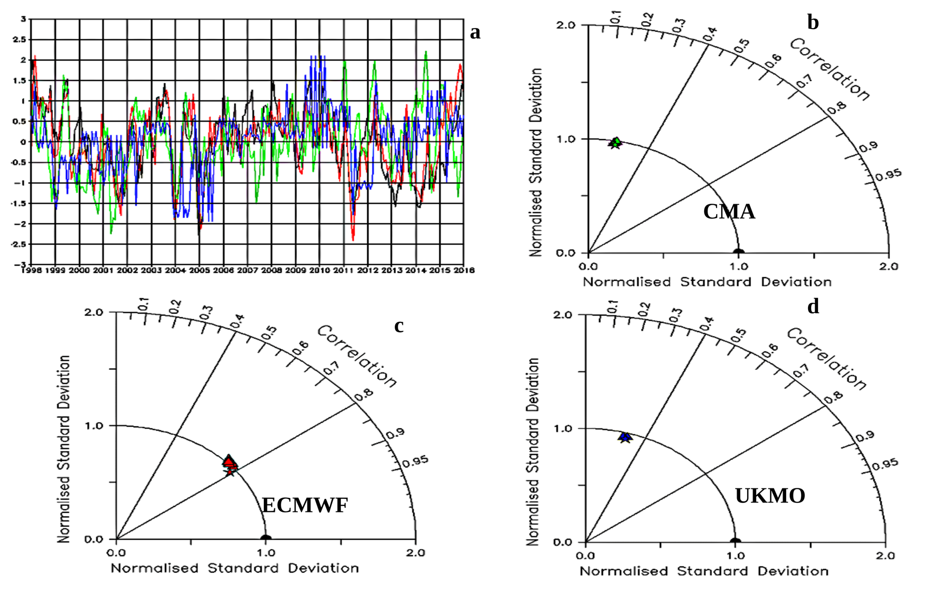

FIGURE | (A) Intra-seasonal variability of standardized SST anomaly over the Gulf of Guinea by the CMA ensemble mean (green-lines), the ECMWF ensemble mean (red-line), and the UK-METOFFICE ensemble mean (blue-line) and observed Era-Interim (black-line); (B, C and D) Taylor diagrams showing the normalized standard deviations and the correlation coefficients of CMA(green) , ECMWF(red) and UK-METOFFICE(blue) S2S ensemble simulations with observation respectfully (triangle--ensemble members; circle for negative correlations), ensemble mean—star and Era-Interim (observation)—black semi-circle.

Table | Summary of the Tele-connection between the inter-annual variability of the anomaly of the Global drivers with the inter-annual variability on the onset anomaly over the Gulf of Guinea, Savannah and the Sahel.

Climate Drivers	Month	Region	Link	Percentage(%) Synchronization	Correlation (r)	P-Value (r)
ITD	March	Sahel	One Year Lag	84	0.3	0.23
	August	GoG	One Year Lag	78	0.3	0.23
Pressure Gradient	January	GoG	Direct	68	0.25	0.3
	March	Sahel	Reverse One Year Lag	78	-0.4	1.0
Temperature Gradient	January	Savannah	One Year Lag	78	0.5	0.035
SST Gulf of Guinea	January	GoG	Direct	68	0.1	0.68
	May	Sahel	Direct	74	0.5	0.029
SST Central Pacific	January	GoG	Direct	74	0.2	0.41
	February	Sahel	Direct	68	0.04	0.87
	April	Savannah	Direct	68	0.03	0.90
UWinds (AEJ and TEJ)	August	GoG	One Year Lag	70	NA	0.4

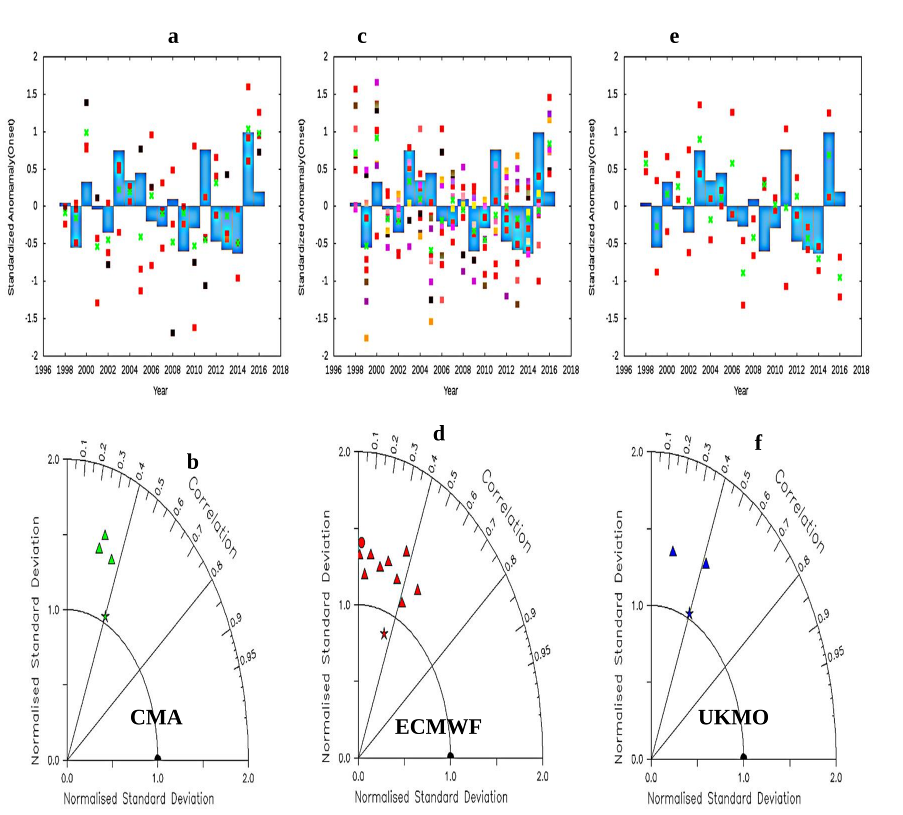

FIGURE | Inter-annual variability of rainfall onset dates standardized anomaly over the Guinea Area of Nigeria from rainguage observation (blue bar) with (A) the CMA ensemble members and ensemble mean (C) the ECMWF ensemble members and ensemble mean and (E) the UK-METOFFICE ensemble members and ensemble mean.; (B, D and F) Taylor diagrams showing the normalized standard deviations and the correlation coefficients of CMA(green) , ECMWF(red) and UK-METOFFICE(blue) S2S ensemble simulations with observation respectfully (triangle--ensemble members; circle for negative correlations), ensemble mean—star and observation—black semi-circle.

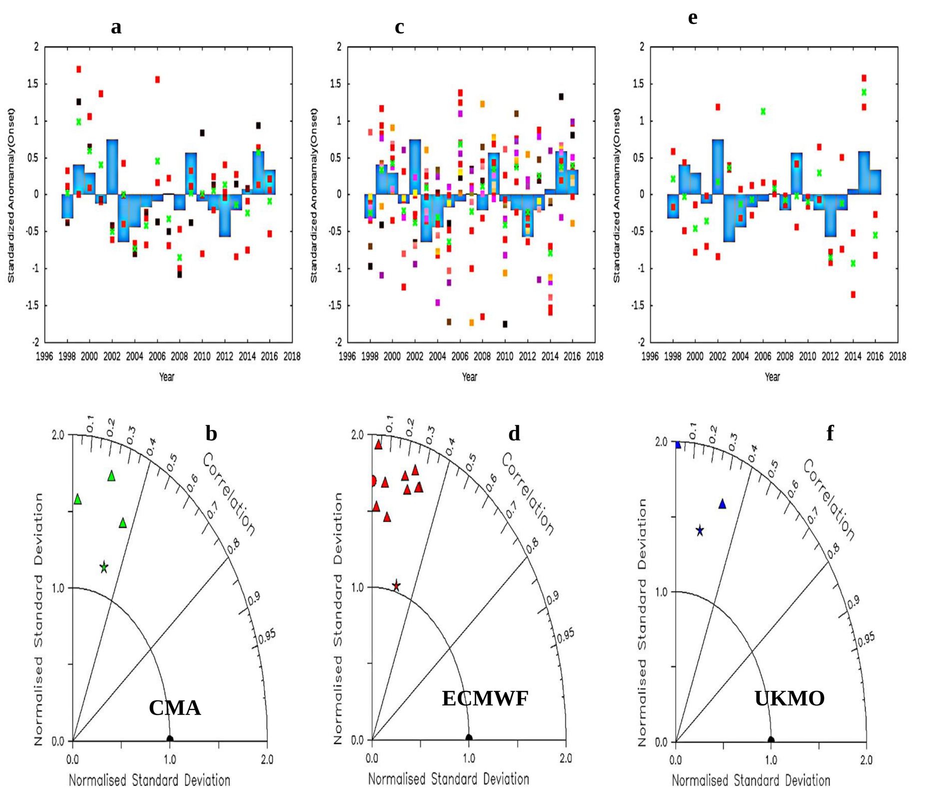

FIGURE 14 | Inter-annual variability of rainfall onset dates standardized anomaly over the Sahel Area of Nigeria from rainguage observation (blue bar) with (A) the CMA ensemble members and ensemble mean (C) the ECMWF ensemble members and ensemble mean and (E) the UK-METOFFICE ensemble members and ensemble mean.; (B, D and F) Taylor diagrams showing the normalized standard deviations and the correlation coefficients of CMA(green) , ECMWF(red) and UK-METOFFICE(blue) S2S ensemble simulations with observation respectfully (triangle--ensemble members; circle for negative correlations), ensemble mean—star and observation—black semi-circle.

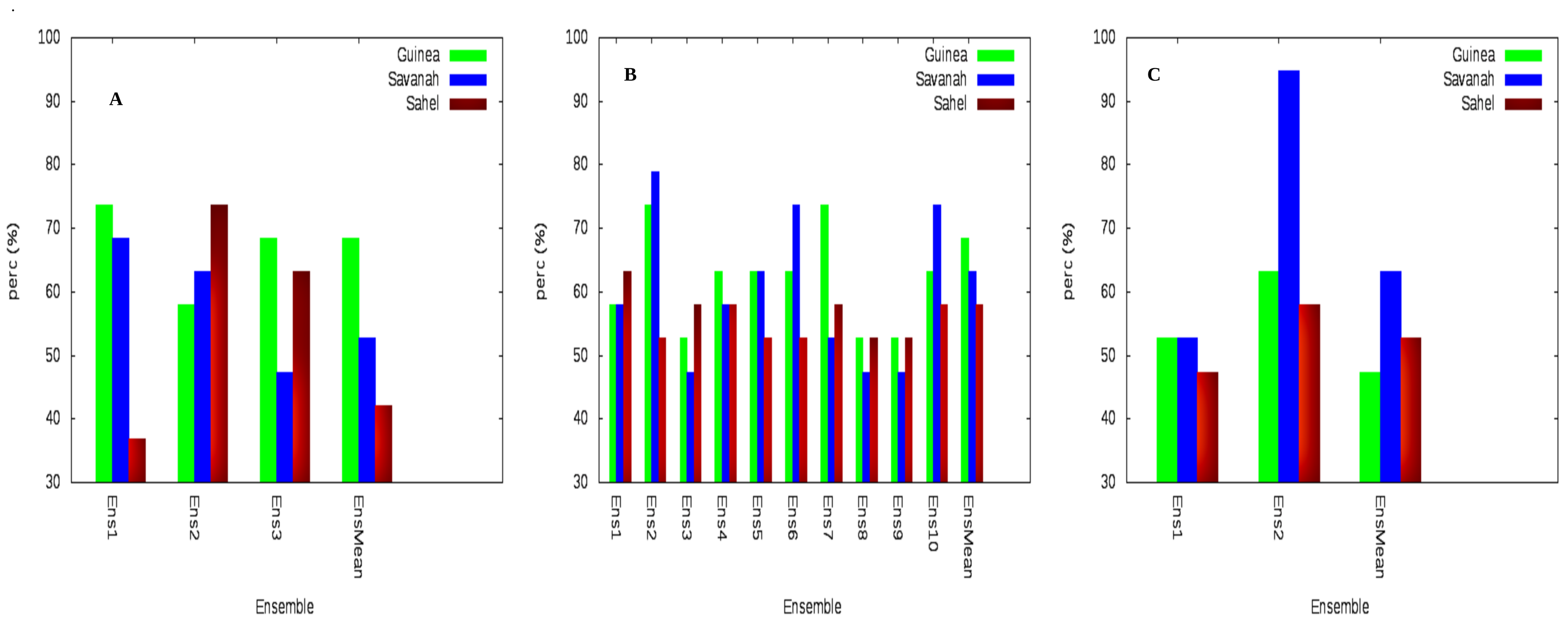

FIGURE | Synchronization (%) of the simulated inter-annual rainfall onset dates anomalies between (A) the CMA Ensemble members and the Ensemble mean (B), the ECMWF Ensemble members and the Ensemble mean and (C) the UK-METOFFICE Ensemble members and the Ensemble mean. All models are with reference to observation over the climatological zones of Nigeria (GoG,Savannah and Sahel).

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