Sensitivity study of the regional climate model RegCM4 to different convective schemes over West Africa.

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BACKGROUNDS

The latest version of RegCM4 with CLM4.5 as a land surface scheme was used to assess the performance and sensitivity of the simulated West African climate system to different convection schemes. The sensitivity studies were performed over the West African domain from November 2002 to December 2004 at a spatial resolution of 50 km × 50 km and involved five convective schemes: (i) Emanuel; (ii) Grell; (iii) Emanuel over land and Grell over ocean (Mix1); (iv) Grell over land and Emanuel over ocean (Mix2); and (v) Tiedtke. It is worth noting that the few previous similar sensitivity studies conducted in the region were performed using BATS as a land surface scheme and involved less convective schemes. Compared with the previous version of RegCM, RegCM4-CLM also shows a general cold bias over West Africa whatever the convective scheme used. This cold bias is more reduced when using the Emanuel convective scheme. In terms of precipitation, the dominant feature in model simulations is a dry bias that is better reduced when using the Emanuel convective scheme. Considering the good performance with respect to a quantitative evaluation of the temperature and precipitation simulations over the entire West African domain and its subregions, the Emanuel convective scheme is recommended for the study of the West African climate system.

DATA AND METHODOLOGY

Five experiments using the convection schemes of (1) Emanuel over land and Grell over ocean (mix1), (2) Emanuel, (3) Grell, (4) Tiedtke, and (5) Grell over land and Emanuel over ocean (mix2) are conducted using RegCM4-CLM4.5 with 18 sigma levels at 50 km horizontal resolution for the period from November 2002 to September 2004. The first 2 months (i.e., November and December 2002) was considered as spin-up time and not included in the analysis. The years 2003 and 2004 have been selected in this study because they corresponded to a dry and wet year in this region, respectively. The analyses will focus on the rainy season from June to September (JJAS). As quantitative measurements of model skills, we consider mean bias (MB), which is the difference between the area-averaged value of the simulation and the observation, the spatial root mean square difference (RMSD), the spatial correlation called pattern correlation coefficient (PCC) and the distribution of the probability density function (PDF) of the temperature bias. The RMSD, PCC and the PDF provide information at the grid-point level, while the MB does so at the regional level. A Taylor diagram (Taylor, 2001) is used to summarize the assessments above and to show the deviation of different model configuration results from observations. These metrics are computed for each of the subregions indicated in Fig. 1. For this sensitivity study, the model was run at its standard configuration with 18 vertical sigma layers (model top at 50 hPa) and with initial and boundary conditions provided by the European Centre for Medium-Range Weather Forecasts reanalysis ERA-Interim (Simmons et al., 2007) at a horizontal resolution of 50 km and a temporal resolution of 6 h (00:00, 06:00, 12:00 and 18:00 UTC). Sea surface temperatures (SSTs) were from NOAA optimal interpolation weekly SST data (Reynolds et al., 1994). The terrain characteristics (topography and land use data) were derived from United States Geological Survey (USGS) Global Land Cover Characterization (GLCC; Loveland et al., 2000) at 10 min horizontal resolution. We focus our analysis on the precipitation and the air temperature at 2 m in the summer of June-July-August-September (JJAS) over mainland West Africa. To reduce uncertainty due to lack of surface climate observations over the region (Nikulin et al., 2012), the simulated precipitation is validated using two observational datasets: the GPCP product (1°×1°)resolution) is a satellite derived dataset developed under the Global Precipitation Climatology Project and made available from late 1996 to present and the 0.25° high-resolution dataset of the Tropical Rainfall Measuring Mission 3B43V7 (TRMM) available from 1998 to 2013 (Huffman et al.,2007). The simulated 2 m temperature is also validated using two observational datasets: the Climate Research Unit (CRU) time series version 3.20 gridded at 0.5° of horizontal resolution from the University of East Anglia, available from 1901 to 2011 (Harris et al., 2013), and the University of Delaware version 3.01 (UDEL) gridded dataset at 0.5° of horizontal resolution, available from 1900 to 2010 (Legates and Willmott, 1990). The simulated atmospheric fields are compared with ERA-Interim reanalysis available from 1979 to present at 1.5° of horizontal resolution (Dee et al., 2011). All products have been regridded to 0.44° × 0.44° using a bilinear interpolation method to facilitate the comparison with RegCM4 simulations (Nikulin et al., 2012). The model performance is further examined in four subregions (Fig. 1), each with different characteristics of the annual cycle of rainfall: central Sahel (10° W-10°E; 10-16°N), west Sahel (18-10°W; 10-16 °N), Guinea coast (15°W-10 E; 3-10 °N) and West Africa (20° W-20 °E; 5°S-21°N).

RESULTS AND DISCUSSION

A- Study area:

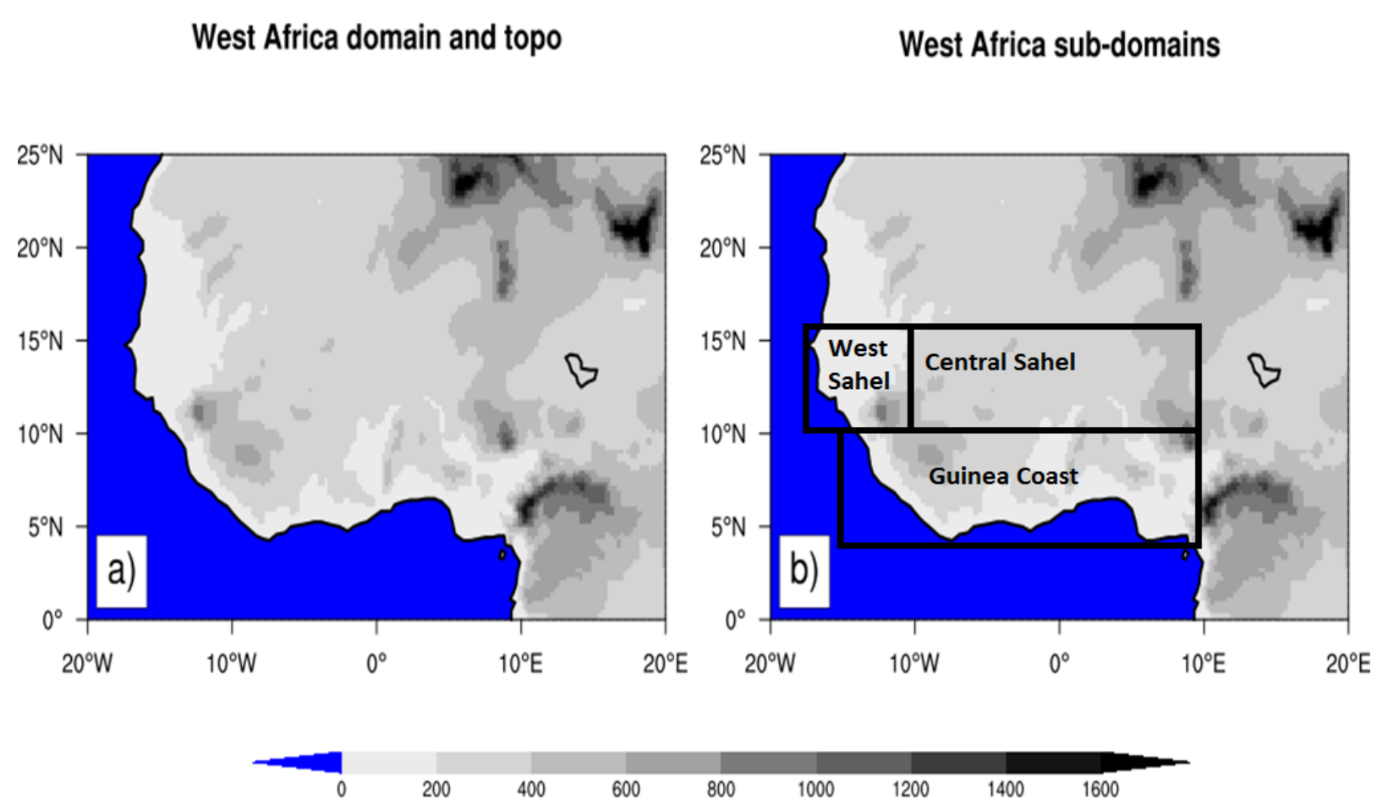

Fig1:Topography of the West African domain. The analysis of the model result has an emphasis on the whole West African domain and the three subregions Guinea coast, central Sahel and west Sahel, which are marked with black boxes.

B- Temperature

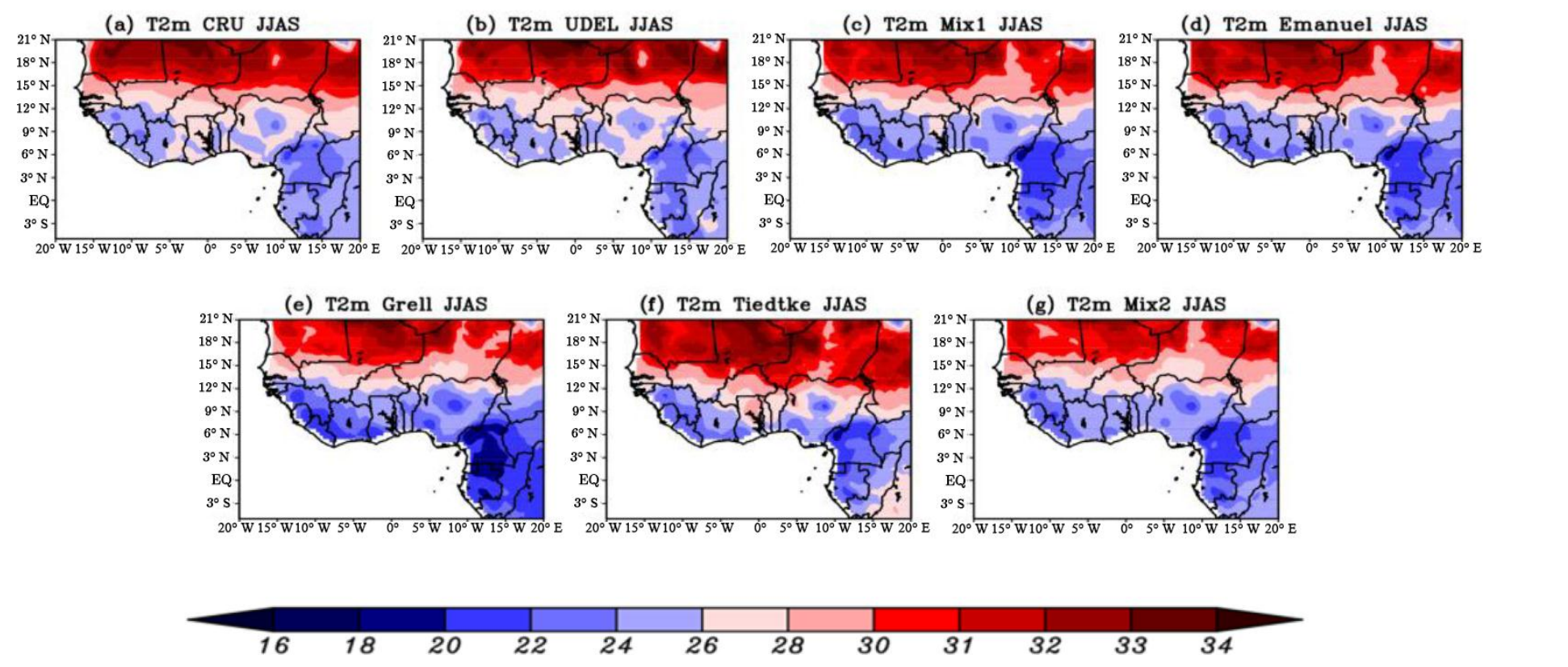

Fig2: Averaged 2003–2004 JJAS 2 m temperature (in °C) over West Africa from (a) CRU, (b) UDEL, (c) Mix1, (d) Emanuel, (e) Grell, (f) Tiedtke and (g) Mix2.

	Guinea coast		Central Sahel		West Sahel		West Africa	
	RMSE (°C)	PCC	RMSE (°C)	PCC	RMSE (°C)	PCC	RMSE (°C)	PCC
UDEL	0.613	0.749	0.475	0.974	0.424	0.981	0.695	0.981
Mix1	1.605	0.768	0.737	0.961	0.720	0.987	1.218	0.978
Emanuel	1.294	0.772	0.673	0.954	0.589	0.986	1.068	0.979
Grell	2.657	0.728	1.406	0.920	1.994	0.985	2.171	0.973
Tiedtke	1.534	0.758	1.360	0.938	0.717	0.982	1.355	0.938
Mix2	1.993	0.781	1.682	0.884	1.568	0.978	1.715	0.964

Table1: Pattern correlation coefficient (PCC) and root mean square difference (RMSD) for JJAS 2 m temperature for model simulations and observations (UDEL) with respect to CRU during the period 2002–2003

The CRU temperatures present a zonal distribution in West Africa with a maximum (> 34°C) in the Sahara and the lowest temperatures (< 22 °C) over the Guinea coast and over complex terrains such as the Jos Plateau, Cameroon mountains and Guinean highlands (Fig, 2). The UDEL observation (Fig. 2b) shows similarity with CRU in terms of spatial distribution with PCC larger than 0.98 over the entire West African domain (see Table 1). All model configurations reproduce the general features of the observed pattern well, including the meridional surface temperature gradient zone between Guinea coast and the Sahara Desert. The Emanuel configuration shows a lower value of RMSD at about 0.67° C and a higher PCC larger than 0.95 compared to the other model simulated temperatures (see Table 1).

C- Precipitation:

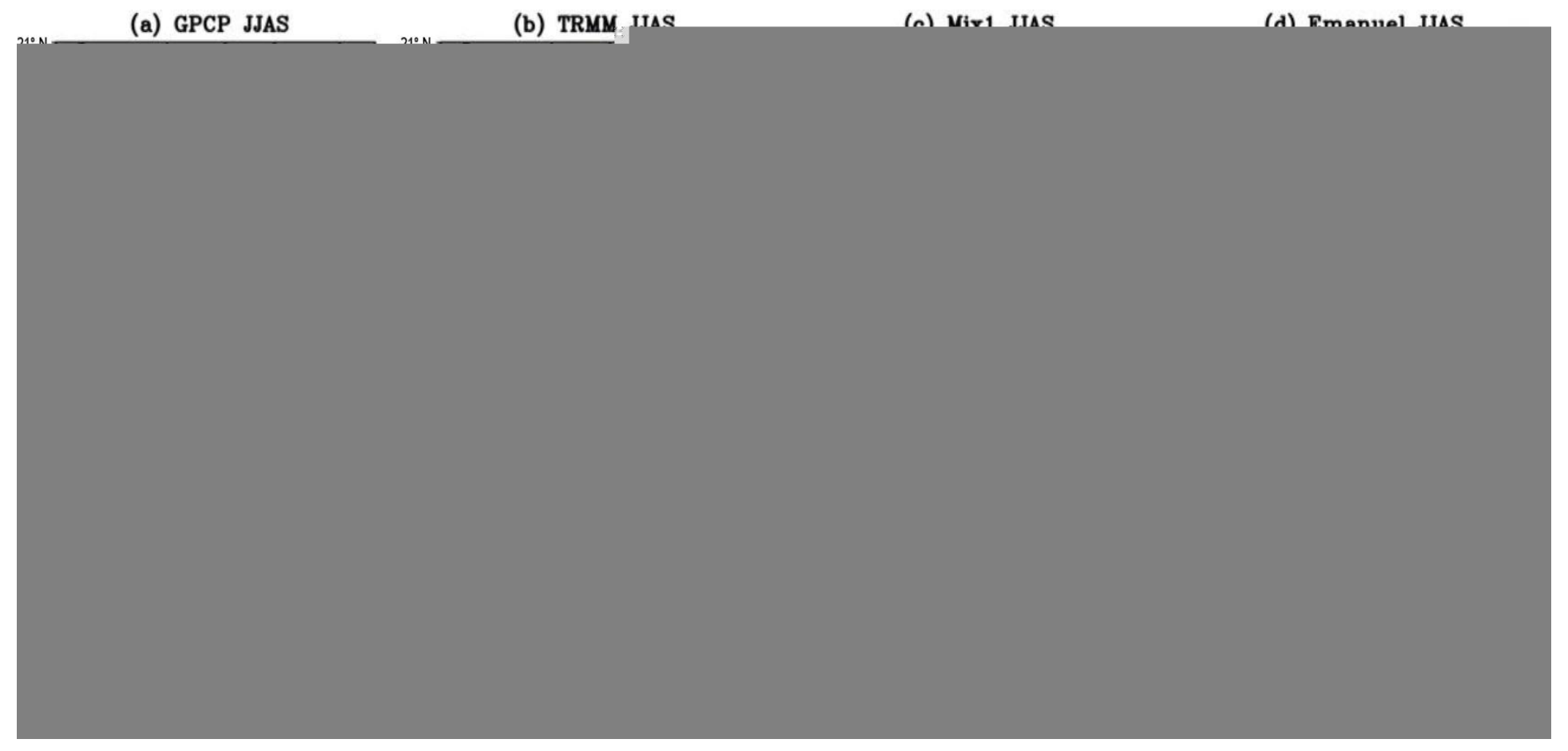

Fig3: Averaged 2003–2004 JJAS precipitation (in millimeters per day) over West Africa from (a) GPCP, (b) TRMM, (c) Mix1, (d) Emanuel, (e) Grell, (f) Tiedtke and (g) Mix2.

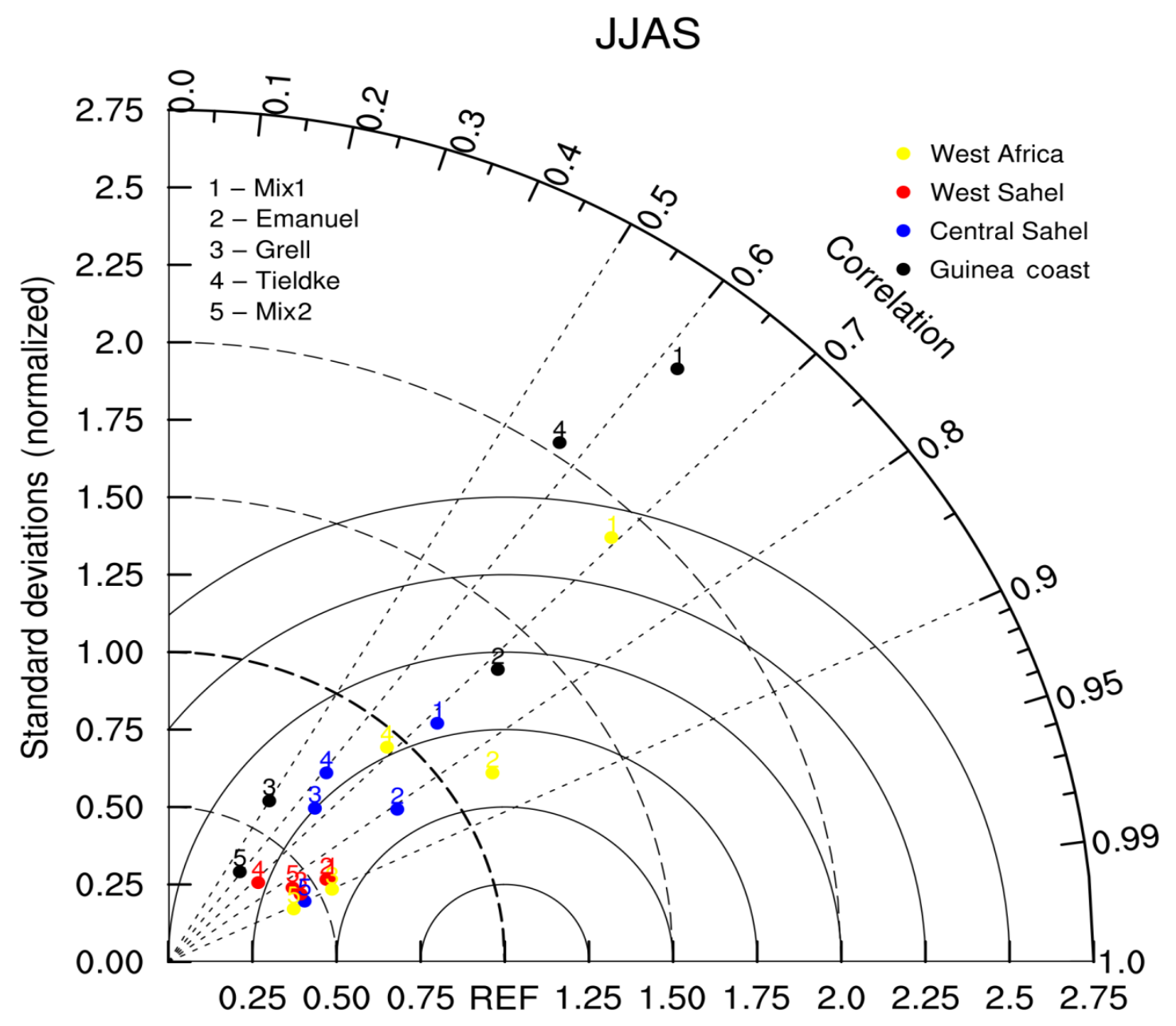

Fig4:Taylor diagram showing the pattern correlation and the standard deviation (normalized) for JJAS precipitation with respect to GPCP from Mix1, Emanuel, Grell, Tiedtke and Mix2 over Guinea coast, central Sahel, west Sahel and West Africa during the period 2002–2003.

GPCP depicts a zonal band of rainfall decreasing from north to south (see Fig. 3). Precipitation maxima are found in orographic regions of the Guinea highlands, Jos Plateau and Cameroon mountains. Although both observation products TRMM and GPCP exhibit some differences, their patterns show a good agreement, with PCCs more than 0.96 over the entire West African domain. A Taylor diagram is used to give a combined synthesized view of the pattern correlation coefficient and the JJAS standard deviation of precipitation from the different sensitivity studies. For the entire West African domain, the diagram shows that Tiedtke and Emanuel outperform the other configurations with values of normalized standard deviation much closer to 1. However, the Emanuel configuration present a better spatial correlation, reaching 0.8 compared to the Tiedke configuration. Over the Guinea coast subregion, Grell and Emanuel present better values of normalized standard deviation. However, regarding the spatial correlation, a value of about 0.7 as in the Emanuel configuration is the best. For west and central Sahel, Mix1 and Emanuel are closer to observations. However, Emanuel outperforms the Mix1 configuration with a good spatial correlation score between 0.7 and 0.8 over the central and west Sahel subregions. From the Taylor diagram, it can be inferred that Emanuel performs better regarding the normalized standard deviation and the pattern correlation over the entire West African domain and its subregions.

D- Precipitation and temperature mean cycle:

Fig5: Averaged 2003–2004 JJAS precipitation (in millimeters per day) over West Africa from (a) GPCP, (b) TRMM, (c) Mix1, (d) Emanuel, (e) Grell, (f) Tiedtke and (g) Mix2.

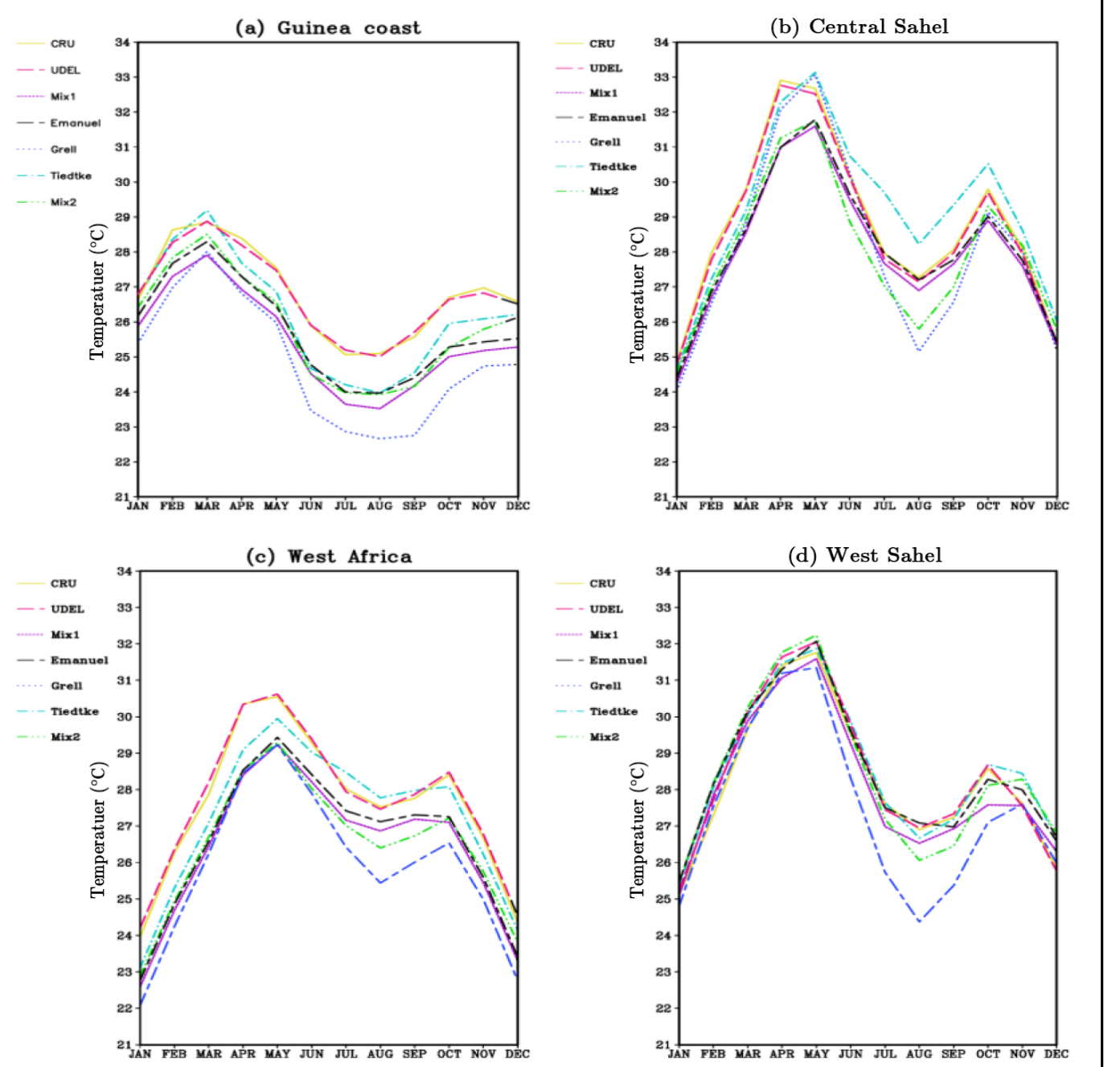

Fig6: Averaged 2003–2004 JJAS 2m temperature mean (in °C) over West Africa from (a) GPCP, (b) TRMM, (c) Mix1, (d) Emanuel, (e) Grell, (f) Tiedtke and (g) Mix2.

The bimodal nature of rainfall associated with the Guinea sub-region is not so well defined when averaging rainfall over the entire West African domain. This emphasizes the importance of separating regions into homogeneous precipitation subregions for evaluation analyses (Figs. 5 and 6). Over West African domain, the Mix1 and Emanuel model simulations are much closer to the observed annual cycle of precipitation compared to the others. The mean annual cycle of temperature is reproduced well in simulation when using the Tiedtke convection scheme throughout the year over the subregions and the entire West African domain compared to the other model simulations.

CONCLUSION AND PERSPECTIVES

Compared with the previous version of RegCM, RegCM4-CLM also shows a general cold bias over West Africa. However, in the central Sahel region, the Tiedtke simulation presents a warm bias. An overall better performance with respect to temperature is obtained when using the Emanuel scheme. With respect to precipitation, the dominant feature in model simulations is a dry bias. Considering the good performance over the entire West African domain and its subregions in the temperature and precipitation simulations, we suggest the Emanuel convection scheme when using RegCM4-CLM4.5 over West Africa. As a more advanced package compared to the previous version of RegCM with BATS, CLM4.5 can be considered as the primary land surface process option in RegCM4. To make this study more complete, we will examine the sensitivity of temperature and precipitation extremes simulated by RegCM4-CLM4.5 to different convective schemes.

REFERENCES

Dee, D. P. and al,: The ERA-Interim reanalysis: configuration and performance of the data assimilation system, Q. J. Roy. Meteorol. Soc., 137, 553-597, https://doi.org/10.1002/qj.828, 2011.
Harris, I and al..: Updated high-resolution grids of monthly climatic observations, Int. J. Climatol., 34, 623–642, https://doi.org/10.1002/joc.3711, 2013
Huffman, G. J. and al.: The TRMM multisatellite precipitation analysis: quasi-global, multiyear, combined-sensor precipitation estimates at fine scale, J. Hydrometeorol., 8, 38–55, 2007.
Nikulin, G. and al. : Precipitation climatology in an ensemble of CORDEX-Africa regional climate simulations, J. Climate, 6057–6078, https://doi.org/10.1175/JCLI-D-11-00375.1, 2012; Legates, D. R. and Willmott, C. J.: Mean seasonal and spatial variability in gauge-corrected, global precipitation, Int. J. Climatol., 10, 111–127, 1990.
Loveland, T. R.: Development of a global land cover characteristics database and IGBP DISCover from 1-km AVHRR Data, Int. J. Remote. Sens., 21, 1303–1330, 2000.
Reynolds, R. W and Smith, T. M.: Improved global sea surface temperature analysis using optimum interpolation, J. Climate, 7, 929–948, 1994.;
Simmons, A. S., Uppala, D. D., and Kobayashi, S.: ERA-interim: new ECMWF reanalysis products from 1989 onwards, ECMWF Newsl., 110, 29–35, 2007
Taylor Karl E. Summarizing multiple aspects of model performance in a single diagram. Journal of Geophysical Reasearch, Vol. 106, NO. D7; pages 7183-7192, April 16, 2001.

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