Influence of slab-ocean parametrization in a regional climate model (RegCM4) over Central Africa

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Abstract

The study aims to assess the local response of the regional climate model version 4.6 (RegCM4.6) to the coupling of ocean-atmosphere interaction in Central Africa. The ability of the model is evaluated over six years (first January 2001, to thirty-first December 2006) by conducting two different experiments with the Grell convective scheme. The experiments are carried out monthly with a spatial resolution of 40 km. The model was forced by ERA-Interim reanalyses and validated by GPCP (Global Precipitation Climatology Project) observational data, ERA 5 and ERA-Interim reanalyses. To evaluate the influence of the slab-ocean, we carried out two different experiments: The first experiment is designed to produce the climatology and force the surface limits of RegCM with the sea surface temperature. The second experiment is designed to couple RegCM with the slab-ocean, which provides mutual interaction between the ocean and the atmosphere. Using statistical tools, we evaluated the model's ability to simulate precipitation, surface temperature and wind. Both experiments reasonably reproduce the main characteristics of the rainfall regime, temperature and wind. A comparative analysis of the different experiments reveals that the performances of the experiments are similar in Central Africa and in the different homogeneous sub-regions as far as rainfall is concerned, but there are subtle differences. Slab-ocean improvement varies from season to season and from the sub-region to sub-region. However, we note a significant improvement in temperature and rainfall over the Indian Ocean.

Keyword RCMs, Central Africa, slab-ocean, precipitation, temperature.

1. Introduction

Central Africa is the second-largest tropical forest basin in the world after the Amazon. Available studies highlight that a large part of the population of this region lives from agriculture, goods and services derived from the Congo Basin forest. (Haensler et al., 2013a; Sonwa et al., 2012; Bele et al., 2013), which makes it vulnerable to climate change (Haensler et al., 2013a). Despite the great improvement in climate studies in recent decades, the climate of Central Africa, particularly that of the Congo Basin, is not yet well studied because of a poor spatial and temporal distribution of data from weather stations. However, the scientific community is interested in the study of this climate, but the complexity of the climate system in Central Africa considerably limits the ability of researchers to understand and predict the fluctuations of this climate. To do this, one of the means available to understand the mechanisms of climate is based on the use of climate numerical models (Cubasch et al., 1994; Murphy et Mitchell, 1995). Furthermore, the current computational resources do not allow us to have Atmospheric General Circulation Models (AGCMs) with sufficiently fine horizontal resolutions and sufficiently detailed physical parameterisation to represent adequately the mesoscale continental phenomena and ocean-atmosphere interaction when coupling the AGCMs to the ocean (Umakanth et Kesarkar, 2017). The ocean is a very important part of the climate system because it dominates by its calorific capacity, which modulates the variability of tropical precipitation through sea surface temperature (SST). Dezfuli et al (2015) showed that SST in the Indian and Atlantic Oceans influences atmospheric convection and circulation in the Congo Basin. Despite the crucial role of SST in the climate of the sub-region, very little work has been done in the evaluation of coupled Regional Climate Models (RCMs) compared to autonomous RCM simulations. In a study, Ratnam et al (2011) used the mixed layer of the Slab Ocean Model (SOM) to couple the regional Weather Research and Forecasting (WRF) model to simulate rainfall over the southern African region. The study confirms that the WRF model coupled to the SOM allows it better simulate the climate of the South African region compared to the stand-alone WRF. Umakanth and Kesarkar (2017) coupled the SOM to the regional climate model (RegCM4.4) to simulate the sub-seasonal variability of the Indian summer monsoon. The result is that the coupling improves RegCM's performance by simulating the spatio-temporal characteristics of the Indian monsoon regime. Furthermore, studies by Singh et al (2007), Chow and Chan (2009), Hartmann and Kristin (2002) have shown that in a regional climate model, the same convective pattern cannot give accurate results over all parts of the globe because the convective process in the tropics is very different from that in mid-latitudes and polar regions. Several studies using the regional climate model have already been carried out in Central Africa (Rockel and Geyer, 2008; Tchotchou and Kamga, 2009; Tanessong et al., 2013; Igri et al, 2015; Fotso-Nguemo et al, 2016; Mbienda et al, 2016; Vondou and Haensler, 2017; Fotso-Nguemo et al, 2017; Vondou et al, 2017; Igri et al, 2018; Fotso-Kamga et al, 2020; Taguela et al, 2020), but none of these studies ever coupled the RCM taken into consideration to the SOM. Nevertheless, these studies underline that the choice of the convective scheme and initial conditions is very important for rainfall simulation in Central Africa. Therefore, it is important to identify appropriate convective schemes in a model before conducting a study. Thus, the physical parameters of the model set in the RegCM4 sensitivity experiments in Central Africa by Mbienda et al (2016), are used in this study. Given the crucial role of SOM in modulating rainfall in Central Africa, this study motivated us to use an approach similar to that of the studies that coupled the SOM with the regional climate model. The overall objective of this study is to assess the response of RegCM version 4.6 to ocean-atmosphere coupling over Central Africa. The specific objectives of this work are to evaluate under the effect of ocean-atmosphere coupling (i) the spatial distribution of average seasonal rainfall, (ii) the spatial distribution of mean seasonal surface temperatures, and (iii) the spatial distribution of seasonal wind averages. The rest of the article is organised as follows: Section 2 describes the model, experimental protocol, data and methodology; the results are presented and discussed in section 3 and the conclusion is in section 4.

2. Description of the model, experimental protocol, data and methodology

2.1 Description of RegCM model

The RegCM regional climate model is a model that was developed by the group of atmospheric physicists and climatologists of the Abdus Salam International Centre for Theoretical Physics (ICTP; Giorgi et al., 1993). Since the release of RegCM3, the model has undergone substantial development in terms of both software code and physical representations, leading to the development of a fourth version of the model (RegCM4) which was published by ICTP in June 2010 as a prototype (RegCM4.0) and in May 2011 as the first full version (RegCM4.1). Since the RegCM4.5 version, the model uses a non-hydrostatic dynamic core, which makes it possible to obtain small horizontal resolutions of the order of a few kilometres. Radiation parameterisation was adapted from the NCAR CCM3 radiation transfer scheme (Kiehl et al., 1996). The non-local boundary layer developed by Holtslag and Boville (1993) is used for the representation of the planetary boundary layer. Large-scale precipitation is calculated by the SUBEX scheme (Pal et al., 2000) and the biosphere-atmosphere transfer system of Dickinson et al. (1993). The BATS scheme takes into account the transfer of energy, mass and momentum between the atmosphere and the biosphere. The model includes options for ocean flow parameterisation scheme, interactive aerosols, microphysics, lake models, etc. The RegCM4.6 version provides five different convective schemes (Giorgi et al., 2012): the modified Kuo scheme (Anthes et al., 1987); the Tiedtke scheme (Tiedtke, 1996); the Emanuel scheme (Emanuel, 1991); the Grell scheme (Grell, 1993); and the Kain-Fritsch scheme (Kain and Fritsch, 1993), with the possibility of combining different oceanic and continental schemes (called mixed convective schemes).

2.1.2 The «slab-ocean» parameterisation

By default, version 4.6 of RegCM includes the flexible mixed layer modelling system of the SOM developed by the Laboratory of Geophysical Fluid Dynamics (LDFG; Giorgi et al. 2012). In our study, SOM is a simple thermodynamic oceanic layer having a constant thickness of 50 m. The ocean surface warms or cools in response to surface heat exchanges with the atmosphere. SOM interacts with the atmosphere to calculate SST and ice parameters by forcing the model with RegCM fluxes. The fluxes that drive each iteration are provided to the SOM for the SST update, which is then transmitted to RegCM for the next iteration. But the lack of ocean dynamics (convection, advection and fusion motions) can lead the model to make poor simulations. To solve the problem, a set of heat flow adjustments is specified by adding a term commonly referred to as « q-flux ». The «q-flux» is being added to the SOM at each time step to provide a realistic SST distribution by the model. The technical documentation of the SOM can be consulted on the following website:

"http://www.gfdl.noaa.gov/fms-slab-ocean-model-technical-documentation".

2.2 Data and methodology

2.2.1 Data

Evaluation of the performance of regional climate models is based on the unidirectional nesting technique, which requires prior reduction of errors that can be inherited from lateral forcing conditions (Giorgi and Mearns, 1999), i.e. GCMs. For this reason, conditions with so-called quasi-perfect limits and approximately similar to observations are used. The following data were used to run the model: ERA-Interim 1.5 gridded data sets (Uppala et al., 2005), with a temporal resolution of 6 h (0000, 0600, 1200 and 1200 UTC). Here, the variables used are air temperature, geopotential height, relative humidity and horizontal wind component. The sea-surface temperature (SST) is taken from the weekly optimal interpolation SST, from the National Administration of the model grid (Reynolds et al., 2002) to the global terrain and land use, we have used the 2-min resolution global land cover characteristics (GLCC; Loveland et al. (2000)) and GTOPO topography data. These data were initialized on January first 2000, with parameters such as air temperature, geopotential height, relative humidity and wind components.

One of the main problems in assessing the performance of RCMs in Central Africa is the lack of high-quality observation databases at appropriate spatial and temporal resolution. The use of different sources of observational data (in-situ and satellite), and reanalyses of rainfall, temperature and wind make it possible to take into account the uncertainties associated with them in Africa (Nikulin et al., 2012). To facilitate the intercomparison between observations and models, we interpolated the data on the model grid. Simulations of precipitation, temperature and wind are compared with the monthly climatology of the data from i) Africa Rainfall Climatology version 2.0 (ARC2); résolution 0.1°×0.1°; Novella et Thiaw 2013); ii) Global Precipitation Climatology Project (GPCP; résolution 0.5°×0.5°; Huffman et al., 1997); iii) Climatic Research Unit (CRU; résolution 0.5°×0.5°; Harris et al., 2013) and (iv) the fifth-generation European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis 0.75°×0.75° (ERA5). Compared to its predecessor ERA-Interim, ERA5 offers a higher spatial-temporal resolution and an improvement of the atmospheric model and data assimilation processes (Hersbach et al., 2020).

2.2.2 Methodology

The range of experience extends from 17.5°S to 17.5°N and 30°W to 80°E. This domain is large enough (Figure 1) so as to take into account the climate continuum of Central Africa, which depends heavily on the Indian Ocean and weakly on the Atlantic Ocean. This area is chosen to include climatic factors at the local level, but also to take into account the diversity of African weather patterns. The domain to be modelled is Central Africa, which extends between longitudes 5°E and 35°E and latitudes 15°S and 15°N. A finite-difference horizontal discretization is done with square meshes of 40 km (i.e. 0.36°×0.36°) on each side. At this resolution, RegCM can better represent orographic forcing than reanalyses for example. The experiments were carried out over seven years (from first January 2000 to thirty-first December 2006) with one year of "spin-up" excluded in the study period. This study period is chosen because it includes two years that did not experience extreme rainfall anomalies, namely the years 2004 and 2006. Therefore, the period from 2000 to 2006 presents a wide range of rainfall variability over the study area (Mbienda et al., 2016). We have done experiments with the Grell convective scheme (Giorgi et al., 1993) which was identified by Mbienda et al (2016) as a suitable RegCM convective scheme for simulations in Central Africa. To examine the influence of «slab-ocean» parameterisation, we carried out two different experiments with RegCM: The first experiment without « slab-ocean » that we call GFC_CTR, is designed for the climatology of the different parameters of the model and activates the SOM surface flux that forces the surface boundaries of RegCM with SST without modelling the ocean-atmosphere feedbacks. The second «slab-ocean» experiment, which we call GFC_SLAB, is designed to couple RegCM with the SOM and is identical to the first experiment except for the activation of the «slab-ocean». It provides mutual interaction of the atmosphere (RegCM) and the ocean (SOM). It uses SST and the climatology created in the first experiment to model the ocean-atmosphere interaction by modulating SST. In this experiment, different methods are adapted to the model to reduce errors due to the complete absence of ocean dynamics in the SOM. The model then uses the q-flux adjustments in SOM to improve the representation of the seasonal cycle of SST. This " q-flux " is obtained by performing a calibration experiment (restoration cycle) during which the observed SOM prognostic SST is established over a five-day interval, then archived and saved in an average monthly climatology for the period 2000-2006. Different statistical approaches have been adopted to estimate the skill of the model according to the different experiments in the different homogeneous sub-regions and the Central African domain as a whole. We used statistical tests such as i) the bias that measures the difference between the observed data (chosen as a reference) and the simulated data; ii) the Taylor Diagram (Taylor, 2001), which provides a fairly simple way to summarize the similarities between the observed and simulated data, this diagram illustrates statistics such as the Pearson Correlation Coefficient (CC), the Mean Square Error (MSE) and the Normalized Standard Deviation, which is the distance between the reference point and any point on the diagram; iii) the Added Value (AV), which is used in our study to highlight the contribution of the "slab-ocean" in the RegCM model. We used the formula adapted by Dosio et al (2014) and defined by equation (1).

$$AV = \frac{\left(X_{GCM} - X_{OBS} \right)^2 - \left(X_{RCM} - X_{OBS} \right)^2}{Max\left[\left(X_{GCM} - X_{OBS} \right)^2, \left(X_{RCM} - X_{OBS} \right)^2 \right]} \qquad (1)$$

The AV calculation is done between the General Circulation Model (GCM) used as a boundary condition of RegCM4, a reference observation (OBS) and the Regional Climate Model (RCM), where X denotes the spatial distribution of the dataset under consideration. Defined in this way, the experiment with the highest AV relative to the GCM will perform best.

In this study, the analysis of spatial distributions was carried out during four seasons of the year defined as follows: December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON). In terms of Taylor diagram and seasonal cycle analyses, the focus was on four sub-regions of the Congo Basin identified by Balas et al. (2007) as being relatively homogeneous in terms of interannual rainfall variability caused by SST fluctuations. These sub-regions are North Central Africa (NCA) and South-Central Africa (SCA) with a monomodal rainfall regime; West Equatorial (WE) and East Equatorial (EE) with a bimodal rainfall regime.

3 Results and discussions

3.1 Average seasonal climatology of temperature and rainfall

3.1.1 Average seasonal temperature climatology

Figures 2 and 3 show respectively, the spatial distribution and biases of the surface temperature for the reanalysis data (ERA 5 and ERA-Interim) and the two experiments carried out with the RegCM model over the period from 2001 to 2006. Reanalysis data (Figure 2 a-h) show that the spatial distribution of temperature is strongly influenced by relief (Kamga, 2001). Thus, the highest temperatures (> 32 °C) are located in the northern part of the domain while the lowest temperatures (< 18 °C) are observed along the coasts of the Atlantic and Indian Oceans, and also around mountainous regions. Biases of about 3°C are reported between the two reanalysis products in high relief areas and land-ocean boundaries (Figure 3 a-d), highlighting the presence of uncertainties between the two data sets. In comparison with the reanalysis data, RegCM's simulations satisfactorily locate the zones of temperature maxima and minima both on the continent and in the oceans. However, as the panels in Figure 3 e-l show, the maxima (minima) are overestimated (underestimated) by the model in both experiments. Nevertheless, we note that experiments with « slab-ocean » present more extensive biases over the Atlantic Ocean but less extended over the continent and almost zero over the Indian Ocean. The reduction or cancellation of the range of biases noted above can be attributed to the presence of the « slab-ocean » which interacts with the atmosphere, forcing it to calculate realistic SST. We also note that the experience with slab-ocean has great added value compared to that without « slab-ocean ».

3.1.2 Average seasonal rainfall climatology

In Figure 4, we make an intercomparison of the climatology of seasonal precipitation from the different experiments carried out and the observational data (ARC2 and GPCP) in the period from 2001 to 2006. Observations (Figure 4 a-h) show that bands of high rainfall (11-12 mm/day) are visible at all seasons. The alternation of dry and wet seasons is well represented. We observe a spatial difference between the observed data (Figure 5 a-d), this difference can be interpreted as the uncertainties (errors) in the production of these data (Nikulin et al., 2012). Although some biases persist, the RegCM experiments (Figure 5 i-p) reproduce the rainfall patterns in the study area fairly well according to observations during all seasons. The experiments carried out successfully capture the positions of the observed rainfall maxima, but fail to represent their amplitudes. We note that both experiments tend to underestimate (up to 5 mm/day) the rainfall band observed on the continent, except in mountainous regions and across the oceans where the opposite effect is observed, this difference could be attributed to a thermal breeze, surface parameterisation and the Foehn effect. Despite the large biases obtained in the two RegCM simulation experiments, those of the slab-ocean experiments seem to be significantly reduced or cancelled in the Indian Ocean compared to the Atlantic Ocean (Figure 5 e-p). This implies that contrary to the majority of the RCMs used in Nikulin et al (2012), which systematically overestimate rainfall over the Indian Ocean, the atmosphere-ocean interactions integrated into this study take into account the dynamics that govern the climate in the Indian Ocean.

3.2 Taylor diagram

We assessed the interannual variability and the degree of similarity between the observed and model-simulated temperature/rainfall using the Taylor diagram (Figure 6). It emerges that the experiments reproduce CC values between 0.6 and 0.9 for temperature and between 0.6 and 0.8 rainfall in the Central African domain. MSE is generally between 0.5 and 1.5°C. As far as standard deviations are concerned, the results are heterogeneous. However, their values are around 1°C in all seasons, with the slab-ocean experiments closer to unity in the case of the whole of Central Africa and also for the NCA, EE and SCA regions. It should be noted that in the WE region, which is closer to the Atlantic Ocean and therefore strongly influenced by its dynamic system, the two experiments in the model show, particularly poor performance. This can be attributed to the fact that the parametrization of the "slab-ocean", which is only a simple approximation of the ocean dynamics, fails to reduce the bias of the SST and thus reduce the high values of MSE and variability on the Atlantic coast.

3.3 Seasonal cycles of temperature and rainfall

Figure 7 shows the seasonal cycle of rainfall (mm/day; first row) and temperature (°C, second row) for the different experiments, observations (ARC2, GPCP and CRU) and reanalyses (ERA 5 and ERA_Interim) in the four sub-regions of the Congo Basin. The shaded area corresponds to the range of variation corresponding to the standard deviation of the observations (GPCP, ARC2 for precipitation and ERA 5, CRU and ERA_Int for temperature) which makes it possible to present the interannual variability envelope. The observation data show an almost similar evolution, but with some slight differences in the intensities in the different sub-regions. The NCA sub-zone is characterised by a single peak of 7 mm/day reached around August. We also observe rainfall of less than 1 mm/day from November to March, which is considered the dry season in this sub-region. As far as temperature is concerned, the annual cycle has a minimum of around 24 °C around August and a maximum of 29 °C in May. We note that the maximum rainfall coincides with the minimum temperature and vice-versa. This behaviour can be explained by the fact that the cloud cover is much denser to the point of reducing the intensity of incoming radiation. In this sub-region, the experiments manage to reproduce the minimum and maximum rainfall and temperature observed. However, the experiments peak in August, one month earlier than ARC2. The large discrepancy between observations and experiments (of the order of 3.5 mm/day) can be observed around May. As far as the temperature is concerned, the experiments tend to reproduce the maximum and minimum temperature observed with a large deviation of 3.5 °C reached around March.

The WE and EE sub-regions present a bimodal rainfall pattern with a maximum in April and October as noted by the majority of studies conducted in the region (Pokam et al., 2014; Vondou and Haensler, 2017; Fotso-Nguemo et al., 2017; Nicholson et al., 2018; Tamoffo et al., 2019; Fotso-Kamga et al., 2020; Taguela et al., 2020). The experiments manage to capture the maxima and minima, but with biases of 2 mm/day on average around April and October. As far as temperature is concerned, we observe a bias of 1°C with the observation data. The experiments tend to capture the maximum but fail to capture the minimum temperature observed with a difference of 3°C around January.

The SCA sub-region shows a peak rainfall of about 6 mm/day, which is reached between November and March during the monsoon season. The experiments reasonably reproduce the seasonality of the rains in this sub-region, but with a slight overestimation. As far as temperature is concerned, we observe a slight bias of about 1°C between the observation data.

The experiments manage to capture the modulations of the maximum at the beginning of the year but fail to represent their amplitude (with a bias of about 3°C). Generally speaking, the experiments represent more or less the annual cycle of rainfall and temperature. It should be noted that the seasonal temperature cycles of the different experiments are outside the range of variability observed in the different sub-regions. A comparative analysis of the different experiments reveals that the slab-ocean experiment is best in the SCA sub-region for rainfall and all sub-regions for temperature. It can be said that slab-ocean parameterisation or ocean-atmosphere coupling has slightly improved the performance of the RegCM model in the SCA sub-region for rainfall and all sub-region about temperature, although it is underestimated.

3.4. Regional circulation

The regional atmospheric circulation of Central Africa is governed by low-level westerly winds, the northern and southern components of the African Easterly Jet (AEJ) and the Tropical Easterly Jet (TEJ). These winds are one of the most important factors related to the convective activity of precipitation through moisture transport from the Atlantic and Indian Oceans to the continent (Nicholson and Grist, 2003; Pokam et al., 2014, Dyer et al., 2017). Figure 8 shows the low-level wind (at 925 hPa) for the period from 2001 to 2006. In this figure, we observe that the regional circulation over the Atlantic and Indian Oceans is well represented by ERA 5 during all seasons. The different experiments capture this regional circulation reasonably well, but with an overestimation of the zonal wind at the eastern border, which is well marked during the JJA season and across the Atlantic Ocean. However, the direction and intensity of the wind are well represented by the different experiments. It is across the Atlantic Ocean that the direction was not well simulated by the experiments. Convergence towards the continent was not well represented.

Figure 9 shows wind at 200 hPa pressure level. We observe that ERA 5 has the TEJ located between 5°S-5°N latitude which extends from the Indian Ocean to the Atlantic Ocean during the DJF, MAM and SON seasons. The experiments tend to reasonably reproduce this TEJ but with an overestimation of the intensity and spatial extent. As far as wind direction and intensity are concerned, the experiments manage to represent them during the DJF, MAM and SON seasons. A comparative analysis of the different experiments reveals that performance is similar but there are important differences.

4. Conclusion

Central Africa's climate presents a considerable challenge for climate modelling. This is due to its complexity and the diversity of dynamic and physical processes involved in the establishment of the Central African monsoon system. Understanding these processes is crucial for researchers in this region (Jenkins et al., 2005). Ocean-air interaction is one of the region's complex processes. The uniqueness of this work resides in the use of version 4.6 of the Regional Climate Model (RegCM) to examine the influence of slab-ocean parameterisation which tells us about ocean-atmosphere interaction using SST. The objective of this analysis was to evaluate the RegCM's response to the SOM in terms of the representation of the seasonal spatial distribution of precipitation, temperature and wind. The model was integrated into Central Africa, according to Grell's convective scheme with the Fritsch-Chappell closure hypothesis (GFC). The ability of the model was assessed by running two series of simulations. The first simulation is designed to force the surface boundaries of the RegCM with the weekly OISSTs (interpolated daily), the second simulation is designed to couple the RegCM with the SOM which provides mutual interaction between the ocean and the atmosphere. The two experiments were initiated on first January 2000 for seven years with one year of "spin-up" excluded in the study period. These experiments are all forced by the ECMWF ERA-Interim (ERA-15) reanalysis. The model's ability to reproduce the seasonality of rain, temperature and wind for the period from 2001 to 2006 was assessed and then cross-compared. The comparison of experiments was made with ARC2, GPCP observation data and ERA 5 and ERA-Interim reanalyses.

The results showed that the experiments satisfactorily reproduced the main characteristics of the rainfall regime, surface temperature and wind in Central Africa and the Congo Basin in all seasons despite a lower performance in terms of temperature. The position of the rainfall maxima and minima is fairly well represented. The surface temperature is well represented, but with an underestimation of 2 to 3°C. Also, the experiments satisfactorily reproduce the different phases of the seasonal cycle of rain and temperature. Finally, the experiments manage to faithfully reproduce the main characteristics of the atmospheric wind dynamics at the surface (925 hPa) and altitude (200 hPa): the positioning of the monsoon flow is satisfactory and agrees well with the ERA 5 reanalysis. A comparative analysis reveals subtle differences between the two experiments: RegCM_CTR and RegCM_SLAB. This difference can be attributed to a large variability associated with slab-ocean convection, which takes into account ocean-atmosphere interaction. These results are similar to those of Umakanth and Kesarkar (2017) conducted in India. Generally, it is understood that the parametrization of the "slab-ocean" which provides information on ocean-atmosphere interaction considerably improves the performance of version 4.6 of the RegCM regional climate model for simulating the Central African monsoon. This work opens new perspectives in the regional climate modelling of Central Africa: it would be appropriate to repeat sensitivity experiments of RegCM different convective schemes and process-based assessment.

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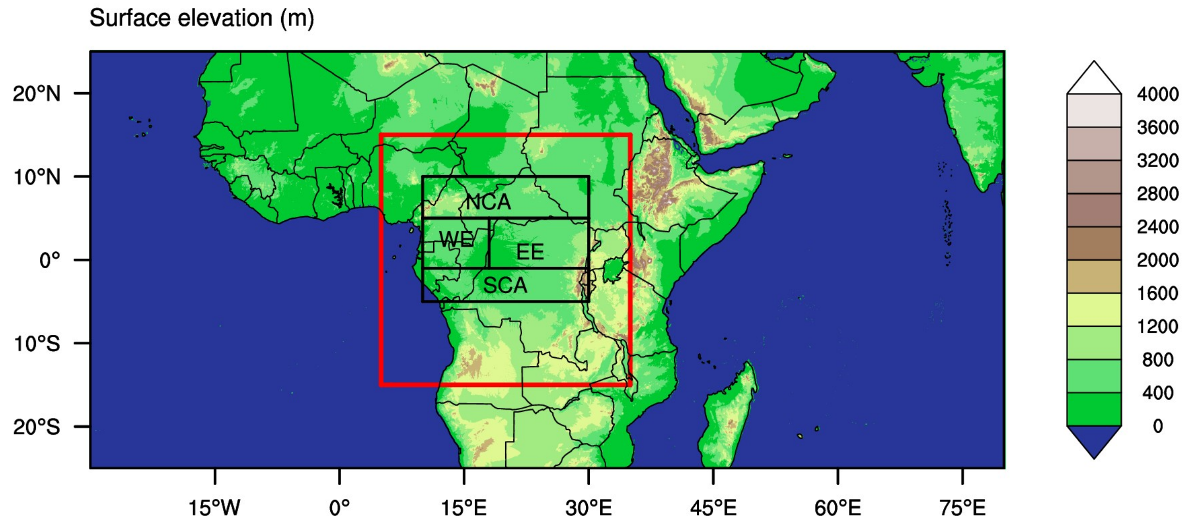

Figure 1. Topography (m) of the simulation domain (17.5° S - 17.5° N, 30° W - 80° E) encompassing the study area indicated by the big box. The four small boxes indicate the four sub-regions, NCA (North Central Africa, 5° N – 10° N, 10° E – 30° E), SCA (South Central Africa -5°S – -1° S, 10° S–30° S), WE (West Equatorial -1° S – 5° N, 10° E – 18° E) et EE (Est Equatorial -1° S – 5° N – 18° E – 30° E).

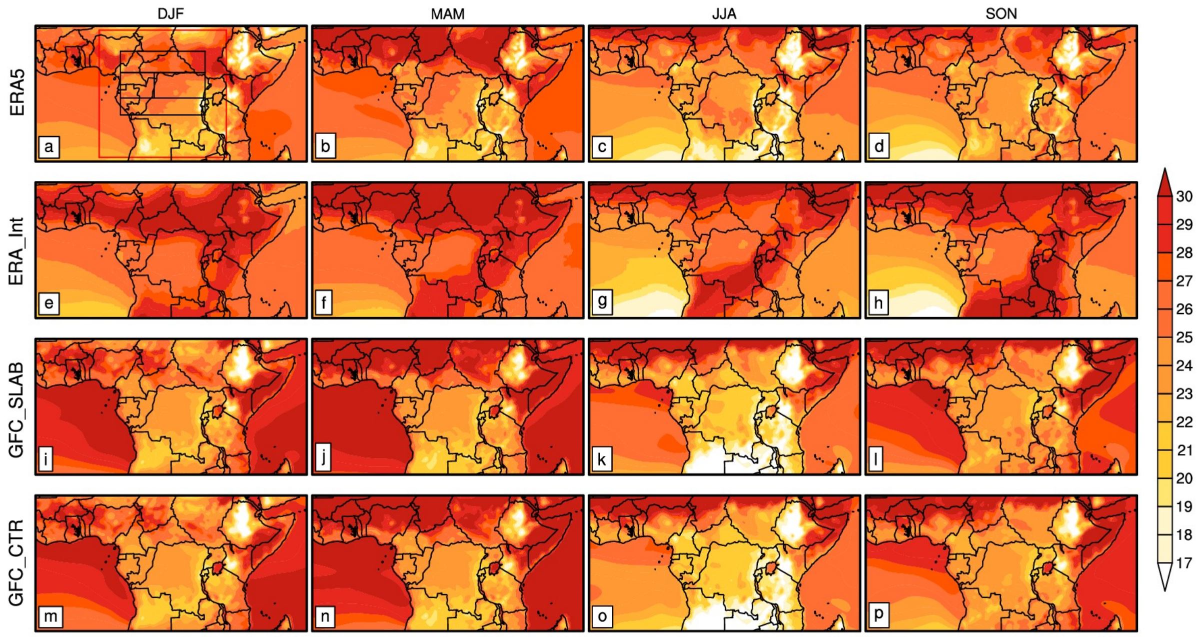

Figure 2. Seasonal means of the surface air temperature (T2m °C) for the period 2001–2006: ERA 5 (a-d), ERA-Interim (e-g), GFC_SLAB (i-l), GFC_CTR (m-p).

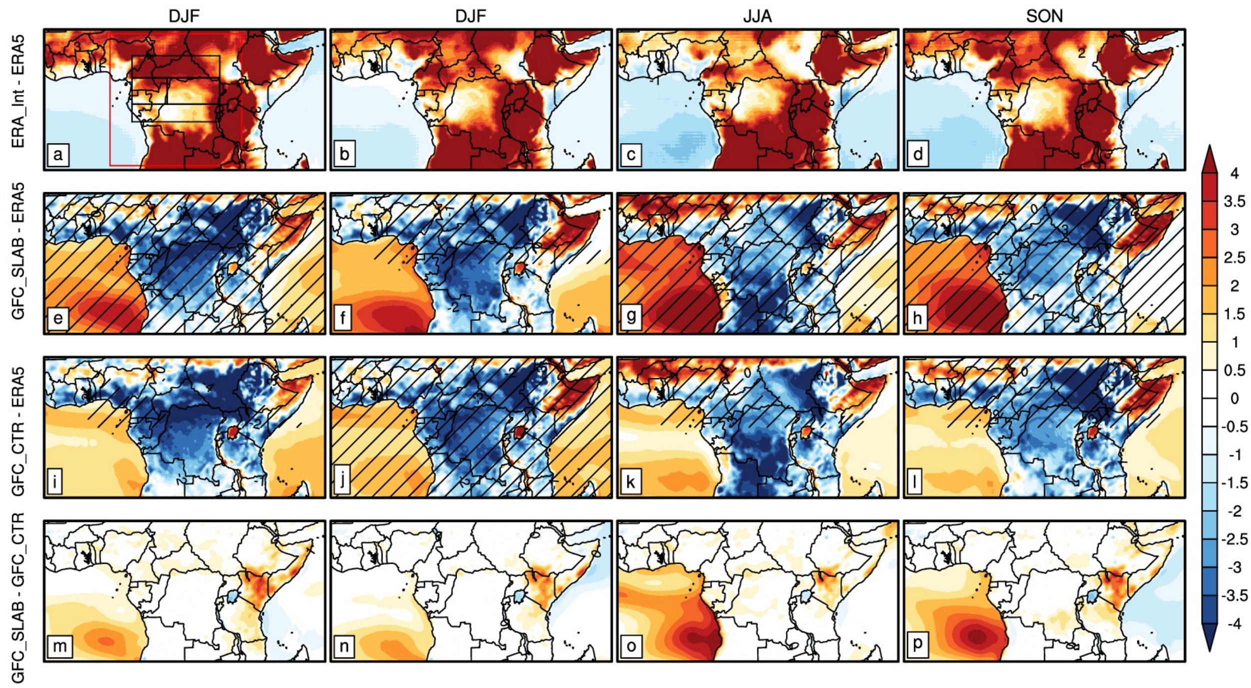

Figure 3. Bias of mean seasonal surface air temperature (T2m °C) for the period 2001–2006: ERA-Interim - ERA 5 (a-d), GFC_SLAB - ERA5 (e-g), GFC_CTR - ERA 5 (i-l), GFC_SLAB - GFC_CTR (m-p).

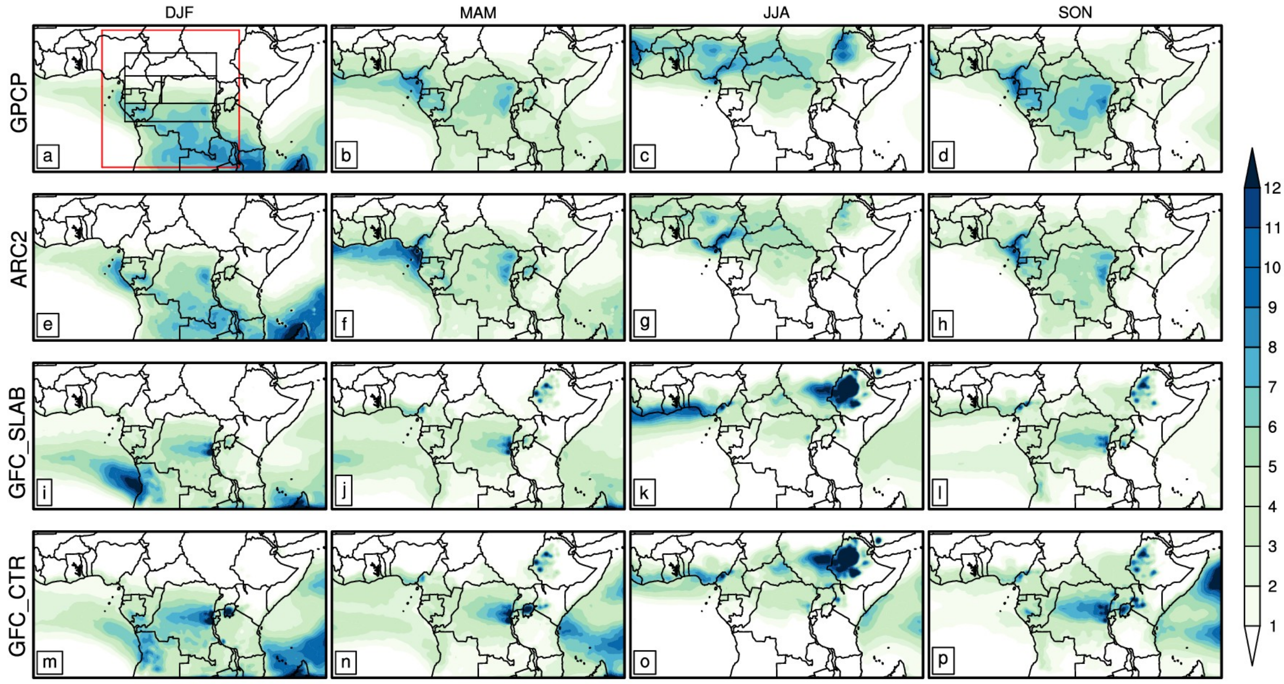

Figure 4. Seasonal means of rainfall in mm day^{-1} for the period 2001–2006: GPCP (a-d), ARC2 (e-h), GFC_CTR (i-l), GFC_SLAB (m-p).

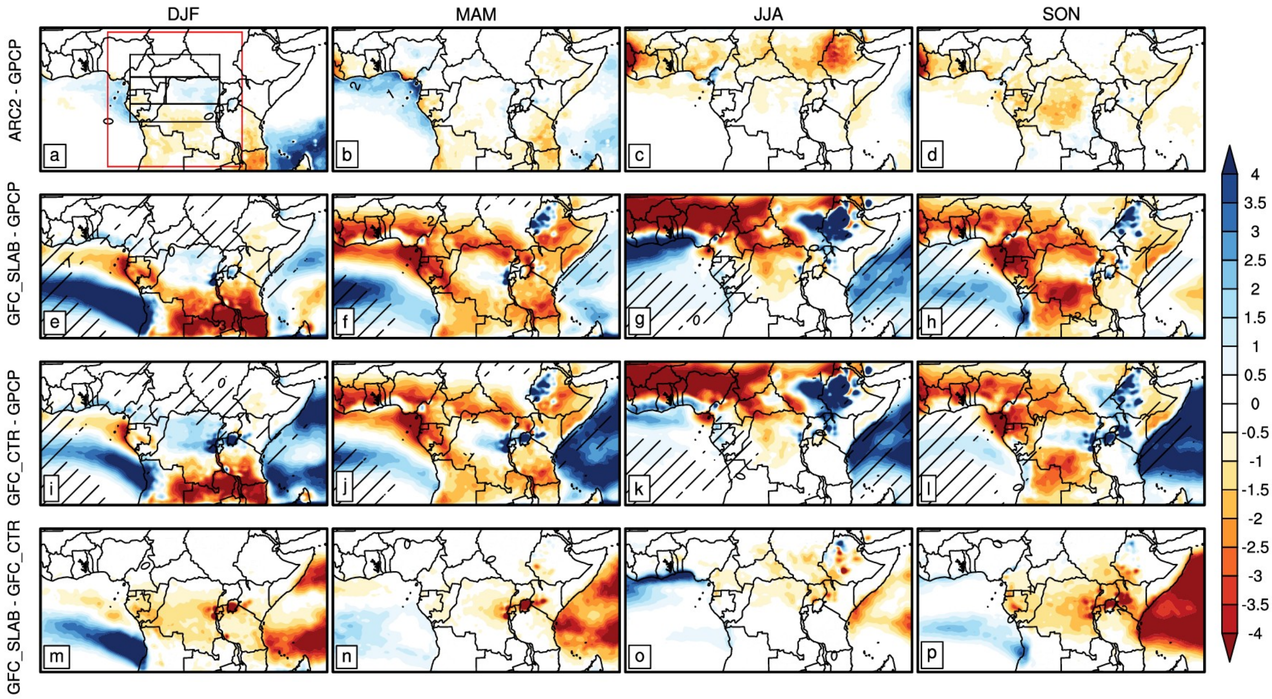

Figure 5. Seasonal mean biases of precipitation in mm day^{-1} for the period 2001–2006: ARC2 - GPCP (a-d), GFC_SLAB - GPCP (e-h), GFC_CTR - GPCP (i-l), GFC_SLAB - GFC_CTR (m-p).

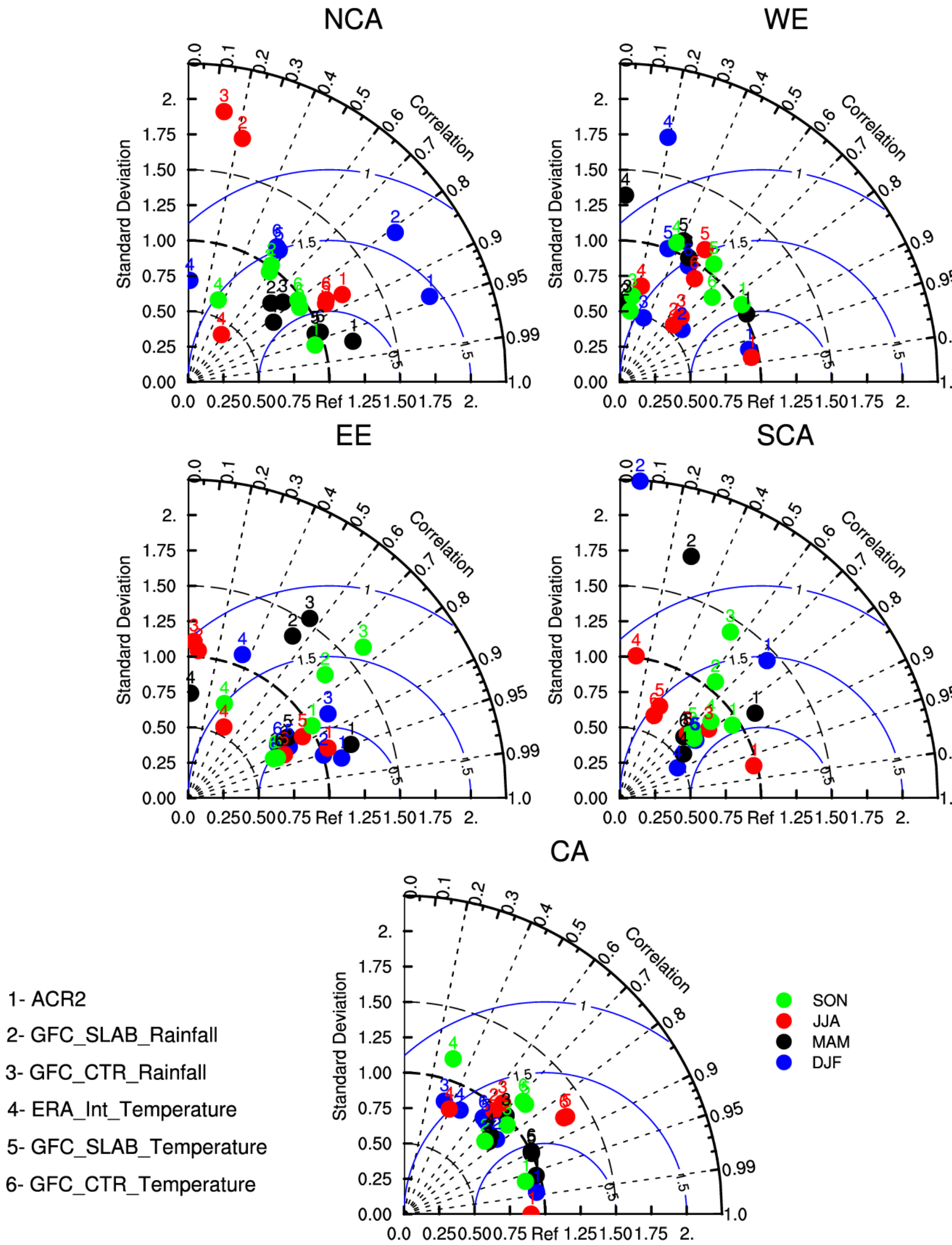

Figure 6. Taylor diagrams for area-averaged seasonal precipitation over North Central Africa (NCA), South Central Africa (SCA), West Equatorial (WE), East Equatorial (EE) and Central Africa (CA) for the period 2001–2006.

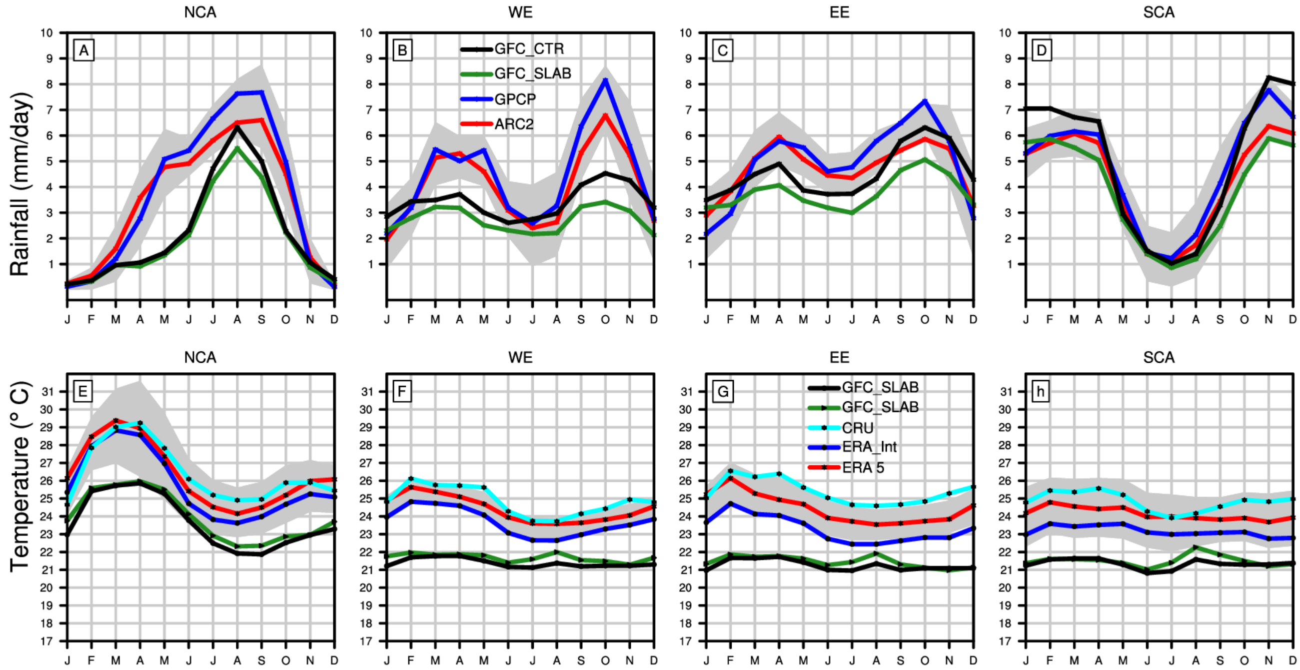

Figure 7. Seasonal rainfall cycle (mm/day) and monthly temperatures (°C) in the four sub-regions for the period 2001 to 2006 for data: ARC2, GPCP, ERA 5, CRU, ERA-Interim and the different experiments shaded in grey, range of variation delimited by +/- standard deviation of the observed data.

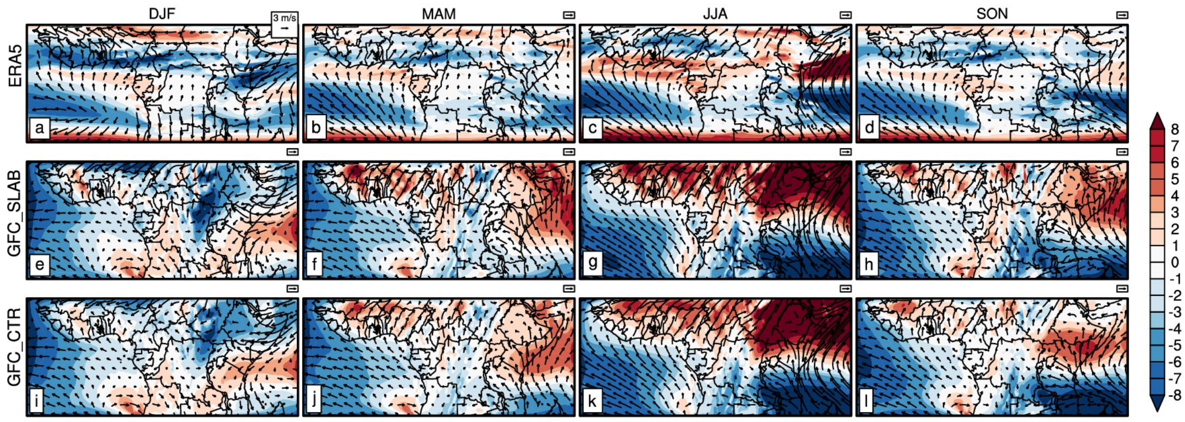

Figure 8. Spatial and seasonal distributions at 925 hPa of zonal wind in colour (m/s) and wind intensity (in m/s vector) for the period 2001-2006 of ERA5 and the different experiments.

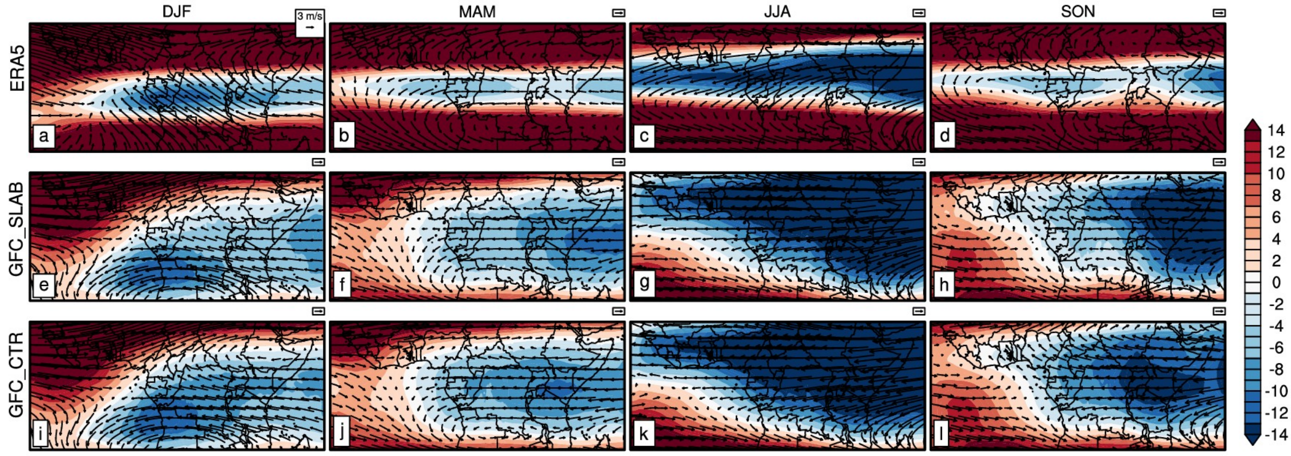

Figure 9. Spatial and seasonal distributions at 200 hPa of zonal wind in colour (m/s) and wind intensity (m/s vector) for the period 2001-2006 of ERA 5 and the different experiments.