Influence of initial soil moisture in a Regional Climate Model study over West Africa. Part 2: Impact on the climate extremes.

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Abstract.

The influence of the initial soil moisture conditions on extreme climate extreme over West Africa was investigated using the fourth generation of Regional Climate Model version 4 (non-hydrostatic) coupled to the version 4.5 of the Community Land Model (RegCM4-CLM4.5) at 25 km spatial resolution. Sensitivity studies were performed for five years (2001-2005), with initial soil moisture conditions prescribed on June 1 and simulations performed over four months (120 days) from June to September (JJAS). The Results were presented for two extreme years 2003 (above normal precipitation year) and 2004 (below normal precipitation year) to estimate the impact limits of internal forcing of initial soil moisture on the new non-hydrostatic dynamical core of RegCM4. We initialized the control runs with the reanalysis soil moisture of the European Centre Meteorological Weather Forecast's reanalysis of the 20th century data (ERA20C), while for the dry and wet experiments, we initialized the soil moisture at the maximum and minimum value over West Africa studied domain, respectively. The impact on extreme precipitation indices of the initial soil moisture, especially over the central Sahel, is linear; that is, dry (wet) experiments decrease (increase) precipitation extreme indices only for precipitation indices related to the number of precipitation events, not for those related to the event intensity. Initial soil moisture conditions unequally affect the daily minimum and maximum temperatures. A stronger impact is found on the maximum temperature than the minimum temperature. Over the entire West African domain, wet (dry) experiments cause a decrease (increase) in maximum temperature. The impact of initial soil moisture conditions on the indices related to the minimum temperature (TNx and TNn indices) is linear only for TNx index over central Sahel, that is, dry (wet)

experiments cause an increase (a decrease) in the TNx index. The performance of RegCM4-CLM4.5 in simulating the ten extreme rainfall and temperature indices used in this study are also highlighted.

1 Introduction

West Africa experienced large rainfall variability during the late 1960s. This variability often leads to flooding events, severe drought, and regional heatwaves, which have major economic, environmental, and societal impacts (Easterling et al., 2000; Larsen, 2003). In recent years, climate extremes have attracted much interest because they are expected to occur more frequently (International Panel on Climate Change (IPCC), 2012) than changes in the mean climate. Yan and Yang (2000) showed that for many cases, the extreme climate changes were five to ten times greater than climate mean change. Many key factors or physical mechanisms could be the cause of the increase in climate extremes (Nicholson, 1980; Le Barbé et al., 2002), such as the effect of increasing greenhouse gases in the atmosphere on the intensification of hot extremes (IPCC, 2007), sea surface temperature (SST) anomalies (Fontaine and Janicot 1996; Folland et al., 1986), and land surface conditions (Philippon et al., 2005; Nicholson (2000)). In addition, smaller-scale physical processes, including the interactions of land–atmosphere coupling, can lead to changes in climate extremes. For the European summer, the influence of soil moisture on land–atmosphere coupling using a regional climate model and focused on the extremes and trends in precipitation and temperature have been studied by Jaeger and Seneviratne (2011). For extreme temperatures, their studies have shown that interactions of soil moisture and climate have a significant impact, while for extreme precipitation, they only influence the frequency of wet days. Over Asia, Liu et al. (2014) studied the impact on subsequent precipitation and temperature of soil moisture anomalies using a regional climate model. They showed that wet (dry) experiences decrease (increase) the hot extremes, decrease (increase) the drought extremes, and increase (decrease) the cold extremes in a zone with strong soil moisture–atmospheric coupling. However, none of these studies examined the impacts of the initial soil moisture conditions on subsequent climate extremes using a regional climate model over West Africa. In part 1, the influence of initial soil moisture on the climate mean was based on a performance assessment of the Regional Climate Model coupled with the complex Community Land Model (RegCM4-CLM4.5) performed by Koné et al. (2018), where the ability of the model to reproduce the climate mean has been validated. In Part 2, before starting to study the influence of initial soil moisture on climate extremes, it was necessary to assess the performance of RegCM4-CLM4.5 in simulating the ten (10) indices of temperature and precipitation extremes used in this study. This has never been done before in West Africa with this version of RegCM with a non-hydrostatical scheme; therefore, we separated the work in two parts, a first one assessing the ability of the model to simulate the climate extreme indices, and a second one investigating how and what is the time limit of the effect of initial soil moisture condition on the magnitude or duration of these climate extremes. The manuscript is organized as follows: Section 2 describes the RegCM4 model, the experimental design, and the methodology used in this study; Section 3 presents results of the two parts of the work and Section 4 documents the main conclusions.

2. Model, experimental design and methodology

2.1 Model description and numerical experiment

The fourth generation of the Regional Climate Model (RegCM4) of the International Centre for Theoretical Physics (ICTP) is used in this study. Since this version, physical representations have been subject to a continuous process of implementation and development. The release used in this study was RegCM4.7. The non-hydrostatic dynamical core of the MM5 (Mesoscale Model version 5, Grell et al., 1994) was ported to RegCM4 while maintaining the existing hydrostatic core. RegCM4 is a limited-area model using a vertical grid sigma hydrostatic pressure coordinate and a horizontal grid of the Arakawa B-grid (Giorgi et al., 2012). The radiation scheme is from the NCAR-CCM3 (National Center for Atmospheric Research and the Community Climate Model Version 3) (Kiehl et al., 1996), and the aerosol representation is from Zakey et al. (2006) and Solmon et al. (2006). The large-scale precipitation scheme used in this study is from Pal et al. (2000); the moisture scheme is called the SUBgrid EXplicit moisture scheme (SUBEX), which considers the sub-grid variability in clouds. The accretion and evaporation processes for stable precipitation are from Sundqvist et al. (1989). The sensible heat and water vapour in the planetary boundary layer over land and ocean, as well as the turbulent transport of momentum, is reported by Holtslag et al. (1990). The heat and moisture and momentum of ocean surface fluxes are from Zeng et al. (1998). Convective precipitation and land surface processes in RegCM4.7 are represented in several options. Based on Koné et al. (2018), the convective scheme of Emanuel (1991) is used. The parameterization of land surface processes is from CLM4.5 (Oleson et al., 2013). In each grid cell of CLM4.5, there are sixteen different plant functional types and ten soil layers (Lawrence et al., 2011; Wang et al., 2016). The integration of RegCM4 over the West African domain is shown in Fig. 1 with eighteen vertical levels and 25 km of horizontal resolution (182 × 114 grid points; from 20°W–20°E and 5°S–21°N). The European Centre for Medium-Range Weather Forecasts reanalysis (EIN75; Uppala et al., 2008; Simmons et al., 2007) provides the initial and boundary conditions. The sea surface temperatures (SSTs) are derived from the National Oceanic and Atmosphere Administration optimal interpolation weekly (NOAA; OI_WK) (Reynolds et al., 1996). The topography is derived from the United States Geological Survey (USGS) Global Multi-resolution Terrain Elevation Data (GMTED; Danielson et al., 2011) at a spatial resolution of 30 arc-s, which is an update of the Global Land Cover Characterization (GTOPO; Loveland et al., 2000) dataset.

The initial soil moisture sensitivity does not exceed four months (Hong and Pan., 2000; Kim and Hong, 2006). (Hong and Pan., 2000; Kim and Hong, 2006). As mentioned in Part I, we performed sensitivity studies on the initial soil moisture conditions over the West African domain for June–July–August–September (JJAS) from 2001 to 2005 with a focus on two contrasting years, 2003 (above normal precipitation year) and 2004 (below normal precipitation year). The two years, 2003 and 2004 (respectively, the wettest and driest years among the five years), were selected to estimate the limits of the impact of internal soil moisture forcing on the new non-hydrostatic dynamical core of RegCM4. Several previous studies used two extreme years for their sensitivity study of initial soil moisture conditions on the models (e. g., Hong et al., 2000; Kim and Hong, 2006). We set up an ensemble of three experiments, each with simulations starting from June 1 to September 30. For each experiment, we applied (i) a reference initial soil moisture condition, (ii) a wet initial soil moisture condition, and (iii) a dry initial soil moisture condition. Kang et al. (2014) compared different land surface schemes (BATS and CLM3) and different spin-up periods to simulate June–July–August precipitation and recommended a 7-day spin-up period. In this study, we used CLM4.5 as the land surface scheme (Oleson et al., 2013), which has a more complex design. The first seven days (Kang et al., 2014) were excluded from the analysis as a spin-up period. We used the soil moisture from the reanalysis of the European Centre Meteorological Weather Forecast's Reanalysis of the 20th century (ERA20C) to initialize the control runs. Wet and dry experiments were initialized for the soil moisture (in volumetric fraction m3•m-

3) at the maximum (= 0.489) and minimum (= 0.117.10-4) soil moisture values over West Africa derived from the ERA20C soil moisture dataset.

2.2 Validation datasets and evaluation metrics

Our investigation focused on the air temperature at 2 m and the precipitation over the West African domain during JJAS for 2003 and 2004. The simulated precipitation fields are validated with two observation datasets: the Climate Hazards Group Infrared Precipitation Stations (CHIRPS) dataset from the University of California at Santa Barbara, available from 1981 to 2020 with 0.05° high-resolution data and the Tropical Rainfall Measuring Mission 3B43V7 (TRMM) dataset with 0.25° high-resolution data available from 1998 to 2013 (Huffman et al., 2007). We validated the 2-m temperature using two observation datasets: the NOAA CPC global daily temperature from the Global Telecommunication System (GTS), gridded at a horizontal resolution of 0.5° from 1979 to 2020 (Fan Y. and Huug van den Dool, 2008), and daily temperature from ERA-Interim (EIN) reanalysis at 0.25° of horizontal resolution available from 1979 to 2020 (Dee et al., 2011). To compare the model simulations with the observation datasets, we re-gridded all the products to 0.22° × 0.22° using a bilinear interpolation method (Nikulin et al., 2012).

The performance of RegCM4-CLM4.5 to simulate the extreme indices was evaluated using four selected sub-regions (Fig. 1) based on the previous work of Koné et al. (2018), which correspond to different annual precipitation cycle features. We used the mean bias (MB), which captures the small-scale differences between the simulation and observation. The pattern correlation coefficient (PCC) is also used as a spatial correlation between model simulations and observations to indicate the large-scale similarity degree.

To quantify the impact of soil moisture anomalies on climate extremes, in their work over Asia, Liu et al. (2014) used the MBs in five subregions. In our study, we used the MBs and the probability density functions (PDF, Gao et al. (2016); Jaeger and Seneviratne (2011)) for this purpose to better capture how many grid points are impacted by initial soil moisture and their highest value.

Significance of differences was tested for the control vs. sensitivity experiments. We used a two-tailed Student's t-test at each grid point as in Liu et al. (2014) over Asia. Owing to the multiplicity problem of independent tests and the spatial dependency of neighboring! grid points, the significant results can only be seen as a crude estimate. Therefore, we perform the land point area-weighted fraction with a statistical significance of 10% and display the seasonal extreme indices maps for 2003 and 2004.

2.3. Extreme rainfall and temperature indices

In this study, to investigate the changes in precipitation and temperature in terms of duration, occurrence, and intensity, six extreme temperature and four extreme rainfall indices were examined using daily minimum and maximum temperature and daily rainfall data (Table 1). These ten extreme indices are recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI, Peterson et al., 2001). We estimated the monthly values of the indices, which allowed us to investigate seasonal variations.

3. Results and discussion

3.1. Seasonal extreme rainfall

In this section, we analyse six extreme rainfall indices based on daily precipitation in RegCM4 simulations over West Africa. All precipitation indices were calculated for JJAS in 2003 and 2004. Table 2 summarizes the PCC and the MB of all precipitation indices studied in this section for TRMM observation and model simulations derived from control experiments with reanalysis of the initial soil moisture ERA20C with respect to CHIRPS observations, calculated for the west Sahel, central Sahel, Guinea coast, and the entire West African domain during JJAS 2003 and 2004.

3.1.1 The index of the number of the wet days (R1mm index)

Figure 2 shows the mean values of the number of wet days (R1mm index, in days) from CHIRPS (Fig. 2a, d) and TRMM (Fig. 2b, e) observations and their corresponding simulated control experiments (Fig. 2c, f) with the initial soil moisture derived from ERA20C reanalysis. We have chosen CHIRPS because of its high resolution, mainly because this product has been widely assessed and used for the study of extreme events in West Africa by Bichet et al. (2018a, b) and Didi et al. (2020). The two observation datasets CHIRPS (Fig. 2a, d) and TRMM (Fig. 2b, e) show a similar large-scale pattern over the West African domain with a PCC up to 0.98 (Table 2). The maximum values of the R1mm index were located over mountainous regions such as the Cameroon Mountains, Jos Plateau, and Guinea Highlands, while the minimum values of the R1mm index were found over the Sahel with the number of wet days decreasing gradually from south to north. However, although the large-scale patterns were similar, at the local scale, some differences were found in terms of the magnitude and spatial extent of these maxima and minima. The TRMM datasets underestimated the number of wet days over the central and west Sahel, and they were overestimated over the Guinea coast for both JJAS 2003 and JJAS 2004 (Table 2). A strongest underestimation was observed over the central Sahel with MB of approximately -6.76 and -7.51 days for JJAS 2003 and JJAS 2004, respectively (Table 2). However, the strongest overestimation was found over the Guinea coast with MB reached 8.89 and 10.44 days for JJAS 2003 and JJAS 2004, respectively (Table 2).

The control experiments (Fig. 2c, f) reproduced well the large-scale structure of the observed rainfall, with PCC values of 0.96 and 0.95 for JJAS 2003 and JJAS 2004, respectively (Table 2) over the entire West African domain, but did exhibit some spatial extent and magnitude biases at the local scale. The control experiment displayed a large and quite homogeneous area of maximum values of the R1mm index below 12° N latitude. The control experiments overestimate the number of wet days over most of the studied domains (Table 2). The largest MBs were found over the Guinea coast with MB more than 53.16 and 55.46 days for JJAS 2003 and JJAS 2004, respectively (Table 2). This overestimation of the number of wet days in RegCM4 was also found by Thanh et al. (2017) with RegCM4 for Asia.

Figure 2 (second panel) displays additional changes in the R1mm index for JJAS 2003 and JJAS 2004 for dry (Fig. 2g and i, for JJAS 2003 and JJAS 2004, respectively) and wet experiments (Fig. 2h and j, for JJAS 2003 and JJAS 2004, respectively) compared to their associated control experiments; the dotted area shows changes with statistical significance at the 10% level. The dry experiments (Fig. 2g, i) decrease the R1mm index while the wet experiments (Fig. 2h, j) favour an increase in the R1mm index, especially over central Sahel and a small part of west Sahel. The impact of initial soil moisture on R1mm was linear over central Sahel. However, over the Guinea coast sub-region, both wet and dry experiments showed a significant increase in R1mm.

For a better quantitative evaluation, Fig. 3 displayed the PDF distributions of the changes in the R1mm index over the studied domains (Fig. 1), during JJAS 2003 and 2004. Table 4 summarizes the maximum values of changes obtained on the PDF’s for extreme precipitation indices used in this study. The results essentially confirmed the linear impact found over central Sahel (Fig. 3a). Over west Sahel, the Guinea coast, and the West African domain (Fig. 3b, c, and d), both dry and wet experiments led to an increase in the R1mm index. The strongest R1mm index increase (decrease) was observed in wet (dry) experiments over west (central) Sahel, with a maximum change of approximately 12 days (-5.19 days) for JJAS 2003 (Table 4).

Summarizing the results of this section, RegCM4 overestimates the number of wet days over most of the studied domains. A linear impact on the R1mm index for the dry (wet) experiments was found over the central Sahel, with a decrease (increase) in R1mm index. These results were compatible with previous work that sustained a strong land–atmosphere coupling in areas between wet and dry climate regimes (Zhang et al., 2011; Koster et al., 2006. The strongest R1mm index increase (decrease) was observed in wet (dry) experiments over west (central) Sahel, with a maximum change of approximately 12 days (-5.19 days) for JJAS 2003.

3.1.2 Simple daily intensity index (SDII).

We analyzed in this section the SDII index which gives the amount of precipitation mean on wet days (daily precipitation >1mm). Figure 4 (first panel) is the same as Fig.2 (first panel) but shows the amount of precipitation mean on wet days (SDII index, in mm.day^{-1}). Over the entire West African domain, the two observations products CHIRPS (Fig.4a, d) and TRMM (Fig.4b, e) presented a similar large-scale pattern with a PCC about 0.86 for both JJAS 2003 and JJAS 2004 (Table 2). However, the maxima SDII index values are quite different in term of spatial extension and magnitude. Over the coastline of the Gulf of Guinea, CHIRPS datasets (Fig.4a, d) depicted the highest values of SDII index, more than 25 mm.day^{-1}. While the SDII index values, in TRMM datasets not exceed 12 mm.day^{-1} over most part of this region. Over the central and west Sahel, TRMM datasets showed large sparse values of SDII index up to 20 mm.day^{-1}, while CHIRPS datasets not exceed 12 mm.day^{-1} for both JJAS 2003 and JJJAS 2004. The largest underestimations of TRMM dataset with respect to CHIRPS were found over the Guinea coast sub-region with MB more than -5.24 and -6.44 mm.day^{-1} (for JJAS 2003 and JJAS 2004, respectively; Table 2). However, strongest overestimations were observed over central Sahel with MB reaching 3.67 and 2.07 mm.day^{-1} (for JJAS 2003 and JJAS 2004, respectively; Table 2).

The control experiments (Fig. 4 c, f) reproduced well the large-scale pattern of observation products with a PCC reaching 0.73 and 0.77 (in JJAS 2003 and JJAS 2004, respectively; Table 2) over the West African domain. However, at the local scale, some biases were observed. Over most of the studied domains, the magnitude of the SDII was underestimated, not exceeding 10 mm•day-1, except over the Cameroon Mountains (Fig. 4c, f). Therefore, precipitation events were less extreme in the control experiments. The largest MBs were located over the Guinea coast with MBs more than −13.62 and −14.65 mm•day-1 (for JJAS 2003 and JJAS 2004, respectively; Table 2).

Figure 4 (second panel) is the same as Fig. 2 (second panel), but the display changes in the amount of mean precipitation on wet days. Unlike the R1mm index, a change in the SDII was not linear over most of studied domains. In general, a similar mixture of both increase and decrease is shown for dry and wet experiments over most of the studied domains (Fig. 4, second panel).

Figure 5 displays PDFs of changes in SDII, as in Fig. 3. The PDFs showed a maximum change value centered approximately on zero (Table 4), indicating that change in the amount of mean precipitation on wet days for wet and dry experiments is not significant.

In summary, RegCM4 underestimated the amount of mean precipitation on wet days over all the domain studies. It is worth noting that precipitation events simulated by RegCM4 with the current parameterization were less extreme, and the SDII did not exceed 10 mm.day^{-1} over the entire West African domain. The impact of precipitation amount on wet days of the dry and wet experiments is not significant and is not sensitive to the contrast of year over the entire studied domain.

3.1.3 Maximum number of consecutive dry days (CDD index).

The duration of consecutive dry days (CDD index), which represents the maximum number of consecutive dry days with precipitation less than 1 mm.day^{-1} was analyzed in this section. Figure 6 (first panel) is the same as Fig. 2 (first panel) but shows the maximum number of CDD (in days). CHIRPS datasets located the largest CDD index values over the Sahara, more than 50 days (Fig. 6a, d). The lowest values were found over the Guinea coast, with CDD index values, less than 8 days. Over the West African domain, both the CHIRPS and TRMM datasets showed quite similar large-scale features over the entire West African domain with PCC more than 0.92. However, at the local scale, the observation datasets exhibited some disparities. In general, these disparities related only to the spatial extent, especially over the Sahel region. In JJAS 2003, the band of CDD index values was in the range of [10; 20] days and extended farther into the Sahel region for TRMM than CHIRPS. For JJAS in 2004, TRMM observations (Fig. 6b, e) presented a narrower band of minimum CDD index values over the Guinea coast around latitude 10° N than CHIRPS, which extended over the Guinea coast. TRMM observations underestimated the CDD index over the entire West African domain, with MB approximately −2.29 and −1.75 days (for JJAS 2003 and JJAS 2004, respectively; Table 2).

The control experiments (Fig. 6c, f) over the entire West African domain, reproduced well the large-scale pattern of the observed rainfall with a PCC more than 0.85 and 0.89 (for JJAS 2003 and JJAS 2004, respectively; Table 1). However, in terms of magnitude, some differences were observed at the local scale. In general, the control experiments overestimated the CDD index over most studied domains, except over the Guinea coast (Table 2). A strongest overestimation CDD index was observed over west Sahel with MB reaching more than 14.49 and 17.51 days (for JJAS 2003 and JJAS 2004, respectively; Table 2). The current model parameterization increase the drought extreme over most of the studied domains, except over the Guinea coast (Table 2).

Figure 6 (second panel) is the same as Fig. 2 (second panel) but shows changes in the maximum lengths of consecutive dry spells (through the CDD index). The initial soil moisture impact on CDD index was linear over the central and west Sahel (Fig. 6, second panel), and the dry (wet) experiments increase (decrease) the maximum lengths of consecutive dry spells (CDD index). However, particularly over the Guinea coast, the dry and wet experiments led to a decrease in CDD index.

Figure 7 is the same as Fig. 3 but displays the PDF distribution of the changes in the CDD index. The impact on the CDD index was linear over the central and west Sahel. A strongest increase (decrease) in the CDD index was observed over the central (west) Sahel in dry (wet) experiments with maximum change value reaching 3.80 (-12.73) days in JJAS 2004 (2003) (Table 4).

In summary, RegCM4 overestimates the maximum number of consecutive dry days over most studied domains, except over the Guinea coast. The linear impact on CDD index was observed over the central and west Sahel, however, over the Guinea coast, the dry and wet experiments led to a decrease in CDD index.

3.1.4 Maximum number of consecutive wet days (CWD index).

The persistence of wet spells (CWD index) which represents the maximum number of consecutive wet days with precipitation ≥ 1 mm.day^{-1} is investigated in this section. Figure 8 (first panel) is the same as Fig.2 (first panel) but shows the CWD index. The observation products TRMM (Fig.8b, e) and CHIRPS (Fig.8a, d) depicted a similar large-scale pattern with the PCCs reached 0.90 and 0.87 (resp. for JJAS 2003 and JJAS 2004, Table 2). CHIRPS observation located the maximum of CWD index over the mountain regions such as

Cameroon Mountains, Jos plateau and Guinea highlands and it is more than 20 days. While the minimum values of CWD index were found over most of the area above the latitude 17°N and did not exceed 4 days (Fig.8a, d). In general, the differences between TRMM and CHIRPS observation concerned the maxima magnitude and its extent, which are more pronounced in TRMM than CHIRPS. Generally, TRMM overestimated the CWD index over most of the studied domains compared to CHIRPS, except over central Sahel (Table 2). The strongest overestimation was found over the Guinea coast region with MB more than 2.47 and 2.38 days (resp. for JJAS 2003 and JJAS 2004, Table 2).

The control experiments well reproduced the large-scale pattern over the entire West African domain, with PCCs values approximately 0.81 and 0.87 (resp. for JJAS 2003 and JJAS 2004, Table 2). However, at the local scale the control experiments exhibit some biases in the minimum and maximum CWD index values in term of magnitude and spatial extent. Control experiments overestimated the CDD index over most of domains studied (Fig. 8 c, f). We noted that, this overestimation area coincides with the excessive values of R1mm index (Fig.2c, f). The strongest overestimation was found over the Guinea coast, reaching 59.21 and 60.51 days (resp. for JJAS 2003 and JJAS 2004, Table 2).

Figure 8 (second panel) is the same as Fig.2 (second panel), but displays changes in CWD index. As for R1mm index, over the central Sahel, the impact was linear, the dry (wet) experiments decrease (increase) CWD index for both JJAS 2003 and JJAS 2004. This result confirms the strong soil moisture impact over the transition zones with a climate between dry and wet regimes (Zhang et al., 2011; Koster et al., 2006). However, over Guinea and the west Sahel, the changes were not linear, both dry and wet experiments lead to cause an increase, in JJAS 2003 and JJAS 2004 (Fig. 8B, c).

Figure 9, as in Fig.3, but shows the PDF distribution of changes in CWD index. The linear impacts were observed over the central Sahel for both JJAS 2003 and JJAS 2004, and over west Sahel only in JJAS 2004 (Table 4). The strongest increase (decrease) on CWD index was found over central Sahel with maximum change reaching 15.58 (-4.48) days in wet (dry) experiments in JJAS 2004.

Summarizing the results of this section, as in R1mm and CDD indices, the CWD index was linear over the central Sahel for both JJAS 2003 and JJAS 2004, and over the west Sahel in JJAS 2004, that is, the dry (wet) experiments decrease (increase) the CWD index. The model RegCM4 overestimates the duration of wet days over most of studied domains. This overestimation is linked with an excessive number of wet days as documented by Diaconescu et al. (2014).

3.1.5 Maximum one-day precipitation accumulation (RX1day index).

The maximum one-day precipitation accumulation (RX1day index) during JJAS 2003 and JJAS 2004 is assessed in this section. Figure 10 (first panel) shows the spatial distribution of the RX1day index. The observation datasets TRMM (Fig. 10b, e) and CHIRPS (Fig. 10 a, d) present notable differences in terms of the spatial extent of the maximum values of the RX1day index, although their large-scale pattern was similar with PCC of more than 0.84 for both JJAS 2003 and JJAS 2004 (Table 2). Over the Guinea and Sahel regions, the spatial extent of RX1day index maximum values more than 80 mm was large in the TRMM datasets, while CHIRPS datasets showed it confined over the coastline of the Gulf of Guinea. TRMM observations overestimated the RX1day index over the most of studied domains. The largest RX1day index was found over the central Sahel, with MB reaching 35.78 and 31.66 (for JJAS 2003 and JJAS 2004, respectively; Table 2).

The control experiments captured the spatial pattern with PCC values of 0.50 and 0.4 (JJAS 2003 and JJAS 2004, respectively; Table 2). This low coefficient of PCC was also obtained by Thanh et al. (2017) over Asia with RegCM4 (correlation < 0.3). The model simulations failed to capture the magnitude and spatial extent of the RX1day index maxima values. The control experiments underestimated the RX1day index over most of studied domains. The RX1day index was underestimated throughout studied domains; this was also due to the excessive light precipitation, simulated by the current physical parameterization of RegCM4. The largest underestimation was located over the Guinea coast and the west Sahel. For instance, over the west Sahel, the MB was approximately −38.07 and −36.67 mm (JJAS 2003 and JJAS 2004, respectively; Table 2).

Figure 10 (second panel) is similar to Fig. 2 (second panel), but displays changes in the RX1day index. For the SDII, the impact of initial soil moisture anomalies on the RX1day index was not linear, and a similar mixture of increase and decrease in RX1day index is shown for dry and wet experiments over most of the studied domains (Fig. 10, second panel).

Figure 11 is similar to Fig. 3, but shows the PDF distribution of changes in the RX1day index. The impact on RX1day index increase for both dry and wet experiments and was found over most of studied domains (Fig.11). The strongest increase in RX1day index was observed over Guinea in wet experiments 26.14 and 14.93 for JJAS 2003 and JJAS 2004, respectively.

In summary, RegCM4 underestimates the maximum one-day precipitation accumulation over most of studied domains. The impact on RX1day index increase for both dry and wet experiments and was found over most of studied domains.

3.1.6 Precipitation percent due to very heavy precipitation days (R95pTOT index)

In this section, we investigated the precipitation percentage due to very heavy precipitation days during JJAS 2003 and JJAS 2004. Figure 12 (first panel) is the same as Fig. 2 (first panel), but shows the spatial distribution of the R95pTOT index. TRMM (Fig. 12b, e) and CHIRPS observations (Fig. 12a, d) presented a similar spatial pattern over the entire West African domain, with a PCC value of 0.91 for both JJAS 2003 and JJAS 2004 (Table 2). However, some biases in spatial extent were noticed for R95pTOT index maxima. TRMM observation extended the maximum R95pTOT index over the Guinea and Sahel regions (Fig. 10, first panel), while CHIRPS confined them over the Guinea coast. Overall, TRMM showed a dominant overestimation compared to CHIRPS over the West African domain by approximately 16.54% and 18.54 % (JJAS 2003 and JJAS 2004, respectively; Table 2). The control experiments (Fig. 12c, f) capture the spatial pattern with PCC values of 0.59 and 0.55 (JJAS 2003 and JJAS 2004, respectively; Table 2). As with SDII and RX1day indices, the control experiments underestimated the values of the R95pTOT index, while they overestimated the R1mm index. This was also due to the current physical parameterisation scheme of the RegCM4 model, which results in a positive bias for the number of wet days with a low precipitation threshold (e. g., 1 mm•day-1), and a negative bias for the indices of the number of wet days with a higher precipitation threshold (e.g., 10 mm•day-1, not shown here).

The control experiments underestimated the R95pTOT index over the different studied domains. The largest underestimation of the R95pTOT index was located over the Guinea coast with MB more than −43.22 and −46.61 % (for JJAS 2003 and JJAS 2004, respectively; Table 2).

Figure 12 (second panel) is similar to Fig. 2 (second panel), but displays changes in the R95pTOT index. Both dry and wet experiments tended to cause an increase in the R95pTOT index over the orographic regions. Therefore, the initial soil moisture conditions, whether dry or wet, tended to reinforce extreme floods.

Figure 13 is the same as Fig. 3 but shows the PDF distribution of changes in the R95pTOT index indicating an increase in the R95pTOT index for both wet and dry experiments over most of the studied domains. The strongest increase in R95pTOT index was found over the west Sahel and Guinea coast with maximum change values around 4.03% (JJAS 2004) and 4.33% (JJAS 2003), respectively (Table 4).

In summary, RegCM4 underestimates the precipitation percentage due to very heavy precipitation days over the West African domain. The initial soil moisture conditions, whether dry or wet, accentuate the precipitation percent due to very heavy precipitation days. This result is consistent with Liu et al.'s (2014) work over Asia using RegCM4. The impact on R95pTOT index led to an increase in wet and dry experiments over most of the studied domains.

3.2. Seasonal temperature extreme indices

In this section, using daily maximum and minimum temperatures, we analyze four extreme temperature indices (Table 1) in RegCM4 simulations over West Africa. All temperature indices were calculated for JJAS 2003 and JJAS 2004. Table 3 summarizes the PCC and MB of all temperature indices studied in this section for EIN reanalysis and model simulations derived from control experiments with initial soil moisture from ERA20C reanalysis, with respect to GTS observations, calculated over the domains presented in Fig. 1, during the JJAS 2003 and JJAS 2004.

3.2.1. Maximum value of daily maximum temperature (TXx index)

In this section, we analyze the TXx index, which gives the hottest day's temperature during JJAS 2003 and JJAS 2004. Figure 14 (first panel) shows the TXx index (in °C) from GTS observations (Fig. 14a, d) and EIN reanalysis (Fig. 14b, e) for JJAS 2003 and JJAS 2004 and their corresponding simulated control experiments (Fig. 14c, f) with the initial soil moisture of the reanalysis ERA20C. The GTS observation showed the highest values of the TXx index observed over the Sahara, at more than 46 °C. The lowest values (less than 32 °C) were found over the Guinea coast (Fig. 14a, d). Fan Y. and Huug van den Dool (2008) in their work showed that the Reanalysis 2 m temperature data sets may not be suitable for model forcing and validation. We have chosen NOAA-CPC GTS observation dataset as reference in this study over ERA-Interim reanalysis, because NOAA-CPC GTS consists of a blending of satellite-based data collection and in situ data archive available in the GTS (Global Telecommunication System). The EIN reanalysis has similar large-scale patterns with a PCC value of 0.99 over the entire West African domain (Table 3). However, some local biases are shown for magnitude and spatial extent of these maxima and minima. The reanalysis of the EIN (Fig. 14b, e) shows lower values (less than 28 °C) of the TXx index over a large area along the Guinea coastline compared to GTS datasets. Conversely, GTS observation presented higher values of the TXx index (up to 48 °C) over a large area compared to the EIN reanalysis (Fig.14a, d), which showed a negative bias of the TXx index over most of the studied domains (Table 3).

The control experiments (Fig. 14c, f) reasonably replicate the large-scale patterns of the TXx index values with PCCs up to 0.99 (Table3) over the entire West African domain; however, they exhibited some biases at a local scale. The control experiments were closer to the maximum and minimum values displayed in the GTS observation. The control simulations overestimated the TXx values over the central and west Sahel, and over the Guinea coast (Table 3). The greatest overestimation was found over the west Sahel with MB of approximately 3.02 and 2.02 °C (for JJAS 2003 and JJAS 2004, respectively; Table 3). However, the biases obtained for the TXx index in this study were much lower than those obtained by Thanh et al. (2017), who used RegCM4 over Asia where it reached 8 °C.

Figure 14 (second panel) displays changes in the TXx index for JJAS 2003 and JJAS 2004 for dry (Fig. 14g, i for JJAS 2003 and JJAS 2004, respectively) and wet experiments (Fig. 14h, j for JJAS 2003 and JJAS 2004, respectively) with respect to their corresponding control experiments; the dotted area shows changes with a statistical significance of 10%. The impact of the initial soil moisture conditions on the TXx index was linear over most of studied domains; that is, the dry experiments led to an increase in the TXx index values, while the wet experiments favoured a decrease in the TXx index values.

The PDF distributions of TXx index changes for JJAS 2003 and JJAS 2004 over (a) the central Sahel, (b) West Sahel, (c) Guinea, and (d) West Africa derived from dry and wet experiments compared to the corresponding control experiments are shown in Fig. 15. Table 5 summarizes the maximum values of changes obtained on the PDF's for extreme temperature indices used in this study. As mentioned above, the results confirmed the linear impact on the TXx index over most of studied domains (Fig. 15). The strongest decrease (increase) in the TXx index was found over the central Sahel with a maximum change values around −2.57 °C (more than 1.69 °C) in wet (dry) experiments in JJAS 2004.

In summarizing this section, during JJAS 2003 and 2004, the RegCM4 model overestimates and underestimates the hottest day's temperature over the Sahel (west and central) and Guinea coast. The impact on the TXx index is linear over most of studied domains; that is, the dry (wet) experiments decrease (increase) the TXx index.

3.2.2. Minimum value of daily maximum temperature (TXn index).

In this section, we investigated the TXn index which gives the lowest day's temperature during JJAS 2003 and JJAS 2004. Figure 16 (first panel) is the same as Fig.14 (first panel) but presents the spatial distribution of the TXn index. GTS observation (Fig.16a, d) and EIN reanalysis (Fig.16b, e) display similar features with PCC reached 0.99 (for JJAS 2003 and JJAS 2004, Table 3). The maxima and minima values of TXn index were located over the Sahara and the Guinea coast respectively. However, there were some differences at the local scale in terms of spatial extent and magnitude. The EIN reanalysis presented a larger spatial extent of the maxima (greater than 36°C) and minima (less than 24°C) compared to GTS observation. Generally, the EIN reanalysis showed a negative bias value over most of the studied domains (for both JJAS 2003 and JJAS 2004 Table3. The strongest negative bias was found over the west Sahel with MB of approximately -1.48 and -1.73°C (resp. for JJAS 2003 and JJAS 2004, Table 3).

The control experiments showed a good agreement with the GTS datasets in the large scale patterns with PCC of approximately 0.99, however, the magnitude of the TXn index over most of studied domains was overestimated. The strongest positive bias was observed over west Sahel domain, the MB of approximately 6.56 and 5.44 °C (resp. JJAS 2003 and JJAS 2004, Table 3). The biases obtained in this study were lower than those of a similar study carried out by Thanh et al. (2017) over Asia using RegCM4.

As for Fig.14 (second panel), the Figure 16 (second panel) displayed changes in TXn index. The impact on TXn index of the initial soil moisture anomalies was linear over most of studied domains, that is, the dry experiments led to an increase of TXn index values while the wet experiments favor a decrease of TXn index values.

Figure 16 (second panel) is similar to Fig.14 (second panel) but displays the PDF distribution of changes in TXn index. The impact on TXn index was linear over most of the domain studied, although this impact is rather weak as compared to the TXx index. The strongest increase (decrease) in TXn index are found over the central (west) Sahel reaching 1.03 °C (-1.67°C) in dry (wet) experiments, in JJAS 2004 (JJAS 2004) (Table5).

In summary, RegCM4 overestimated the lowest day's temperature during JJAS 2003 and JJAS 2004 over the whole West African domain. As for TXx index, the impact on TXn index to soil moisture anomalies was linear over most of studied domains, that is, dry (wet) experiments cause an increase (decrease) of TXn index values.

3.2.3. Minimum value of daily minimum temperature (TNn index).

In this section, we examine the TNn index, which gives the lowest temperature at night during JJAS 2003 and JJAS 2004. Figure 18 (first panel) is the same as Fig. 14 (first panel) but displays the spatial distribution of the TNn index. GTS observations (Fig. 18 a, d) show the maxima of TNn index values above 15° N latitude, not exceeding 27 °C, while the minima values are less than 17 °C and are located over the mountainous regions such as the Cameroon Mountains, Jos Plateau, and Guinea Highlands. The EIN reanalysis showed a similar spatial pattern as GTS observation, with a PCC value of approximately 0.99 over the entire West African domain (Table 3) despite some biases at the local scale. The EIN reanalysis (Fig. 18 b, e) displayed the highest value of the TNn index (exceeding 27 °C) compared to GTS observation, and were located over a large area above 15° N. The EIN reanalysis also showed the lowest values (less than 21 °C) of the TNn index compared to the GTS observation, located over the orographic regions. The EIN reanalysis overestimated the TNn index values over most of the studied domains. The strongest positive bias was observed over the west Sahel, the MB reached 3.43 and 2.98 °C for JJAS 2003 and JJAS 2004, respectively (Table 3).

The control experiments (Fig. 18 c, f) showed good agreement with GTS observations with PCC values of approximately 0.99; however, they exhibited some biases at the local scale. The control experiments overestimated the magnitude of the TNn index over most of studied domains.

The strongest positive bias was observed over the west Sahel, the MB was approximately 3.30 °C and 2.55 °C for JJAS 2003 and JJAS 2004, respectively (Table 3). These positive biases obtained in simulating the TXx, TXn, and TNn indices were opposite to the cold bias known from RegCM4 in mean climate simulation (Koné et al., 2018, Klutse et al., 2016). It is difficult to determine the origin of RegCM4 temperature biases, as they can depend on several factors, such as surface energy fluxes and water, cloudiness, and surface albedo (Sylla et al., 2012; Tadross et al., 2006).

Figure 18 (second panel) is the same as Fig. 14 (second panel), but displays changes in the TNn index. Over the central and west Sahel, both dry and wet experiments led to a decrease. Conversely, over the Guinea coast, we found an increase.

Figure 19 is the same as Fig. 15 but shows the PDF distribution of changes in the TNn index. A linear impact was found over west Sahel and Guinea coast only in JJAS 2004, that is, wet (dry) experiments increase (decrease) the TNN index (Fig.19; Table 5). The strongest increase (decrease) in TNn index in wet (dry) experiment was found over Guinea coast (west Sahel), with maximum change values around 0.11 °C and (−1.15 °C) in JJAS 2004 (JJAS 2003) (Table 5).

In summary, RegCM4 overestimated the lowest temperature at night during JJAS 2003 and JJAS 2004 over the different studied domains. A linear impact was found over west Sahel and Guinea coast only in JJAS 2004, that is, wet (dry) experiments increase (decrease) the TNN index

3.2.4. Maximum value of daily minimum temperature (TNx index)

In this section, we turned our attention to TNx index, which gives the warmest night temperature during JJAS 2003 and JJAS 2004. Figure 20 (first panel) is the same as Fig. 14 (first panel), but for the TNx index. GTS observations (Fig. 20 a, d) showed that the maxima of the TNx index values over the Sahara reached 40 °C, while the minima around 24 °C were located over the Guinea coast sub-region. The EIN reanalysis (Fig. 20b, e) showed similar large-scale patterns with PCC values of 0.99, but some biases can be noticed between the GTS and EIN datasets. The EIN reanalysis underestimated the maxima (not exceeding 38 °C) and minima (less than 22 °C) located over the Sahara and the orographic regions such as the Cameroon Mountains, Jos Plateau, and Guinea Highlands. The EIN reanalysis displayed negative MB over the Guinea coast with MB approximately −3.11 °C and −3.14 °C (JJAS 2003 and JJAS 2004, respectively; Table 3).

The control experiments (Fig. 20c, f) successfully reproduced the general features of the TNx index with a PCC value of 0.99, but some differences were shown at the local scale. Unlike the TNn index, the control experiments underestimated the TNx index over most of the studied domains. The strongest negative bias was found over the central Sahel, MB was approximately −3.35 °C and −3.32 °C (for JJAS 2003 and JJAS 2004, respectively; Table 3). This underestimation of the TNx index seems to be systematically related to the cold bias in RegCM4 over West Africa, which has been reported in several papers (Koné et al., 2018, Klutse et al., 2016).

Figure 20 (second panel) is the same as Fig. 14 (second panel) but displays changes in the TNx index. Like for the TNn index, the impact on the TNx index of initial soil moisture conditions was somewhat linear over the central Sahel, and dry experiments led to an increase in the TNx index values, while the wet experiments favoured a decrease in the TNx index values. However, over the west Sahel, both wet and dry experiments led to a dominant decrease. Conversely, over the Guinea coast, although the signal was weak, both dry and wet experiments led to a dominant increase.

Figure 21 is the same as Fig. 15 but displays the PDF distributions of the changes in the TNx index. Like for the TNn index, the impact on the TNx index changes was linear over the central Sahel. The strongest increase (decrease) in TNx index was found over the central Sahel in dry (wet) experiments with maximum change approximately 0.25 (−1.67 °C) in JJAS 2003 (JJAS 2004) (Table 5).

In summary, RegCM4 underestimates the warmest night temperature during JJAS 2003 and JJAS 2004 over most of studied domains. The impact on the TNx index of initial soil moisture conditions was linear over the central Sahel, that is, dry (wet) experiments led to an increase (decrease) in the TNx index values.

4. Conclusions

The impact on the subsequent summer extreme climate of the initial soil moisture conditions over West Africa was investigated using the RegCM4-CLM45. In addition, the performance of RegCM4-CLM4.5 in representing six extreme indices of precipitation and four extreme indices of temperature over West Africa was also evaluated. Results have been presented for JJAS 2003 (wet year) and JJAS 2004 (dry year). We performed sensitivity studies over the West African domain, with a spatial resolution of 25 km. We initialized the control runs using ERA20C reanalysis soil moisture, at its maximum and minimum values over the West Africa domain, respectively, for dry and wet experiments.

Compared to the extreme indices of the observation datasets, the model overestimated and underestimated the number of wet days for a low (1 $mm.day^{-1}$) and high threshold rain rate (e.g., 10 $mm.day^{-1}$, not shown here). RegCM4 also underestimated the simple precipitation intensity index (SDII), the maximum 1-day precipitation (Rx1day index), and the precipitation percentage due to very heavy precipitation days (R95pTOT index). The current physical parameterization scheme of the RegCM4 model used in our study results in a positive bias for the number of wet days with a low precipitation threshold (e. g. 1 mm•day-1), while in a negative bias for a higher precipitation threshold (e.g. 10 mm•day-1, not shown here). However, RegCM4 generally overestimated the maximum number of CWD and CDD over the West African domain studied. The temperature extreme indices used in this study (TXx, TXn, and TNn) were also overestimated, except the TNx index, which was underestimated over most of studied domains.

The impact on extreme precipitation indices of the initial soil moisture conditions was linear only for indices related over the central Sahel to the number of precipitation events (R1mm, CDD, and CWD indices) and not for those related to the amount of precipitation (SDII, RX1day, and R95pTOT). The dry and wet experiments accentuated the precipitation percentage due to very heavy precipitation days and maximum one-day precipitation accumulation (R95pTOT and RX1day indices, respectively) over most of the studied domains.

The initial soil moisture conditions unequally affected the daily maximum and minimum temperatures over the West African domain. There was a greater impact on daily maximum temperature extremes than on the daily minimum temperature extremes. These results are consistent with those of previous studies (Jaeger and Seneviratne, 2011; Zhang et al., 2009).

The wet (dry) experiments resulted in an increase (decrease) in the TXx and TXn indices over most of the studied. The impact of initial soil moisture conditions on the indices related to the minimum temperature (TNx and TNn indices) was linear only for TNx index over central Sahel. The dry (wet) experiments cause an increase (a decrease) in the TNx.

This study helps to understand the impact of the initial soil moisture conditions on extreme events of precipitation and temperature in terms of intensity, frequency and duration over West Africa. This is a contribution to the improvement of extreme event forecasts in West Africa in highlighting the crucial role of initial soil moisture. For a proper assessment of the dependence of the model in our results, it would be appropriate to repeat the investigation using different RCMs in a multi-model framework.

Author contribution

The authors declare to have no conflict of interest with this work. B. Koné and A. Diedhiou fixed the analysis framework. B. Koné carried out all the simulations and figures production according to the outline proposed by A. Diedhiou. B. Koné and A. Diedhiou, S. Anquetin and A. Diawara worked on the analyses. All authors contributed to the drafting of this manuscript.

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TABLES AND FIGURES.

Extreme indices		Definition	Units
Extreme Rainfall Indices			
1	R1mm	Number of wet days (daily precipitation ≥ 1mm)	day
2	SDII	The amount of precipitation mean on wet days (daily precipitation ≥ 1mm)	$mm.day^{-1}$
3	CDD	Maximum number of consecutive dry days (daily precipitation < 1 $mm.day^{-1}$)	day
4	CWD	Maximum number of consecutive wet days (daily precipitation ≥ 1 $mm.day^{-1}$)	day
5	RX1day	The maximum one-day precipitation accumulation	mm
6	R95pTOT	Precipitation percent due to very heavy precipitation days.	%
Extreme temperature indices			
7	TXn	Minimum value of daily maximum temperature	°C
8	TXx	Maximum value of daily maximum temperature	°C
9	TNn	Minimum value of daily minimum temperature	°C
10	TNx	Maximum value of daily minimum temperature	°C

Table1: The 10 extreme climate indices used in this study.

		Central Sahel		West Sahel		Guinea coast		West Africa	
		MB	PCC	MB	PCC	MB	PCC	MB	PCC
R1mm	TRMM_2003	**-6.76**	0.98	-3.15	0.99	**8.89**	0.99	-1.12	**0.98**
	CTRL_2003	33.17	0.98	-5.25	0.96	**53.16**	0.96	22.18	**0.96**
	TRMM_2004	**-7.51**	0.98	-3.42	0.99	**10.44**	0.98	-1.34	**0.98**
	CTRL_2004	29.50	0.98	1.34	0.96	**55.46**	0.96	23.85	**0.95**
SDII	TRMM_2003	**2.67**	0.96	0.22	0.94	**-5.24**	0.95	1.20	**0.86**
	CTRL_2003	-7.52	0.97	-9.95	0.94	**-13.62**	0.77	-7.67	**0.73**
	TRMM_2004	**2.07**	0.96	0.45	0.96	**-6.44**	0.94	1.16	**0.86**
	CTRL_2004	-7.01	0.97	-9.37	0.94	**-14.65**	0.81	-7.59	**0.77**
CDD	TRMM_2003	1.21	0.95	0.89	0.93	-0.93	0.94	**-2.29**	**0.92**
	CTRL_2003	0.93	0.90	**14.49**	0.91	**-7.84**	0.66	**2.63**	**0.85**
	TRMM_2004	2	0.95	1.58	096	-3.17	0.92	**-1.75**	**0.94**
	CTRL_2004	4.75	0.91	**17.51**	0.95	**-9.43**	0.68	**6.99**	**0.89**
CWD	TRMM_2003	**-0.48**	0.92	0.80	0.94	**2.47**	0.92	0.37	**0.90**
	CTRL_2003	45.56	0.83	18.44	0.75	**59.21**	0.88	31.20	**0.81**
	TRMM_2004	**-0.68**	0.92	0.97	0.92	**2.38**	0.89	0.26	**0.87**
	CTRL_2004	36.78	0.79	20.48	0.78	**60.51**	0.82	29.74	**0.79**
RX1day	TRMM_2003	**35.78**	0.92	25.31	0.89	14.31	0.86	26.02	**0.84**
	CTRL_2003	-26.46	0.78	**-38.07**	0.91	**-30.28**	0.54	-20.08	**0.50**
	TRMM_2004	**31.66**	0.91	20.19	0.91	10	0.88	22.19	**0.85**
	CTRL_2004	-22.89	0.46	**-36.67**	0.88	**-42.44**	0.42	-20.23	**0.40**
R95pTOT	TRMM_2003	23.19	0.92	13.31	0.94	-0.23	0.96	**16.54**	**0.91**
	CTRL_2003	-27.67	0.67	-33.39	0.77	**-43.22**	0.65	-29.12	**0.59**
	TRMM_2004	23.26	0.91	12.32	0.94	-0.93	0.95	**18.54**	**0.91**
	CTRL_2004	-24.38	0.46	-31.75	0.80	**-46.61**	0.60	-27.45	**0.55**

Table 2: The pattern correlation coefficient (PCC) and the mean bias (MB) of R1mm (in day), SDII (in mm.day-1), CDD (in day), CWD (in day), RX1day (in mm) and R95pTOT (in %) indices for TRMM observation and their corresponding control experiments (initialized with initial soil moisture of ERA20C reanalysis) with respect to CHIRPS, calculated over Guinea coast, central Sahel, west Sahel and the entire West African domain for JJAS 2003 and JJAS 2004.

		Central Sahel		West Sahel		guinea		West Africa	
		MB	PCC	MB	PCC	MB	PCC	MB	PCC
TXx	EIN_2003	**-2.17**	0.99	**-3.05**	0.99	**-4**	0.99	**-2.77**	**0.99**
	CTRL_2003	2.10	0.99	**3.02**	0.99	-1.34	0.99	0.32	**0.99**
	EIN_2004	**-2.44**	0.99	**-3.86**	0.99	**-3.84**	0.99	**-2.94**	**0.99**
	CTRL_2004	1.14	0.99	**2.02**	0.99	-1.41	0.99	-0.16	**0.99**
TXn	EIN_2003	0.31	0.99	**-1.48**	0.99	-0.70	0.99	0.50	**0.99**
	CTRL_2003	5.12	0.99	**6.56**	0.99	3.76	0.99	**5.65**	**0.99**
	EIN_2004	-0.76	0.99	**-1.73**	0.99	-1.38	0.99	-0.32	**0.99**
	CTRL_2004	3.43	0.99	**5.44**	0.99	2.75	0.99	**4.14**	**0.99**
TNn	EIN_2003	3.08	0.99	**3.43**	0.99	1.28	0.99	3.15	**0.99**
	CTRL_2003	2.37	0.99	**3.30**	0.99	1.53	0.99	1.45	**0.99**
	EIN_2004	3.28	0.99	**2.98**	0.99	1.20	0.99	3.11	**0.99**
	CTRL_2004	2.09	0.99	**2.55**	0.99	1.28	0.99	0.71	**0.99**
TNx	EIN_2003	-0.69	0.99	-1.79	0.99	**-3.11**	0.99	-1.62	**0.99**
	CTRL_2003	-1.91	0.99	-2.86	0.99	**-3.35**	0.99	-3.85	**0.99**
	EIN_2004	-0.82	0.99	-1.43	0.99	**-3.14**	0.99	-1.71	**0.99**
	CTRL_2004	-1.90	0.99	-2.54	0.99	**-3.32**	0.99	-3.99	**0.99**

Table 3: The pattern correlation coefficient (PCC) and the mean bias (MB in°C) of TXx, TXn, TNn and TNx indices from the EIN reanalysis and their corresponding control experiments (initialized with initial soil moisture of ERA20C reanalysis) with respect to GTS, calculated for Guinea coast, central Sahel, west Sahel and the entire West African domain for JJAS 2003 and JJAS 2004.

Precipitation indices		Central Sahel		West Sahel		Guinea coast		West Africa	
		ΔWC	ΔDC	ΔWC	ΔDC	ΔWC	ΔDC	ΔWC	ΔDC
R1mm (day)	2003	8.14	**-5.19**	**12.02**	0.69	3.92	2.88	4.67	1.75
	2004	10.01	-3.79	10.14	0.56	4.90	3.57	7.90	2.61
SDII (mm/day)	2003	0.07	0.11	-0.11	0.14	0.70	0.17	0.29	0.31
	2004	0.03	0.09	0.26	-0.07	0.56	0.22	0.24	0.21
CWD (day)	2003	13.25	-3.15	6.61	0.64	12.24	4.05	9.43	1.09
	2004	**15.58**	**-4.48**	7.20	-0.19	6.08	3.18	11.89	-0.37
CDD (day)	2003	-2.80	2.58	**-12.73**	0.83	-0.68	-1.31	-1.53	0.19
	2004	-5.92	**3.80**	-7.75	2.75	-0.93	-1.46	-3.57	-0.44
RX1day (mm)	2003	1.97	3.78	0.11	0.65	**26.14**	4.17	7.16	7.27
	2004	3.35	3.03	7.05	0.19	**14.93**	15.73	6.46	2.28
R95pTOT (%)	2003	1.54	1.77	2.88	1.53	**4.33**	2.37	2.83	2.46
	2004	1.66	0.89	**4.03**	0.43	1.69	0.92	1.37	2.43

Table 4: Summary Table of maximum values of change on PDF's for R1mm, SDII, CDD, CWD, RX-1day and R95pTOT indices.

Temperature indices		Central Sahel		West Sahel		Guinea coast		West Africa	
		ΔWC	ΔDC	ΔWC	ΔDC	ΔWC	ΔDC	ΔWC	ΔDC
TXx	2003	-2.54	1.14	-2.11	0.90	-0.34	0.68	-0.89	1.06
	2004	**-2.57**	**1.69**	-1.58	0.98	-0.32	1.01	-0.86	1.27
TXn	2003	-1.37	0.81	**-1.67**	-0.05	-0.06	0.28	-0.50	0.59
	2004	-1.09	**1.03**	-0.93	0.55	-0.04	0.31	-0.38	0.61
TNn	2003	-0.37	-0.20	-0.23	**-1.15**	0.05	0.04	-0.20	0.03
	2004	-0.03	-0.37	0.06	-1.07	**0.11**	-0.03	-0.05	-0.11
TNx	2003	-1.29	**0.25**	-0.94	-1.37	0.12	0.04	-0.49	0.13
	2004	**-1.67**	0.15	-0.62	-1.13	0.02	0.03	-0.51	-0.07

Table 5: Summary Table of maximum values of change on PDF's for TXx, TXn, TNn and TNx indices.

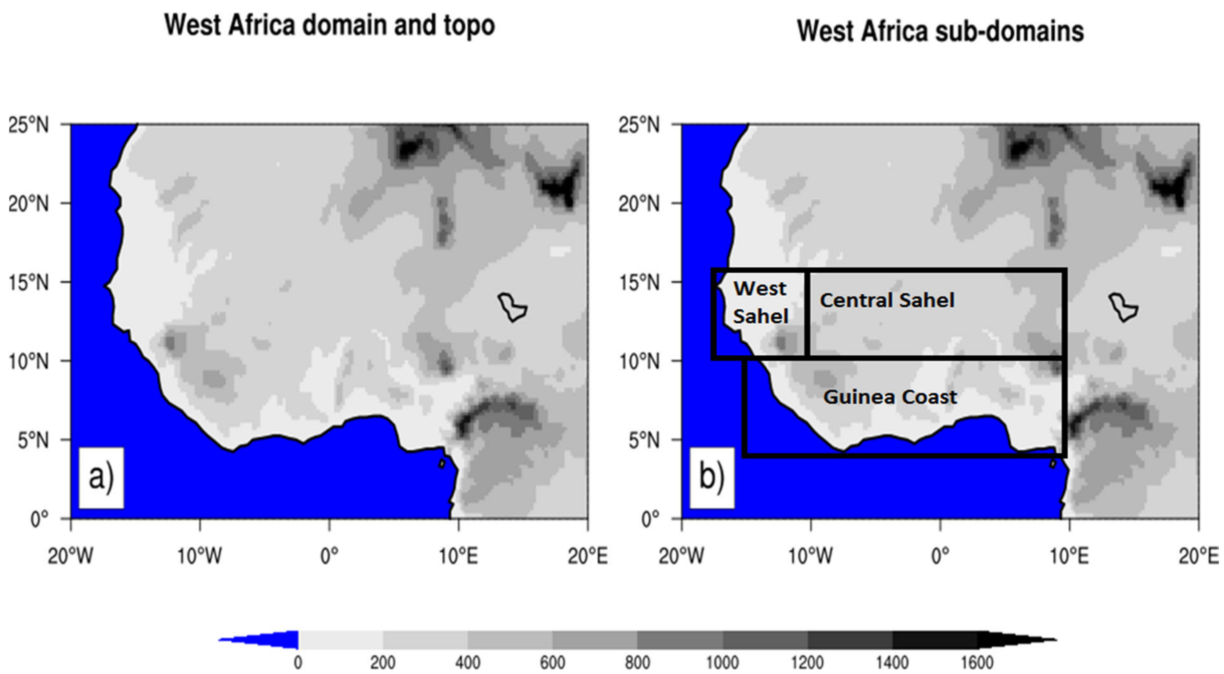

Figure 1: Topography of the West African domain. The analysis of the model result has an emphasis on the whole West African domain and the three subregions Guinea coast, central Sahel and west Sahel, which are marked with black boxes.

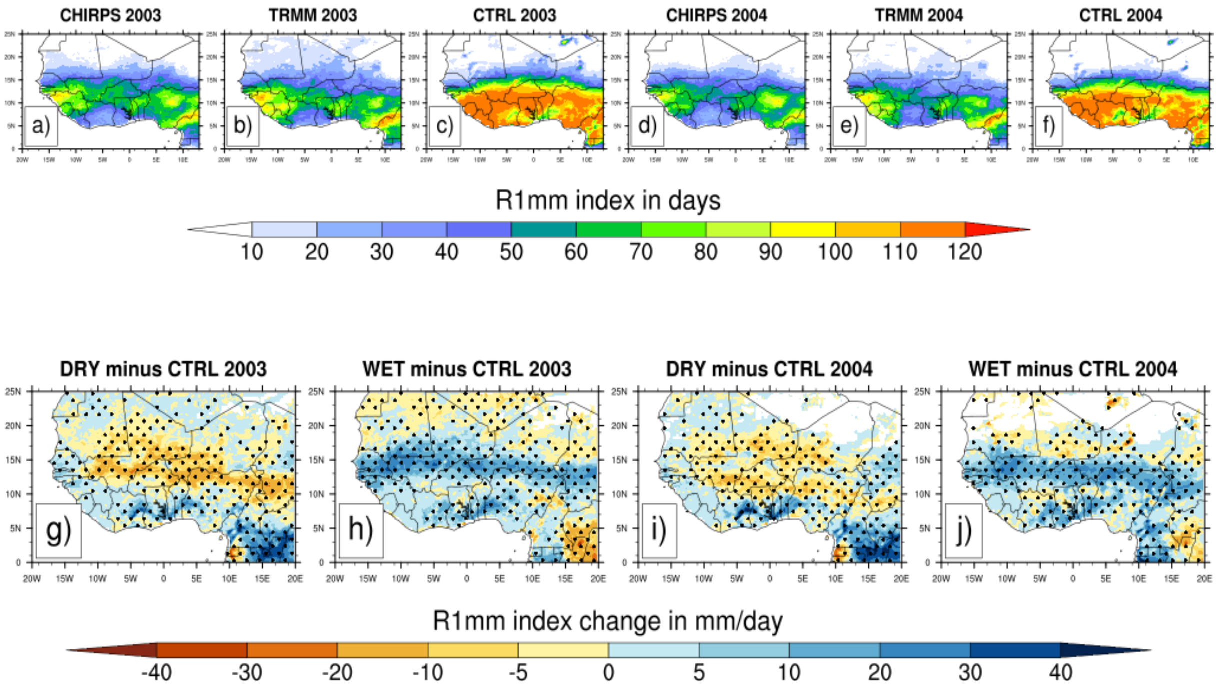

Figure2: Mean values of the number of the wet days (R1mm index in days) from CHIRPS (a and d) and TRMM(b and e) observations for JJAS 2003 and JJAS 2004 and their corresponding simulated control (CTRL) experiments (c and f) initialized with initial soil moisture of the reanalysis of ERA20C (first panel) and changes in R1mm index in days (second panel) for JJAS 2003 and JJAS 2004, from dry (g and i) and wet (h and j) experiments with respect to the corresponding control experiments. Areas with values passing the 10% significance test are dotted.

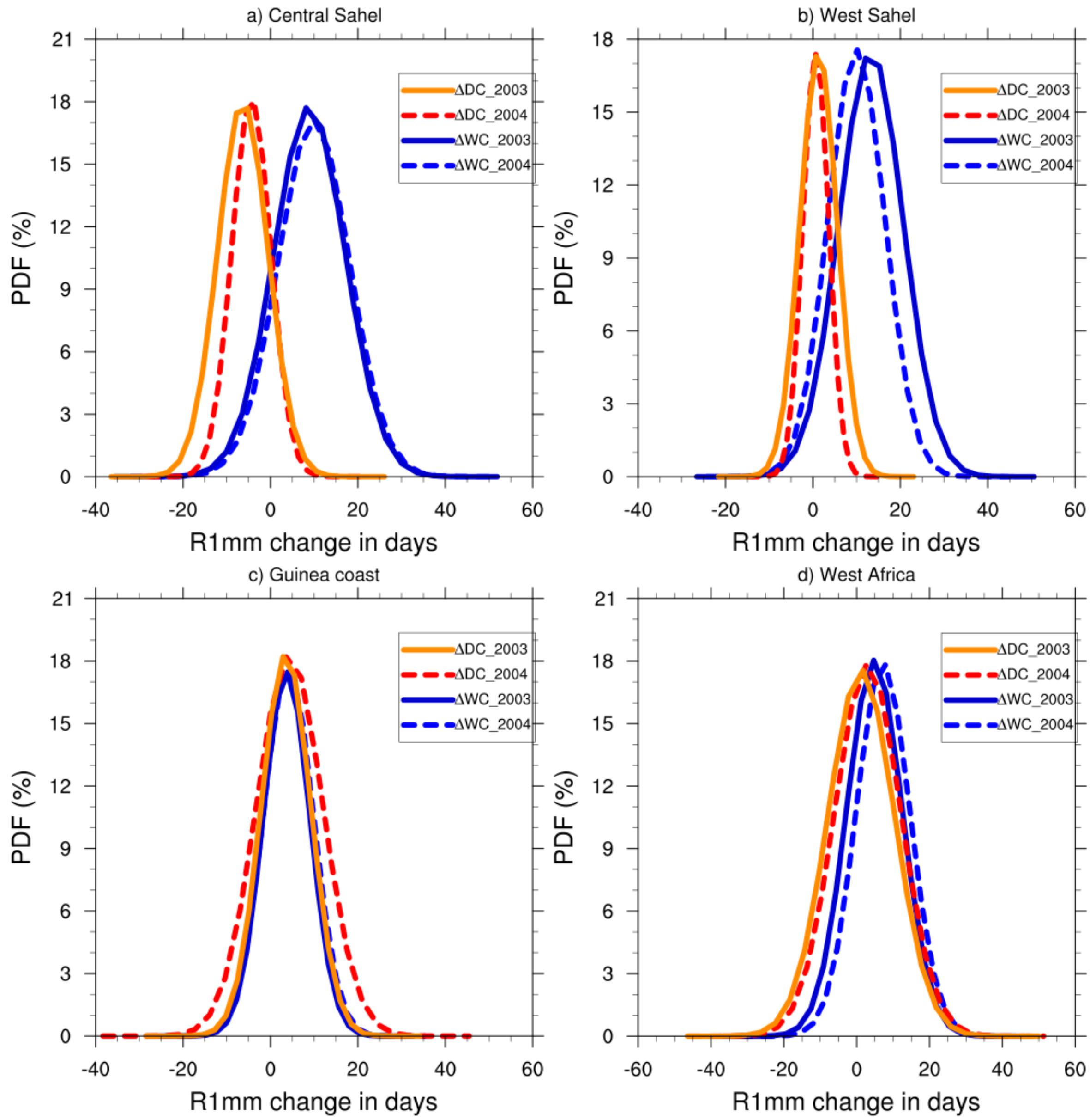

Figure3: PDF distributions (%) of mean values of the number of the wet days change in JJAS 2003 and JJAS 2004, over (a) central Sahel , (b) West Sahel, (c) Guinea and (d) West Africa derived from dry (ΔDC) and wet (ΔWC) experiments with respect to their corresponding control experiment.

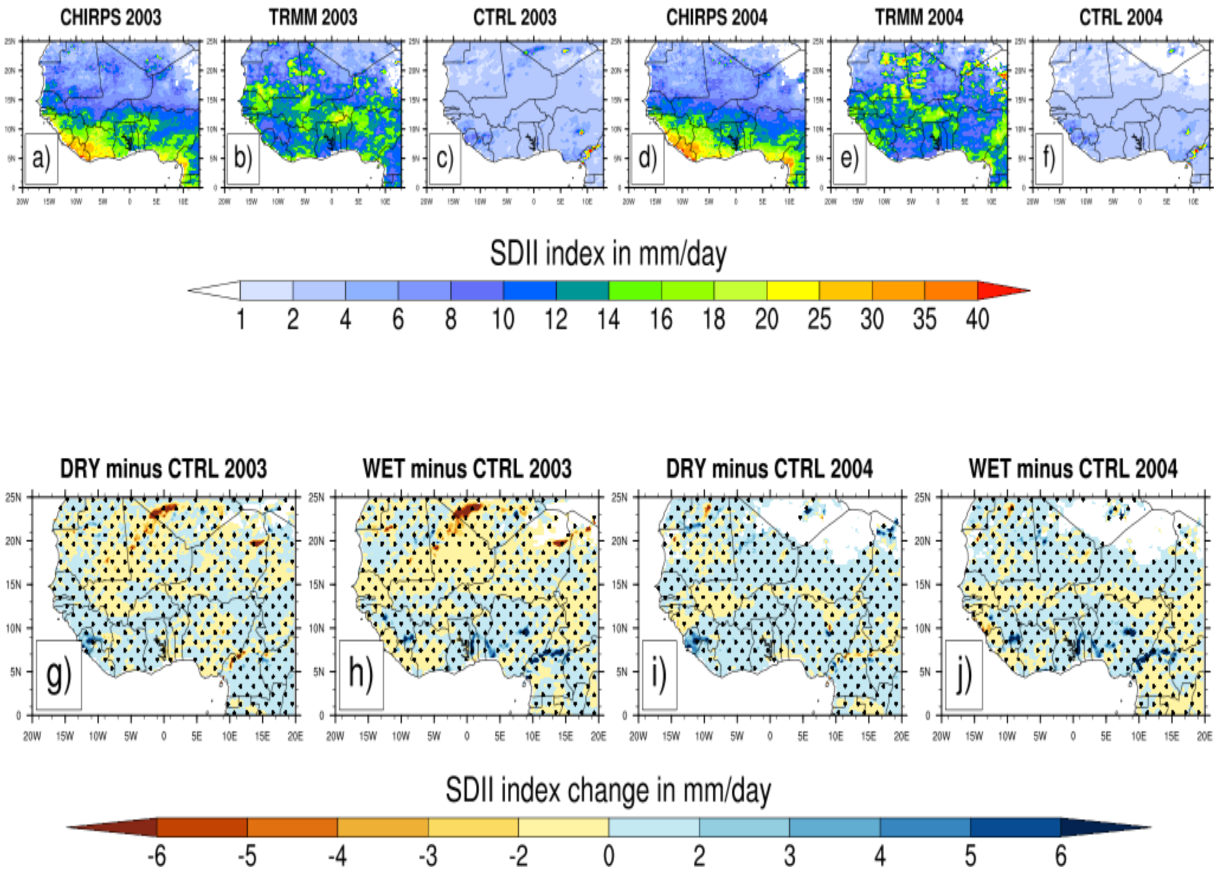

Figure4: Same as Fig. 2 but for the SDII index (in mm.day^{-1}).

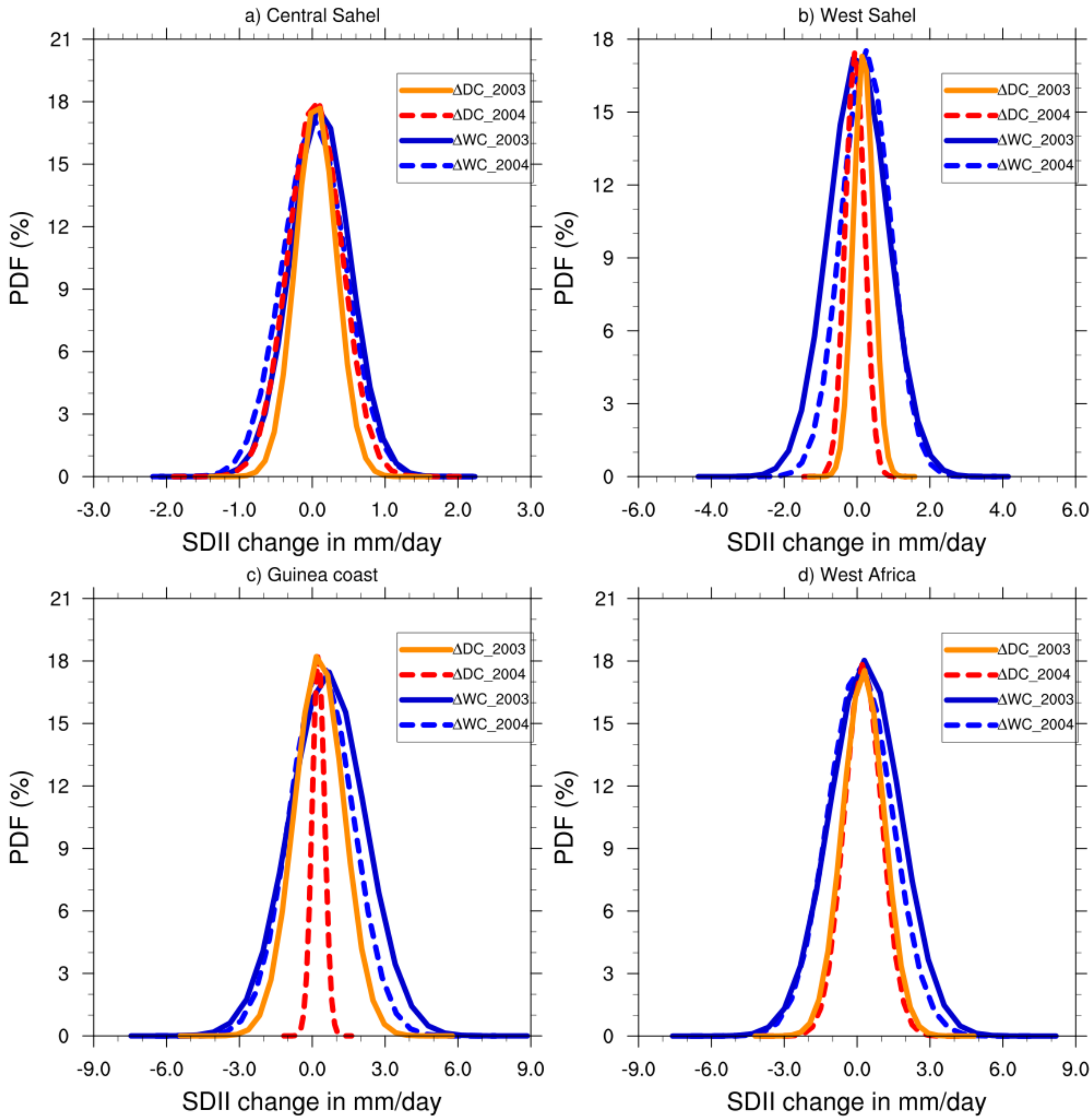

Figure 5: Same as Fig. 3 but for the SDII index (in mm.day^{-1}).

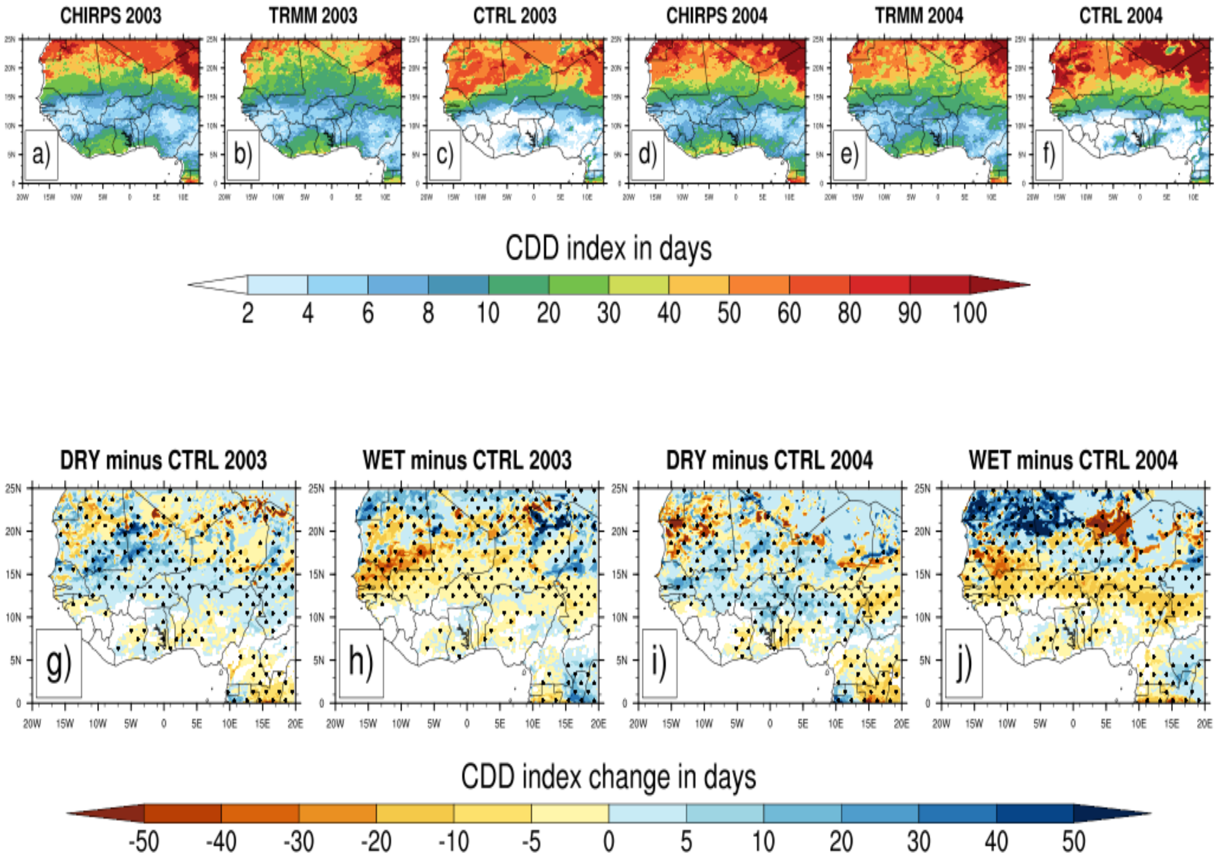

Figure 6: Same as Fig. 2 but for the CDD index (in day).

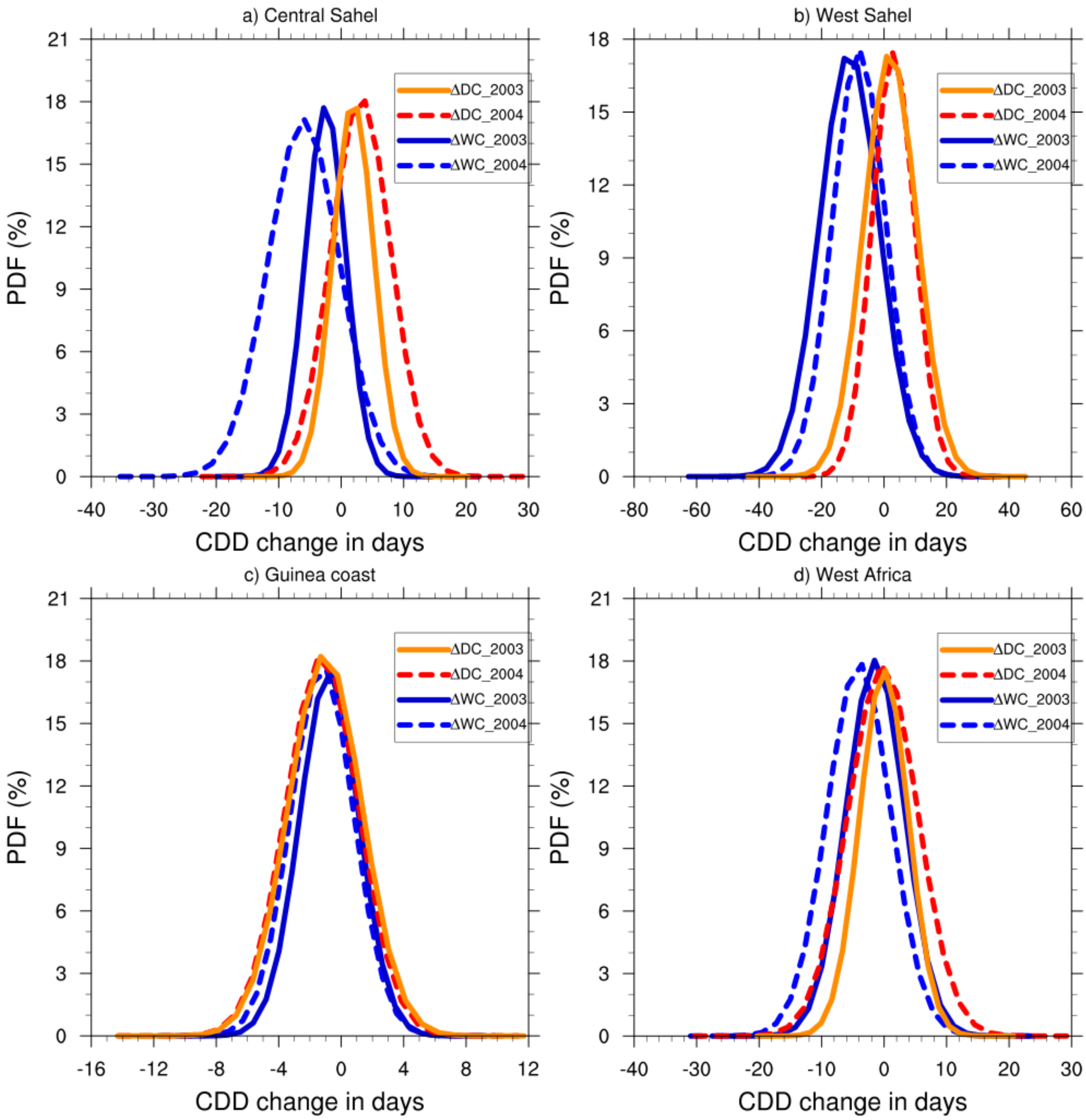

Figure 7: Same as Fig. 3 but for the CDD index (in day).

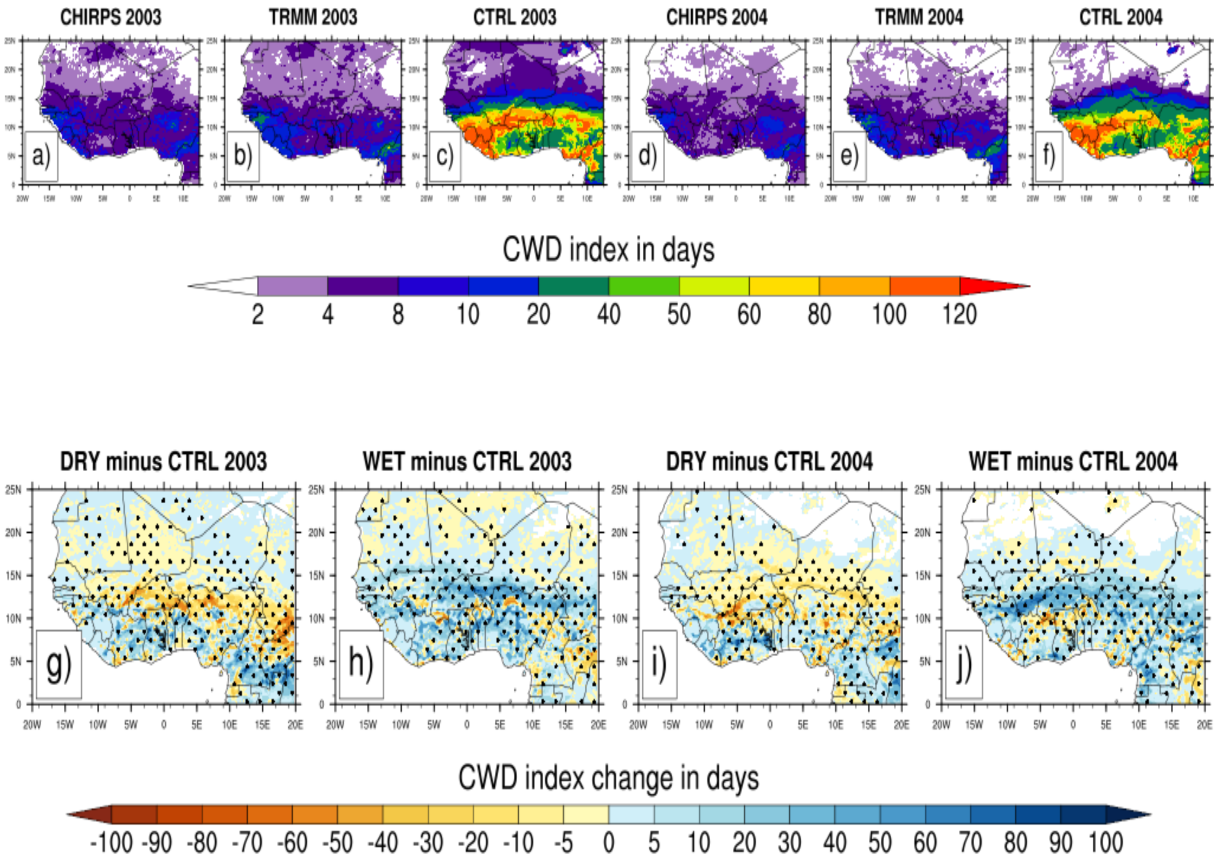

Figure 8: Same as Fig. 2 but for the CWD index (in day).

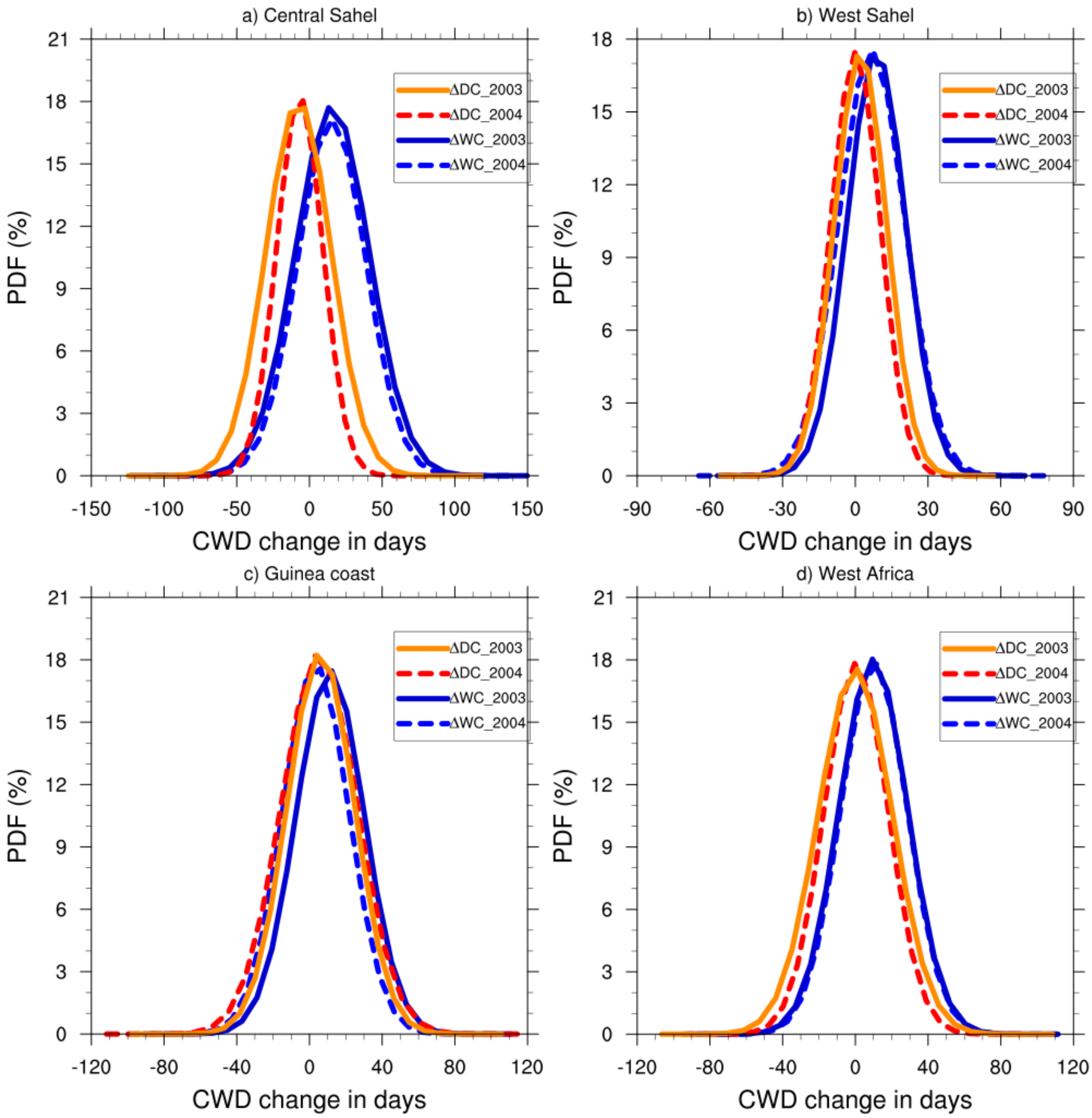

Figure 9: Same as Fig. 3 but for the CWD index (in day).

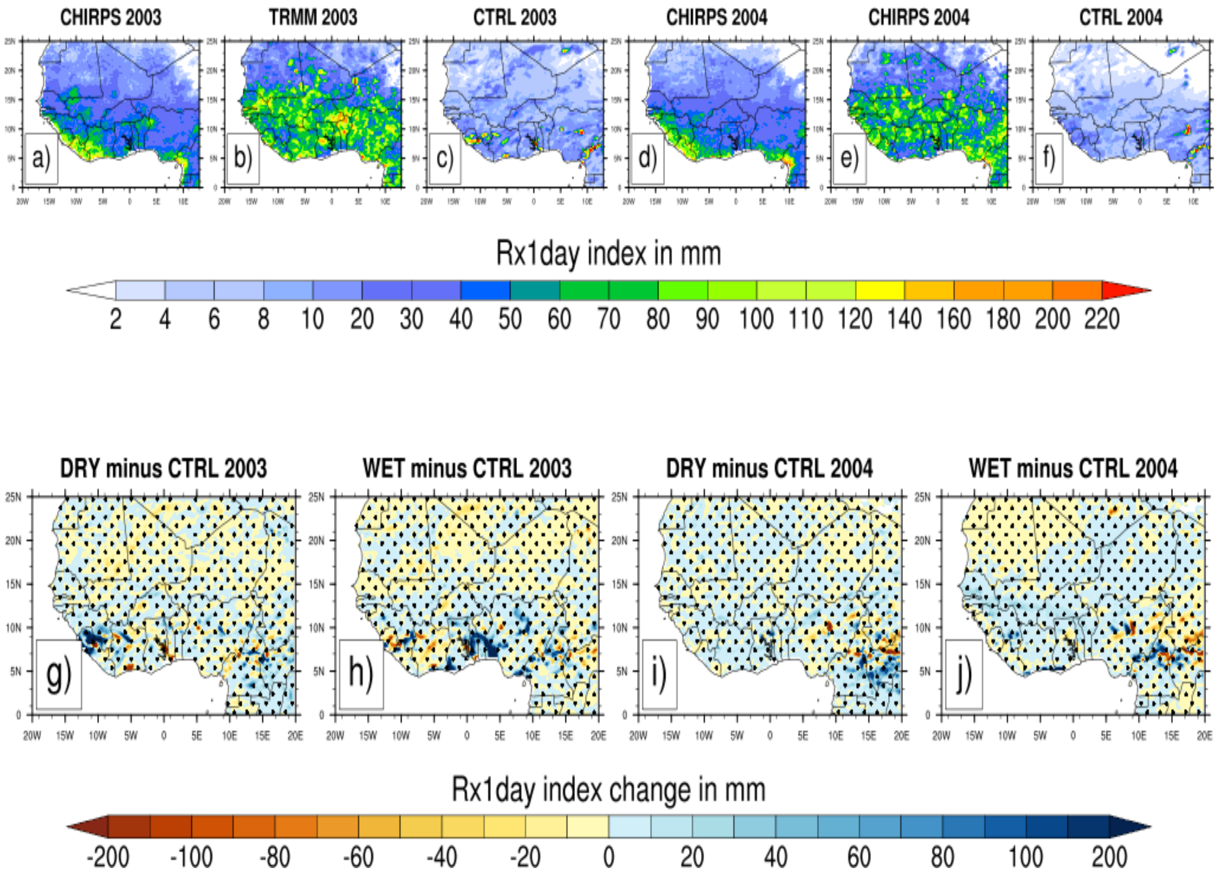

Figure 10: Same as Fig. 2 but for the RX1day index (in mm).

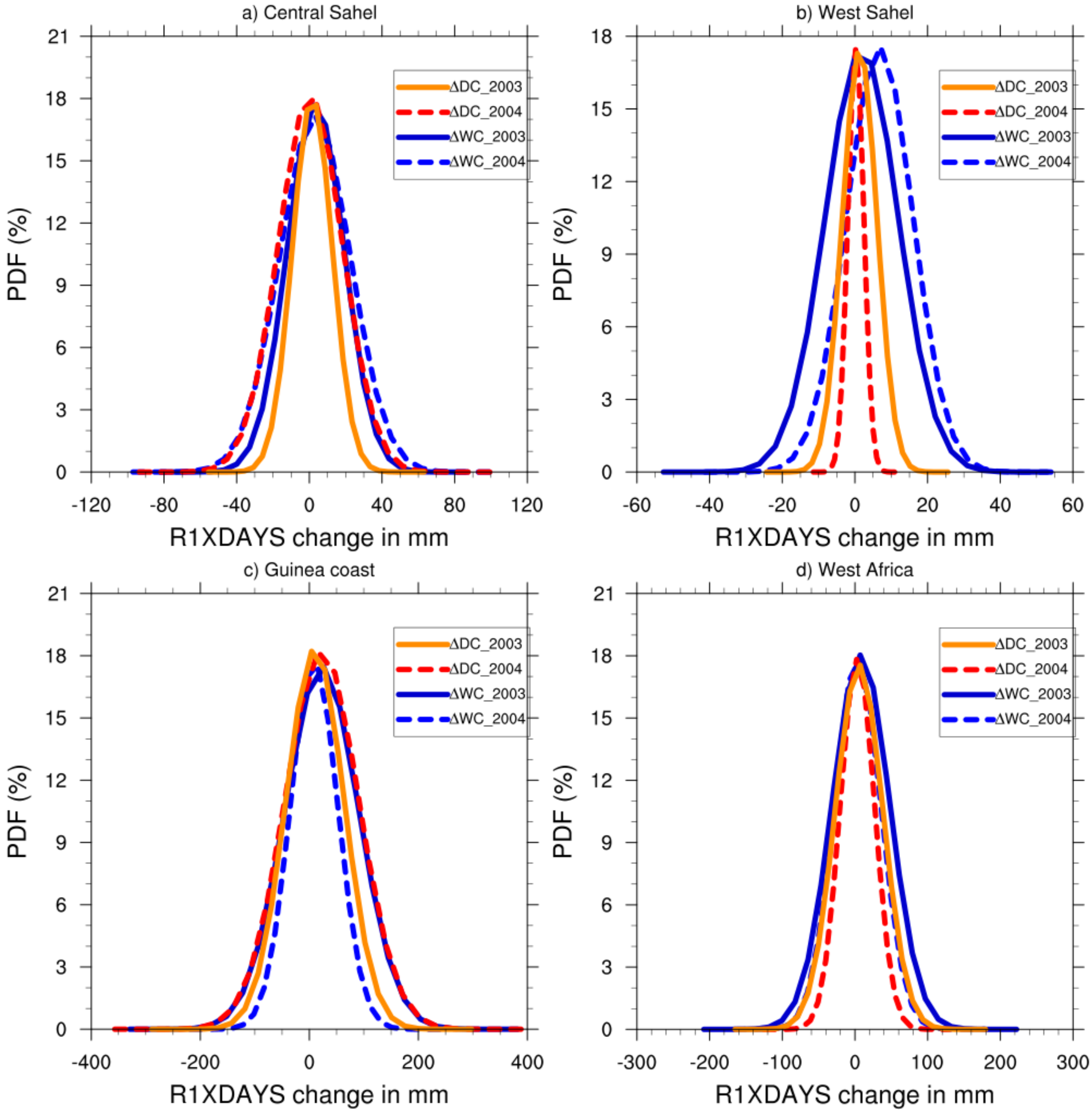

Figure 11: Same as Fig. 3 but for the RX1DAY index (in mm).

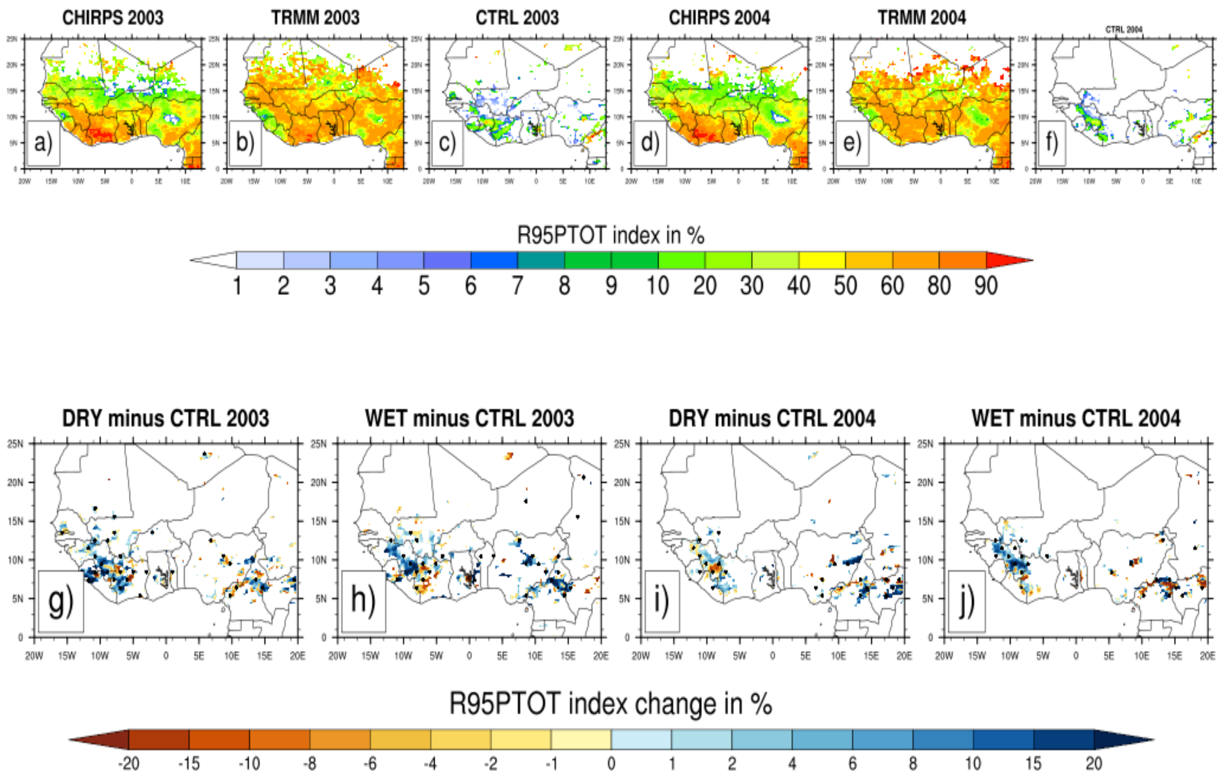

Figure 12: Same as Fig. 2 but for the R95pTOT index (in %).

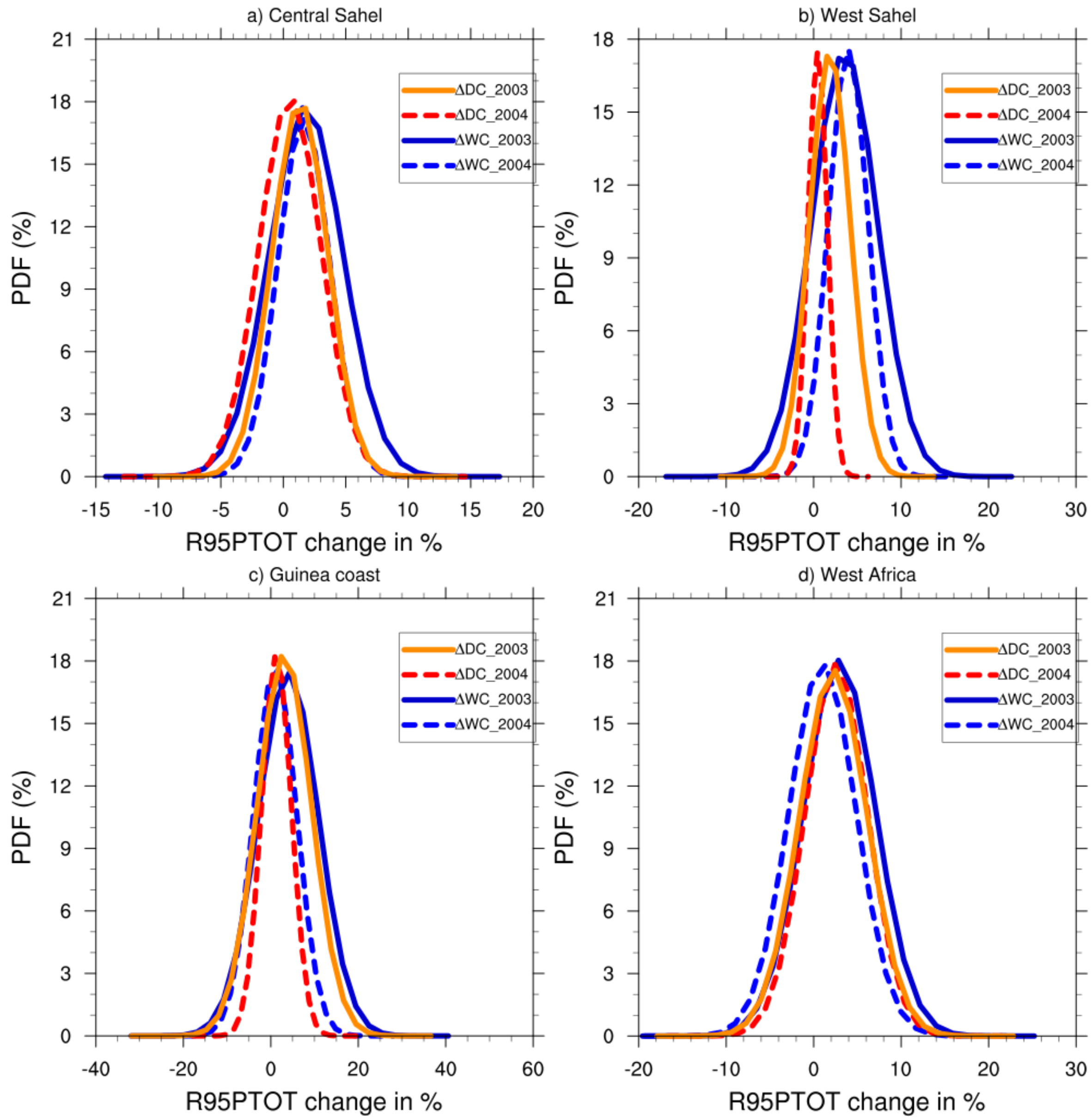

Figure 13: Same as Fig. 3 but for theR95pTOT index (in %).

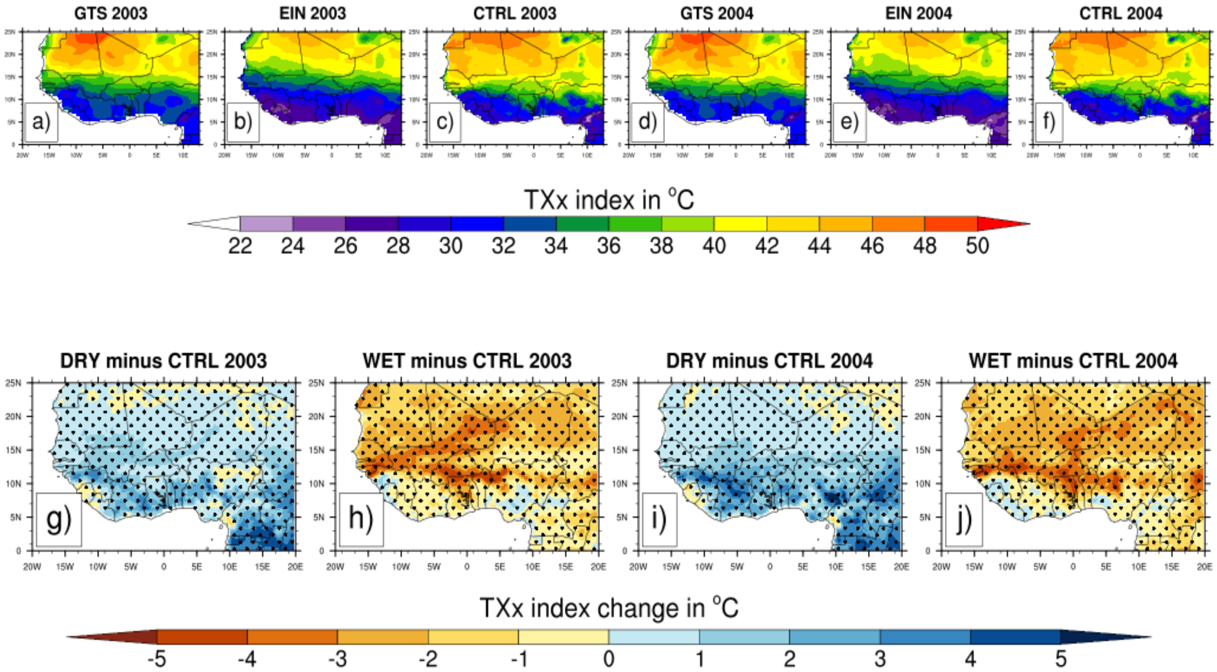

Figure 14: The mean maximum value of daily maximum temperature (TXx index in°C) from GTS observation (a and d) and The EIN reanalysis (b and e) for JJAS 2003 and JJAS 2004 and their corresponding simulated control (CTRL) experiments (c and f) initialized with the initial soil moisture of the ERA20C reanalysis (first panel) and changes in TXx index in°C (second panel) for JJAS 2003 and JJAS 2004, from dry (g and i) and wet (h and j) experiments with respect to the corresponding control experiments. Areas with values passing the 10% significance test are dotted.

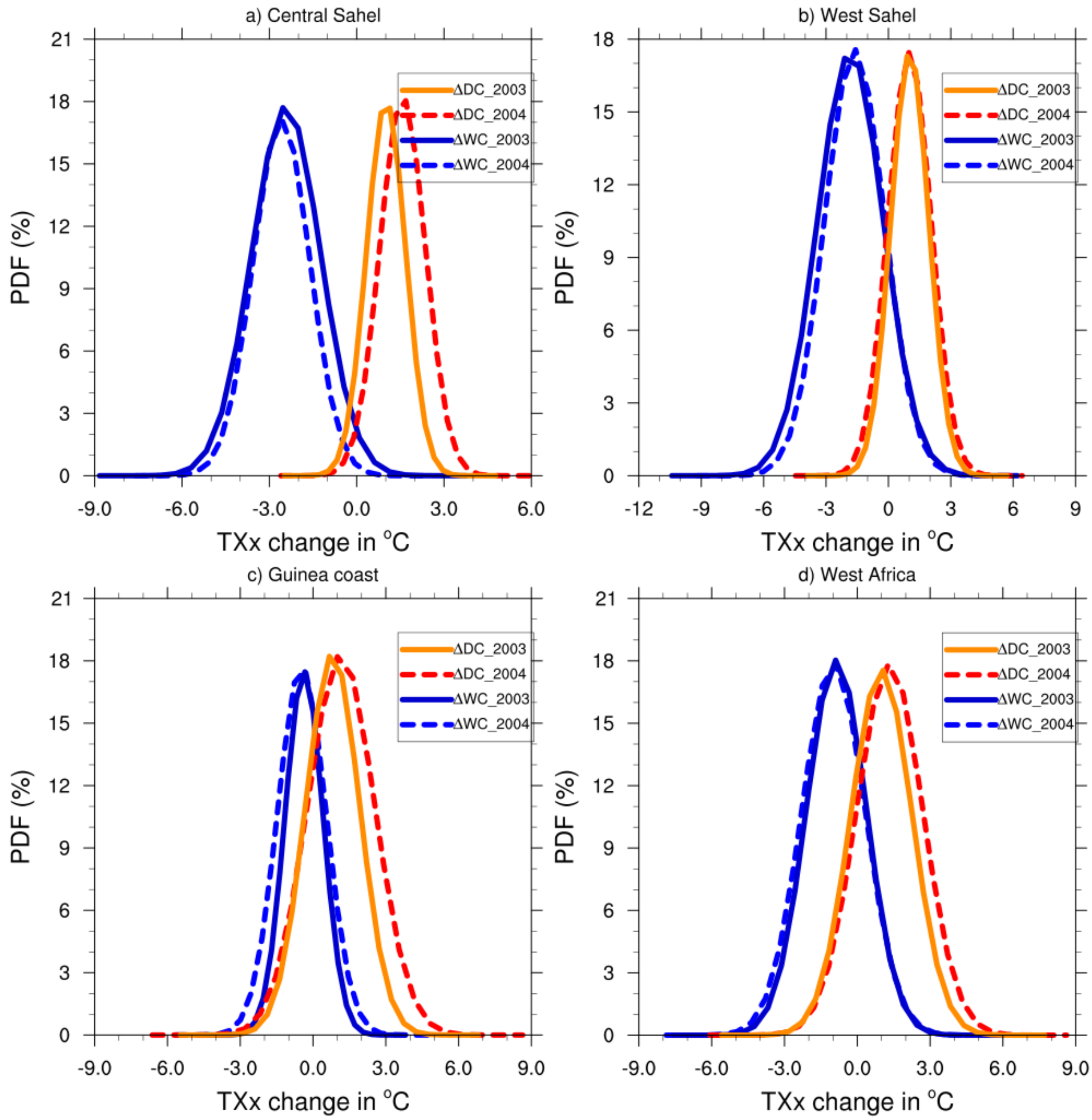

Figure 15: PDF distributions (%) of change in maximum value of daily maximum temperature (TXx index, in°C) for JJAS 2003 and JJAS 2004, over (a) central Sahel , (b) West Sahel, (c) Guinea and (d) West Africa derived from dry (ΔDC) and wet (ΔWC) experiments compared to their corresponding control experiment.

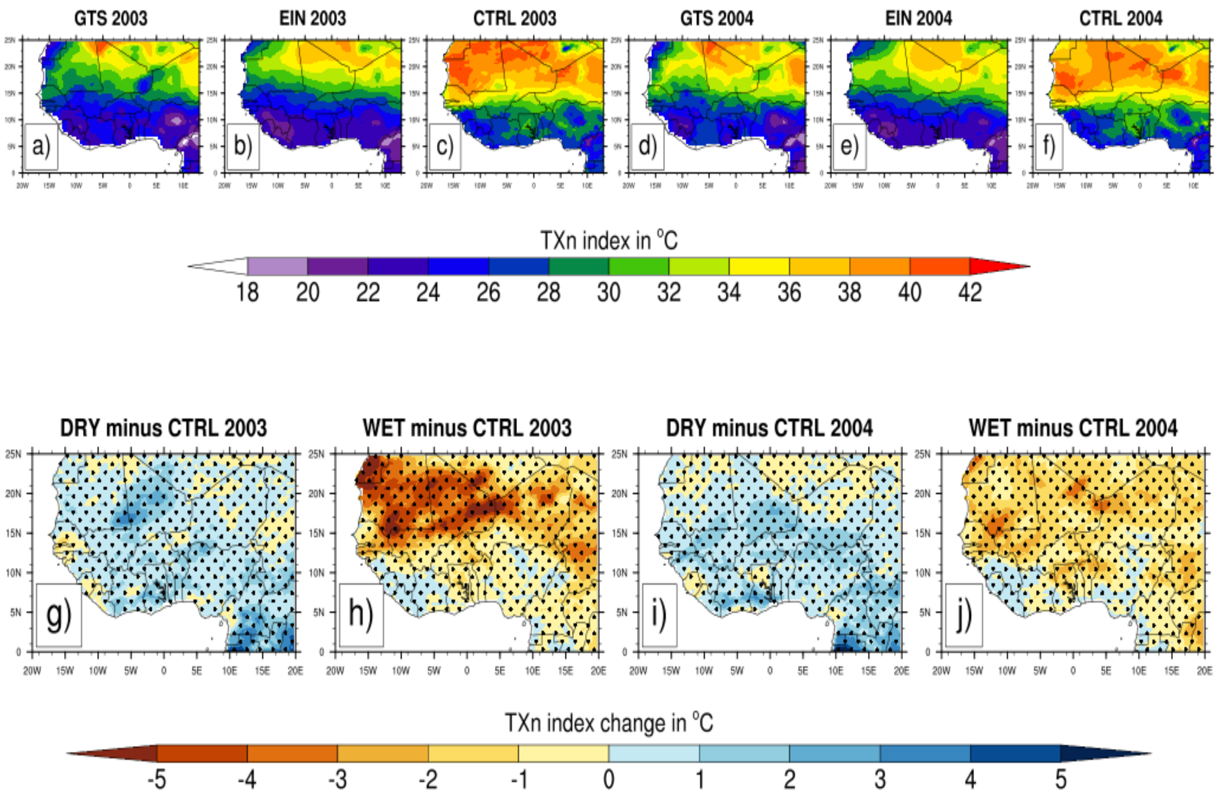

Figure 16: Same as Fig. 14 but for the TXn index

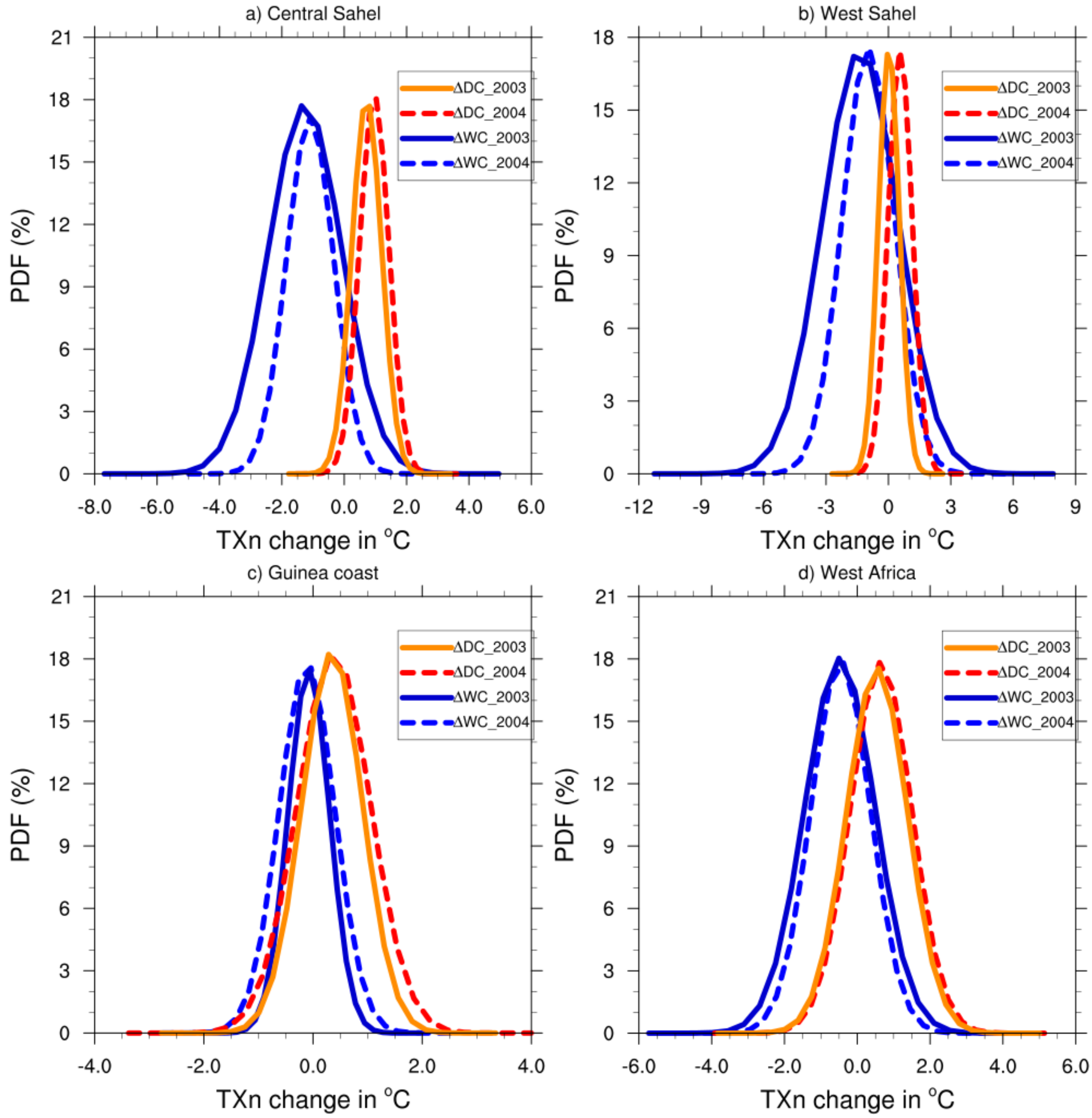

Figure 17: Same as Fig. 15 but for the TXn index.

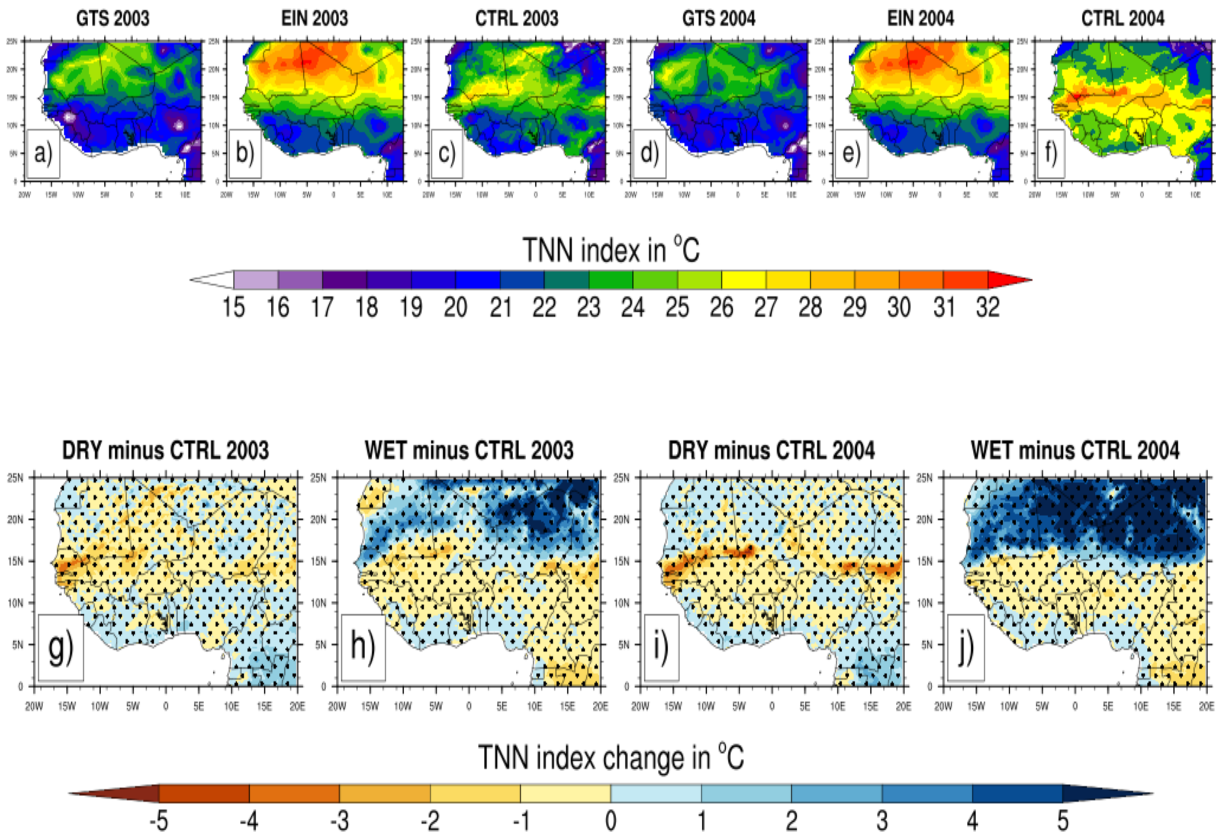

Figure 18: Same as Fig. 14 but for the TNn index.

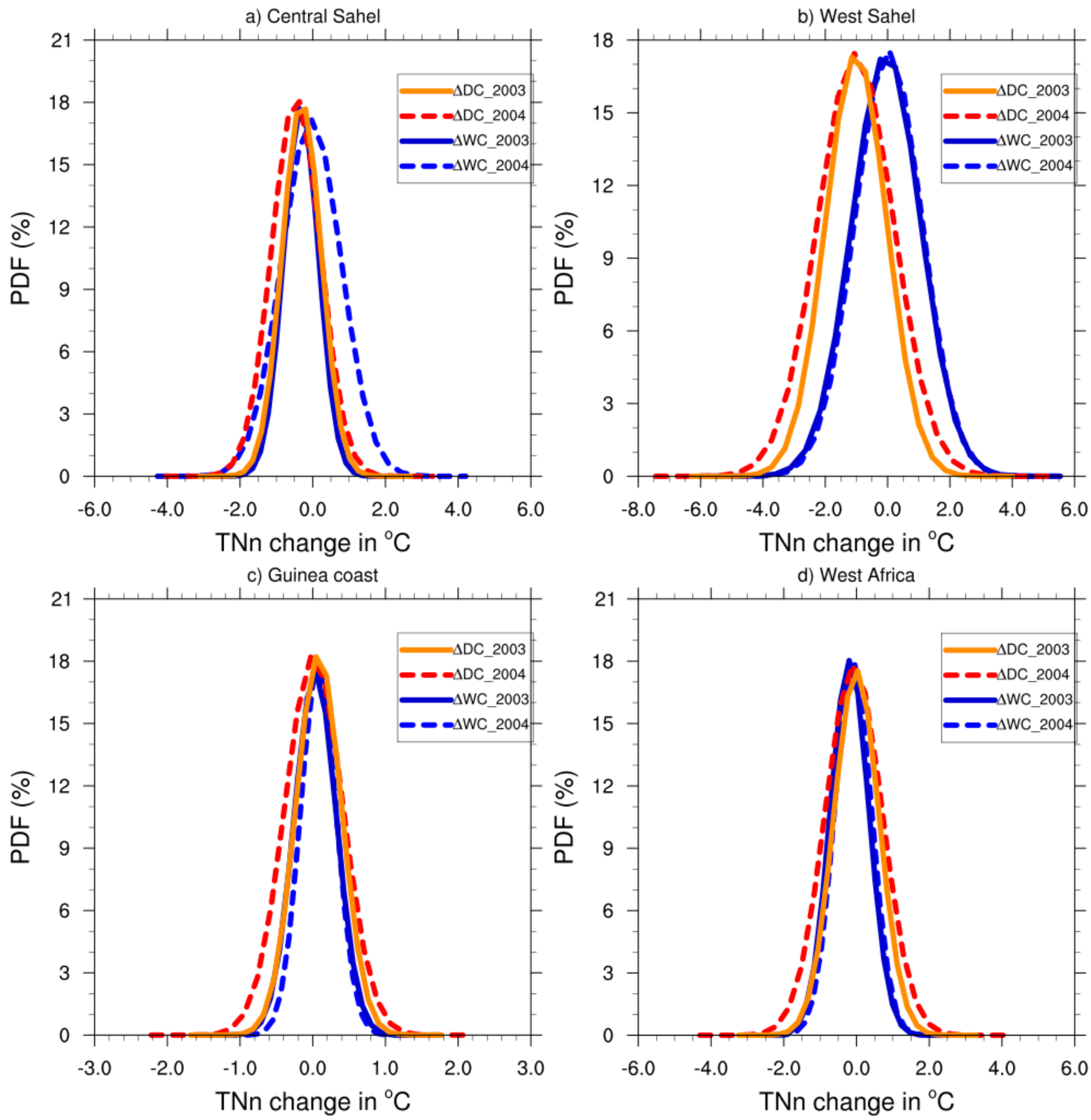

Figure 19: Same as Fig. 14 but for the TNn index.

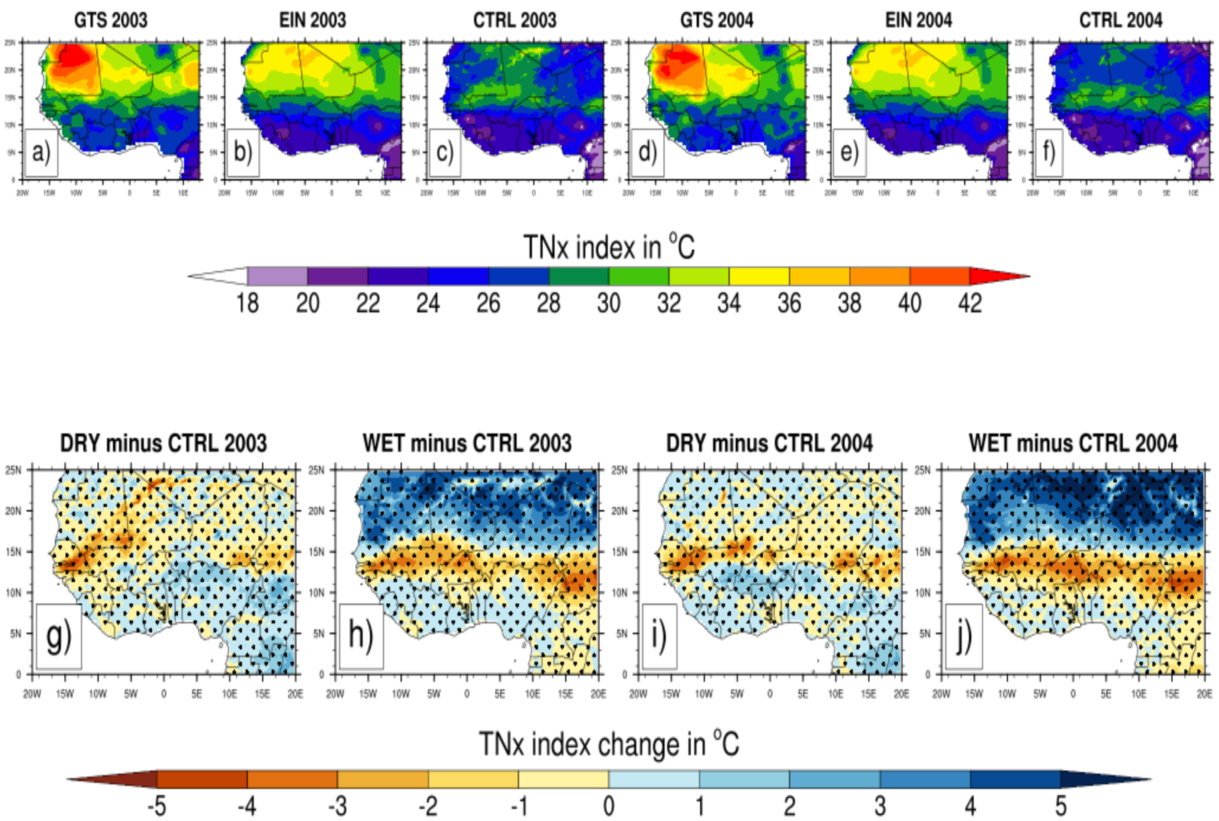

Figure 20: Same as Fig. 14 but for the TNx index

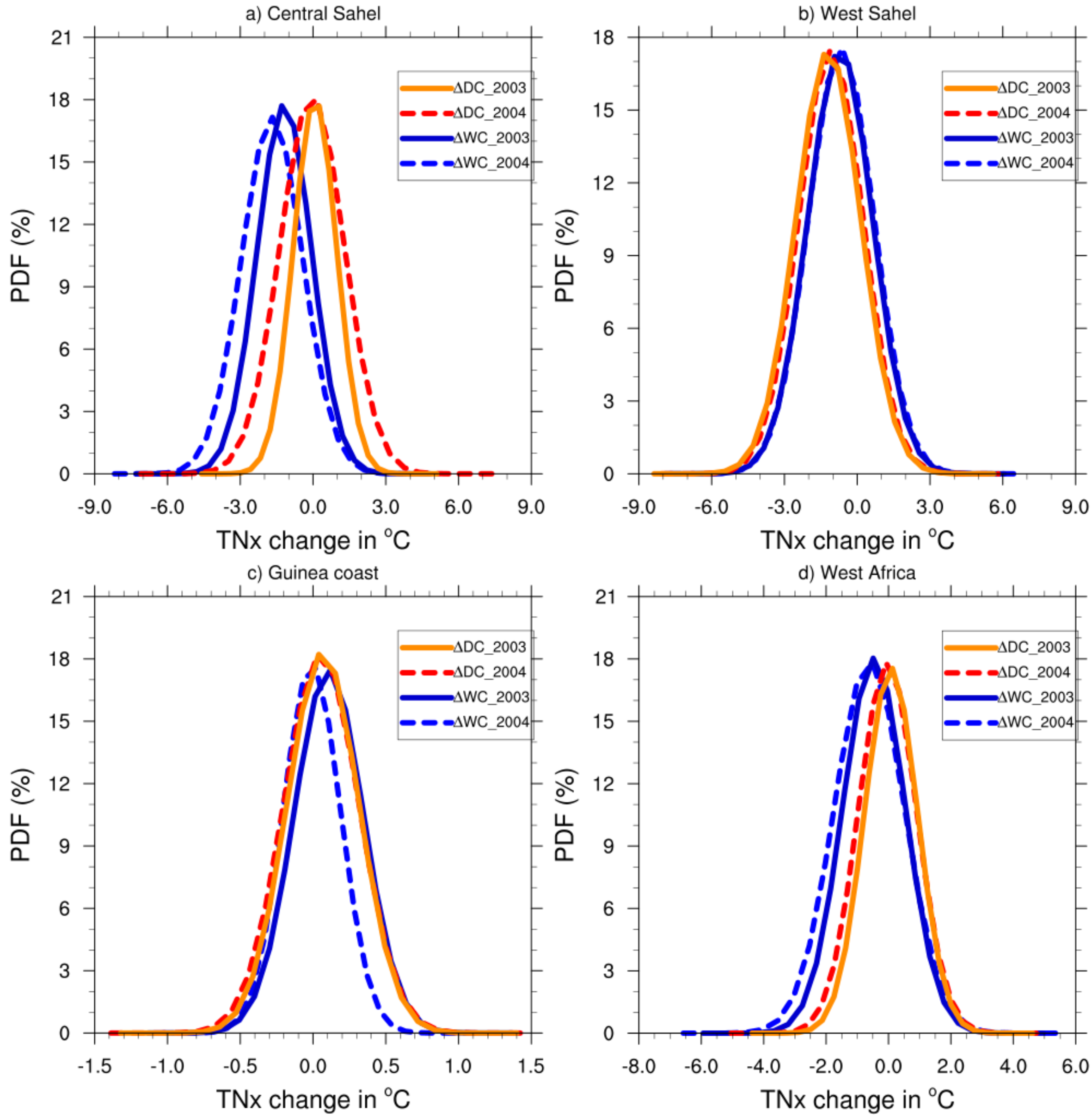

Figure 21: Same as Fig. 15 but for the TNx index.