Potential effect of bias correction on extreme precipitation and temperature changes over Senegal River Basin (West Africa)

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Abstract

In recent climate change impact studies, bias correction is often used to overcome the well-known biases in global and regional models output. This study assesses the potential impact of bias correction on extreme precipitation and temperature of the Regional Climate Model REMO over the Senegal River Basin under the representative concentration pathways (RCP4.5 and RCP8.5). Changes in climate indices are analyzed with uncorrected and bias corrected simulations over the 21st century relative to the reference period (1971-2000). The results show in general a decrease of consecutive wet days (CWD) and an increase in the length of consecutive dry days (CDD) although slight increase of heavy rainfall is found particularly in the northern basin with similar spatial patterns of both data. Higher decadal variability of the maximum 5-day precipitation with the uncorrected in RCP8.5 is projected, while both data depicted similar variability for extremely wet days. The basin is likely to experience more warming of minimum temperature than maximum temperature. The bias correction affected mainly the magnitude of the climate change signal which was lower in the bias corrected data.

Keywords: Bias correction technique, extreme events, temperature, precipitation, climate change, Senegal River Basin

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1. Introduction

The recurrence of droughts in West Africa, has led to a significant decline of water flows in many river basins. Rivers constitute the main water resource for drinking, irrigation, and industrial purposes in inland areas (Mouri et al., 2011). Africa is one of the most vulnerable continents due to its high exposure and low adaptive capacity (IPCC, 2014). The impacts of climate change over West Africa have increased its vulnerability in critical sectors such water resources, agriculture, health, etc. Studies on extreme climate over the region have shown an increase in extreme events (Karambiri *et al*. 2011, Ly *et al*. 2013, Sillmann *et al*. 2013, Klutse *et al*. 2015). Changes in river discharge are almost twice than those in precipitation over four large African river basins (Limpopo, Niger, Ubangi, and Upper Blue Nile) according to Aich et al. (2014). A comparison of lot a studies by several time slices has revealed that the impacts of climate change are more pronounced in the late 21st century by the rising greenhouses gases concentrations (Roudier et al. 2014). Ruelland et al. (2012) found a considerable decrease of rainfall and continuing increase of potential evapotranspiration that is likely to reduce runoff in the Bani catchment towards the 21st century. A probable intensification of droughts events is expected for the period 2020-2040 by Faramazi et al. (2013) through an increase of dry days and the frequency of their occurrences. Furthermore, over Burkina Faso Ibrahim et al. (2014) have found an increase of heavy rainfall events that are greater than 50 mm towards the mid-century.

In recent climate impact studies, the use of Regional Climate Models (RCMs) is gaining interest due to their high resolution and their ability to represent the main climate features over hot spot regions of complex climate such as West Africa. Although RCMs have considerable added value when compared to General Circulation Models (GCMs) that are well known for their coarse resolutions, they biases were underlined by several authors (Roosmalen *et al*.,2011; Gbobaniyi *et al*., 2013, Muerth *et al*., 2013). The biases in the regional climate model simulations can rise from shortcomings of the RCMs themselves, but also from erroneous forcing data as it was suggested by Schoetter et al. (2012). Then, bias correction is widely used to improve climate models output. However, there is lack of understanding the impact of statistical post-processing on extreme climate at the basin scale. Then, our study attempt to address the issue of bias correction effect on extreme precipitation and temperature changes over the Senegal River Basin. This is capital to inform stakeholders and water resources managers in order to increase awareness and to support the development of adaptation strategies.

Description of the data and methods used in this paper are given in Section 2. In Section 3 we present the results; section 4 exhibits the discussion, and finally the conclusion is given in section 5

2. Materials and methods

2.1. Senegal River Basin

The Senegal River Basin is located in Western Africa. From its source in Guinea it flows through the western Sahel region in Mali, Mauritania and Senegal (Figure 1). Its catchment is about 300.000 km2 (OMVS, 2009) and it has a length of 1800 km. The basin is subject to a large north–south precipitation gradient ranging from 150 mm/year in the north to more than 1800 mm/year in the south.

Temperatures go up to more than 40 degree Celsius in the northern basin and to 14°C in the Fouta Djalon Mountains (South).The predominantly natural vegetation of the region follows this rainfall gradient, ranging from semi-arid savannah in the north to sub-humid forest in the south (Stisen *et al*., 2008).

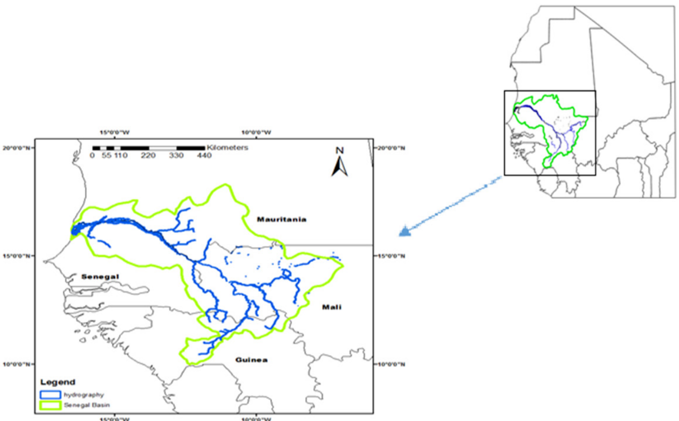

Figure 1: Senegal River Basin (SRB)

2.2 Datasets

Daily uncorrected and bias corrected climate model simulations (daily precipitation, minimum and maximum temperatures) from the Regional Climate Model REMO from 1971 to 2100 were used in this study. The REMO simulations were forced with data from the global climate model MPI-ESM-LR (Stevens *et al.,* 2013) following the newly developed representative concentration pathways (RCP4.5 and RCP8.5) emission scenario in the context of the Coordinated Regional Climate Downscaling Experiment (CORDEX, Giorgi et al., 2009) over Africa. The climate model output has been bias corrected following Piani et al. (2010) approach. The bias correction was based on a fitted histogram equalization where the corrected variable is a function of the modelled counterpart and the derived transfer function is such that the intensity histogram of the corrected variables matches the intensity histogram of the observed one (Piani et al., 2010). The Water and Global Change (WATCH) forcing data methodology applied to ERA-interim reanalysis data known as WFDEI based on the work of Weedon et al. (2014) were used to bias correct the REMO output.

The following equations were used to bias correct precipitation andtemperature:

In the case of precipitation, the following transfer functions (TFs) were used:

$$P_{cor} = a + bP \quad (1)$$

$$\ln(P_{cor}) = a + b\ln(P - P_0) \quad (2)$$

$$P_{cor} = (a + bP)(1 - e^{(-(P-P_0)/\tau)}) \quad (1)$$

Where P_{cor} represents the bias corrected precipitation, P is a given value to be corrected and, a, b, P_0 and τ are fit parameters and ln represents the natural logarithm. In the linear equation (1), the coefficients a, and b are respectively additive and multiplicative correction factors. P_0 is the value of precipitation below which modeled precipitation is set to zero. Equation (2) is expressed as a linear relation between the logarithms; and Equation (3) is composed by an exponential that tends to a linear asymptote (a+bP); τ is the rate at which the asymptote is approached and P_0 is the dry day correction term.

For temperature, the bias correction is done in mean daily temperature (T_{mean}), minimum (T_{min}) and maximum (T_{max}) daily temperatures. The bias correction is done by correcting directly $T_{min,}$ T_{max} and T_{mean}, the diurnal range (ΔT) and the skewness (σ) defined as follow:

$$\Delta T = T_{max} - T_{min} \quad (4)$$

$$\sigma = (T_{mean} - T_{min})/\Delta T \quad (5)$$

2.3 Simulations analyses

The analyses are mainly focused on extreme climate indices as such the maximum consecutive wet days (CWD), the maximum consecutive dry days (CDD), the heavy rainfall events (95th percentile), the maximum 5-day precipitation total and the extremely wet days (99th percentile). A day is assumed wet or dry when rainfall is greater or less than 1mm, respectively. The 1mm threshold is commonly used in most climate change studies for calculating extreme climate indices (Sillmann et al., 2013, Piani et al., 2010, Ly et al., 2013, Ibrahim et al., 2013, Kluste et al., 2015, Zhang et al., 2011, Sylla et al., 2015, Déqué et al., 2017, Mbaye et al., 2015, etc.)

The changes of CWD and CDD represent the difference between the scenario period (2071-2100) and the reference period (1971-2000). The changes are focused on the end of 21st century because substantial changes are expected during the late century as it was suggested by Roudier et al. (2014) and Aich et al. (2014). For the 95th and 99th percentiles, the rainfall values that exceed these percentiles are considered for the analysis. As for extreme temperatures, the percent's of warm days and warm nights were computed by taking the values of maximum temperature and minimum temperature at the scenario period that are above the 90th percentiles of these temperatures in the reference period. Additionally the decadal variability is computed by 10 years running standard deviation from 2006 to 2100. The temporal variations are obtained by an average over the whole SRB.

3. Results

3.1 Changes in extreme precipitation

Figure 2 displays the changes in maximum consecutive wet days (CWD), maximum consecutive dry days (CDD) and the frequency of heavy rainfall at the end of 21st century (2071-2100) that are above the 95th percentile of rainfall during the present day (1971-2000). This figure shows a clear decrease of wet days length (up to 20 days) and an increase of dry days to more than 35 days. The increase of length of consecutive dry days is more pronounced in the northern basin which is the driest and hottest part of the Senegal basin than the southern basin. However, this part of the basin is likely to face the highest frequency of heavy rainfall (12 %) eventhough there is prolonged dry spells.

In order to investigate the decadal variability of extreme precipitation, the 10 years running standard deviation of the maximum 5-days total precipitation and the extreme wet days (99th percentile) are shown in Figure 3.

The bias correction highy reduced the total 5-day precipition from present day climate to end of 21st century when comapred to uncorrected simulations. Both data depict a decadal variability that is more amplified with raw data in the extreme scenario (up to 36 mm). The variability is higher during the decades 2011-2021, 2041-2051, 2061-2071 and 2071-2081 with RCP8.5. As for RCP4.5, the most substantial variations are found after mid century to 2081 (maximum reached at 39 mm) with original climate model output. The bias correction somewhat mismatches the magnitude of the decadal variability of accumulated precipitation.

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Furthermore, the extreme wet days are likely to be more variable

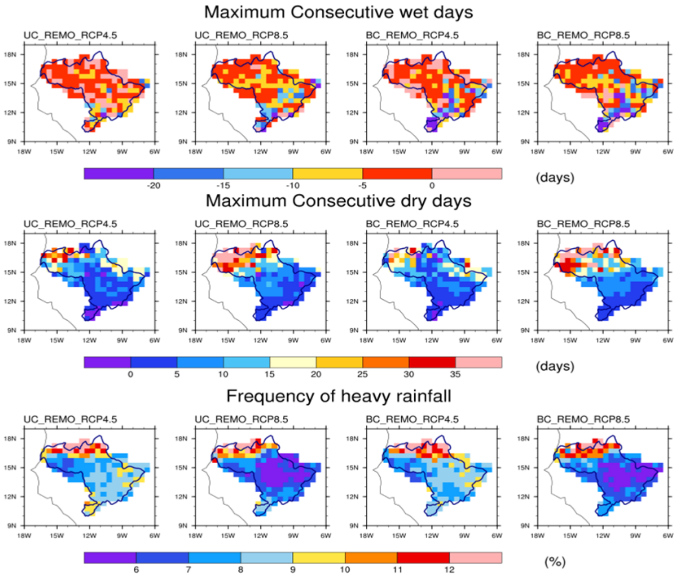

Figure 2: Projected CWD, CDD and frequency of heavy rainfall above the 95th percentile

(up to 2.8 %) during the decades 2021-2031, 2061-2071, 2081-2091 with RCP8.5 for both data. Additionally, in RCP4.5 the decadal variability is projected to be more important from 2061 to 2081 for all simulations. In this later result the bias corection does not alter the climate change signal as found by Mbaye et al. (2015).

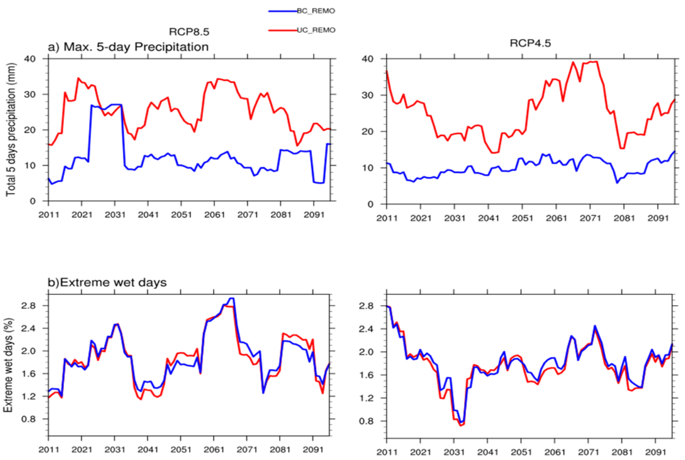

Figure 3: (a) 10 years running standard deviation of maximum 5-days total precipitation and (b) extreme wet days (99th percentile)

3.2 Future evolution of extreme temperature

The warm days (Figure 4a) and nights indices (Figure 4b) exhibit considerable increase of up to 95% towards the end of century in the extreme scenario. The increase in this later scenario (70-95%) is almost twice as much as that in RCP4.5 (40-65%) for both warmings and more pronounced from the central to southern part of the basin. It should be noted that the higher the radiative forcing the more substantial the changes; this confirms the work of Sillmann et al. (2013).

The uncorrected data show the highest increase of warming days and nights. With regards to the range between warm days and nights (Figure 4c), it varies from -10 to 0%. These negative values indicate that the percent of warm nights is greater than the percent of warm days. This means that minimum temperature increases faster than maximum temperature as found by Sillmann et al. (2013).These spatial findings are also confirmed in their temporal variations (from 2006 to 2100) as shown in Figure 5. The projected warm days and warm nights depicted an increase towards the end of century with substantial interannual variations (15-95 %). This warming was also observed by Ly et al. (2013) over West Africa from 1960 to 2010. The general warming is greater in the extreme RCP8.5 scenario (with a maximum of 95%) than in RCP4.5 (with a higher of 60%).

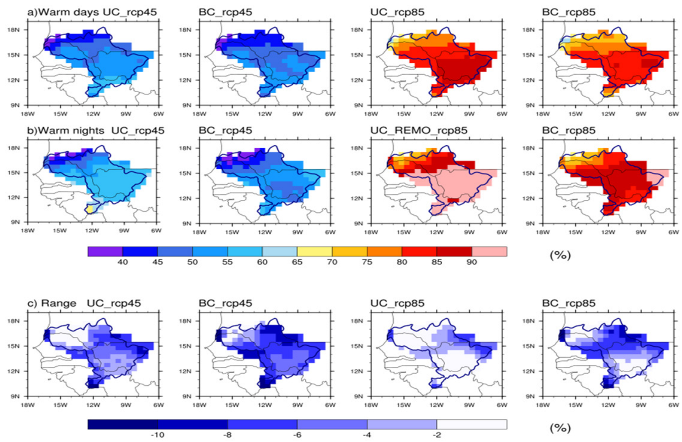

Figure 4: Spatial Percent of (a) warm days, (b) warm nights and (c) their range

The global increase in warm nights and warm days could lead to increase water losses through evaporation that reduce soil water content in this semi-arid region which depends highly on crop productivity. The higher evaporation rate will lead to more atmospheric water vapor which generate cloud by condensation; the increase of cloudiness will in turn increase also minimum temperature during nighttime and decrease maximum temperature during daytime. This general warming confirms the work of Ly et al. (2012) and Sillmann et al. (2013) over West Africa.

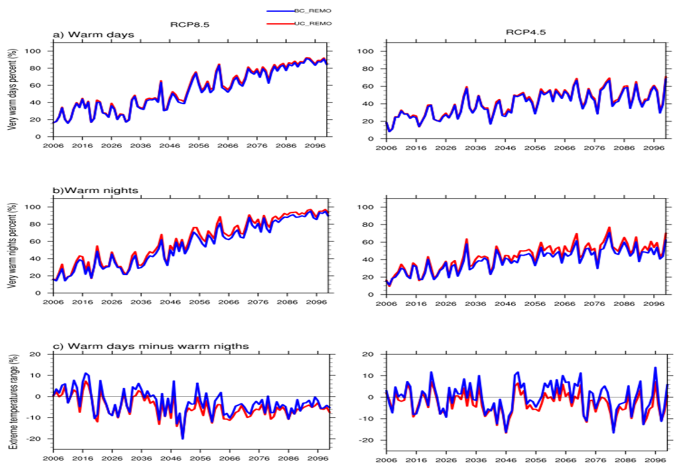

Figure 5: Interannual Percent of (a) warm days, (b) warm nights and (c) their range

4. Discussion

The northern basin (Figure 2) is likely to experience the highest frequency of heavy rainfall (12 %) eventhough there is prolonged dry spells as found by Vizy and Cook (2012). This later findings was also pointed out by Klutse et al. (2015) over West Africa. The decrease of wet days and the increase of dry days can be due to limited moisture in this dry and hot region (Sahel). This limited moisture availability influences the local evaporation that is found to be the origin of about 27% of the precipitation over West Africa (Gong and Eltahir 1996).

The spatial patterns of the projected climate change signals are similar between uncorrected and bias corrested data althought slight deviations exist in term of magnitude. Thus, rainfall is likley to dercerase towards the end of 21st century with a slight increase of extreme events. The severe precipitation decline over the northern basin can be related to the weakness of the monsoonal flow which does not move far enough northward. This decrease is similar to that found by Laprise et al. (2013) over West Africa. The drastic decrease of wet days over the northern basin might be related to the strengthening of warm and dry air advection from the Sahara.

Therefore apart from the dampening effect of the bias correction on the largest 5-day precipitation total (Figure 3), accentuated decadal variability is projected in the coming decades. This could increase the uncertainty in potential flood risks because extreme hydrological events are usually preceded by several heavy rainfall events. These results show also that the radiative forcing that is related to the green house gases emission, have an important impact on the projected climate change signals. Addionally, the basin's drying could be the result of the weakness of the monsoon due to more warming in global tropical oceans and particularly to the warming of the southern Atlantique that reduce the trade winds which transport moisture northward. The increase of extreme events over the region was suggested by Giannini et al. (2013) by using CMP3 and CMIP5 simulations.

The warming with uncorrected data seems to be higher than the warming of bias corrected data in all scenarios (Figure 5). This suggests the cooling effect on statistical post-processing on temperature. The warm range (Figure 5c) in RCP8.5 shows a decreasing range particularly in the three last decades of the century. With regards to the RCP4.5, there is no clear tendency of decreasing or increasing warm range although in some periods it increases (e.g 2056-2066) and seems to decrease from 2076 to 2090. Moreover, the projected climate signals is not changed by the statistical bias correction technique.The faster increase of minimum temperature may be due to the higher effect of green house gases in absorbing infrared radiation during nights.

It has to be mentioned that the bias correction has the potential to alter the projected patterns of extreme precipitation and temperature; this is not limited to this study or region but has been shown for other catchments, e.g. Hurkmans et al. (2010) have underlined an alteration of the spatial pattern of precipitation and temperature over the Rhine Basin due to bias correction. In general the bias correction does not alter considerably the projected sign of the signal as has been shown for other regions of the globe (Hagemann et al., 2011) and also conserved the larger scale spatial structure of the projected changes.

5. Conclusion

This study has been focused in the future evolution of extreme precipitation and temperature by using uncorrected and bias corrected REMO simulations over the Senegal River Basin. More prolonged dry spells were found in combination with decreased length wet days for both data. These findings indicate probable meteorological drought over the basin. Moreover, the basin is likely also to face more decadal variability in extremely wet days and accumulated 5-days precipitation, pronounced with uncorrected data with the extreme scenario. As for extreme temperatures, a general warming was well noticed. This warming has revealed that warm nights will increase more than warm days towards the end of century which indicate that minimum temperature increase faster than maximum temperature. The results exhibited that the changes are more substantial with the intensification of the radiative forcing. The increase of dry days and the general warming will enhance more the drying of the basin and could have severe consequences on the economies of the basin's population that is predominantly rural. As for the effect of the bias correction, it mainly affects the magnitude of the climate change signal rather than the direction of changes. Due to model uncertainty and post-processing technique uncertainty of model output, further climate modeloutputs and bias correction techniques are required.

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References

Aich, V., Liersch, S., Vetter, T., Huang, S., Tecklenburg, J., Hoffmann, P., Koch, H., Fournet, S., Krysanova, V., Müller, E. N., and Hattermann, F. F. (2014) Comparing impacts of climate change on streamflow in four large African river basins. *Hydrology and Earth System Sciences*, 18, 1305-1321. http://dx.doi.org/10.5194/hess-18- 1305

Déqué M, Calmanti S, Christensen OB, Aquila AD, Maule CF, Haensler A, Nikulin G and Teichmann C, 2017. A multi-model climate response over tropical Africa at +2◦C Clim. Serv. 7 87–95

Faramarzi, M., Abbaspour, K. C., Ashraf Vaghefi, S., Farzaneh, M. R., Zehnder, A. J. B., Srinivasan, R., and Yang, H. (2013) Modeling impacts of climate change on freshwater availability in Africa. *Journal of Hydrololgy*, 480, 85–101. http://dx.doi.org/10.1016/j.jhydrol.2012.12.016

Gbobaniyi E, Sarr A, Sylla MB,Diallo I, Lennard C, Dosio A, Dhiédiou A, Kamga A, Klutse N A B, Hewitson B, Nikulin G and Lamptey B, 2013. Climatology, annual cycle and \interannual variability of precipitation and temperature in CORDEX simulations over West Africa. *Int. J. Climatol*. **4**: 2241–2257. http://dx.doi.org/10.1002/joc.3834.

Giannini A, S Salack, T Lodoun, A Ali, A T Gaye, O Ndiaye., 2013. A unifying view of climate change in the Sahel linking intra-seasonal, interannual and longer time scales. *Environmental Research Letters* 8, 024010.

Giorgi F, Jones C, Asrar G. 2009. Addressing climate information needs at the regional level: the CORDEX framework. *World. Meteorol. Org. Bull*. **58,** 175-183. http://wcrp.ipsl.jussieu.fr/RCD_Projects/CORDEX/CORDEX_giorgi_WMO.pdf

Gong, C., and E. A. B. Eltahir., 1996. Sources of moisture for rainfall in West Africa, *Water Resources Research*, 32(10), 3115–3121.

Hagemann, S., Chen, C., Haerter, J. O., Heinke, J., Gerten, D., Piani, C., 2011. Impact of a Statistical Bias Correction on the Projected Hydrological Changes Obtained from Three

GCMs and Two Hydrology Models. J*ournal of Hydrometeorology*, 12, 556– 578.

http://dx.doi.org/10.1175/2011JHM1336.1

Hurkmans, R. T. W. L., Terink, W., Uijlenhoet, R., Torfs, P. J.

J. F., Jacob, D., and Troch, P. A., 2010. Changes in streamflow dynamics in the Rhine basin under three high-resolution climate scenarios, J. Climate, 23, 679–699, doi:10.1175/2009JCLI3066.1.

Ibrahim B, Polcher J, Karambiri H, Yacouba H, Ribstein P, 2014. Changes in rainfall regime over Burkina Faso under the climate change conditions simulated by 5 regional climate models. *Clim Dyn*, 42:1363–1381. DOI 10.1007/s00382-013-1837-2

IPCC, 2014. Climate Change: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. *Cambridge University Press*, Cambridge,United Kingdom and New York, NY, USA

Karambiri H, Garcıa Galiano SG, Giraldo JD, Yacouba H, Ibrahim B, Barbier B, Polcher J,2011. Assessing the impact of climate variability and climate change on runoff in West Africa: the case of Senegal and Nakambe River basins. *Atmos. Sci. Lett.* **12**:109-115. http://dx.doi.org /10.1002/asl.317.

Klutse N. A.B, Sylla MB, Diallo I, Sarr A, Dosio A, Diedhiou A, Kamga A, Lamptey B, Ali A, Gbobaniyi EO., Owusu K, Lennard C, Hewitson B, Nikulin G, Panitz H.J, Büchner M, 2015. Daily characteristics of West African summer monsoon precipitation in CORDEX simulations. Theor Appl Climatol, DOI 10.1007/s00704-014-1352-3

Laprise R, Hernandez-Dıaz L, Tete K, Sushama L, Separovic L, Martynov A,

Winger K, Valin M., 2013. Climate projections over CORDEX Africa domain using the fifth- generation Canadian Regional Climate Model (CRCM5), *Clim Dyn* 41:3219– 3246 DOI 10.1007/s00382-012-1651-2.

Ly Mouhamed , Seydou B. Traore, Agali Alhassane , Benoît Sarr, 2013. Evolution of some observed climate extremes in the West African Sahel. *Weather and Climate Extremes.1:19-25.* doi:10.1016/j.wace.2013.07.005

Mbaye, M. L., Haensler, A., Hagemann, S., Gaye, A. T., Moseley, C. and Afouda, A.,

2015. Impact of statistical bias correction on the projected climate change signals of the regional climate model REMO over the Senegal River Basin. Int. J. Climatol.doi: 10.1002/joc.4478

Mouri, G., Takizawa, S., Oki, T., 2011. Spatial and temporal variation in nutrient parameters in stream water in a rural–urban catchment, Shikoku, Japan: effects of land cover and human impact. J Environ Manage. 92(7):1837-48. doi: 10.1016/j.jenvman.2011.03.005.

Muerth, M. J., Gauvin St-Denis, B., Ricard, S., Velázquez, J. A., Schmid, J., Minville,

M., Caya, D., Chaumont, D., Ludwig, R., and Turcotte, R. , 2013. On the need for bias correction in regional climate scenarios to assess climate change impacts on river runoff, Hydrol. Earth Syst. Sci., 17, 1189-1204, https://doi.org/10.5194/hess-17-1189-2013

OMVS, 2009. Sdage du fleuve Sénégal, rapport de phase 1 : état des lieux et diagnostic. Version finale, décembre, 457pp

Piani C, Weedon GP, Best M, Gomes S, Viterbo P, Hageman S, Haerter JO, 2010. Statistical bias correction of global simulated daily precipitation and temperature for the application of hydrological models. *J. Hydrol.* **395**:199–215.

http://dx.doi.org/10.1016/j.jhydrol.2010.10.024.

Roosmalen V, Lieke S, Torben OJ, Karsten HC, Roosmalen JH, 2011. Comparison of Hydrological Simulations of Climate Change Using Perturbation of Observations and Distribution-Based Scaling. *Vadose Zone J.* **10**:136–150. http://dx.doi.org/10.2136/vzj2010.0112.

Roudier P, Ducharne A, Feyen L., 2014. Climate change impacts on runoff in West Africa: a review.*Hydrol. Earth Syst. Sci.,* 18, 2789–2801. doi:10.5194/hess-18-2789-2014

Ruelland, D., Ardoin-Bardin, S., Collet, L., and Roucou, P., 2012. Simulating future trends in hydrological regime of a large Sudano–Sahelian catchment under climate change. *Journal of Hydrology*, 424– 20 425, 207– 216. http://dx.doi.org/10.1016/j.jhydrol.2012.01.002

Schoetter R, Hoffmann P, Rechid D, Heinke Schlünzen K., 2012. Evaluation and Bias Correction of Regional Climate Model Results Using Model Evaluation Measures. J. Appl. Meteor. Climatol., 51, 1670–1684.

Sillmann, J.,V.V.Kharin, F. W. Zwiers,X. Zhang, and D. Bronaugh, 2013. Climate extremes indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections, J. Geophys. Res. Atmos., 118, 2473–2493, doi:10.1002/jgrd.50188

Stevens, B., Giorgetta, M., Esch, M., Mauritsen, T., Crueger, T., Rast, S., Salzmann, M., Schmidt, H., Bader, J., Block, K., Brokopf, R., Fast, I., Kinne,S., Kornblueh, L., Lohmann, U., Pincus, R., Reichler., Th., Roeckner, E, 2013. The atmospheric component of the MPI-M earth system model: ECHAM6. *Journal in Advances Modeling Earth System, 5, 146–172.* http://dx.doi.org/10.1002/jame.20015

Stisen S, Karsten H, Jensen, Inge S, David IF, Grimes, 2008. A remote sensing driven distributed hydrological model of the Senegal River basin. Science Direct: *J. Hydrol*. **354**:131– 148. http://dx.doi.org/ 10.1016/j.jhydrol.2008.03.006

Sylla M.B., F. Giorgi, J.S. Pal, P. Gibba, I. Kebe, M. Nikiema, 2015. Projected\changes in the annual cycle of high-intensity precipitation events over West Africa for the late twenty-first century J. Clim., 28 pp. 6475-6488

Vizy, E.K., and Kerry H. Cook., 2012. Mid-Twenty-First-Century Changes in Extreme Events over Northern and Tropical Africa. *J. Climate*, 25, 5748–5767.

Weedon GP, Balsamo G, Bellouin N, Gomes S, Best MJ, *and* Viterbo P, 2014. The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data. *Water Resour. Res*. **50:**7505–7514.

http://dx.doi.org/10.1002/2014WR015638

Zhang, X., L. Alexander, G. Hegerl, P. Jones, A. Klein Tank, T. C. Peterson, B. Trewin, F.W.

Zwiers, 2011. Indices for monitoring changes in extremes based on daily temperature and precipitation data. Wiley Interdisciplinary Reviews – Climate Change, doi:10.1002/wcc.147