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The intensification of thermal extremes in west Africa

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ABSTRACT

This study aims in filling the gap in understanding the relationship between trend and extreme in diurnal and nocturnal temperatures (Tx and Tn) over the Gulf of Guinea area and the Sahel. Time-evolution and trend of Tx and Tn anomalies, extreme temperatures and heat waves are examined using regional and station-based indices over the 1900–2012 and 1950–2012 periods respectively. In investigating extreme temperature anomalies and heat waves, a percentile method is used. At the regional and local scales, rising trends in Tx and Tn anomalies, which appear more pronounced over the past 60 years, are identified over the two regions. The trends are characterized by an intensification of: i) nocturnal/Tn warming over the second half of the 20th century; and ii) diurnal/Tx warming over the post-1980s. This is the same scheme with extreme warm days and warm nights. Finally annual number of diurnal and nocturnal heat waves has increase over the Gulf of Guinea coastal regions over the second half of the 20th century, and even more substantially over the post-1980s period. Although this trend in extreme warm days and nights is always overestimated in the simulations, from the Coupled Model Intercomparison Project Phase 5 (CMIP5), those models display rising trends whatever the scenario, which are likely to be more and more pronounced over the two regions in the next 50 years.

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1. Introduction

Post-1970s warming temperatures over West Africa, and in particular over the Sahel, have been reported somewhat faster than at the global scales (ECOWAS-SWAC/OECD/CILS, 2008; Hulme, 2001): Saharo–Sahelian, Sahelian and Sudano–Sahelian temperatures have risen by between 0.2 °C and 0.8 °C. Current state-of-the-art CMIP5 coupled models (Taylor et al., 2012) are reasonably consistent in predicting warm conditions over West Africa, but there are large discrepancies in terms of intensity of changes (Stocker et al., 2013). According to the last report of the Intergovernmental Panel on Climate Change, land areas might warm by as much as 1.6 °C by 2050 over the Sahara and semi-arid parts of southern Africa (Stocker et al., 2013).

At the global scale, Braganza et al. (2004), have reported a decrease in daily temperature range (i.e., maximal/diurnal minus minimal/nocturnal daily temperatures [Tx-Tn]), which is characterized by greater rises in minimal/nocturnal temperatures (Tn) than in maximal/diurnal temperatures (Tx). According to Stone and Weaver (2002), the observed decrease in daily temperature range could be the climate system's response to the increase in greenhouse-gas concentrations in

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the atmosphere. However, such a discrepancy in between the trend of Tx and Tn trend have never been studied over the West-African regions. In addition, as proposed at the global scale (e.g., Christensen et al., 2007; Pachauri and Reisinger, 2008; Stocker et al., 2013), warming temperatures is likely to contribute in increasing occurrences of extreme temperatures, as well as heat wave (HW) events. For instance, at the global scale, Meehl (2004) noted that warming nocturnal temperatures is associated with an increase in the number of HWs.

HWs have been defined as a period of consecutive days where conditions are excessively hotter than normal at that time of the year. There is therefore no universal definition of heat waves, and many definitions could apply depending on the study region (Meehl, 2004; Alexander et al., 2006; Donat et al., 2013). Since the Chicago HW of July 1995 and that of Western Europe in August 2003 – both followed by supernumerary rises in death rates – such events have been extensively studied in the mid-latitudes of the Northern Hemisphere (e.g., Beniston and Diaz, 2004; Bessemoulin et al., 2004; Black et al., 2004; Trigo et al., 2005). Extreme heat events in the tropics have been much less studied, even though it also concerns the tropical areas, as shown by the extreme heat experienced in Niamey in April 2010 (daily Tx overtaking 44.5 °C from 18 till 22 April). This event had significant effects on agriculture, hydrological processes and health of populations. HWs can indeed be accompanied by increased rates of atmospheric pollution. Air pollution is a major threat to population health, as it is the cause of a number of respiratory and cardiovascular diseases (World Health Organization, 2002).

This study aims in filling the gap in understanding the relationship between trend and extreme in diurnal and nocturnal temperatures (Tx and Tn) over the Gulf of Guinea area (4°–10°N; 10°W–10°E; cf. Fig. 1) and the Sahel (10°–20°N; 10°W–10°E; cf. Fig. 1). This study also helps to determine whether this relationship, which is here discussed through seasonal fluctuations, is different from that reported at the global scale. For instance, are the trend greater in Tn than in Tx, and are this associated with an increase of nocturnal HWs. In addition, potential definition of thermal extreme and HW indices will be discussed for the Gulf of Guinea coastal regions and the Sahel. Data and methods are described in Section 2. We then present the seasonal temperature fluctuations in the West African region, before to focus on two regions: the Gulf of Guinea (Abidjan) coastal regions and the Sahel (Niamey). In Section 3.1, time-evolution and trend of Tx and Tn anomalies during the 20th century is investigated. In Section 3.2, we focus on the extreme values in the seasonal temperature anomalies through different indices, which allow to examine the time-evolution and trend of HWs. Finally, in Section 3.3, observed trends of extreme heat events are compared to those simulated by the global climate models from the CMIP5.

2. Data and methods

2.1. Data

We use National Centers for Environmental Prediction/National Center for Atmospheric Research Reanalysis data (NCEP/NCAR-1; Kalnay et al., 1996), with a horizontal resolution of 2.5° × 2.5°, to represent the seasonal evolution of mean temperatures (at 2 m above the ground) over West Africa between 1951 and 1980 (i.e., baseline period of seasonal temperature anomalies in Sections 3.1–3).

Tx and Tn trends are analysed at the regional and local scales. At the regional scale, the daily homogenised Berkeley Earth Surface Temperatures (BEST) observation data set has been used. Between 1900 and 2012, these data show daily Tx and Tn anomalies with a spatial resolution of 1° × 1° (Rohde et al., 2013). These daily anomalies were calculated by subtracting for each day its monthly climatology (i.e., the monthly mean) with respect to the 1951–1980 base period. Gridded temperature anomalies from BEST are derived from, approximately, 39,000 weather stations distributed around the world, which is five times more than other data sets (e.g., CRU/Hadley Centre, NCDC/NOAA and GISS/NASA). Despite this, density of observation network remains an intractable problem over the Sahara. A variety of treatments (e.g., filter, interpolation and merge) have been done on the raw data. The different steps are listed in Berkeley Earth website in http://berkeleyearth.org/about-data-set. At the local scale, daily Tx and Tn anomalies are examined in Abidjan and Niamey between 1950 and 2012. This data were provided by the *Société D'EXportation et de dévelopement Aéroportuaire, Aéronautique et Météorologique* (SODEXAM) of Abidjan Port-Bouët, and the *Direction de la Météorologie Nationale* (DMN) of Niger. These stations have been selected for their long temporal lengths (i.e., 60 years) without big gaps, but also for their quality. Several homogeneity tests, such as Pettitt, Mann–Whitney–Wilcoxon Buishand, Cumulative deviation, Worsley, has been applied. These tests show a significant break in 1983 for Niamey and 1986 for Abidjan (not shown), which were not associated with modifications of measurement conditions, such as gauge displacement, measurement instrument replacement, change in gauge exposure or environment (Rome et al., 2015).

Finally, simulations from five coupled models of the CMIP5 project, and an ensemble mean of 24 CMIP5 models (Taylor et al., 2012), have been used to be compared with observations (Table 1). The "one model, one vote" approach of Santer et al. (2009), i.e., the first realization of each model, has been used. It ensures that each model has the same weight and that the results are due to "outlier" model or to stronger weight for given climate centre. Comparisons with observations have been done using "historical" runs. Between 1900 and 2005, these simulations provide a realistic representation of global climate variation

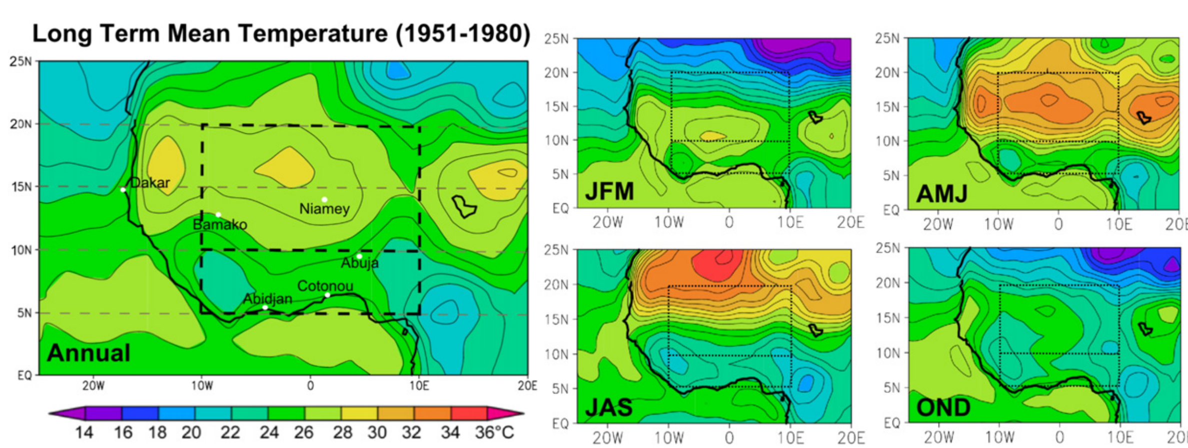

Fig. 1. Mean air temperatures in West Africa between 1951 and 1980 (in °C) using the NCEP/NCAR-1 reanalysis. The yearly mean is shown on the left; seasonal means are shown on the right. The dotted rectangles correspond to the two regions studied: the Central Sahel (10°–20°N; 10°W–10°E) and the Gulf of Guinea area (4°–10°N; 10°W–10°E).

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