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Review

Climate extreme indices derived from observed daily precipitation and temperature data over Cameroon: the need for further assessments

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ABSTRACT: Understanding, monitoring and predicting weather and climate extremes is important because of their severe impacts on communities and ecosystems. In many parts of the world, climate extreme indices have been calculated from daily precipitation and temperature data. However, in Cameroon very few analyses of daily precipitation and temperature data have been carried out. This review is thus a call for an immediate, systematic analysis of observed climate extreme indices from daily precipitation and temperature data. The analysis will provide an understanding of the temporal and spatial variability of weather and climate extremes over Cameroon as well as contributing to the ongoing World Climate Research Programme Grand Challenge on Weather and Climate Extremes.

KEY WORDS weather and climate extremes; climate extreme indices; precipitation and temperature data; Cameroon; WCRP Grand Challenge

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1. Introduction

Weather and climate extreme events (e.g. floods, droughts, heat waves and tropical cyclones) have the most severe and damaging impacts on the economy, the natural environment, human health and infrastructures (Hartmann *et al*., 2013). With the projected anthropogenic climate change, the frequency, intensity, duration and spatial coverage of these extremes are expected to be amplified (Seneviratne *et al*., 2012). It is thus important for local, national and international policymakers to take into account observed and future changes in extreme climate events when planning for climate change adaptation and mitigation (e.g. Klein Tank *et al*., 2009).

In order to monitor the risk as well as study the present and future changes in these extremes (such as the changes in the heaviest daily or monthly rainfall amount over the years or the intensity and duration of heat waves), digitized long-term daily (or higher resolution) weather records are required (Peterson, 2005; Alexander *et al*., 2006; Donat *et al*., 2014b; Alexander, 2016). For consistent worldwide monitoring, a set of indices (or indicators) of weather and climate extremes based on observed daily precipitation totals, daily maximum (day time) and daily minimum (night time) temperatures has been developed by the joint World Meteorological Organization (WMO) Commission on Climatology (CCl)/World Climate Research Programme (WCRP) Climate Variability and Predictability project (CLIVAR)/Joint Commission on Marine Meteorology (JCOMM) Expert Team on Climate Change Detection and Indices (ETCCDI) (see, for example, Karl *et al*., 1999; Zhang *et al*., 2011).

These indices (often referred to as the ETCCDI indices in the literature), which can be used locally, nationally, regionally or globally, were recommended because, first, they link some aspects in the variation of temperature and precipitation to the impacts of extremes (Zwiers *et al*., 2013). Second, these indices bypass the restrictions placed on the free exchange of daily data by some National Meteorological and Hydrological Services (NMHSs) but are willing to share indices derived from these data (e.g. Donat *et al*., 2013). It is important to note here that this restriction is in violation of WMO Resolution 40 which allows for free and unrestricted exchange of meteorological data for research purposes that will benefit all countries (Klein Tank *et al*., 2009). Lastly, as stated above, these indices allow straightforward comparison between analyses carried out in different parts of the world (Peterson, 2005; Peterson and Manton, 2008). The indices are used to assess extremes that occur at least once a year (usually called 'moderate' extremes) and not those that occur, say, once every 10 years. However, since this has recently been criticized for being inadequate in addressing some climate science sectors (such as climate change adaptation), the WMO/CCl's Expert Team on Sector-specific Climate Indices has been assigned to develop indices (which at the moment are also based on daily precipitation and temperature observations) for specific sectors such as agriculture, water resources and health (see Alexander (2016) and associated references). Thus, these indices are based on simple climate statistics (e.g. very low daily temperature or very high daily rainfall amounts that occur yearly) and not extremes driven by complex events (e.g. floods, droughts and tropical cyclones). It should be noted here that the indices that describe monthly variations may also be associated with

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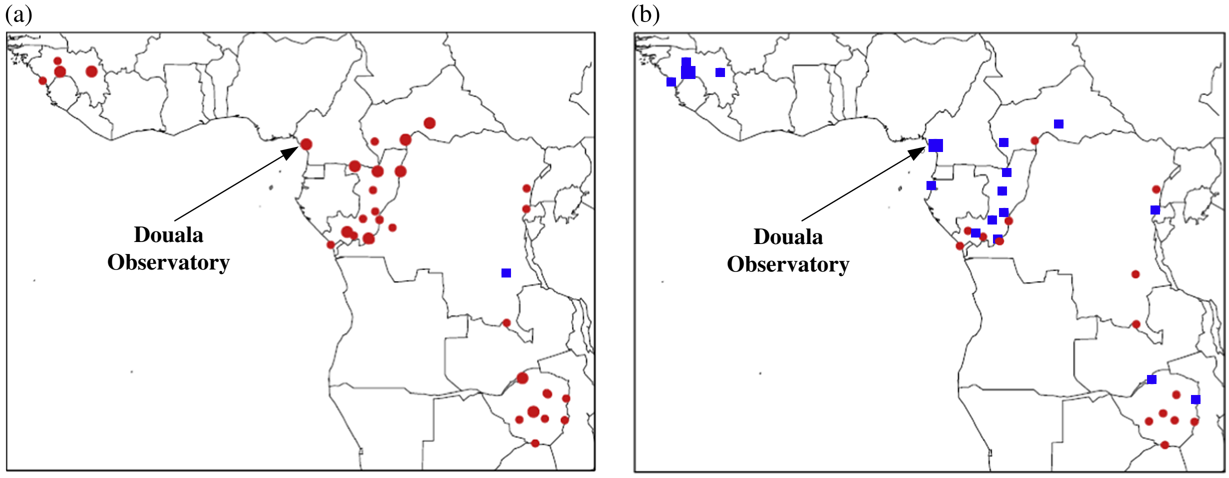

Figure 1. Temperature (a) and precipitation (b) trends for Douala Observatory from 1955 to 2003. (a) Annual warmest daily maximum temperature showing significant positive trend (large circle). (b) Annual very wet daily precipitation showing significant negative trend (large square). Smaller circles and squares indicated non-significant trends. (Reprinted with permission from Aguilar *et al.* (2009). Copyright 2009 by the American Geophysical Union.) [Colour figure can be viewed at wileyonlinelibrary.com].

complex events. Some of the indices are absolute (e.g. annual maximum 5-day precipitation amount or annual maximum of daily maximum temperature) while others are based on specific thresholds (e.g. the number of days with precipitation amount >10 mm or the number of days when the daily minimum temperature is below the 10th percentile). Details of the set of 27 core indices recommended by the ETCCDI can be obtained from Klein Tank *et al.* (2009), Zhang *et al.* (2011) and Alexander (2016). The ETCCDI has also developed and provided free standardized software packages, one written in R (RClimDex) and the other in FORTRAN (FClimDex), for data quality control and calculation of climate indices. These packages together with another package for testing the temporal homogeneity of temperature and precipitation data can be downloaded freely from http://etccdi.pacificclimate.org/software.shtml

The development of the ETCCDI indices was the first step in promoting the global analyses of extremes, in a bid to fill in data gaps, which was first highlighted by the 1996 Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (see Peterson and Manton (2008) and references therein). The second step was the organization of regional climate change workshops (in data sparse regions such as Africa, Southern Asia and South America) by the ETCCDI in order to encourage the analyses of daily climate data by various NMHSs and thus develop both regional and global datasets on climate extreme indices (e.g. Easterling *et al.*, 2003). During these workshops, participants from neighbouring countries brought daily temperature and precipitation data from some of their countries' stations. Under the mentorship of a team of experts, these data were quality controlled and tested for homogeneity and indices were computed from them using the recommended procedure and software. Results from these workshops have provided an overview of the trends and variability of climate extremes across the respective regions (e.g. Peterson *et al.*, 2002; Vincent *et al.*, 2005; Zhang *et al.*, 2005; Klein Tank *et al.*, 2006; New *et al.*, 2006; Aguilar *et al.*, 2009; Omondi *et al.*, 2013; Donat *et al.*, 2014a). Results from some of the workshops, together with data from other sources, have been combined to produce a global dataset of precipitation and temperature extreme indices (see, for example, Alexander *et al.*, 2006; Donat *et al.*, 2013). The IPCC reports on observed changes in climate extremes have also been partly based on the ETCCDI indices computed from some of the workshops (Klein Tank *et al.*, 2009; Hartmann *et al.*, 2013).

Cameroon has participated in only one ETCCDI workshop (Aguilar *et al.*, 2009). Beyond this ETCCDI organized workshop, there has seemingly been no further analyses of daily climate data for climate extreme studies in Cameroon. Thus, because of its societal importance, there is an urgent need for an updated analysis and assessment of observed climate extremes in this country. It is hoped that this review will mobilize the climate research community on the need for long-term precipitation and temperature extreme analysis and monitoring in Cameroon (and surrounding regions) for both national and global needs. In Section 2, a review on the observed extremes analysis carried out in Cameroon is presented, while in Section 3 a way forward is proposed. The conclusions of this review are discussed in Section 4.

2. Analysis of precipitation and temperature extremes over Cameroon

Cameroon participated in the ETCCDI climate change regional workshop organized in Brazzaville, Congo, from 23 to 27 April 2007 (Aguilar *et al.*, 2009). The lone participant from Cameroon took data from five stations (Maroua-Salak, Garoua, Ngaoundéré, Douala Observatory and Yaoundé) to the workshop but data from only one station (Douala Observatory) was used in the final regional analysis due to homogeneity issues. The data used during this workshop covered the time period 1955–2006. Despite both the temporal and spatial limitations of the data, results from this work showed that there was significant warming and decrease in total precipitation over western central Africa (Cameroon, Central Africa Republic, Democratic Republic of Congo, Gabon and Republic of Congo), as shown in Figure 1. As mentioned above, apart from this workshop, there is no literature on any analysis of observed climate extremes from daily precipitation and temperature data in Cameroon. The challenges that may have hindered further analyses of daily data include the reluctance of the National Department of Meteorology (NDM), Yaoundé, to make its data readily available, the lack of digitized data and the lack of awareness of the importance of studying

Table 1. List of stations with currently available digitized data. The years in which digitized data are available will increase with an increase in digitization.

Station name	WMO number	Latitude (° N)	Longitude (° E)	Period temperature	Period precipitation
Maroua-Salak	**64851**	10.450	14.250	1953–2005	1953–2005
Garoua	**64860**	09.333	13.383	1951–2010	1951–2010
Ngaoundere	**64870**	07.350	13.217	1964–2005	1970–2006
Douala Observatory	**64910**	04.017	09.733	1950–2010	1950–2010
Yaoundé	**64950**	03.833	11.517	1970–2008	1970–2008
Abong-Mbang	–	03.967	13.200	1951–2005	1951–2005
Akonolinga	64956	03.767	12.233	1991–2004	1991–2004
Ambam	64980	02.383	11.250	1990–2004	1990–2004
Bafia	**64920**	04.733	11.283	1961–2005	1961–2005
Bafoussam	64894	05.533	10.350	1970–2006	1970–2006
Bamenda	**64892**	06.050	10.116	1980–2000	1980–2000
Banyo	**64880**	06.783	11.817	1970–2006	1970–2006
Batouri	**64931**	04.433	14.367	1971–2009	1971–2009
Bertoua	**64930**	04.600	12.733	1970–2009	1970–2009
Edea	64935	03.767	10.067	1970–2006	1970–2006
Ekona	–	04.183	09.333	1965–2002	1965–2002
Eseka	64952	03.617	10.733	1990–2005	1990–2005
Guider	64858	09.933	13.950	1982–2008	1982–2008
Kaéle	64855	10.083	14.450	1970–2008	1970–2008
Kousseri	64850	12.083	15.033	1972–2008	1975–2008
Kribi	**64971**	02.950	09.900	1980–2005	1980–2005
Lomié	**64961**	03.150	13.617	1977–2007	1977–2007
Mamfe	**64890**	05.717	09.283	1981–2009	1981–2009
Meiganga	**64882**	06.533	14.367	1970–2006	1970–2006
Mokolo	64854	10.733	13.800	1980–2010	1980–2010
Nanga-Eboko	64922	04.650	12.400	1976–2000	1976–2000
Ngambe	–	04.267	10.600	1982–2005	1982–2005
Nkongsamba	**64911**	04.950	09.933	1939–2001	1939–2001
Koundja	**64893**	05.650	10.750	1972–2002	1970–2002
Poli	64863	08.483	13.250	1988–2004	1988–2004
Sangmelima	64974	02.933	11.950	1980–2010	1980–2010
Tibati	64881	06.483	12.600	1975–2003	1974–2004
Tignere	64868	07.367	12.650	1981–2004	1981–2004
Tiko	**94912**	04.083	09.367	1983–2010	1981–2010
Yabassi	–	04.650	10.000	1979–2005	1978–2005
Yagoua	64856	10.333	15.233	1970–2006	1970–2006
Yokadouma	64964	03.550	14.367	1985–2009	1985–2009
Yoko	**64900**	05.550	12.367	1981–2007	1981–2007
Bétare-Oya	–	05.600	14.150	1977–2005	1977–2005
Dschang	64891	05.333	10.050	1943–2001	1943–2001
Ebolowa	64972	02.900	11.167	1927–2008	1927–2008

The World Meteorological Organization (WMO) numbers in bold are currently in use while the others are the proposed numbers not yet in use.

climate extremes from daily data. However, some efforts have been made by meteorologists at the NDM, Yaoundé, towards an increase in the digitization of Cameroon's daily climate data (Peterson and Manton, 2008; Aguilar *et al*., 2009).

3. The need for further analysis of daily precipitation and temperature data in Cameroon

Further analysis of daily temperature (maximum and minimum) and precipitation data in Cameroon will definitely increase the understanding of the observed changes in climate extremes, which clearly have a direct impact on agricultural production, Cameroon's major economic activity (see, for example, Amougou *et al*., 2013), and other sectors. This analysis should be carried out by researchers at the NDM, Yaoundé, in collaboration with researchers at local universities (such as the Universities of Yaoundé 1 and Buea). These data should be quality controlled and assessed for homogeneity, and climate extreme indices should be calculated from them using the software developed and maintained by the ETCCDI (or similar approach). The analysis should also cover all 41 operational meteorological stations (see Table 1) that are under the management of the NDM, Yaoundé, as well as those managed by other para-public institutions (such as the Institute of Agricultural Research for Development, Yaoundé, and the Cameroon Development Corporation, Limbe, southwest region of Cameroon). Considering the fact that meteorological measurements in Cameroon have been kept since 1926 (see Nkobe *et al*., 2013), the analysis should go as far back in time as possible. Of course, recent data beyond those used in the April 2007 Brazzaville, Congo, workshop are also expected to be analysed.

The data from this work should go a long way towards filling the weather and climate extreme data 'gaps' over Cameroon (and central Africa by extension) and can subsequently be incorporated into the production of new global datasets such as those produced by Alexander *et al*. (2006) and Donat *et al*.

(2013). Clearly this will contribute greatly to (especially, the ‘Document’ theme of) the WCRP Grand Challenge on Weather and Climate Extremes (see Alexander (2016) and associated references).

Other benefits of this analysis include the increase in the digitization of Cameroon’s weather and climate data, which can eventually be made available to interested users (such as national and international research institutes and universities) for other purposes, apart from studies related to climate extremes; the provision of a set of climate extreme indices that can be used to evaluate climate models and for climate change projections over Cameroon (e.g. Sillmann and Roeckner, 2008; Orlowsky and Seneviratne, 2012); and the establishment of a research collaboration between institutions that carry out routine meteorological measurements in Cameroon.

Cameroon has been affected by several natural disasters over the years, with some of them related to extreme weather and climate (e.g. WMO, 2015). Despite the government’s efforts in developing adaptation and mitigation strategies to minimize the effects of these disasters, these policies are based upon limited evidence of climate change at the national level. Thus, it is expected that the results from this extreme analysis will provide stronger support to Cameroon’s government formulation of adaptation and mitigation strategies and other policies such as the climate change policy (see Klein Tank *et al*. (2009) for details).

4. Conclusions

Research on observed climate extremes in Cameroon has been relatively low-key. Due to the enormous societal impacts of weather and climate extremes, a detailed analysis of daily climate data is urgently required. The effect of large-scale climate variability (such as the El Niño Southern Oscillation) on climate extremes over Cameroon is an important aspect that also needs investigation. This analysis should establish a research collaboration network between Cameroonian institutes that record meteorological data and also contribute to the World Climate Research Programme Grand Challenge on Weather and Climate Extremes.

Even though this paper is focused on Cameroon, the issues raised here are also experienced by a number of other countries (especially those in central and western Africa). Thus, these countries where limited analyses of daily climate data for climate extreme studies have been carried out should also find the discussions (and recommendations made) in this paper applicable to them.

Finally, it should be noted that at the moment enormous efforts are being made to analyse climate extremes over all 41 operational meteorological stations of the National Department of Meteorology, Yaoundé, in Cameroon.

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