

Long-Term Variation of Sunshine Duration and Their Inter-Action with Meteorological Parameters over Chad, Central Africa

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Abstract

This study aims to evaluate the long-term variations of sunshine duration and to estimate its interaction with meteorological parameters from 1950 to 2010 in Chad, Central Africa. The results show that Chad is the one of world's sunniest countries. Each year, Chad receives more than 3030.91 ± 176.33 hours of sunning corresponding to 8.9 hours daily. Likewise, a strong north-south gradient is noted over Chad. For instance, the daily insolation is 10 ± 0.41 hours in the north, 8.85 ± 1.1 hours in the center and 7.75 ± 1.8 hours in the south. Furthermore, there is a marked seasonality of sunshine duration with maximums in dry season and minimums during the rainy season. The lowest values of sunshine duration are found in August. On the contrary, maximums are recorded from November to February with values greater than 9.5 hours per day. Moreover, the annual anomalies study allowed determining three great periods in terms of sunshine variability in Chad. Firstly, the period between 1950 to 1970 (named humid period) is characterized by the lowest values of sunshine duration in Chad. Secondly, from 1970 and 1990, the region suffered an unprecedented drought which resulted in an increase of sunstroke duration in Chad. And finally, the period from 1990 to 2010 called the return period is characterized by a rapid year-to-year fluctuations of insolation duration. Unlike to surface temperature, we have also shown that there is a direct relation between the duration of insolation and the meteorological parameters such as precipitations and relative humidity.

Keywords

Sunshine Duration, Solar Energy, Climate, Variability, Chad, Central Africa

1. Introduction

Sunshine is a key factor in most climate processes e.g. Earth's radiative balance and hydrological cycle (Ranzi *et al.*, 1995) [1]. The sunshine hour is the most important influencing parameter of evapotranspiration process (Pandey *et al.* 2014, 2016) [2] [3]. Thus, Sunshine duration variations can disrupt the hydrological cycle by reducing evaporation, resulting in reduced precipitation and agricultural yields in some areas. Overall, Sunshine duration has been used for decades in many different applications. It is applied in sectors such as tourism, public health, agriculture, vegetation and solar energy (Murthy *et al.*, 2011; Wang *et al.*, 2013; Wang *et al.*, 2015; Babikir *et al.*, 2018) [4] [5] [6] [7]. Besides with the dramatic global climate change in recent years, there has been a great deal of interest in varying the duration of sunshine (Yang *et al.* 2009; Lenuta *et al.* 2014) [8] [9]. For instance, the duration of sunshine decreased in the Northern and Eastern Austria in the 30-year period of 1960-1989 while a remarkable increase in sunshine duration was observed in high mountain regions (Dobesch, 1992) [10]. In Western Europe, the annual sunshine duration showed an overall decrease since the 1950s until the early 1980s, followed by a recovery during the next two decades (Sanchez-Lorenzo *et al.*, 2008) [11]. However, few studies have been published on sunshine duration in Africa despite its good solar potential (Babikir *et al.*, 2018) [7]. Indeed, the sunshine duration has a fairly direct relationship with the solar radiation received at the surface. Consequently, the knowledge of the Sunshine variability represents a determining factor for design, dimensioning, performance assessment, and energetic management of renewable energy conversion systems for countries devoid of solar radiation measurement. The focus of this work is on a Chad, country located between Sahel and Central Africa. Its climate is characterized by warm and dry continental type. From north to south of Chad, we have a succession of Saharan climate in the north, Sahelian in center and Sudanese in the South (Bedoum *et al.*, 2013, Maharana *et al.*, 2018) [12] [13]. As most Sahelian countries, Chad endured an intense drought from the early 1970s to the late 1980s. This drought has been manifested by a rainfall deficit that has had a negative impact on the region agriculture and economy (Lebel *et al.*, 1996; Lebel and Ali, 2009; Nicholson, 1998; Nicholson *et al.*, 2000; Bigot *et al.*, 1998; Mahe *et al.*, 2001; Malhy *et al.* Wright, 2004; Guenang *et al.* Mnkankam Kamga., 2012; Bedoum *et al.*, 2013, Redelsperger *et al.*, 2002) [14]-[23]. One of the major questions is to know if the recently fluctuations of Africa climate (great drought of the 70s and recently global climate change) have had an impact on sunshine duration. The aim of this work is to study the long-term variability of sunshine duration and its interaction with climatic parameters in Chad, Central Africa. The paper is organized as follows. "Data and Methodology" presents the study area (the map of Chad with her 7 ground stations), the datasets used in this work and the methodology. The results are presented in "Results and discussions".

2. Data and Methodology

2.1. Study Area Presentation

Figure 1 represents our study area which is Chad, a country located between the Sahel and Central Africa; and having an area of 1,284,000 km². It's situated from 7°N and 24°N north latitude; and between 14°E and 24°E longitude. Furthermore, this country spread over the length of 1700 km from North to South and 1000 km from East to West. Chad is the fifth largest country in Africa after Algeria, the Democratic Republic of Congo, Sudan and Libya and the 21st largest in the world. For this study, seven stations measuring the insolation duration over Chad (**Figure 1**) were used. In the north of the country, we have the Faya-Largeau station (long 19°07', Lat 17°55', Alt 233). The center region has 3 stations composed of the stations of Abéché (long 20°51', Lat 13°51', Alt 545) of N'Djamena (long 15°02', Lat 12°08', Alt 294) and Amti-man (long 20°17', Lat 11°02', Alt 435). And finally, the 3 stations of the south of the country are those of Moundou (long 16°04', Lat 8°02', Alt 420), Sarh (long 18°22', Lat 9°00' Alt 300) and Pala (Long 14°55', Lat 9°22', Alt 454).

2.2. Datasets Collection

In this study, in situ data of sunshine duration, precipitation, humidity, Temperature (Average, Maximum and Minimum), for the 1950-2010 period (60 years) have been collected from the General Directorate of Meteorology (GDM) of Chad. For each of 7 ground stations (see **Figure 1**), daily insolation measurements (at sunrise and at sunset) are carried out using a Campbell-Stokes heliograph while the others parameters are measured by conventional weather station.

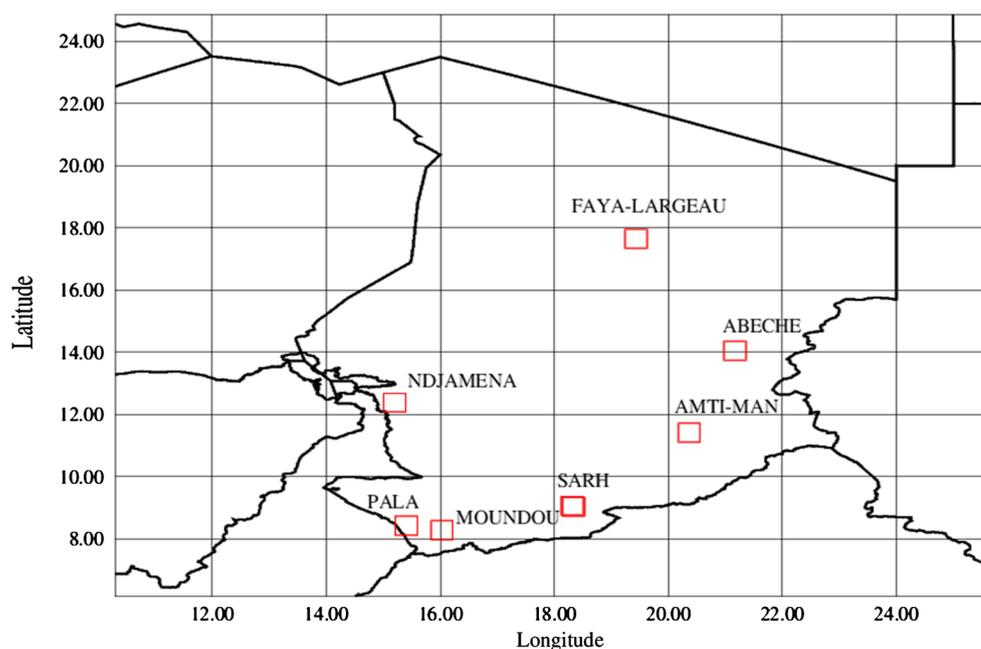


Figure 1. Map of Chad with the seven (07) stations measuring the duration of insolation which are: Faya, Abeche and Moundou.

The usefulness of this system is that all stations include a monthly time series of good quality over the considered period.

2.3. Methodology

In this study we have subdivided Chad into three zones according to the climate of the ground station. Therefore, the northern zone is composed of one station, the central zone of 3 stations and the zone south zone of 3 stations. For each zone, we average the data of different stations to obtain a data by climate zone. In addition, the data representing the whole country are calculated with the average from the 3 climate zones. Anomalies calculations (over the considered period) have been performed on all parameters except for precipitation for which it is rather the Standardized precipitation index SPI is used (McKee *et al.*, 1993; 1995) [24] [25].

3. Results and Discussion

3.1. Annual and Seasonal Characterization of Sunshine Duration

We begin by shown in the **Figure 2**, the annual distribution of sunshine duration from 1950 to 2010 in Chad. **Figures 2(a)-(d)** represent respectively the north, center, south and for the whole country (Chad). The north of Chad (**Figure 2(a)**) represented by the Faya-largeau station which is located in the desert is characterized by a strong annual sunshine with an annual average around (3612.33 hrs/year). Indeed, this region is one of the sunniest areas in the world. From 1970 to 1975 during the great drought of Sahel, the sunshine in this part of

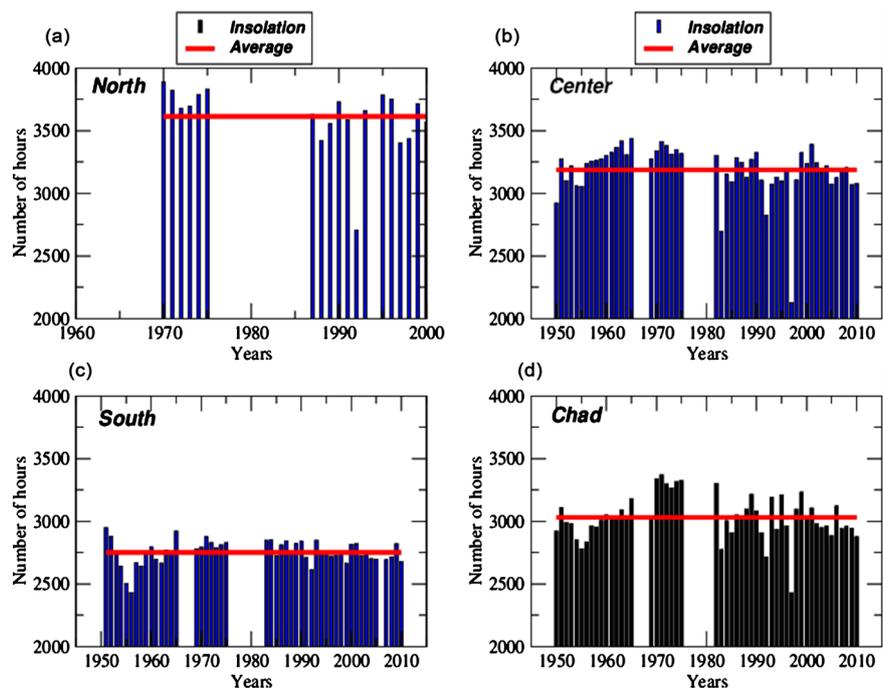


Figure 2. Annual distribution of sunstroke duration in North, Central, Southern Chad and Chad from 1950-2010.

the country is above the annual average with peaked around 3889.28 h/year for the year 1970. Then it decreases gradually from 1987 to 1992 and increases slightly in 1993, 1995, 1996 and 1999. However, the years 1988 and 1992 are the least sunniest in the series with values lower than 2703.17 hrs/year especially in 1992. The center (**Figure 2(b)**) composed by Abeche, N'Djamena and Amti-man stations, is characterized by strong insolation during the dry years (from 1960 to 1975) higher than average. From 1983, there is a slight decrease until 2000 and a gradual increase between 2001 and 2005 and finally another decline from 2010. This Sahelo-Sudanian zone received more than 3411.94 hrs/year of sunshine in 1971 (dry year). However, we note that in 1983, a decreasing trend values lower than 2125.48 hrs/year in 1997. In the south of the country (**Figure 2(c)**), sunshine is significant between the years 1951 and 1984 (above average) with a maximum of 2947.38 hrs/year in 1951. It varies around the average between 1954 and 1958. However, the minimum in insolation (2430.85 hrs/year) is noted in 1958 during the wet years. The Chad sunshine average is represented in **Figure 2(d)**. There is an insolation greater than 3030.91 hrs/year from 1959 to 1975, with a maximum of 3369.44 hrs/year in 1971. However, the downward trend starts in 1992 up to 1997 with values of around 2427.64 hrs/year.

Figure 3 illustrates the monthly distribution of sunshine duration between 1950 to 2010 in hour per day respectively in the north (**Figure 3(a)**), center (**Figure 3(b)**), south (**Figure 3(c)**) and an average over Chad country (**Figure 3(d)**). In the north of the country, the sunshine duration is about 10 h/day each month. We note an homogeneous monthly distribution in all seasons. However, the minima are noted in march and september with values lower than 9.3 h/day.

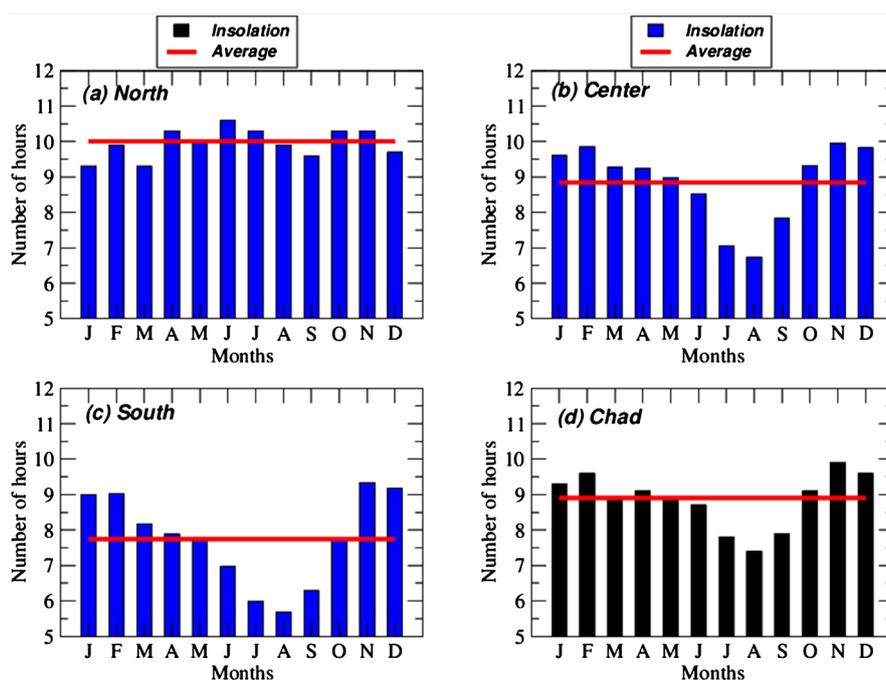


Figure 3. Monthly distribution of the duration of insolation in North, Central and South of Chad and in Chad from 1950 to 2010.

Unlike the north, the sunshine duration in the center the country follows a very marked seasonality. The maxima are noted during the dry season between October and May exceeding 9.85 h/day and the minima in the rainy season between June and September. The minimum is recorded in the month of August with values lower than 6.73 h/day. Moreover, there is a marked seasonality of sunshine duration in the south with maxima (exceeding 9 h/day) in the dry season and minima in the rainy season (values lower than 5.68 h/day) in August). **Figure 3(d)** summarizes the monthly distribution of sunshine over Chad from 1950 to 2010. It shows a marked seasonality of sunshine distribution with maxima during the dry season (from October to May) and minima in the rainy season from June to September. The peak is recorded in November and February with values around 9 h/day while the minima are noted during the rainy season in July and August with values less than 7.4 h/day.

Table 1 summarizes the annual and monthly of sunshine duration on the different parts of the country and an average over the whole country. The table is revealing a strong gradient between the north and the south.

To better highlight the different periods in terms of variability of sunshine at Chad, we represent in the **Figure 4** the annual anomaly of insolation duration

Table 1. Annual and Monthly Insolation in North-Central-South of Chad and Chad.

Insolation	Chad	North	Center	South
Average annual Insolation (hrs/year)	3030.91 ± 176.33	3612.33 ± 261.18	3185.50 ± 208.78	2753.39 ± 95.92
Average monthly Insolation (hrs/day)	8.9 ± 0.8	10 ± 0.41	8.85 ± 1.1	7.75 ± 1.28

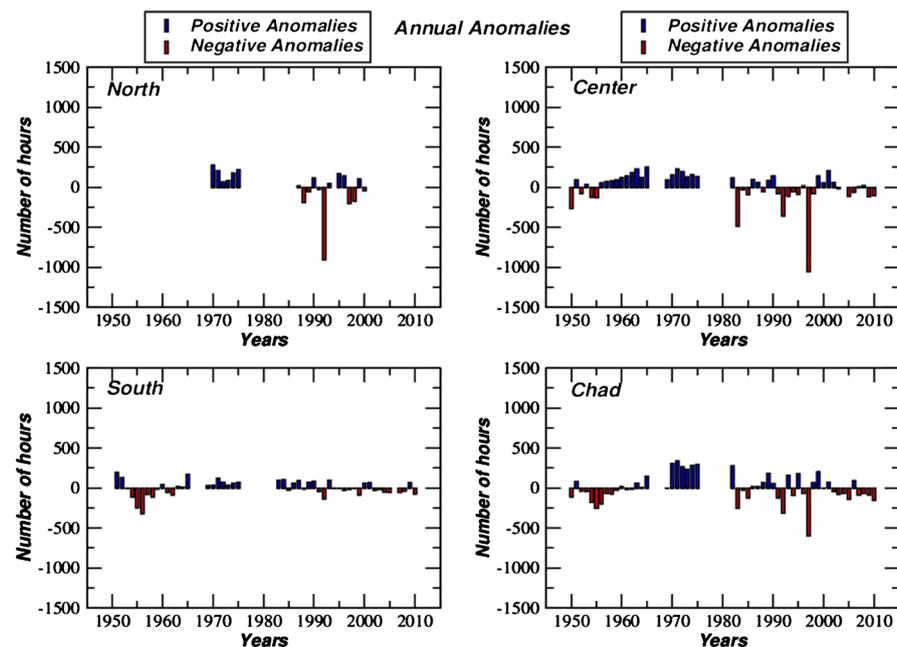


Figure 4. Trend of the anomalies of the duration of sunshine between 1950 to 2010 in North, Central, and South of Chad and in Chad.

from 1950 to 2010. **Figures 4(a)-(d)** represent respectively the annual anomaly in the north, center, and south and for the whole country (Chad). These figures clearly show a variability of sunshine depending of climatic periods in Sahel region. They show the existence of three major periods in terms of insolation. At, we record negative anomalies from 1950 to 1970 corresponding to the wet years in Chad and the Sahel. Then, the period from 1970 to 1990 corresponds to the great drought that occurred throughout the region. This period is manifested by positive anomalies in insolation all over Chad. And finally, the period from 1993 to 2010 called the return period of the rainfall is characterized by a very marked annual variability of sunshine duration. During this period, the positive and negative anomalies succeeding from year to year.

Table 2 summarizes the insolation anomalies for each period and for the different regions of Chad. We note a north-south gradient and also the effect of the three climatic periods on sunshine duration. For instance, the anomaly goes from -23.47 h/year during the humid period to 73.12 h/year during the great drought and to -43.53 h/year for the return period.

3.2. Effect of Seasonal Variability of Meteorological Parameter on Insolation Duration

In order to assess the annual impact of meteorological parameters on sunshine duration, we begin by analyzing the Standardized precipitation index (SPI) in Chad from 1950 to 2010. **Figure 5** presents annual anomalies of insolation (**Figure 5(b)**) and precipitation (SPI index in **Figure 5(a)**) from 1950 to 2010 over Chad. The SPI index (**Figure 5(a)**) showed that Chad experienced three major climatic periods in terms of precipitation. At first, Chad and the Sahel experienced a very wet period from 1950 to 1970. This was manifested in Chad by positive SPI (see **Figure 5(a)**) from 1950 and 1970. Consequently, the sunshine duration was lower during this wet period with negative anomalies around -200 hrs/year. Afterwards, the region has suffered an unprecedented drought during the period 1970-1990 (Ali and Lebel, 2009; Dai *et al.*, 2004b) [26] [27]. This sudden decrease of rainfall has affected the entire Sahel region, making it the strongest climatic signal that the earth has received since meteorological measures exist (Dai *et al.*, 2004b; Hubert & Carbonnel, 1987; Hubert *et al.*, 1989; [Giannini *et al.*, 2008; [27] [28] [29] [30]. This dry period resulted by an increase of sunshine duration from 1970 to 1990. During this period, Chad earns more than 250 hours per year on average. The last two decades (from 1990 to 2010) are characterized by the more or less return of rains. Indeed, there is a very marked

Table 2. Annual North-Central-South Anomalies of Chad and Chad.

Periods	Chad (hrs/year)	North (hrs/year)	Center (hrs/year)	South (hrs/year)
Wet	-23.47		-16.04	-24.92
Dried	73.12	76.92	47.72	42.56
Return	-41.53	-85.45	-87.13	-12.63

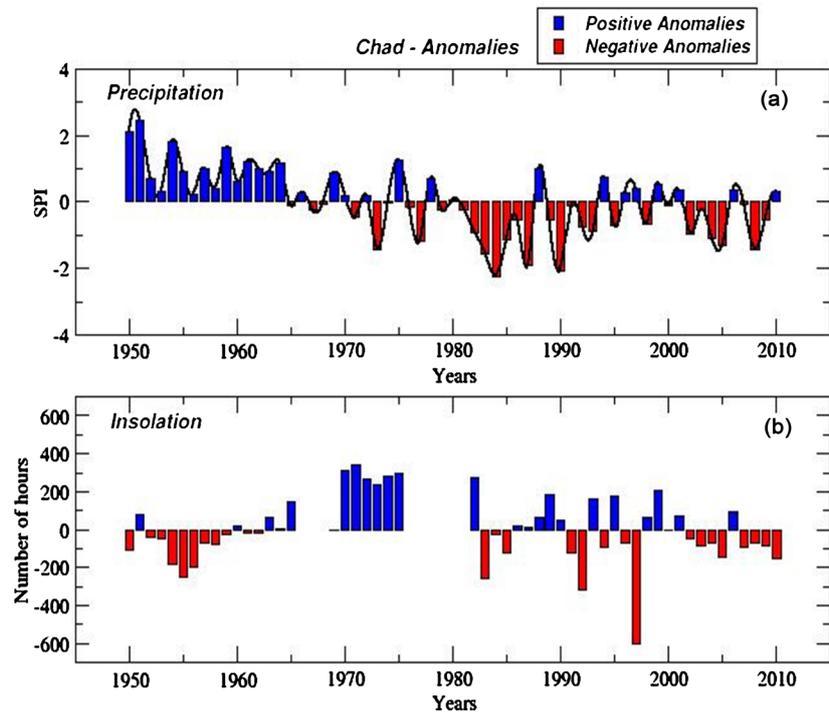


Figure 5. Trend in sunshine duration and precipitation anomalies between 1950 and 2010 in Chad.

interannual variability of SPI from year to year. Further, the sunshine duration varies from year to year during this period.

Figure 6 illustrates the anomalies of relative humidity, temperature means, temperature maximum and temperature minimum from 1950 and 2010 in Chad. We note that, the relative humidity follows the same trend as the sunshine duration. Indeed, insolation is a parameter that depends on relative humidity and therefore the cloud cover. We recognize the signature of the three major climatic periods of Chad. In fact, the positive anomalies of relative humidity (**Figure 6(a)**) are noted between 1950 and 1970. From 1970 to 1990, the relative humidity decreases by more than 5% per year. And beyond the 1990s, there are fluctuating anomalies from year to year. However, temperatures (mean, maximum and minimum) do not follow the same trend with sunshine and precipitation (**Figures 6(b)-(d)**). Here, only two periods in terms of change are noted. The period from 1950 to 1990 is a period with negative anomalies. From the 1990s we have noted a continued increase of temperatures in Chad. Thus, we can say that the increase of temperatures in Chad is not synonymous with an increase in the duration of insolation. In fact, the variability of temperatures in recent decades is mainly due to climate change on a global scale.

Table 3 summarizes the impact of these three periods of sunshine on the different meteorological parameters in Chad. Overall, the anomaly of relative humidity goes from 0.32 during the humid period to -1.39 during the great drought period and to 1.02 for the return period. Likewise, the anomaly of precipitations goes from 0.83 during the humid period to -0.56 during the great

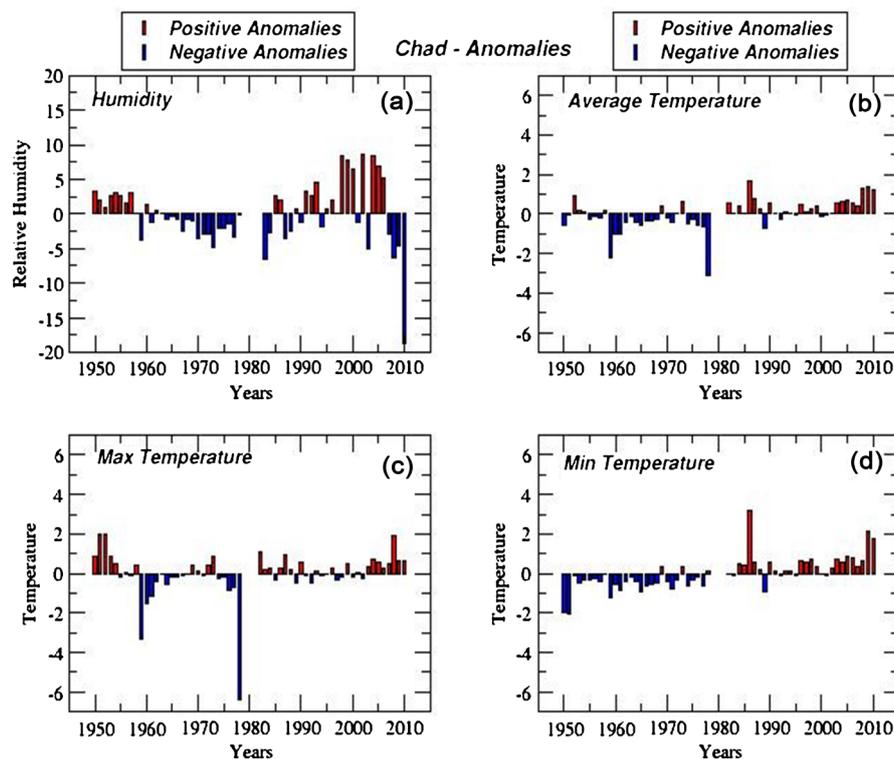


Figure 6. Trend of relative humidity temperature anomalies between 1950 and 2010 in Chad.

Table 3. Chad periods.

Periods	humidity	Temperature_Max	Temperature_Min	Temperature_Moy	Precipitation
Wet	0.32	-0.02	-0.6	-0.3	0.83
Dried	-1.39	-0.22	0.1	-0.09	-0.56
Return	1.02	0.3	0.6	0.39	-0.28

drought period and to -0.28 for the return period. Between the wet and dry period, there is an increase for average and minimum temperatures; and a maximum temperature increase. These changes are probably due to climate variability at the regional scale. However, between the dry period and return, the temperatures increase considerably. These increases are due to global scale climate change and therefore does not have a strong impact on the duration of sunshine.

4. Conclusions

The objective of this study was to evaluate the long-term variability of insolation duration and its interaction with meteorological parameters such as surface temperature, precipitation and relative humidity in Chad from 1950 to 2010. On average Chad receives more than 3030.91 ± 176.33 hours per year. This corresponds to 8.9 ± 0.8 hours per day. Likewise, there is a strong gradient between the north and south of the country. For instance, the daily insolation is about 10 ± 0.41 hours in the north, 8.85 ± 1.1 hours in the center and 7.75 ± 1.8 hours in

the south of the country. Furthermore, there is a marked seasonality of sunshine duration with maximums in the dry season and minimums during the rainy season. The study of anomalies highlight three great periods in terms of duration of insolation. At first, there is the period where anomalies of insolation duration were negative (called humid period) between 1950 to 1970. Indeed, during this period Chad and the whole Sahelian region were wet. From 1970 to 1990, the region suffered a severe drought which resulted in an increase in the duration of sunstroke in Chad. And finally, the period between 1990 to 2010 called return period is characterized by rapid fluctuations (from year to year) of the insolation duration. This work also showed that the duration of insolation had a direct relation with precipitations and relative humidity.

This shows the regional aspect of these three parameters which are: insolation duration, precipitations and relative humidity. However, the relationship between temperatures and sunstroke duration is not direct, especially during the period of return of the rains between 1990 and 2010. During this period, temperatures increase rapidly with the emergence of regular heat waves, mainly due to the global climatic changes.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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