Journal of Applied and Natural Science
15(3), 1292 - 1298 (2023)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Inter-annual variation of the mean temperature and rainfall in Chad and the solar activity during the period from 1950 to 2020

Ali Mahamat Nour *
Department of Physics, Faculty of Exact and Applied Sciences, University of N'Djamena, N'Djamena, Chad
Masrabé Djimtolgar
Laboratory of Physics of the Atmosphere, Climate and Environment (LaPACE), University of N'Djamena, N'Djamena, Chad
Galmai Orozi
Laboratory of Physics of the Atmosphere, Climate and Environment (LaPACE), Department of Physics, Faculty of Exact and Applied Sciences, University of N'Djamena, N'Djamena, Chad

* Corresponding author. Email: nouralimht@yahoo.fr

Article Info
https://doi.org/10.31018/jans.v15i3.4836
Received: June 22, 2023
Revised: September 9, 2023
Accepted: September 16, 2023

How to Cite
Nour, A. M. *et al.* (2023). Inter-annual variation of the mean temperature and rainfall in Chad and the solar activity during the period from 1950 to 2020. *Journal of Applied and Natural Science*, 15(3), 1292 - 1298. https://doi.org/10.31018/

Abstract
Given the increased variability of rainfall, the resurgence of extreme meteorological phenomena such as droughts, floods, heat waves, and violent winds and considering the influence of solar activity on certain meteorological parameters, a study on the variation of temperature and rainfall in relation to solar activity is necessary. The present study aimed to analyze the inter-annual evolution of meteorological parameters (mean temperature and rainfall) in Chad over the period from 1950 to 2020 in two geographically distinct areas (Sudanian and Sahelian zone) and then to establish a link between these parameters and solar activity to predict the variations of these two parameters over time. The rainfall results showed that the wettest years were 1959 in N'Djamena and 1951 in Moundou. On the other hand, the driest years recorded were 1984 in N'Djamena and 1998 in Moundou. The study of the mean temperature in these two areas during the same period led to the conclusion that the hottest year was 2010 in N'Djamena; however, in Moundou the hottest year recorded was 1997. Globally, in the two zones concerned, analysis of the results on variations in rainfall showed a downward trend. However, the study of average temperature showed a steady rise over the same period. The superposition of rainfall and mean temperature with the sunspot numbers Rz led to the conclusion that high sunspot activity increases temperature and thus warming, while low sunspot activity brings high precipitation.

Keywords: Chad, Climate variability, Mean temperature, Sunspot number Rz

INTRODUCTION

Chad consists mainly of a vast basin bordered by mountainous massifs. The Chadian territory can be subdivided into three bioclimatic zones: Sahara, Sahelian, and Sudanian (PANA, 2010). In the north, there is a Saharan zone which is characterized by very low rainfall and this zone is limited in the south by the 200 mm/year isohyets. In the center, there is a Sahelian zone which is between 200 and 800 mm/year isohyets and in the south, there is a Sudanian zone which is characterized by high rainfall intensity and this zone is between 800 and 1200 mm/year isohyets (Bedoum *et al.,* 2017).
Chad's rainfall regime is linked in summer to the seasonal movement of the Inter-tropical Convergence Zone and the circulation of the West African monsoon. Indeed, the seasons follow one another according to the meridian movement of the tropical convergence zone, and rainfall is marked by a strong irregularity in its spatial and temporal distribution. On the other hand, the thermal regime is marked by a relatively cold period from December to February (11° to 22º C) and a hot period from March to June (39 to 45°C).The average minimum and maximum temperatures across the country range from 19 to 21°C and 34 to +37°C, respectively (Strategie Nationale de Lutte contre les Changements Climatiques SNLCC, 2017).
Several meteorological parameters, including tempera-

ture and rainfall, play a key role in climate change. Numerous scientific studies on climate in the sub-region (Groupe d'experts Intergouvernemental sur l'Evolution du Climat GIEC, 2007a, b) ;(GIEC, 2014); Ly *et al.* (2013); Alhassane *et al.* (2014), Sarr *et al*. (2015) have made it possible to highlight the major current climate changes variations in rainfall marked by a sudden alternation of wet and dry years, an increase in temperature and an increase in extreme weather events (floods, droughts, heat waves, high winds, etc.) that have occurred in Africa, and more particularly in Chad. Climate changes over the last few decades in Chad showed, like in other African countries south of the Sahara.

These meteorological phenomena are the main facts of climate change recorded over the last few decades in Chad (PANA, 2010; Mbaiguedem, 2012; Bedoum *et al.,* 2017).

According to the (GIEC, 2014) conclusions and by taking into account the report of (OCHA, 2022), these phenomena will become increasingly intense and frequent during this century. To cope with this situation, it is important to make a detailed study of these meteorological parameters and to see their link with solar activity because most of the disturbances observed in the near-Earth environment are attributed to the different variations of the sun's solar activity and solar events Ouattara *et al*. (2009); Zerbo, (2012a,b).

The solar activity originates from a magnetic field inside the sun. This magnetic field passes through the photosphere and into the chromospheres and corona. This solar magnetic field has two forms: i) A form not open to the interplanetary medium (toroidal field) responsible for sunspots, faculae, chromospheric eruptions, active centres, etc., ii) An open form (dipole field) on the interplanetary medium responsible for holes and coronal jets. Either form contributes to the observed events Ouattara F. Thesis (2009).

Previous studies have shown a strong correlation between solar activity and meteorological parameters, as well in Africa, Europe, America and Asia

(De Jager, 2008; Tsiropoula, 2003; Hiremath and Mandi, 2004; Hiremath, 2006; Zerbo, 2013a; Nitka and Burnecki, 2019; Laurenz *et al.,* 2019; Mohamed and El-Mahdy, 2021). Some studies have already shown that the sun influences the Earth's surface temperature. For example, in the 17th century, no sunspot was observed for a period of 70 to 80 years. This decrease in solar activity coincided precisely with the "mini -ice age" of the second half of the 17th century (Eddy, 1976). Also, in 1991, Friis-Christensen and Lassen showed that the variation of the solar cycle length agrees remarkably well with the air temperature in the northern hemisphere over the last 130 years. The existence of a very good correlation between the geomagnetic index aa and the solar wind has made it possible to classify geomagnetic activity into four categories. Each activity has a solar origin. The work of Ouattara *et al.* (2009); (Ouattara and Amory-Mazaudier, 2009); and Zerbo *et al.* (2011) was proof of this classification. The present study aimed firstly to validate the classification of geomagnetic activity made by Legrand and Simon (1989), i.e. quiet activity, fluctuating activity, recurrent activity and shock activity and then to establish the solar origin of these different geomagnetic activities by using the values of the geomagnetic indices aa and the sunspot numbers Rz existing since 1868.

MATERIALS AND METHODS

Data

The data used in this study were three meteorological parameters, namely temperature, rainfall and solar index Rz. The period of study was 1950 -2020.

The temperature and rainfall database was retrieved from Chad's ANAM (National Agency of Meteorology). It concerns two geographically distinct cities in Chad: Moundou and Ndjamena, belonging respectively to a Sudanian and a Sahelian zone.

Data on sunspot numbers Rz are currently available in daily, monthly and annual averages, and systematically distributed on the NOAA (National Oceanic and Atmospheric Administration) websites (https://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-indices/sunspotnumbers/american/tables/).

Methods

The Nicholson index was used to study the inter-annual variability of rainfall. This index is expressed as follows:

$$ISP = \frac{Pi - \overline{P}}{\sigma} \qquad \text{Eq. 1}$$

where

ISP: Standardized Rainfall Index

Pi: Cumulative rainfall in year i (in mm),

$\overline{P}$: Average rainfall over the study period (in mm),

σ: Standard deviation of rainfall over the study period.

Thus when:

ISP < -1: The year is dry

-1 ≤ ISP ≤ 1: The year is normal

ISP> 1: The year is wet

Determination of the sunspot number Rz

The relative sunspot number, known as the "Wolf number" Rz is defined as follows: Rz = k (10g +f) where k denotes the weighting coefficient which depends on the instrument used by the observer for counting sunspots and their subdivision into groups; g is the number of sunspot groups; and f represents the total number of sunspots.

The Sunspots number Rz makes it possible to determine the different phases of the solar cycle. Thus, solar cycle phases are determined by considering the criteria of the following conditions from Doua *et al.* (2013):

1) Minimum phase: Rz < 20, where Rz is the annual average value of the sunspot number;

2) Ascending phase: 20 ≤ Rz ≤ 100 and Rz greater than the value of the previous year; 3) Maximum phase: Rz > 100. For solar cycles where the maximum Rz (Rzmax) is smaller than 100, the maximum phase is obtained by considering Rz > 0.8 Rzmax;

4) Descending phase: 100 ≥ Rz ≥ 20 and Rz smaller than the previous year's value.

RESULTS AND DISCUSSION

The rainfall in Chad from 1950 to 2020 in two different climatic zones is presented in Fig.1. Panel a) concerns the city of N'Djamena and panel b) deals with the city of Moundou.

Fig.1 (a) deals with the city of N'Djamena recording the year 1959 as the wettest year of this period. On the other hand, the driest year was the year 1984. The period from 1950 to 1961 was the wettest period in the present study (Maharana *et al.,* 2018; Pattnayak *et al*., 2019). However, the period from 1979 to 1987 was the driest. And everywhere else, an alternation of wet and dry years was noticed. This figure shows an overall decreasing trend in rainfall over the study period. This result corroborates the work carried out by Bedoum *et al.* (2017) during their study from 1960 à 2008 and by Maharana *et al.* (2018); Pattnayak *et al*. (2019) in Chad. In panel b), which concerns the Sudanian zone, the wettest year was 1951 and the driest was 1998. The wettest period was from 1958 to 1965. On the other hand, the dryest period started from 1980 to 1990 (Maharana *et al.,* 2018; Pattnayak *et al*., 2019).

Elsewhere, alternating wet and dry years during our study period were in the south of the country. Overall, the rainfall trend is declining in this area, as it is for the town of N'djamena (Djeko and Seingué, 2017).

Fig. 2 deals with the average temperature from 1950 to 2020 in two different climate zones. Panel a) concerns the city of N'Djamena and b) deals with the city of Moundou.

In Fig. 2 of panel a), which corresponds to the city of N'Djamena, the curves showed the following hottest years: 1973, 1982, 1990, 2005, 2010 and 2013 with mean temperature values above 29°C. The warmest

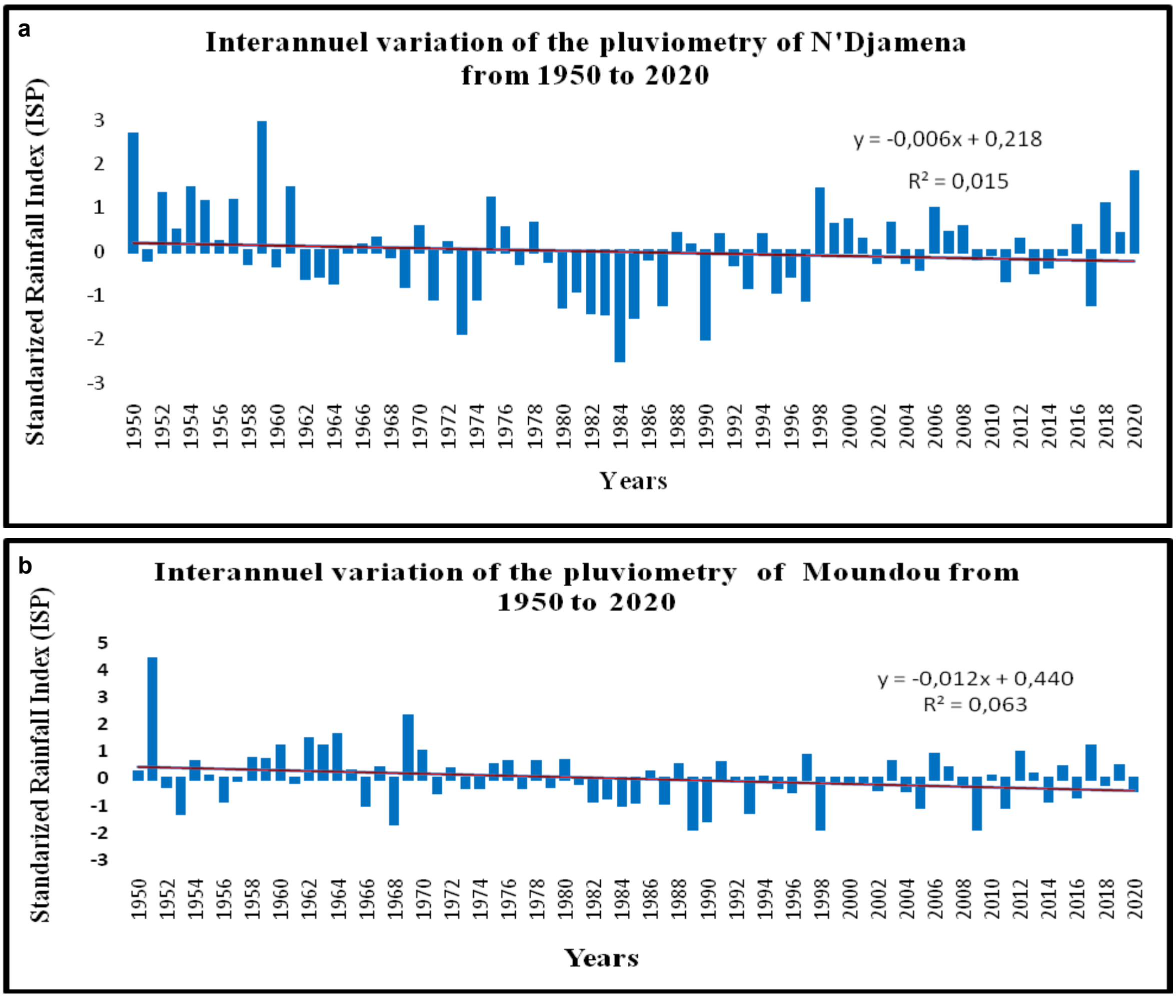

Fig. 1. *Inter-annual rainfall variation from 1950 to 2020 in Chad: a) N'Djamena and b) Moundou.*

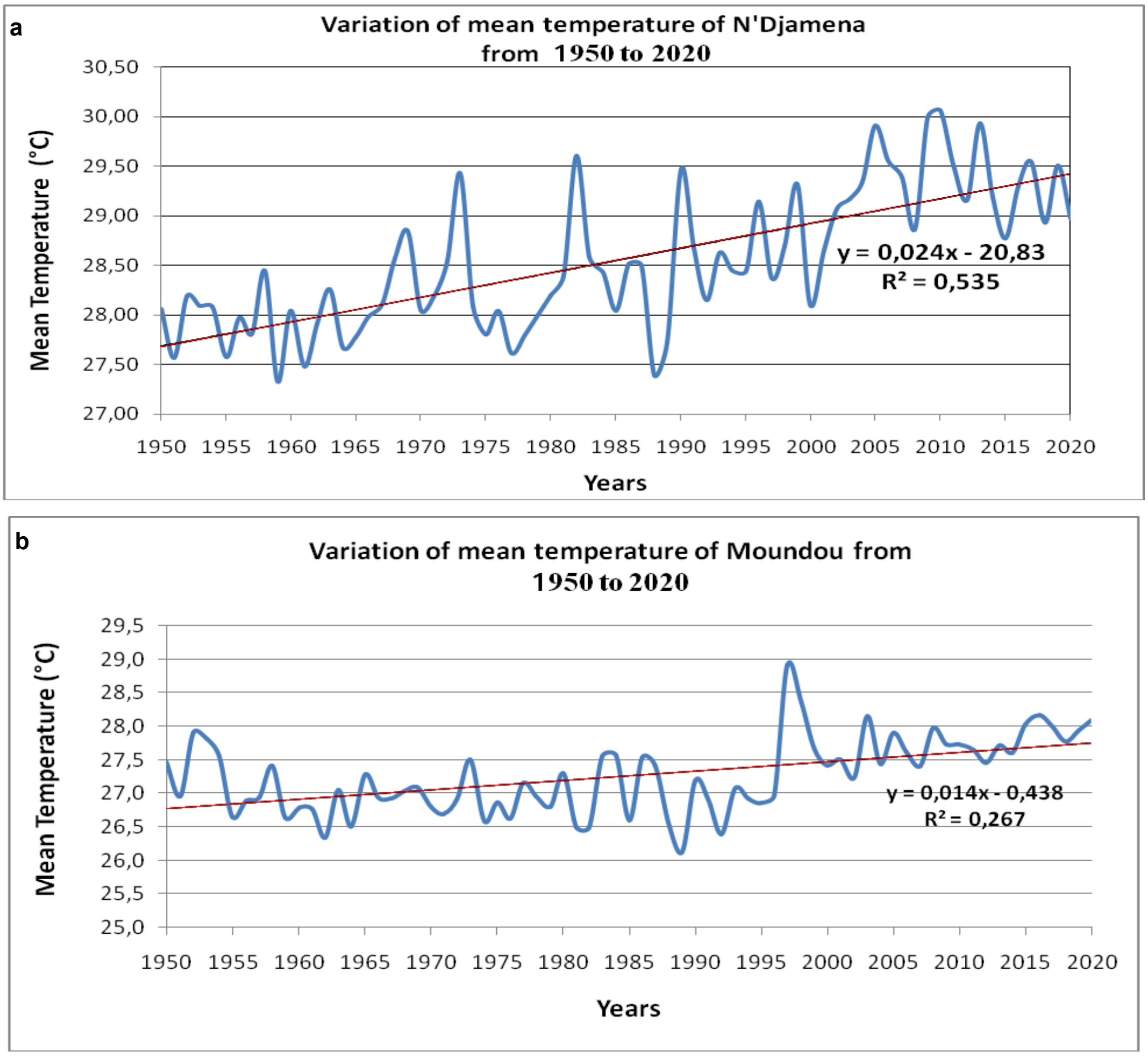

Fig. 2. *Evolution of the average temperature over the period 1950-2020 in Chad: a) N'Djamena and b) Moundou*

year was 2010 with an average temperature of 30.06°C. However, the coldest years were 1959, 1961, 1977, and 1988.The coldest year during that study period was 1988°C, with an average temperature of 27.39°C. Overall, there is an increasing trend in the average temperature in the Sahelian zone. The same result was found by Bedoum et *al.* (2017) during their study from 1960 to 2008 in Chad and by Maharana *et al.* (2018; Pattnayak *et al*. (2019).

Fig. 2 (b) shows the inter-annual mean temperature for 1950-2020 in Moundou.

The years 1952 and 1997 were the warmest years of this period, with mean temperature values of 27.9°C and 28.9°C, respectively. The years 1989 (26.1°C) and 1962 (26.3°C) were the least warm years in present study period.

In the Sudanian zone, the average temperature trend was slightly increasing (Djeko and Seingué, 2017; Maharana *et al.,* 2018; Pattnayak *et al*., 2019).

Fig. 3 shows the superposition of rainfall and sunspot number Rz for 1950-2020. Panel a) deals with the city of N'Djamena, and panel b) corresponds to the city of Moundou.

The curves of Fig. 3 (a) show that the solar minimums of the different cycles of the study period (1954, 1964, 1976, 1986, 1996 and 2008) corresponded to the rainfall peaks and the solar maximums of these different cycles coincided with the lowest rainfall values excepted for the solar maximum 2000.These results corroborate the work of Zerbo *et al*. (2013b) and Hiremath (2006), which concerned the Sahelian zone. This result also corresponded with the work carried out by Obiegbuna *et al.* (2023) in Nigeria (Sokoto and Port Harcourt) and by Mohamed and El-Mahdy (2021) in Sudan and Sudan South. In their study on the annual rainfall variation, these two authors and several sunspots Rz in Nigeria and Sudan obtained a negative correlation. This-This means that the maxima of precipitations can correspond at least to the sunspots' numbers Rz and sharp-poured.

The same is true for the Sudanian zone for the solar maximums, but there was an exception for the solar

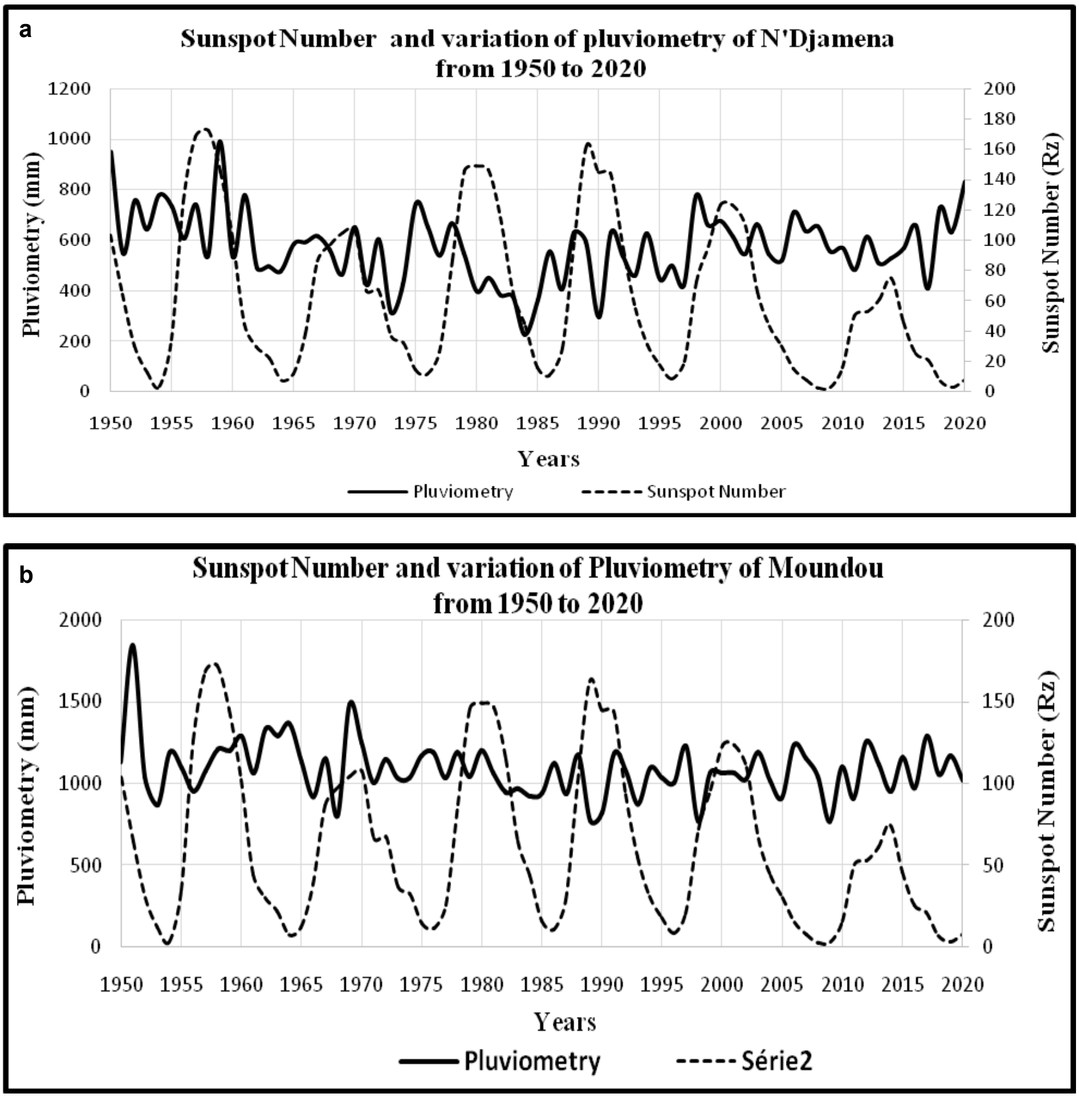

Fig. 3. *Profiles of rainfall and sunspot number Rz from 1950 to 2020 in Chad: a) N'Djamena and b) Moundou*

minimums 1996 and 2008, which coincided with the low values of the pluviometry of the corresponding year.

Fig. 4 shows the superposition of Rz Sunspot Numbers and temperatures in two different cities in Chad: panel a) deals with the city of N'Djamena and panel b) corresponds to the city of Moundou.

The curves of the two panels through the data show that at solar minima of different cycles in the present study period (1954, 1964, 1976, 1986, 1996 and 2008), temperatures decreased in both study cities, except for the solar minimums 1996 of the data for N'Djamena city and 2008 in Moundou. However, at solar maximums, temperatures fluctuated in N'Djamena (Sahelian zone). These results corroborate the work of Zerbo *et al.* (2013b). In Moundou (Sudanian zone), it was noticed that the maximum temperatures coincide with the solar maximums during this phase, except for the solar maximum in 2014.

During the increasing phase, rainfall decreases in the two zones studied, but temperatures increase during this period. This result corroborates Zerbo et al. (2013b) work in West Africa (Burkina Faso). In the decreasing phase, rainfall decreases, and temperature increases in the Sahelian zone. This is consistent with Zerbo et al. (2013b) work realized in Burkina-Faso (Sahelian zone). However, in the Sudanian zone the present study recorded a decrease in temperature during this phase.

The analysis of the long series of data available for the Aa geomagnetic indices makes it to understand that in the context of the sunspot cycle, the different classes of activity have different occurrences throughout the phases of the sunspot cycle. Thus, the quiet day activity, which was caused by the slow solar winds coming from the heliosheet, occurred mostly during the phase minimum, while the shock activity, which was due to the coronal mass injections or CMEs, was preponderant during the solar maximum as reported by Zerbo *et al.* (2011).

Considering these previous works, it was revealed that

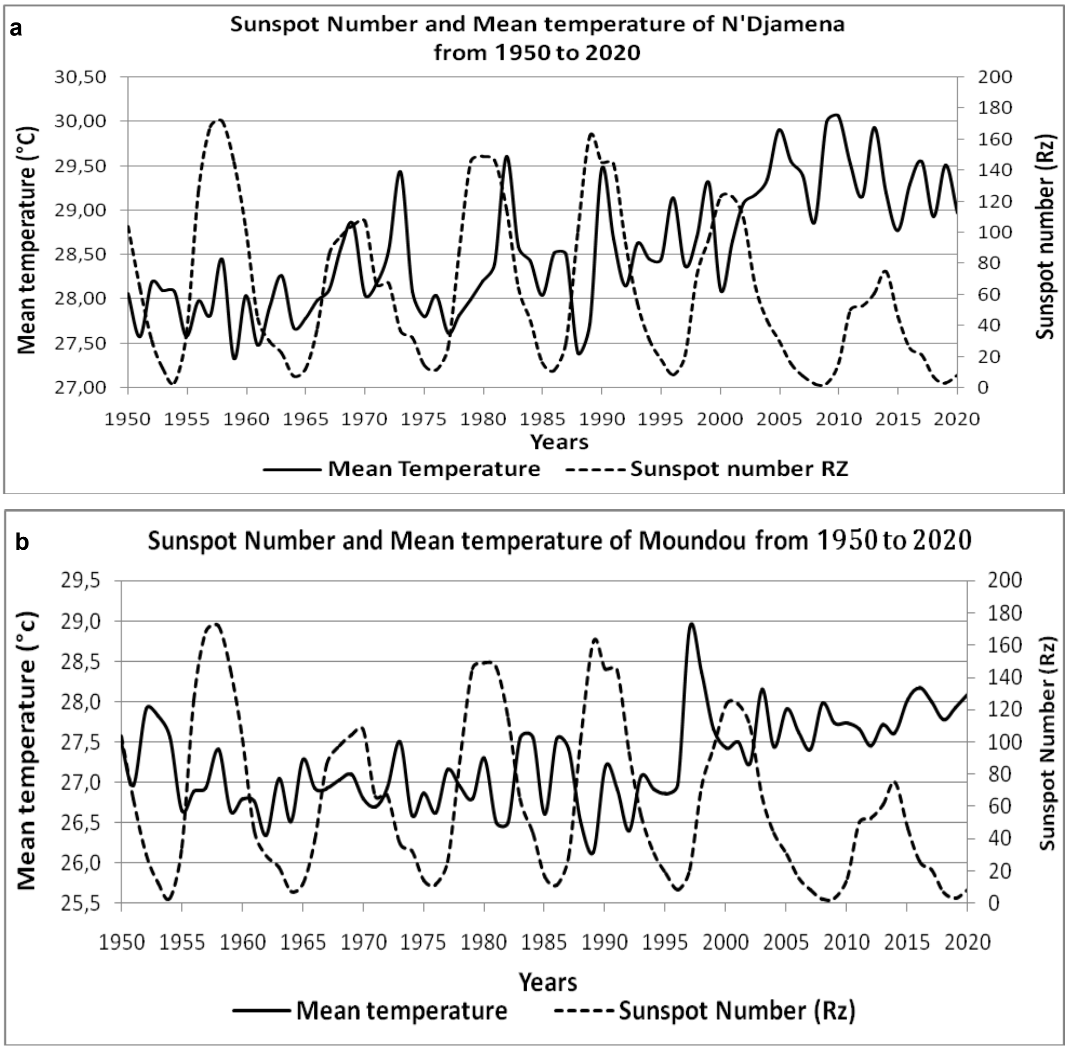

Fig. 4. *Temperature profiles and Rz Sunspot numbers from 1950 to 2020 in Chad: a) N'Djamena and b) Moundou*

the increase in precipitation during minimum phases could be due to slow solar winds coming from the heliosheet. Coronal mass ejections cause a decrease in precipitation.

Conclusion

The study of climatic variability in Chad in two different bioclimatic zones leads to the conclusion that the maximum values of cumulative rainfall and mean temperature vary from one zone to another. However, the overall trends during that period for these two parameters were the same for both zones. From 1950 to 2020, for both zones concerned, there was a decreasing trend in rainfall and an increasing trend in mean temperature. The study of the sunspot number index (Rz) with precipitation leads to the conclusion that a quiet period of solar activity corresponds to high rainfall; however, at the peak of solar activity, low rainfall was recorded. The study showed that an active sun is associated with less cloudy weather and that a calm sun leads to overcast skies and rainfall. This study in Chad confirmed the link between solar activity and the climate in the lower atmosphere. Therefore, solar activity plays an important role in studying climate change.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Alhassane, A., Salack, S., Ly, M., Lona, I., Traoré, S.B. & Sarr, B. (2014). Evolution of agro-climatic risks associated with recent trends in rainfall patterns in Sudano-Sahelian West Africa. *Sécheresse*, 24 (4), 282-293.
2. Bedoum, A., Biona, C. B., Jean-Pierre, B., Adoum, I., Mbiaké, R. & Baohoutou, L. (2017). Évolution des indices des extrêmes climatiques en République du Tchad de 1960 à 2008. *Atmosphere-ocean,* 55 (1), 42-56.
3. De Jager, C. (2008). Solar Activity and Its Influence on Climate. *Netherlands Journal of Geosciences,* 87 (3), 207-213.
4. Djeko, M. D. & Seingue, R. G. (2017). Réponses paysannes à la variabilité climatique au sud du Tchad. *Afrique SCIENCE,* 13, (1), 337- 348.

5. Doua, A. G., Ouattara, F., Emmanuel, N., François, Z. (2013). foF2 Diurnal Variability at African Equatorial Stations: Dip Equator Secular Displacement Effect. *International Journal of Geosciences*, 4, 1145-1150. http://dx.doi.org/10.4236/ijg.2013.48108
6. Eddy, J. A. (1976). Le minimum de Maunder. *Sciences* 192 (4245), 1189–1202.
7. Friis-Christensen & Lassen, K. (1991).The length of the solar cycle and indicator of the solar activity close associated with climate. *Science,* 254 (5032), 698-700.
8. GIEC (2007a). Bilan des changements climatiques. Contribution des Groupes de travail I, II et III au quatrième Rapport d'évaluation du Groupe d'experts intergouvernemental sur l'évolution du climat. Genève, Suisse, 53 pp.
9. GIEC (2007b). Bilan des changements climatiques. Contribution des Groupes de travail I, II et III au quatrième Rapport d'évaluation du Groupe d'experts intergouvernemental sur l'évolution du climat. Genève, Suisse, 103 pp.
10. GIEC (2014). Groupe d'experts Intergouvernemental sur l'Evolution du Climat. Changements climatiques, éléments scientifiques, pp.36 : 11-12.
11. Hiremath, K.M. & Mandi, P.I. (2004). Influence de l'activité solaire sur les pluies de mousson indiennes**.** *Nouvel Astre*, 9 (8), 651 – 662. 10.1016/j.newast.2004.04.001
12. Hiremath, K. M. (2006). L'influence de l'activité solaire sur les précipitations en Inde : variation d'un cycle à l'autre. *Journal d'Astrophysique et d'Astronomie*, 27, 367-372.
13. Laurenz, L., Ludecke, H. & Luning, S. (2019). Influence of solar activity changes on European rainfall. *Journal of Atmospheric and Solar-Terrestrial Physics*, 185, 29-42.
14. Legrand, J.P. and Simon, P. (1989). Solar Cycle and Geo -magnetic Activity: A Review for Geophysicists. Part I. The Contributions to Geomagnetic Activity of Shock Waves and of the Solar Wind. *Annales Geophysicae, 7, (6), 565-578.*
15. Ly, M., Traoré, S., Alhassane, A. & Sarr, B. (2013). Evolution of some observed climate extremes in the West African Sahel. *Weather and Climate Extremes*, 1, 19-25.
16. Maharana, P., Abdel-Lathif, A. Y. & Pattnayak, K. C. (2018). Observed climate variability over Chad using multiple observational and reanalysis datasets. *Global and Planetary Change,* 162, 252-265.
17. Mbaiguedem, M. (2012). Etude de vulnérabilité et adaptation des femmes rurales face au changement climatique: Cas du Département du Chari au Tchad. Mémoire Mastère Changement Climatique et Développement Durable. Centre Régional AGRHYMET, Niger, 85 p.
18. Mohamed, M. A. & El-Mahdy, M. E. (2021). Impact of sunspot activity on the rainfall patterns over Eastern Africa: a case study of Sudan and South Sudan. *Journal of Water and Climate Change* (312), 2104- 2124.
19. Nitka, W. & Burnecki, K. (2019). Impact of solar activity on precipitation in the United States. *Physica A: Statistical Mechanics and its Applications,* 527, 121387.
20. Obiegbuna, C.D., Orji, O.P. & Enwelum, C.U. (2023). Comparing the impact of solar activities on rainfall under varying climates during the solar cycle 24. IOP Conference Series: *Earth and Environmental Science,* 1178 (2023) 012028. doi:10.1088/1755-1315/1178/1/012028
21. Office for the Coordination of Humanitarian Affairs. (2022). *Chad Situation Report*. Retrieved from https://reports.unocha.org/en/country/chad/
22. Ouattara, F. (2009). Contribution à l'étude des relations entre les deux composantes du champ magnétique solaire et l'ionosphère équatoriale. Thèse d'état soutenue à l'Université Cheikh Anta Diop de Dakar.
23. Ouattara, F., Amory-Mazaudier, C., Menvielle, M., Simon, P. & Legrand, J.P. (2009). On the Long Term Change in the Geomagnetic Activity during the XXth Century. *Annales Geophysicae,* 27(5), 2045-2051. http://dx.doi.org/10.5194/angeo-27-2045-2009.
24. Ouattara, F. & Amory-Mazaudier, C. (2009). Solar–geomagnetic activity and Aa indices toward a Standard. *J. Atmos. Solar-Terr. Phys, 71*, 1736-1748.
25. Pattnayak, K. C., Abdel-Lathif, A. Y., Rathakrishnan, K. V., Sing, M., Dash, R. & Maharana, P. (2019). Changing Climate Over Chad: Is the rainfall over the major cities recovering? *Earth and Space Science*, 6, 7, 1149-1160.
26. Programme d'Action National d'Adaptation aux changements climatiques (PANA). (2010). PNUD/CCNUCC, pp. 92.
27. Sarr, B., Atta, S., Ly, M., Salack, S., Ourback, T., Subsol, S. & Alan, G. D. (2015). Adapting to climate variability and change in small holder farming communities: A case study from Burkina Faso, Chad and Niger. *Journal of Agricultural Extension and Rural Development*, 7 (1), 16-27. https://DOI: 10.5897/JAERD2014.0595.
28. Stratégie Nationale de Lutte contre les Changements Climatiques au Tchad (SNLCC). (2017). Ministère de l'Environnement, de l'Eau et de la Pèche, pp 14.
29. Tsiropoula, G. (2003). Signature of Solar Activity Variability in Meteorological Parameters. *Journal of Atmospheric and Solar-Terrestrial Physics*, 65, (4), 469- 482.
30. Zerbo, J.L., Ouattara F., Zoundi, C. & Gyébré, A. (2011). A Solar cycle 23 and geomagnetic activity since 1868. *Revue CAMES serie A*, 12 (2), 255-262.
31. Zerbo, J.L., Amory-Mazaudier, C., Ouattara, F. & Richardson, J. (2012a). Solar Wind and Geomagnetism, toward a Standard Classification 1868-2009. *Annals Geophysicae*, 30 (2), 421-426. http://dx.doi.org/10.5194/angeo-30-421-2012
32. Zerbo, J.L., Amory-Mazaudier, C. & Ouattara, F. (2012b). Geomagnetism during Solar Cycle 23: Characteristics. *Journal of Advanced Research*, 4(3), 201, 265- 274. http://dx.doi.org/10.1016/j.jare.2012.08.010
33. Zerbo, J. L., Ouattara, F., Amory-Mazaudier, C. & Legrand, J.P. (2013a). Solar Activity, Solar Wind and Geomagnetic Signatures. *Atmospheric and Sciences*, 3, 610-617.
34. Zerbo, J.L., Ouattara, F., Emmanuel, N. (2013b). Solar Activity and Meteorological Fluctuations in West Africa: Temperatures and Pluviometry in Burkina Faso, 1970-2012. *International Journal of Astronomy and Astrophysics*, 3, 408-411.