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RESEARCH ARTICLE

STATISTICAL EVALUATION OF THE CLIMATIC WARMING IN NDJAMÉNA AND MOUNDOU – CHAD PERIOD FROM 1986 TO 2015

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ABSTRACT

Climatic warming is effectively slowly going on in both localities. The annual means of the maximal temperature of the air increased at the rates of 0.045°C/year and 0.023°C/year and of the minimal temperature of the air,the rates of 0.032°/year and 0.013°/year in Ndjaména and Moundou respectively. The consequences should be socially and economically catastrophic. To prevent and even eradicate this warming, it is strongly recommended the creation and management of green spaces all over the cities.

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INTRODUCTION

Up today, many scientists and politics around the world continue to pay more attention to the problem of the climatic changing in general, and warming in particular, (BAD, 2012, Sylvestre, 2015). Various investigations have been done generally at the global scale. Their results have divided the researchers into two groups. One says the ongoing climatic warming has not yet reached the catastrophic level and moreover, it occurs slowly. Another goes to the opposite direction. Both groups accept that some climatic warming is going on but their ideas on its rate are different. It is evident that any change always starts locally before covering a wide territory. So, to appreciate in detail the ongoing climatic warming, we should start investigations at local scales, whence the importance of the present paper which concerns the localities of Ndjaména (the capital of Chad) and Moundou (its second important city). As main cities, they are well-equipped with good meteorological stations and acceptable trained personnel. Thus, our results will be acceptable as issued from the analysis of fair chronological data series. This work has five sections. The first and present one introduces the problem. The second exposes the data and the methodology. The results and their analysis are in the third section. In the fourth one are the conclusion, recommendation and the acknowledgements. The bibliography in alphabetic order in the fifth section ends the work.

Data and methodology

Data: The chronological series of the minimal and maximal temperatures of the air for the periods from 1986 to 2010 for Moundou and 1986 to 2015 for Ndjaména were statistically treated. These temperatures were registered using minimal and maximal thermometers placed in a meteorological cabin in stations of observations. Observations were made five times a day: at 06, 09, 12, 15 and 18 hours, universal time. They were monthly and annual means archived in tabular forms at the National Meteorological Service of Chad in Ndjaména. Hence, we did not deal with primary data in this investigation.

METHODOLOGY

The full periods of investigation were divided into sub periods of five years each and were numerated as follows: 1986-1990–1; 1991-1995–2; 1996-2000–3; 2001-2005–4; 2006-2010–5; 2010-2015–6. Sub period monthly and annual means and their corresponding standard deviations were calculated. If when passing from a sub period up to another these means were increasing, then we concluded that the climatic warming was going on. And inversely. Similar analysis was done for the full periods comparing the first and last sub period means. Time trend of the annual means of these temperatures was analyzed. Put T(t) the temperature as function of year t.

The points T(t) were plotted in a coordinate system with t on the abscissa and T on the ordinates. Analyzing the obtained cloud of points enabled us to determine the form of the relationship between t and T. The least square method permitted us to establish the equations of regression and to conclude if these temperatures were increasing or decreasing during the considered periods.

RESULTS AND ANALYSIS

According to the above methodology, the treatment of the maximal temperature of the air enabled us to draw Table 3.1 of sub periods monthly and annual means. In each cell, the first number represents the mean and the second, its corresponding standard deviation. The same presentation is in Table 3.2. SP on left top and P at the last row stand for sub and full periods, respectively. Table 3.1 shows that higher values of the sub period monthly means of the maximal temperature of the air either in Ndjaména or in Moundou were registered from March to June with the absolute maximal value of 42.8°C in April (for Ndjaména) and 39.9°C in March (for Moundou), both in the fourth sub period. In a given month, when passing from a sub period up to another, these sub period monthly means used to increase. When they decreased, it was less than the first variation. Thus, as final result, they increased during the full period of investigation. The values of the standard deviation were frequently at most 1.0°C, indicating the lower time variability of this parameter. The highest values were 4.3°C and 2.1°C in Ndjaména and Moundou in February during the third and the first sub periods, respectively.

Table 3.1. Sub period monthly and annual means and their corresponding standard deviations of the maximal temperature of the air in Ndjaména and Moundou. Periods 1986-2010 (Moundou) and 1986-2015 (Ndjaména)

Ndjaména													
S P/Month	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1	32.0 2.0	34.1 0.0	38.3 1.7	41.7 1.1	40.5 1.0	38.0 1.3	33.5 1.8	31.8 1.2	34.0 2.1	37.1 1.1	36.7 1.1	33.0 2.1	35.9 0.9
2	31.1 1.2	34.3 2.2	39.3 0.3	40.9 0.0	39.5 2.0	37.9 0.3	33.7 0.7	30.7 1.0	33.3 0.9	37.2 0.9	35.9 1.5	32.6 1.3	35.5 0.3
3	32.1 3.6	33.6 4.3	37.0 3.9	40.6 1.5	40.6 1.2	38.3 1.2	35.7 4.0	31.8 2.1	34.1 2.2	36.5 2.0	35.0 2.2	31.6 3.1	35.6 1.5
4	32.4 1.6	36.3 2.3	39.5 1.3	42.8 0.3	41.5 0.9	37.9 0.8	34.2 1.1	31.9 0.8	34.3 1.0	37.8 0.8	37.5 0.3	34.7 1.2	36.7 0.3
5	34.0 2.8	38.4 1.0	40.2 0.7	42.1 1.2	41.2 1.2	38.9 0.9	34.8 1.1	31.8 0.9	34.0 1.0	37.9 0.8	35.8 3.4	34.5 1.3	36.9 0.6
6	33.4 1.3	37.6 1.5	40.3 2.0	41.9 1.0	41.1 1.1	38.3 1.8	34.4 1.7	31.0 1.1	34.1 0.6	37.6 0.7	37.4 0.3	32.8 2.3	36.5 0.8
P	32.4 1.0	35.7 2.0	39.1 1.3	41.7 0.8	40.7 0.7	38.2 0.4	34.4 0.8	31.5 0.5	34.0 0.3	37.4 0.5	36.4 1.0	33.2 1.2	
Moundou													
1	34.4 1.6	36.4 2.1	38.9 0.9	39.5 0.3	36.2 1.5	32.9 0.7	30.4 0.8	30.4 0.5	31.1 0.8	33.8 0.2	35.9 0.4	34.2 1.5	34.5 0.5
2	33.6 0.9	36.4 1.5	39.2 0.7	38.2 0.9	34.7 1.4	33.0 0 .5	30.7 0.5	29.8 0.5	31.7 0.6	33.6 0.6	35.2 0.5	33.8 0.8	34.2 0.3
3	35.3 0.5	36.7 2.0	39.3 1.0	39.0 1.8	36.2 1.3	32.6 0.8	30.8 0.5	30.6 0.6	31.4 0.3	33.5 0.7	35.5 1.2	34.7 0.5	34.7 0.4
4	34.4 1.3	37.3 1.1	39.9 0.5	39.2 0.4	36.5 1.1	32.4 0.8	31.1 0.4	30.4 0.4	31.3 0.4	33.3 0.2	35.8 0.5	35.1 0.8	34.8 0.8
5	34.8 1.9	37.0 1.7	39.6 0.3	38.0 1.5	34.8 1 .0	32.3 0.7	31.0 0.7	29.3 1.1	30.9 0.8	33.1 0.3	34.7 0.0	34.7 0.9	34.7 0.6
P	34.5 0.6	36.8 0.4	39.4 0.4	38.8 0.6	35.7 0.9	32.6 0.3	30.8 0.3	30.1 0.5	31.3 0.3	33.5 0.3	35.4 0.5	34.5 0.5	

Table 3.2. Sub period monthly and annual means and their corresponding standard deviations of the minimal temperature of the air in Ndjaména and Moundou. Periods 1986-2010 (Moundou) and 1986-2015 (Ndjaména)

Ndjaména													
S P/Month	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1	14.5 2.1	16.9 2.1	21.5 2.1	25.3 1.3	26.5 0.5	25.1 1.0	23.4 1.0	22.7 0.3	23.0 0.7	22.2 1.0	19.2 1.6	16.3 1.6	21.4 0.8
2	14.2 1.5	16.8 1.7	22.6 0.4	26 2 0.7	26.3 0.7	25.6 0.5	23.6 0.4	22.5 0.4	23.1 0.6	22.1 1.0	18.8 1.2	15.1 1.3	21.4 0.2
3	15.5 0.6	17.9 1.9	22.2 1.2	26.0 0.5	27.1 1.2	25.6 0.5	23.6 0.6	22.6 0.4	23.4 0.6	23.2 1.2	18.1 3.1	15.7 0.7	21.7 0.5
4	13.9 1.3	17.8 2.5	22.4 1.8	26.6 0.5	26.7 0.5	25.2 0.4	23.8 0.4	23.0 0.3	23.3 0.5	22.7 0.6	19.4 1.0	16.0 0.9	21.7 0.6
5	15.8 1.8	20.2 0.9	21.6 1.6	26.3 1.0	27.1 0.8	25.6 0.6	24.0 0.5	23.1 0.5	23.6 0.3	23.4 0.7	19.7 1.1	15.8 1.2	22.2 0.4
6	15.0 1.1	19.7 1.6	22.8 1.2	26.2 1.1	27.2 0.6	26.0 0.7	24.0 0.2	22.8 0.3	23.5 0.3	23.4 0.7	19.3 0.9	15.6 1.6	22.0 0.6
P	14.8 0.7	18.2 1.4	22.2 0.5	26.1 0.4	26.8 0.4	25.5 0.3	23.7 0.2	22.8 0.2	23.3 0.2	22.8 0.6	19.1 0.6	15.8 0.4	
Moundou													
1	15.6 1.6	18.9 1.2	22.5 1.9	24.6 0.8	23.6 1.5	22.6 0.4	21.5 0.4	21.2 0.3	21.3 0.4	21.1 0.4	17.9 1.6	15.2 1.5	20.5 0.5
2	16.3 1.1	18.3 1.1	22.9 1.1	24.8 0.5	23.4 0.5	22.5 0.6	21.2 0.5	21.4 0.1	21.1 0.4	21.1 0.4	17.7 1.8	14.4 1.4	20.4 O.4
3	16.1 0.5	19.2 1.4	22.3 0.8	24.6 1.0	25.1 2.4	22.2 0.5	21.5 0.2	21.5 0.3	21.0 0.1	21.5 0.4	17.6 1.6	14.4 0.9	20.6 0.3
4	15.7 0.6	19.0 0.8	23.6 1.3	25.1 0.7	23.9 0.5	22.2 0.4	21.6 0.2	21.4 0 .2	21.2 0.3	21.0 0.6	18.1 1.0	15.3 0.7	20.5 0.5
5	16.9 0.9	19.4 1.3	23.0 0.5	24.9 0.5	23.7 0.5	22.6 2.0	21.9 0.1	21.6 0.2	21.5 0.2	21.7 0.5	18.2 1.3	15.3 1.3	20.0 2.0
P	16.1 0.5	19.0 0.4	22.9 0.5	24.8 0.2	23.8 0.8	22.4 0.2	21.5 0.3	21.4 0.1	21.2 0.2	21.3 0.3	17.9 0.3	14.9 0.5	

Table 3.3. Simulation the annual means of the maximal temperature of the air in Ndjaména (period 1986 – 2015) and Moundou (period 1986 – 2010). lel is the absolute value of e

t	$T_{i,max}$	$T_{th,max}$	lel	$T_{i,max}$	$T_{th,max}$	lel
Ndjaména				Moundou		
-14	36.1	35.6	0.5	-	-	-
-13	36.4	35.6	0.8	-	-	-
-12	35.5	35.7	0.2	34.6	34.3	0.3
-11	34.7	35.7	1.0	35.1	34.3	0.8
-10	36.8	35.8	1.1	34.3	34.4	0.1
-9	35.6	35.8	0.2	33.7	34.4	0.7
-8	35.2	35.8	0.6	34.8	34.4	0.4
-7	35.9	35.9	0.0	34.2	34.4	0.2
-6	35.4	35.9	0.5	33.8	34.5	0.7
-5	35.6	36.0	0.4	34.5	34.5	0.0
-4	36.7	36.0	0.7	34.3	34.5	0.2
-3	34.9	36.1	1.2	34.0	34.5	0.5
-2	35.1	36.1	1.0	34.6	34.6	0.0
-1	37.5	36.2	1.3	34.1	34.6	0.5
0	33.7	36.2	2.5	35.2	34.6	0.6
1	36.3	36.2	0.1	34.9	34.6	0.3
2	36.7	36.3	0.4	34.5	34.6	0.1
3	36.6	36.3	0.3	34.8	34.7	0.1
4	36.9	36.4	0.5	34.1	34.7	0.6
5	37.2	36.4	0.8	36.2	34.7	1.5
6	36.9	36.5	0.4	34.5	34.7	0.2
7	36.8	36.5	0.3	34.4	34.8	0.4
8	36.0	36.6	0.6	34.5	34.8	0.3
9	37.6	36.6	1.0	34.2	34.8	0.6
10	37.3	36.7	0.7	35.2	34.8	0.4
11	37.1	36.7	0.4	34.3	34.9	0.6
12	36.2	36.7	0.5	35.5	34.9	0.6
13	37.4	36.8	0.6	-	-	-
14	36.4	36.8	0.4	-	-	-
15	35.5	36.9	1.4	-	-	-

Table 3.4. Simulation the annual means of the minimal temperature of the air in Ndjaména (period 1986 – 2015) and Moundou (period 1986 – 2010). lel is the absolute value of e

t	$T_{i,max}$	$T_{th,max}$	lel	$T_{i,max}$	$T_{th,max}$	lel
Ndjaména				Moundou		
-14	21.8	21.3	0.5	-	-	-
-13	21.5	21.3	0.2	-	-	-
-12	21.3	21.3	0.0	20.8	20.4	0.4
-11	20.1	21.3	1.2	20.6	20.5	0.1
-10	22.2	21.4	0.8	20.5	20.5	0.0
-9	21.7	21.4	0.3	19.7	20.5	0.8
-8	21.1	21.4	0.3	21.0	20.5	0.5
-7	21.3	21.5	0.2	20.8	20.5	0.3
-6	21.5	21.5	0.0	20.3	20.5	0.2
-5	21.3	21.5	0.2	20.8	20.5	0.3
-4	21.6	21.6	0.0	20.3	20.5	0.2
-3	21.8	21.6	0.2	20.0	20.6	0.6
-2	22.3	21.6	0.7	20.7	20.6	0.1
-1	21.2	21.7	0.5	20.3	20.6	0.3
0	-	-	-	21.0	20.6	0.4
1	21.0	21.7	0.7	20.5	20.6	0.1
2	21.4	21.8	0.4	20.5	20.6	0.1
3	21.8	21.8	0.0	20.2	20.6	0.4
4	21.8	21.8	0.0	20.4	20.7	0.3
5	22.7	21.9	0.8	20.1	20.7	0.6
6	22.2	21.9	0.3	20.4	20.7	0.3
7	22.0	21.9	0.1	21.4	20.7	0.7
8	21.8	22.0	0.2	20.7	20.7	0.0
9	22.4	22.0	0.4	20.7	20.7	0.0
10	22.8	22.0	0.8	20.8	20.7	0.1
11	22.0	22.1	0.1	21.2	20.7	0.5
12	22.2	22.1	0.1	-	-	-
13	22.5	22.1	0.4	-	-	-
14	22.2	22.1	0.1	-	-	-
15	20.9	22.2	1.3	-	-	-

The means calculated for the full periods of investigation from the annual and sub period monthly means were almost the same with different standard deviations. For Ndjaména the first method gave 36.2°C with a standard deviation of 0.6°C, and the second method, 36.2°C and 3.3°C. For Moundou, these values were respectively 34.6°C and 0.2°C, 34.5°C and 3.0°C. The differences were due to the roundup errors. Moreover the substantial differences in the standard deviations can be explained by the fact that the variability of the temperature is less for a given sub period than a given month.

Analyzing Table 3.2, one easily remarks that the same conclusions like what obtained in the case of the maximal

temperature are kept for both localities. The absolute maximal values of the sub period monthly means of the minimal temperature of the air were 27.2°C with a standard deviation of 0.6°C registered in Ndjaména in May during the sixth sub period, 25.1°C with standard deviations of 0.7°C and 2.4°C registered in Moundou in April and May during the fourth and third sub periods, respectively. The absolute minimums of 13.9°C and 15.6°C with standard deviations of 1.3°C and 1.6°C were registered in January during the fourth sub period in Ndjaména and first sub period in Moundou. It is evident that minimal and maximal values of both temperatures occurred respectively in winter and summer periods in the northern hemisphere. Very important to be informed that as from year 2014, the temperature of the air over 42.0°C is frequently registered in Ndjaména during the period from April to June. Sometimes it is even around 45.0°C. The means calculated for the full periods of investigation from the annual and sub period monthly means gave almost the same result with different standard deviations. For Ndjaména the first method gave 21.7°C with a standard deviation of 0.3°C, and the second method, 21.8°C and 3.8°C. For Moundou, these values were respectively 20.4°C and 0.2°C, 20.6°C and 3.0°C. The reasons are the same like above.

The full period annual means of these temperatures were plotted and analyzed in order to determine if the climate in these localities were under the warming process or not. Coordinates systems were used to plot the points T(t). The analysis of the obtained cloud of points indicated that the relationship between the time t and temperature T was of linear form. Applying the least square method enabled us to find the needed linear regression equations. To facilitate the computational process, a fictive zero was introduced such that year 2000 corresponded to t = 0. Thus, years 1999 and 2001 corresponded to t = -1 and t = 1, respectively. And so on. For the maximal temperature, these linear regression equations for Ndjaména and Moundou were respectively:

$$T_{max,th}(t) = 0.045t + 36.2, \quad (3.1a)$$

$$T_{max,th}(t) = 0.023t + 34.6. \quad (3.1b)$$

The degree of fitness, e, of each formula was given by the expression:

$$e = T_i - T_{th}, \quad (3.2)$$

where T_i is the value of the temperature issued from the observations, and T_{th} – its theoretical value calculated with the established linear regression equation. The results of simulation of the annual means of the maximal temperature of the air in Ndjaména and Moundou are in Table 3.3. It shows that almost all the values of the degree of fitness of each formula were at most 1.0°C, indicating that our formulas could be used in operative work as they enough perfectly describe the time trend of that temperature. The very small coefficients of these linear regression equations indicated the lower rate of the process of warming in both localities. According to these coefficients, the annual means of the maximal temperature of the air will increase in a century, i.e. in year 2119, by 4.5°C in Ndjaména and 2.3°C in Moundou.

No doubt that these augmentations should be catastrophic. Between other consequences, the evapotranspiration will increase, affecting the agricultural activities, the human being comfort will be reduced, and consequently the daily activities of the inhabitants. So it is clear that the socio-economic consequences of this climatic warming will be a disaster for the concerned areas. Thus, on time measures should be urgently taken to avoid a deeply propagation of this process. For the minimal temperature of the air, these linear regression equations for Ndjaména and Moundou were respectively:

$$T_{min,th}(t) = 0.032t + 21.7, \quad (3.3a)$$

$$T_{min,th}(t) = 0.013t + 20.6. \quad (3.3b)$$

The results of its simulation are in Table 3.4. Its analysis brings us to the same conclusions like what established for the maximal temperature. If the actual tendencies will be kept, then in a century the annual means of the minimal temperature of the air in Ndjaména and Moundou will increase respectively by 3.2°C and 1.3°C. The consequences of these augmentations will be almost the same like what indicated above for the maximal temperature.

Conclusion

It is clear that the climatic warming is going on in the considered localities and this process goes slowly such that the situation does not yet seem to be catastrophic. It is obvious that if as from now urgent measures will not be taken to prevent or even to eradicate it, inhabitants of these localities should wait for a disaster in the nearest future, particularly if warming will go increasingly with time. As first urgent measure, public green parks and gardens must be created in the cities. Trees should be planted all over. These spaces should be permanently managed and protected from fire and destruction by inhabitants looking for firewood. It is a pleasure to inform that they have started creating such spaces in Ndjaména in the place called Gaoui. We hope that it will be protected and that they will keep on doing the same thing in other localities. We extend our sincere thanks and gratitude to the Laboratoire de Physique de l'Atmosphère, Climat et Environnement, LAPACE, of the Department of Physic, Faculty of Exact and Applied Sciences, University of Ndjaména – Chad, which took in charge the full publication fees of the present article. We are looking forward for such further collaboration.

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