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Global Warming and the Sudan: Variation of Air Temperature over Sudan and South Sudan during the Last Fifty Years

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ABSTRACT

Annual mean air temperature for Sudan and South Sudan for the periods 1961- 1990 and 1981-2010 was obtained as normal data for 19 stations for each period from Sudan Meteorological Authority and analyzed for variation with the course of time and for correlations between mean, maximum and minimum air temperature on the one hand and latitudes, longitudes and elevations on the other hand. The results showed an increase of about 0.30 degrees Celsius in the mean temperature of the 19 stations of the last period relative to the previous period. The maximum and minimum temperatures increased on the average by 0.47 and 0.27 degrees Celsius respectively. Both mean and minimum temperatures showed strong to moderate correlations with longitudes and altitudes, while latitudes showed no effects on air temperatures.

Keywords: *Air temperature, variation, coordinates, elevation, Sudan*;

INTRODUCTION

Global warming, a widely used term particularly in connection with climate change refers to the increase in the earth temperature as more carbon dioxide and other green house gases like methane, nitrous oxide, water vapor, hydrofluorocarons are added to the atmosphere. Climate change on the other hand refers to a significant deviation in the mean of one or more of climate elements for long period that continues from decades to centuries, while climate variability refers to shorter periods that extend from years to few decades. According to Hansen [1] human-made climate change has become an issue of surpassing importance to humanity and that global warming is the first order manifestation of increasing greenhouse gases that are predicted to drive climate change. Importance of air temperature in our everyday life is well documented in the literature, [2]. Air temperature determines the rate of biochemical reactions and there by affects the growth and development of plants. It affects the energy balances of surfaces, evapotranspiration, human comfort and almost every aspect of living organisms. That was probably the cause of early start of temperature measurements which goes back to the seventeenth century, so that systematic records in some areas of the world may be as old as two hundred years. Now days, the issue of a changing climate due to an observable rise in air temperature is causing a great global concern, [3]. An increase in the global temperature affects the patterns of ocean currents, air masses, atmospheric circulations and generally the global climate. The changing rain patterns in many areas around the globe, the melting polar ice, and the unusual droughts elsewhere are examples of a changing climate. Numerous indicators showed that the global temperature during the last 150 years increased by about 0.7 degrees Celsius. In a previous paper the author, [4] showed that air temperature over Sudan and South Sudan increased over the last century by about 0.7 degrees on the average, with the main increase attributed to the minimum air temperature rather than the maximum. The objective of this paper is to study the change in air temperature over Sudan and South Sudan during the last fifty only years and to investigate linkages between air temperatures and the stations coordinates and elevations. The study made use of the normal climate temperature data where Normal means a statistical average of a climate factor for thirty years; a period considered being sufficient to yield a reliable means.

EXPERIMENTAL PROCEDURES

The study included a set of 19 stations representing each of the periods 1961/1990 (first period) and 1981/2010 (second period). The stations are scattered a long and across the Sudan and South

Sudan**.** The mean, maximum and minimum temperatures data was obtained from Sudan Meteorological Authority. Table 1 shows the stations and their latitudes, longitudes and altitudes. The data was analyzed using Excel statistical package for descriptive statistics and for regression and correlations between the temperatures on the one hand and coordinates and elevations on the other hand.

Table1. *Meteorological stations used in the study periods 1961/1990 and 1981/201 and their coordinates and elevations.*

City	Latitude(N)	Longitude(E)	Altitude (masl)
W.halfa	21.82	31.35	190
Karima	18.55	31.85	249
Atbara	17.7	33.97	345
Khart.	15.6	32.55	380
Dongola	19.17	30.48	228
Medani	14.38	33.48	405
Sennar	13.55	33.62	418
Malakal	9.55	31.65	390
Juba	4.87	31.6	457
Portsud	19.58	37.22	2
Abuham	19.53	33.33	315
Kassala	15.47	36.4	500
Damaz.	11.78	34.38	470
Fasher	13.63	25.33	730
Kadugl	11	29.72	499
Elobied	13.17	30.23	574
Gedaref	14.03	35.4	599
Kosti	13.17	32.73	380
Nyala	12.05	24.88	674

RESULTS

Time Course of Air Temperatures

Maximum Air Temperature

Table 2 shows that the mean maximum air temperature for the 19 stations was higher in the second period by about 0.47 degrees Celsius.

Table2. *Maximum, minimum and mean air temperatures in degrees Celsius for the 19 stations and for the two periods*

Temperature/ Period	1961-1990	1981-2010	Change in temp.
Maximum temperature	35.67	36.14	0.47
Minimum temperature	20.87	21.14	0.27
Mean temperature	28.36	28.66	0.30

Minimum Air Temperature

The mean minimum air temperature in the last period was higher by about 0.27 degrees Celsius compared to the first period, (Table2). Similar increase in minimum temperature was reported for Nairobi near surface temperature, [5]. A night time rise in air temperature was reported while investigation of surface temperature of Eastern Africa for the period 1939-1992 [6].

Mean air temperature

The mean air temperature in the last period was higher by about 0.30 degrees Celsius compared to the first period, (Table2). Similarly, a global increase in air temperature of 0.8 degrees Celsius for the period 1880 onwards was reported by NASA [7] However, NASA report stated that two thirds of the increase occurred from 1975 onwards. A warming range of the global temperature of 0.65 to 1.06 degrees Celsius was reported for the period 1880 and 2012[3]. An increase of about 0.5 degrees Celsius in air temperature was reported for Japan between 1916 and 1965 [8].

Correlation between Air Temperature and the Stations Coordinates

Mean Maximum Air Temperatures

As can be seen from table 3a, neither latitudes nor altitudes had effects on maximum air temperature of the two periods, showing low correlations and no significances. Longitudes on the other hand showed weak to strong effects on maximum air temperature of the two periods, with (R) ranging between 0.37 and 0.40 and (P) ranging from 0.11 to 0.08. The combinations of latitude with longitudes and latitudes with

altitude showed almost no effect on maximum temperature in the two periods. However, the combination of longitude and altitude and that of the three factors showed moderate correlations and weak effects on maximum temperatures as shown in Table 3b.

Table3a. *Coefficient of correlation (R), standard error, (SE) and significance, (P) for the regression of each factor on mean, minimum and maximum temperatures for the two periods.*

Parameter/Temp.	**1961/1990**			**1981/2010**		
Latitude	**R**	**SE**	**P**	**R**	**SE**	**P**
Max.	0.19	1.34	0.42	0.24	1.39	0.30
Min.	0.02	1.47	0.91	0.01	1.49	0.96
Mean	0.11	1.06	0.64	0.15	1.10	0.51
Longitude						
Max.	0.37	1.27	0.11	0.40	1.32	0.08
Min.	0.60	1.17	0.005	0.59	1.20	0.007
Mean	0.65	0.81	0.002	0.66	0.84	0.002
Altitude						
Max.	0.02	1.37	0.91	0.05	1.44	0.82
Min.	0.33	1.38	0.15	0.29	1.43	0.21
Mean	0.21	1.04	0.37	0.23	1.08	0.33

Mean Minimum Air Temperatures

Latitudes showed no effects on minimum air temperatures in both periods and likewise were the altitudes as shown in Table 3a.. Longitudes on the other hand showed very strong correlations with minimum air temperatures in both periods, with (R) ranging from (0.59) to (0.60) and (P) of (0.007).The combination of Latitudes and longitudes showed strong correlation with minimum air temperature in both periods, (R=0.61-0.63, P=0.02-0.01) as shown in Table 3b. Latitudes and altitudes together showed weak linkage with minimum air temperatures during both periods. Longitudes and altitudes showed strong correlations and high significances with minimum air temperatures where (R) varied from (0.59 to 0.60) and (P) varied from (0.02 to 0.03). The three factors together also showed strong correlations and high significances with minimum air temperatures, (R=0.62-0.65, P=0.05 to 0.03).

Mean Air Temperatures

Latitudes showed no clear effects on mean air temperatures in both periods and likewise were the altitudes as shown in Table 3a. Longitudes showed strong linkages and very high significances with mean air temperatures for both periods with (R) varying between (0.65 and 0.66) and (P) of (0.002). The combinations of Latitudes and longitudes showed strong effects on mean air temperatures with (R) varying between (0.65 and 0.66) and with (P) of (0.01) as shown in Table 3a. Latitudes and altitudes showed no effects on mean air temperatures during the both periods. Longitudes and altitudes showed very strong effects on mean air temperatures in both periods, (R=0.67, P=0.007 to 0.008).The three factors together also showed strong correlation and high significance with mean air temperatures and in both periods, (R=0.67-0.68, P=0.02).Over all, it was clear from this study that neither latitudes nor altitudes as individual factors had significant effects on air temperature over the area during the period concerned. It was also clear that the maximum air temperature was not affected significantly by the combination of factors. Longitudes on the other hand and with the exception of the effects on maximum air temperature during the first period showed very highly significant effects on air temperatures. The combinations of Latitudes and longitudes, longitudes and altitudes and the three factors showed a significant to highly significant effects on minimum and mean air temperature during both periods. On the other hand, Latitudes and altitudes showed no significant effects on air temperature during the both periods. The greatest influences therefore were those exerted on minimum and mean temperatures in both periods by longitudes, latitudes and longitudes, longitudes and altitudes and by the three factors.

Table3b. *Coefficient of correlation (R), standard error, (SE) and significance, (P) for the regression of combination of factors on mean, minimum and maximum temperatures for the two periods*

Lat.&Long.	R	SE	P	R	SE	P
Max.	0.39	1.30	0.26	0.42	1.34	0.19
Min.	0.63	1.17	0.01	0.61	1.21	0.02
Mean	0.65	0.83	0.01	0.66	0.86	0.01
Lat.&Alt..						
Max.	0.26	1.36	0.55	0.27	1.42	0.52
Min.	0.44	1.36	0.17	0.38	1.42	0.28
Mean	0.21	1.08	0.67	0.23	1.12	0.63
Long.&Alt.						
Max.	0.46	1.25	0.14	0.44	1.33	0.17
Min.	0.60	1.20	0.02	0.59	1.24	0.03
Mean	0.67	0.81	0.008	0.67	0.85	0.007
Three param.						
Max.	0.56	1.21	0.11	0.54	1.28	0.13
Min.	0.65	1.18	0.03	0.62	1.24	0.05
Mean	0.67	0.84	0.02	0.68	0.87	0.02

Figures1a and b show the linear correlation between mean air temperatures and longitudes for the two periods. The correlations were all highly significant. The equation in each of the figures can be used to predict the mean air temperature at any given longitude during that period. In fact the two equations demonstrated clearly the increase in mean annual temperature between the two periods. For example at longitudes 35 the expected mean temperatures are 28.88 and 29.08 for the two periods respectively, giving an increase in mean annual temperature of about 0.33 degrees Celsius.

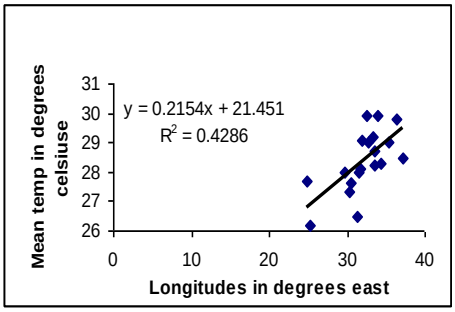

Figure1a. *Mean temperature for 19 stations for 1961/1990 vs. longitudes*

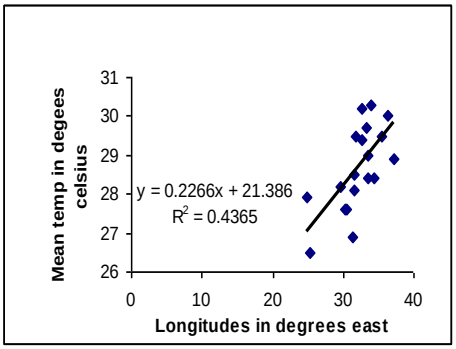

Figure1b. *Mean temperature for 19 stations for 1981/2010 vs. longitudes*

Figures 2a and b show the linear correlation between minimum air temperatures and longitudes for the two periods. The correlations were all highly significant. In fact the two equations demonstrated clearly the increase in minimum annual temperature from the first period and onwards. For example at longitudes 35 the expected minimum annual temperatures are 21.67 and 21.92 for the two periods respectively, giving an increase in minimum annual temperature of about 0.25 degrees Celsius. Figures3a and b show a clear linear correlation between maximum air temperatures and longitudes for the two periods in spite of the deviating Port sudan point as can be seen from the figure. The two equations demonstrated clearly an increase in maximum annual temperature from the first period and onwards.

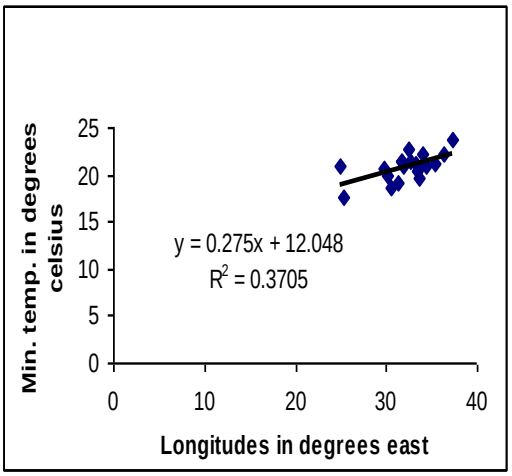

Figure2a. *Minimum temperature for 19 stations for 1961/1990 vs. longitudes*

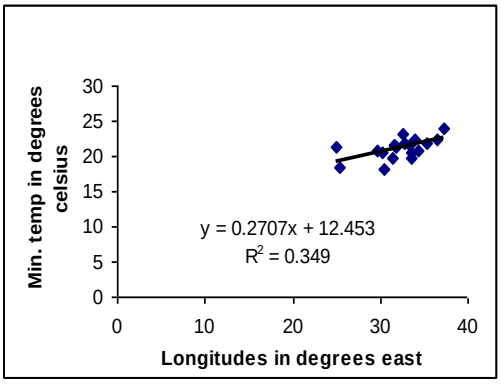

Figure2b. *Minimum temperature for 19 stations for 1981/2010 vs. longitudes*

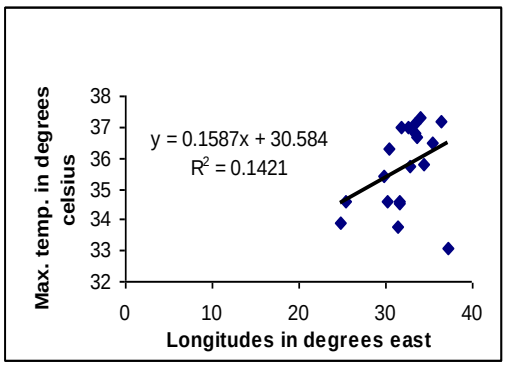

Figure3a. *Maximum temperature for 19 stations for 1961/1990 vs. longitudes*

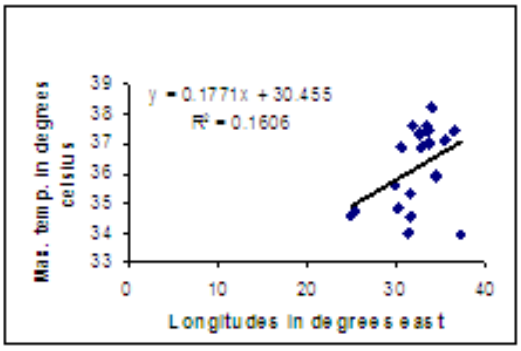

Figure3b. *Maximum temperature for 19 stations for 1981/2010 vs. longitudes*

For example at longitudes 35 the expected maximum annual temperatures are 36.13 and 36.65 for the two periods respectively, giving an increase in maximum annual temperature of about 0.52 degrees Celsius. Similar correlations were developed for various climatic elements as for the relative humidity [9], Piche evaporation [10] and rainfall, [11]. The increases in air temperature were also consistent with those of Hansen [12]. However, the results revealed that the second half of the last century recorded higher maximum temperatures compared to the first half of the century, and that the increase in the minimum temperature during the second half of the century was less compared to that of the first half. .

CONCLUSIONS

In conclusion the study which was based on reliable normal data for two periods and in spite of ten years overlap showed that the surface mean temperature over Sudan and South Sudan increased substantially over the last fifty years. It showed that the increase in the mean was attributed to an increase in both minimum and maximum air temperature. The study showed that the surface temperatures, in particular the mean and minimum temperatures are strongly correlated to longitudes and can be estimated using simple equations. The increase in surface temperature confirms the global rise in temperature reported by the IPCC, [3]. This increase will affect the dynamics of the atmosphere and will be reflected on many aspects of life including agriculture, health and human comfort. The various sectors of concern in the country should therefore take the lead and address nationally the issue of warming in as far as the future dictates.

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