Sunspot Cycles and the Climate of Colombo

Introduction

EXCEPT for the very negligible heat energy received from the earth *per se* (i.e., from within the interior of the earth) it is solar radiant heat energy that is, in the ultimate, responsible for initiating and maintaining atmospheric activity. The sun certainly is the principal source of the energy which by devious means, becomes the internal, potential and kinetic energy of the atmosphere. It is a truism when reference is made to the solar constant being the fundament of weather and climate. Though the processes involved are indeed complex, yet there is no doubt whatsoever, that the sequence of weather changes represented by mean diurnal and seasonal variations of weather over the earth, could be explained by reference to corresponding diurnal and seasonal variations of the position of the earth and from its astronomical distance from the sun. In other words, it is possible to establish a causal relationship, between regular radiation variations and terrestrial weather changes, from astronomical and trigonometrical considerations. However, it must be realized, that it does not necessarily follow that irregular variations in solar radiation would therefore be directly reflected in immediate corresponding weather anomalies ; this is simply because of the complexity in the processes in operation within the total atmosphere separating the earth from the sun. Furthermore, not all of these processes are yet properly understood and even more so less are they easily measurable. There is also sufficient evidence to suggest, that non-solar factors are often responsible for weather anomalies. Two such terrestrial factors so far demonstrated have been vulcanism[1] and fluctuations in the carbon dioxide content within the atmosphere[2] ; other such factors involved are changes in the atmospheric content of ozone, water vapour and the like.[3]

1. Humphreys, W. J. : " Volcanic Dust and other Factors in the Production of Climatic Changes and their Possible Relation to Ice Ages," *Mount Weather Observatory Bull.*, No. 6 (1913) ; Brooks, C. E. P. and Hunt, T. M. " The Influence of Explosive Volcanic Eruptions on the Subsequent Pressure Distribution over Western Europe," *Meteor. Mag.*, 64 (1929), pp. 24—26.
2. Callendar, G. S. : " The Composition of the Atmosphere through the Ages." *Meteor. Mag.*, 74 (1939), pp. 33—35.
3. Dobson, G. M. R. : " Variations in Atmospheric Ozone and Weather conditions." *Quart. J. R. Met. S.*, 62, Suppl. 52 (1936) ; Meetham, A. R., " Correlation of Atmospheric Ozone with other Geophysical Phenomena." *Quart. J. R. Met. S.*, 62, Suppl. 59 (1936).

It has been observed that weather and climatic aberrations upon the earth have been in effect responses to four types of variations of the solar radiation. Of these, variations of the solar constant itself i.e., variations in the rate of solar energy emitted by the sun and reaching the earth, has been the subject of much controversy. The long-accepted solar constant, namely the mean value of 1.94 cal cm^{-2} min^{-1} as ascertained by observations at the Smithsonian Observatory[4] has recently been challenged and instead, a corrected value of 2.00 cal cm^{-2} min^{-1} has been suggested[5] based on computations from rocket-borne spectographs. It has also been shown, that at most a two percent probable error may be accepted for this new value. There is nevertheless, general agreement that the variation if any, is of negligible value and hence may be ignored in respect of being the cause of marked weather changes. The next two possible variations, namely variations in the ultraviolet (UV) radiation-band of the solar spectrum[6] and those of corpuscular radiation[7] have, however, been shown to be causally connected to weather changes. In both these cases, there is much more to be investigated and understood in respect of the *modus operandi* by which weather anomalies are induced. Hence it is in respect of variations in the appearance of " spots " on the sun, that there seems to be clear evidence of direct or indirect response, as exemplified in weather fluctuations and climatic changes. Observations have shown that spots on the sun occur in certain regular sequences, so much so that reference may be made to sunspot cycles. This sunspot cycle-weather anomaly relationship has been found to be best exemplified in the tropics.

The climatic elements instrumentally recorded for over eighty years at Colombo will be analysed and an attempt will be made in this paper to ascertain the possible existence of any relationship with the sunspot cycle. Finally, a correlative study will be made in respect of climatic variations at Colombo, sunspot activity and river and lake-level regimes of tropical areas.

4. ALDRICH, L. B. AND HOOVER, W. H. : " The Solar Constant." *Science* 116 (1952), pp. 3—4.
5. JOHNSON, F. S, : " The Solar Constant." *Jour Met.*, 11 (1954), pp. 431-433.
6. WEXLER, H. : " Radiation Balance of the Earth as a Factor in Climatic Change." in *Climatic Change* ed. H. Shapley (Harvard University Press, 1953), pp. 73—105.
7. MANZEL, D. H.: " On the Causes of the Ice Ages." in *Climatic Change* ed. H. Shapley, (Harvard University Press, 1953), pp. 117—122.

Climatic Variations at Colombo

(a) *Rainfall Variations*

In a previous paper[8] the rainfall data maintained at Colombo for over eighty years were analysed for possible evidence of secular variations. The apparent fluctuation-pattern revealed by simple examination was substantiated when investigated with the aid of statistical devices such as the mean deviation graph, the moving-average or overlapping-means curve and the residual mass graph. Deviations were computed from the long-period average (1881-1950) instead of using the short-period (1911-1940) standard average in use for Ceylon as adopted by the Ceylon Meteorological Department. The investigation revealed unmistakeably a secular fluctuation-trend of an approximate twenty-year (20-year) periodicity. This trend was demonstrated to be true not only in respect of the annual rainfall (Fig. I) but also of the seasonal rainfall—the convergence-convectional, the south-west monsoonal and the north-east monsoonal regimes. The residual mass curves helped to establish the exact dates of the phase-changes of " wet " and " dry " periods. The following approximate " wet and dry " rainfall phases were thus recognized :—

TABLE I

RAINFALL PHASES AT COLOMBO

	Phase	Period	Annual and seasonal rainfall tendency
D1	DRY	1870—1876	negative
W1	WET	1877—1902	positive
D2	DRY	1903—1922	negative
W2	WET	1923—1943	positive
D3	DRY	1944—1952	negative

In a subsequent paper[9] the annual rainfall of the whole island was analysed and using the same statistical devices employed in the earlier paper[10] it was demonstrated that the rainfall phases revealed by the analysis of Colombo's rainfall were true for the island as well.[11] In both these papers no attempt was made to suggest a meteorological *modus operandi* for

8. THAMBYAHPILLAY, GEORGE : " Secular Fluctuations in the Rainfall Climate of Colombo." " *University of Ceylon Review*", Vol. XVI, Nos. 3 & 4, (July-October, 1958), pp. 93—106.
9. THAMBYAHPILLAY, GEORGE. : " Rainfall Fluctuations in Ceylon." *The Ceylon Geographer* Vol. 12, Nos. 3—4, (July-December, 1958 : issued in 1960), pp. 51—74.
10. THAMBYAHPILLAY, GEORGE. : " Secular fluctuations. ." *op. cit.*
11. The analysis was in respect only of the annual data ; a similar analysis of the seasonal data is in progress and will appear soon.

this remarkable secular trend. Neither was any attempt made to incorporate an analysis of the temperature and pressure data of the island. The latter course was deliberately adopted in view of the circumstance, that such data maintained in Ceylon were not of sufficient reliability and have not been observed for a suitably long period, so as to permit the computation of a reasonably useful average. However, in the context of the present nature of investigation, the pressure and temperature data recorded for Colombo are being used with certain reservations.

(*b*) *Temperature Variations*

In view of the non-homogeneity of temperature observations maintained in Ceylon, it was not found feasible to compute an average value. Most of the temperature observations previous to 1880 are not available at the Colombo Observatory (Department of Meteorology) even in manuscript form, since they perished in a fire. It is also unfortunate that the available temperature records are those that were obtained under varying conditions of exposure. Thus, observations between 1869 and 1884 were obtained from thermometers exposed in open verandahs ; those between 1885 and 1927 on the other hand were obtained from thermometers exposed in specially constructed 'sheds' with thatched roofs. It was only in 1928 that thermometers came to be exposed within the now internationally-approved Stevenson Screens. It is clear that under these considerations it was futile to compute any 'average' value necessary to obtain deviation values.

Nevertheless an attempt has been made to represent the annual temperature values recorded at Colombo during the period 1870-1953 in Table II and in graphical form in Figure Ib. The graph is seen to exhibit a markedly fluctuating pattern from year to year. It is also to be noted that certain 'trends' are discernible, exemplifying as it were "warm" and "cool" phase-patterns. This characteristic is even more clearly demonstrated by the superimposition of the 10-year moving-averages curve[12] as seen in Figure Ib. The moving-averages curve exhibits both positive and negative trends, significantly highlighting the approximate dates of phase-changes. Thus, at the turn of the century it may be observed that the temperature trend is suggestive of a negative and therefore a 'cool' phase ; similarly in the early twenties may be observed the inauguration

12. For a consideration of these statistical methods, see Thambyahpillay, George, "The Investigation of Climatic Fluctuations." *The Ceylon Geographer*, Vol. 12, Nos. 1—2, (January-June, 1958 : issued in 1959), pp. 25—30.

TABLE II

SUNSPOT NUMBERS, ANNUAL TEMPERATURE AND PRESSURE DATA, 1870—1953, AND ANNUAL RAINFALL DEVIATIONS 1870—1953 FROM LONG-PERIOD MEAN (1881—1950).

SS=Sunspot numbers T=Temperature °F P=Pressure mb. R=Rainfall inches

Year	SS	T	P(10+)	±R	Year	SS	T	P(10+)	±R
1870	139.1	80.4	08.9	+10.5					
1871	111·2	80·3	09·3	−17·1	1911	5·7	81·6	10·2	−22·6
1872	101·7	81·3	08·7	−29·2	1912	3·6	81·0	10·1	− 0·1
1873	58·3	80·6	09·4	−11·0	1913	1·4	80·4	10·3	− 5·6
1874	44·7	80·6	09·7	−29·3	1914	9·6	81·1	10·5	−25·6
1875	17·1	81·1	09·3	− 2·5	1915	47·4	81·0	10·1	− 4·3
1876	11·3	81·0	09·6	− 0·3	1916	57·1	80·2	09·5	+ 2·7
1877	12·3	81·0	10·5	+27·0	1917	103·5	80·1	09·4	−18·6
1878	3·4	82·0	09·5	+58·8	1918	80·6	80·5	10·4	−22·6
1879	6·0	80·9	09·2	+ 3·4	1919	63·6	81·0	10·6	− 7·1
1880	32·7	81·2	09·7	− 9·5	1920	37·6	80·5	10·5	−11·4
1881	54·3	81·4	09·7	+ 9·2	1921	26·1	80·6	10·0	−33·1
1882	59·7	81·0	09·6	− 1·3	1922	14·2	80·0	10·4	−12·6
1883	63·7	80·6	09·5	+22·7	1923	5·8	79·8	10·0	+ 7·6
1884	63·5	80·3	10·9	+ 1·2	1924	16·1	80·1	09·6	+12·3
1885	52·2	81·0	10·8	+ 4·7	1925	44·3	79·9	09·8	+20·4
1886	25·4	81·0	09·3	+ 6·1	1926	63·9	80·5	09·7	+ 4·5
1887	13·1	80·1	09·6	+ 3·2	1927	68·0	80·2	10·2	− 4·1
1888	6·8	80·9	10·4	+20·2	1928	77·8	80·7	10·3	+ 3·5
1889	6·3	81·1	09·7	+27·7	1929	65·0	80·1	10·4	− 3·4
1890	7·1	80·6	09·6	− 8·1	1930	35·7	80·5	10·7	+18·9
1891	35·6	80·5	10·0	+38·1	1931	21·2	80·9	10·6	+ 9·9
1892	73·0	80·9	09·1	−20·1	1932	11·1	80·3	10·8	+28·3
1893	84·9	80·3	09·5	+ 8·8	1933	5·7	79·8	10·9	+13·5
1894	78·0	80·7	09·4	− 3·4	1934	8·7	79·9	11·2	+14·3
1895	64·0	81·6	09·5	+11·3	1935	36·1	80·4	10·9	+ 4·8
1896	41·8	81·8	09·6	+20·2	1936	79·7	80·3	11·1	+ 4·7
1897	26·1	82·2	09·4	+ 1·8	1937	114·4	80·7	10·7	+ 9·4
1898	26·6	81·6	09·1	+22·2	1938	109·6	80·6	10·5	−22·4
1899	12·1	81·8	10·1	− 7·4	1939	88·8	80·4	11·2	− 3·3
1900	9·5	82·2	10·2	+ 3·1	1940	67·8	80·9	11·5	− 9·9
1901	2·7	82·0	09·0	− 3·3	1941	47·5	81·1	11·4	− 0·5
1902	5·0	81·7	10·1	+37·8	1942	30·6	80·6	10·4	−15·3
1903	24·4	81·9	09·6	− 1·5	1943	16·3	80·2	09·8	+ 5·3
1904	42·0	80·7	10·4	− 4·3	1944	9·6	80·5	09·7	− 3·0
1905	63·5	81·5	10·4	−15·4	1945	33·2	80·7	09·7	− 5·5
1906	53·8	81·6	09·7	− 9·4	1946	92·6	81·0	09·8	+16·0
1907	62·0	81·0	09·8	−10·3	1947	151·6	80·5	09·8	0
1908	44·9	81·3	09·7	−22·5	1948	136·3	80·8	09·8	−13·5
1909	43·9	81·0	09·6	−14·8	1949	134·7	80·6	10·0	+ 8·2
1910	18·6	80·6	09·4	−35·2	1950	83·9	80·6	09·7	− 8·0
					1951	69·4	80·4	10·1	+11·9
					1952	31·5	80·7	10·2	−15·6
					1953	13·9	80·6	10·5	+22·8

of a positive and hence a 'warm' phase. The significance of these characteristics of the temperature climate of Colombo will be considered at a subsequent stage in this paper. It may nevertheless be pointed out at this stage, that it is difficult to discern as to what extent this seeming 'phase-patterns' are due truly to meteorological circumstances and to what degree they are related to non-homogeneity of the data.

(*c*) *Pressure Variations*

Pressure observations have been maintained in Ceylon in at least twelve stations since 1871. However, here again as in the case of temperature observations, the data before and after 1911 differ in respect of their reliability. Thus, before 1911 pressure observations were not corrected either for the altitude factor or for the latitudinal factor. Adjustments were however, made in respect of Index Error and capillarity and corrections made to 32_0F. In order to adopt the data for the present discussion, all values were ascertained to have been properly adjusted for latitude 45°, so as to introduce a certain degree of homogeneity. The pressure values (converted from the original 29-inches to millibars) for Colombo, covering the period 1870-1953 have been shown in TABLE II and graphically represented in Figure Ia.

It will be seen that year-to-year fluctuations are notable as in the case of temperature (Figure Ib). The superimposition of the 10-year moving-averages curve brings out the prevalence of a positive and hence an increasing pressure trend just before the turn of the century ; a marked negative and hence a decreasing pressure trend may also be observed since 1940. While reference to the significance of these pressure trends may be reserved for later consideration, it may be observed here that the 10-year moving-averages curves of temperature (Figure Ib) and pressure (Figure Ia) at Colombo exhibit almost opposite-phase trends. This is as is to be expected in terms of the known physical law that temperature and pressure are inversely related, viz., low temperature and high pressure and *vice-versa.*

Sunspot Activity and Weather Relationship

That 'spots' often appear on the surface of the sun and that this appearance exhibits a periodicity, was known to the Chinese as borne out by records maintained as early as A.D. 188. It was not until the 17th century, however, that in Europe observations were being made of sunspot activity, and today there is available a reliable record of sunspot numbers

(i.e., a measure of the number as well as the size of spots) dating back to 1749[13]. It was found that sunspot numbers and activity varied periodically through phases of maxima and minima, of approximately 11-year intervals. Thus a 11-year periodicity has been found to manifest itself in varve chronologies, tree-rings, tropical lake-levels, and river-regime fluctuations, all of which are certainly 'climatic indicators.' Furthermore, such a periodicity has also been evident in respect of pressure, temperature and rainfall patterns, in thunderstorm activity and similar weather manifestations. While such evidence seem to suggest that perhaps there is a close relationship between the sunspot cycle and weather phenomena, yet since such a relationship is not universally manifest, the connection must be accepted to be complex in character. Other weather periodicities also came to be evident, ranging from a three-year pattern to that once-widely acclaimed 35-year Bruckner cycle.[14] All such periodicities were considered to be either sub-multiples or multiples of the simple 11-year sunspot cycle. This claim was partly justified, in view of the general acceptance that the solar constant is the fundament of atmospheric activity. Hence, it was natural to relate weather variations to variations of the solar constant. The increased energy output incident upon sunspot activity was, therefore, attributed to be in some way related to weather phenomena variation, operating through variations in circulation patterns.

For some time though, there came to be evident that both weather phenomena and climatic 'indicators' exemplified not only approximate 11-year periodicities but also a seemingly superimposed approximate 20-year periodicity. A 22½-year cycle was first observed in an analysis into sunspot-number graphs[15] ; a later study[16] showed that a 23-year periodicity fitted the sunspot cycle better than the then-accepted 11-year periodicity. But it was not until Hale[17] discovered that a reversal of polarity in the magnetic fields of sunspots occurred with the advent of a new cycle at sunspot minimum that the reality of a 23-year double sunspot cycle was accepted. It may be pointed out that a true sunspot

13. The Wolf-Wolfer series may be obtained from the *World Weather Records* (Smithsonian Institute, 1944) and the *Greenwich Observatory Records.*
14. BRUCKNER, EDUARD. : *Klimaschwankungen seit* 1700, *nebst Bermerkungen uber die Klimaschwankungen ser Diluvialzeit* (1890).
15. ABBOT, C. G. : "Solar Radiation and Weather Studies." *Smith Misc. Coll.*, 94, No. 10 (1935), 89 pp.
16. ALDRICH, L. B. : "The Solar Constant and Sunspot Numbers." *Smith. Misc. Coll.*, Vol. 104, No. 12 (1945), 5 pp.
17. HALE, GEORGE. : "Sunspots and the Periodic Reversal of their Polarity." *Nature*, 113, (1924) p. 105.

cycle would therefore range through one minimum to the next minimum and through one maximum to the next maximum, thereby exhibiting a 23-year periodicity.

While evidence will be brought out at a later stage in connection with the double sunspot cycle periodicity and phases demonstrated by climatic 'indicators', a summary will now be attempted here in respect of sunspot activity as related to weather phenomena.

(i) *Sunspots and temperature*

The credit of having first observed a temperature-sunspot relationship in 1651 is attributed to Riccioli, while it also appears that Herschel in his address to the Royal Society in 1801, seems to have made suggestions in respect of an inverse temperature relationship to sunspot activity. However, it was the findings of Koppen in 1873 (on the basis of world-wide observations) that once and for all, established the fact that surface temperatures on the earth exhibited inverse relationships at sunspot maxima and *vice versa*.[18] Since then, there have been sufficient evidence[19] to substantiate this relationship. This paradoxical circumstance of lower temperatures at sunspot maxima, seem to find two explanations. Firstly, that though in fact sunspot activity ("storms" on the sun's surface and increased emission of heat energy) is directly related to temperature (i.e., temperatures increase with increasing sunspot numbers), yet on the earth's surface the inverse relationship is exemplified due to increased cloudiness and precipitation ; the latter being due to increased radiation and evaporation. The second explanation invokes the possibility of some form of "opacity"—not cloudiness—which being induced at sunspot maximum may in turn cause an impediment to transmission of radiation to the earth. Recent studies seem to lend support to the latter view. This inverse temperature-sunspot activity relationship is found to be particularly noteworthy in the tropics.

(ii) *Sunspots and pressure*

During early investigations[20] into the possible computation of correlation coefficients between sunspot activity and pressure patterns, Walker noted that pressure contrasts were accentuated at sunspot maxima ; he

18. Koppen, W. : "Lufttemperaturen, Sonnenflecken und Vulkanausbruche." *Meteorol. Zeitsschr.*, 31 (July, 1914), pp. 305—308 ; the original appeared in, Koppen, W. "Uber Mehrjahrige Perioden der Witterung insbesondere uber die 11-jahrige Periode der Temperatur," *Zeit. ost. Ges. Meteor.*, 8 (1873). pp. 241—248.
19. Clayton, H. H. : *World Weather*, (New York : Macmillan, 1923).
20. Walker, G. G. : "Correlation in Seasonal Variation of Climate." *Ind. Met. Mem.* Vol. XX. No. vi (1906-1910), pp. 117—124.

observed that while a rise of pressure occurred in locations over Europe, parts of South America and the Pacific, a fall of pressure and hence a reverse situation prevailed in southwest Asia, the Indo-Australasian region and most parts of Africa. This negative or inverse correlation in the Indian area was also noted by subsequent meteorologists.[21] A much later investigation using data from seven low-latitude and seven high-latitude stations[22] clearly demonstrated that the greatest pressure contrasts between these latitudes occurred at sunspot maxima. Since the general circulation is to a great extent induced directly by pressure contrasts on a latitudinal basis, it is quite clear that sunspot activity is related to alternate patterns of circulation. In effect a recent investigation[23] has shown that alternating high-index and low-index circulation patterns were related to sunspot maxima and were effected over a 20-year periodicity.

It is clear then that pressure conditions are accentuated at sunspot maxima i.e., high pressure centres ("centres of action") tend to exhibit increasing pressure and *vice-versa* ; negative correlations are notable in the tropics and positive correlations in the permanent and semi-permanent anticyclonic areas. Finally, while pressure contrasts are accentuated at sunspot maxima, at sunspot minima pressure accentuations are virtually absent.

(iii) *Sunspots and precipitation*

In view of the strong influence of local terrestrial factors upon the incidence of precipitation at individual stations and even within localized zones, it is not surprising that no clear relationship could be established between sunspot activity and precipitation. However, while this is only true of single-year relationships, there have been sufficient evidence to support the case for the existence of a real relationship between sunspot cycles and precipitation. Furthermore, of even more significance is the evidence from climatic 'indicators' reflecting in varves, tree-rings, lake-levels and river-regimes, both the single sunspot-cycle and the double sunspot-cycle. Walker, who pioneered sunspot-weather phenomena re-

21. Hanzlik, S. : "Der Luftruckeffekt der Sonnenfleckenperiode". I. Mitteilung : Jahresmittel. *Beitr. Geophys.*, 28 (1930). pp. 114—125 : English abstract on p. 114 ; also Clayton, H. H. "World Weather and Solar activity." *Smith. Misc. Coll.*, Vol. 89. No. 15 (1934).
22. Schell, I. I. : "The Sun's Spottedness as a Possible Factor in Terrestrial Pressure." *Bull. Amer. Met. Soc.*, Vol. 24, No. 3, (March, 1943), pp. 85—93.
23. Willet, H. C. : "Extrapolation of Sunspot-Climate Relationships," *Jour. Met.* Vol. 8. No. 1, (February, 1951), pp. 1—6;— , "Patterns of World Weather Changes." *Trans. Amer. Geophys. Union*, Vol. XXIX, No. 6 (December, 1948). (pp. 803—809).

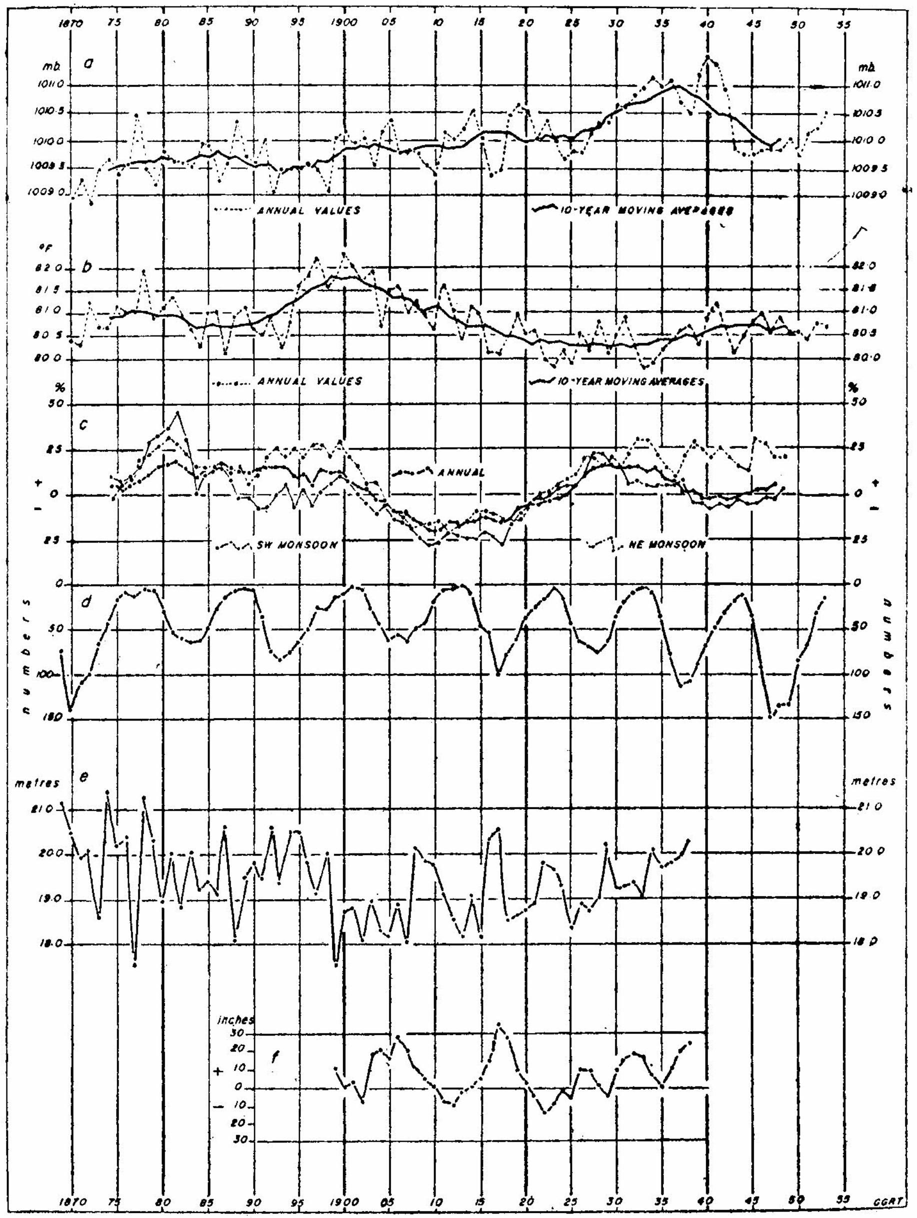

FIG. 1—CORRELATION CHART TO SHOW RELATIONSHIP BETWEEN CLIMATIC VARIATIONS AT COLOMBO, VICTORIA NYANZA LAKE-LEVELS, RIVER NILE REGIME AND SUNSPOT CYCLES.

(*a*) Annual pressure fluctuations and 10-year moving averages curve at Colombo (*b*) Annual temperature fluctuations and 10-year moving averages curve at Colombo (*c*) Annual, SW monsoonal and NE monsoonal rainfall 10-year moving averages curves at Colombo (*d*) Sunspot numbers of the Wolf-Wolfer series, with unsmoothed inverted graph (*e*) River Nile floodstages based on official readings at the Roda Gauge, Cairo (*f*) Victoria Nyanza elevations based on readings of the lake-gauge at the Kisumu Kavirondo Gulf.

lationships, has shown that within the Indo-Australasian region, there prevails a positive correlation between sunspot cycles and precipitation.[24]

Sunspot activity and Climatic Fluctuations at Colombo

In the light of the context of known relationships between sunspot activity and weather variations, the climatic data for Colombo may be examined. At attempt has been made in Figure I to represent graphically the year-to-year fluctuations and the 10-year moving averages of temperature and pressure data for Colombo and 10-year moving averages of annual, SW monsoonal and NE monsoonal rainfall, all for the period 1870-1953. It may be observed that the sunspot-numbers for this period are also graphically represented but as an unsmoothed curve as well as being inverted.

(*a*) *Temperature*

The year-to-year fluctuations of temperature show a fairly satisfactory correspondence with sunspot-numbers, bearing of course an inverse relationship. But since the sunspot-number curve is inverted in form, in Figure Ib and Id, the temperature is seen to be positively related. However, the expected sunspot-temperature relationship is not everywhere clearly evident i.e., in some years the inverse relationship is not brought out in the chart. This anomaly may be to some extent explained in the context of the varying exposure conditions under which observations were made ; in fact previous to 1928 such discrepancies must have been numerous, since Stevenson Screens were not used to house the thermometers. Bearing this important circumstance in mind it is noteworthy that some relationship is seen to be evident even from the graph. Thus, temperatures immediately succeeding sunspot maxima and minima, reveal the expected tendencies as shown in TABLE III below.

TABLE III

TEMPERATURE TENDENCIES IN THE YEARS SUCCEEDING SUNSPOT MAXIMA AND MINIMA YEARS SINCE 1920

Sunspot minimum year	Sunspot number	Sunspot maximum year	+1
1923	5·8		+
	77·8	1928	—
1933	5·7		+
	114·4	1937	—
1944	9·6		+
	151·6		—

24. WALKER, G. G. : " Correlations in Seasonal Variations in Weather, IV. Sunspot and Rainfall." *Ind. Met. Mem.*, XXI. No. x (1915). pp. 17—59.

(b) Pressure

The year-to-year pressure fluctuations (Fig. Ia) are seen to exhibit a fairly close correspondence to the sunspot-number curve (Fig. Id). However, the noticeable anomalies in this respect may in some way be related to omission of the necessary 'adjustments' to pressure values. In general, it may be mentioned that the expected accentuation of pressure at maxima (positive) and at minima (negative) seems to be reflected at Colombo.

(c) Rainfall

The individual-year fluctuations (TABLE II) do not seem to reflect always the positive sunspot maxima-rainfall relationship, which is the expected pattern in the tropics. In fact, the relationship seems to hold true in some years grouped together and untrue in other years also in a grouped form. Thus, irrespective of sunspot maxima and minima years, positive correlation is observed from the maximum year 1870 and the minimum year 1878 to the minimum year 1889 to the maximum year 1893. In a similar way, a negative correlation may be observed from the minimum year 1901 and the maximum year 1905 to the minimum year 1913 to the maximum year 1917. In like manner, from the minimum year 1923 and the maximum year 1928 to the minimum year 1933 and the maximum year 1937, a positive correlation may be observed.

TABLE IV

ANNUAL RAINFALL TENDENCIES AT COLOMBO, IN THE YEAR IMMEDIATELY PRECEDING AND IMMEDIATELY FOLLOWING SUNSPOT MINIMA AND MAXIMA YEARS, RESPECTIVELY

−1	Sunspot minimum year	Sunspot number	Sunspot maximum year	+1
		139·1	1870	−
+	1878	3·4		
		63·7	1883	−
+	1889	6·9		
		84·9	1893	−
+	1901	2·7		
		63·5	1905	+ ? ?
+	1913	1·4		
		103·5	1917	−
+	1923	5·8		
		77·8	1928	−
+	1933	5·7		
		114·4	1937	−
+	1944	9·6		
		151·6	1947	−

A paradoxical relationship seems, however, to prevail in respect of annual rainfall tendencies in the years immediately preceding and immediately following, years of sunspot minima and maxima, respectively and is brought out in TABLE IV.

Double Sunspot Cycles and Climatic Fluctuations at Colombo

In the analyses of temperature, pressure and rainfall data of Colombo, it was brought out that some form of relationship seem to prevail between sunspot minima/maxima years and variations of these climatic elements. More detailed statistical analyses must be undertaken before any quantitative relationship may be pointed out.[25] At the present stage, therefore, an attempt will be made to suggest a possible meteorological relationship between sunspot cycles and climatic variations at Colombo.

In a previous paper,[26] a case was made for the existence of secular fluctuations in the rainfall climate of Colombo. A glance at TABLE II will reveal a general grouping of positive and negative rainfall years. The results of the earlier investigation aforementioned is presented in TABLE I of this paper. The statistical analysis strongly suggested an approximate 20-year periodicity in Colombo's rainfall climate (Fig. Ic).

It was brought out earlier in this paper, that quite for some time, there have been forthcoming evidence from all over the world, both on the basis of instrumental data and climatic 'indicators' that an approximate 20- to 25-year periodicity seemed to be exemplified in respect of climatic variations. Such evidence range from dendrochronologic evidence in the south-western United States,[27] temperature trends in Canada[28] and Northern Europe,[29] fluctuations of the levels of the Great Lakes of North America,[30]

25. More certainty may be obtained by the use of the Schuster Periodogram and also by computing Correlation Coefficients ; such analyses, however, involve laborious calculations and as such were not thought worthwhile in the context of this paper. The author is engaged presently in such analyses of the climatic data of the island as a whole and the results will appear in a paper on fore-casting Ceylon's weather.
26. THAMBYAHPILLAY, "Secular fluctuations....," *op. cit.*
27. SCHULMAN, E. : "Tree-ring Evidence for Climatic Changes." in *Climatic Change : ed.* H. Shapley (Harvard University Press, 1953), pp. 209—220.
28. LONGLEY, R. W. : "The Length of Dry and Wet Periods." *Quart. J. R. Met. S.*, Vol. 79, No. 342 (October, 1953), pp. 520—527.
29. SIMOJOKI, H. : "On the Consideration of the Double Sunspot Cycle in Climatic Investigations," *Geophysika.* Vol. 6, No. 1 (January, 1957). pp. 25—29.
30. WOOD, S. M. : *The Cycles of the Great Lakes*, (1936), 20 pp.

varve chronologies in the United States[31] and glacier responses.[32] In respect of tropical-area analyses, of foremost note is the centuries-long indices of climatic fluctuation of the flow and flood-patterns of the river Nile. There is mention of this fluctuation even by Herodotus. Despite the many periodicities observed in this connection, Brooks[33] suggests the 22-year periodicity and its sub-multiples and multiples to be most satisfactory. A similar periodicity has been ascertained in respect of the Victoria Nyanza.[34] The fluctuation-patterns of the Nile and the Nyanza are graphically represented, in Figure I. Rainfall studies of the West Indian islands[35] and of Mexico[36] in recent times may also be cited.

While the long-accepted 11-year sunspot cycle is not to be voted out, it was brought out that since Hale's discovery of the reversal of polarity, the double sunspot cycle of a 22- to 23-year periodicity has come to be accepted as the truly complete sunspot-phase rhythm. In view of the circumstance that solar radiation forms the fundament of weather and climate, it may be justifiably accepted that variations of this factor must surely induce responses in the surface weather patterns of this earth. By the same reasoning then, since sunspot activity results in variations in solar radiation, it must inevitably follow that such activity would be reflected in surface weather aberrations. In view of the clear evidence of approximate 20-year periodicities of climatic "changes," the double sunspot cycle may surely be cited as a highly probable cause. The *modus operandi* by which sunspot activity brings about these "changes" is perhaps highly complex and must await further atmospheric 'probings.'

In Figure I, it is seen that the river Nile floodstages and the Victoria Nyanza lake-level elevations seem to exhibit "trends" corresponding to those of the rainfall fluctuation-patterns at Colombo (Fig. Ic). It is also seen from TABLE V that the positive and negative variations of the annual rainfall at Colombo, computed in respect of the long-period mean, are

31. ABBOT, ... *op. cit.*
32. FAEGRI, K.: "On the Value of Palaeoclimatological evidence." in *Centenary Proc. R. Met. S.* (1950), pp. 188—194.
33. BROOKS, C. E. P.: "Periodicities in the Nile Floods." *Mem. R. Met. S.* Vol. 2, No. 12 (1928).
34. WOOD, S. M.: *The Cycles of Victoria Nyanza and Some attended Phenomena.* (privately printed) 24 pp.
35. FASSING, O. L.: "Rainfall of Barbados." *Bull. Amer. Met. Soc.*, Vol. 12 (1931), p. 173.
36. WALLEN, C. C.: "Climatic Fluctuations in Mexico." *Geogr. Ann.*, Vol. 37 (1955), pp. 57—63.

TABLE V

CORRELATION OF DOUBLE SUNSPOT CYCLES AND ANNUAL RAINFALL VARIATIONS (PERCENTAGES) FROM LONG-PERIOD MEAN (1881—1950) AT COLOMBO

Year	Sunspot Cycles		Annual Rainfall at Colombo Variations (percentages) from mean (1881-1950)	
	Maximum Number	Minimum Number	Calendar Year (Jan.-Dec.)	Seasonal Year (March-Feb.)
1870	139·1		+15.5 ? ?	
1878		3·4	+58·8	+52·3
1883	63·7		+22·7	+19·4
1889		6·9	+27·7	+26·5
1893	84·9		+ 8·8	+ 1·9
1901		2·7	− 3·3	−13·1
1905	63·5		−15·4	−15·4
1913		1·4	− 5·6	− 9·6
1917	103·5		−18·6	−20·5
1923		5·8	+ 7·6	+ 7·9
1928	77·8		+ 3·5	+16·3
1933		5·7	+13·5	+17·6
1937	114·4		+ 9·4	+ 2·1
1944		9·6	− 3·0	−12·8
1947	151·6		± 0	−10·4

related to maxima and minima sunspot years but on a double-sunspot cycle basis. In conclusion, therefore, it is here suggested that the double sunspot cycle may truly be the *raison d'etre* of the climatic rhythm brought out in evidence for Colombo.[37]

GEORGE THAMBYAHPILLAY

37. A paper is in preparation wherein a more detailed correlative study will be made between climatic fluctuations in Ceylon and world-wide factors with special reference to the double sunspot cycle.