THE FLUCTUATIONS OF LAKE VICTORIA.

By C. E. P. Brooks, M.SC.

The variations of level which Lake Victoria undergoes from time to time are of great importance in the economy of Uganda, and since 1895 several lake-level gauges have been in use at various points, by means of which the level is measured daily. These gauges consist of pillars of wood, stone or metal firmly fixed in the lake; on these pillars a scale is marked in inches. The records are now sufficiently long for an attempt to be made to analyse them, and the results of such an analysis are here set out (1). The lake-level data employed are those from the gauge maintained by the Lake Engineering Division of the Uganda Railway at Kisumu, at the head of the Gulf of Kavirondo on the eastern side of the lake. This gulf is a small inlet connected with the main body of water by a narrow channel; it has no large river flowing into it and is in every respect suitable for the observations of level. These records have been continuous from August 23rd, 1899, to the present time. From the beginning of 1896 until July 31st, 1899, the records taken at Port Victoria have been utilised; this at the south-western end of Berkeley Bay, an inlet of moderate size on the north-east shore of the lake. From August, 1897, to September, 1898, there was a gap in the Port Victoria records owing to the Soudanese mutiny; this gap has been partially filled by means of observations taken on the gauge at Luba's, near the outflow of the lake into the Nile. Between August 1st and 22nd, 1899, the Port Victoria gauge was moved to its present site at Kisumu (formerly termed Port Ugowe); the difference between the base levels of the old and new sites was computed from the observations at Luba's and Port Alice (Entebbe), but there is a possible error of two or three inches. Thus from January, 1896, to July, 1899, the observations are mainly those taken at Port Victoria, plus a correction to make them refer to the same zero as the later observations; from August, 1899, onwards the observations were taken without a break at Kisumu.

At first sight it may seem rash to calculate the changes of level of so large a body of water as Lake Victoria from the observations at a single gauge, but for the purpose of arriving at general conclusions one gauge is sufficient. The only way in which considerable differences of level between one part of the lake and another could arise is through displacement of the water by considerable differences

(1) Th materials on which this study is based are mainly derived from the following publication by the Meteorological Office, London: Geophysical Memoirs, no. 20 Variationss in the levels of the Central African Lakes Victoria and Albert, by C. E. P. Brooks, M.Sc.

of atmospheric pressure over different parts of the lake or by continuous strong winds, neither of which are found in Uganda. In the Baltic it has been found that the variations of level in the course of a few days due to these causes may reach several feet, but in Lake Victoria the maximum difference is probably never more than a few inches, while the average level during one year may differ from that during another year by nearly four feet, so that the short period and local changes are negligible in comparison with the changes from year to year.

Table 1 shows the mean level of the lake at Kisumu in each year from 1896 to 1923. The zero of the gauge is stated to be at a height of 3,726.15 feet above mean sea level. The means were obtained by taking the average of the highest and lowest gauge readings each month, as the average monthly range is about a foot, this mean is not likely to differ by more than an inch from the mean of the daily readings, and will serve for our present purpose. Previous to 1896 we have no gauge readings, but certain earlier data are available from the reports of travellers, and these have been summarised by Col. H. G. Lyons. They are fairly continuous from 1888 onwards:

TABLE 1.—LEVEL OF LAKE VICTORIA AT KISUMU, AND SUNSPOT NUMBERS

	Lake Level.	Sunspot Number.
1888-1890	General fall on southern shore	7
1891	Low	7
1892	Very high, heavy rainfall, tendency to rise	73
1895	Very high	64

Year.	Lake Level. (inches)	Sunspot Number.	Year.	Lake Level. (inches)	Sunspot Number.
1896	20	42	1910	1	19
1897	20	26	1911	−7	6
1898	22	28	1912	−11	4
1899	12	12	1913	−3	1
1900	−2	9	1914	−2	10
1901	3	3	1915	4	47
1902	−10	5	1916	15	57
1903	13	24	1917	35	104
1904	18	42	1918	27	81
1905	15	63	1919	8	64
1906	29	54	1920	3	38
1907	21	62	1921	−5	25
1908	10	49	1922	−16	15
1909	8	44	1923	−9	5

From these remarks and from Table 1 we see that the lake was low in 1890, 1902, 1912, and 1922, and high in 1895, 1906, and 1917; both the low and high levels recur at intervals of about eleven years. It is well known that the number of spots on the sun also has an eleven-year periodicity, and it is interesting to compare the maxima and minima of the lake-level with the maxima and minima of sunspots:

Lake Level.		Sunspots.	
Minima.	Maxima.	Minima.	Maxima.
1890		1889	
	1895		1893
1902		1901	
	1906		1905
1912		1913	
	1917		1917
1922		1923	

The annual means of the sunspot numbers are shown in Table 1. The agreement is very close. It is brought out in figure 1, in which the level of Lake Victoria is plotted on the same diagram as the mean sunspot numbers. The level previous to 1896 has been sketched in from the data given above. The parallelism between the two curves is so remarkable that it is quite evident there must be some connection between them. Since we cannot suppose that Lake Victoria influences the sunspots the only inference is that in some way the sunspots influence Lake Victoria.

Let us first of all study the various factors which affect the level of a lake. In a cistern partly filled with water the level of the water is determined by the amount of water put in and the amount of water taken out. It is the same with a lake—the level is determined by the water put in, by rivers flowing into it and by rain falling directly on its surface, and by the water taken out, by rivers flowing out of the lake and by evaporation. The amount of water brought into the lake by rivers is the amount of rain falling on the lake basin, less that lost by evaporation from vegetation and from the soil. Therefore the change of volume of the lake is equal to the rainfall over the lake and its basin less the sum of the evaporation over the lake and its basin and the run-off in rivers. Let us try to determine these quantities.

Statistics of the rainfall over the Lake Plateau are collected each year by the Physical Service of Egypt, which takes great interest in the sources of supply of the Nile, and Mr. P. Phillips, Director of the Hydrological Department, has been good enough to send me (through *Nature*) a copy of the average fall over the Plateau each year from 1904 onwards. The annual average rainfall is 57 inches. Over the lake itself the annual average is probably about 40 inches. The area of the lake is about 66,000 square miles. Thus during an average year some 76 cubic miles of water fall over Lake Victoria and its basin, and have to be disposed of somehow. Sir William Garstin's measurements show that about 4½ cubic miles annually flow out of the lake into the upper waters of the Nile at Ripon Falls, so that the balance, rather more than 70 cubic miles, or 94 per cent., must be lost by evaporation.

A comparison between the change of level of the lake between January 1st of one year and January 1st of the succeeding year on the one hand, and the rainfall over the lake basin during the year on the other hand (table 2), shows that when the rainfall is above normal the lake rises, and when the rainfall is below normal the lake falls. The rise or fall of the lake is almost exactly proportional to the excess or deficit of the rainfall compared with the average. Thus during the two years 1916 and 1917 the total rainfall (both years together) was 139 inches, giving a total excess of 25 inches in the two years, and the lake rose by 33 inches. In 1918 the rainfall was only 37 inches, giving a deficit of 20 inches, and the lake fell by 28 inches. In this way, taking all the figures into account, we find that on the average, a rainfall of 10 inches above the normal causes a rise of the lake of 14 inches; similarly a deficit of 10 inches of rainfall causes a fall of 14 inches. The area of lake and basin together is 3½ times the area of the lake alone, however, so that if all the rain found its way into the lake an excess of 10 inches should cause the lake to rise by 35 inches instead of only 14. The difference of 21 inches can be accounted for in two ways, firstly by supposing that part of the rainfall goes into the soil and only reaches the lake gradually, and secondly by supposing that there is very great evaporation from the soil and from the vegetation. The remarkably close agreement between the rainfall in one year and the change of level in the same year shows that the amount of water held in the soil cannot differ greatly from year to year; it also shows that the evaporation from the soil and vegetation must be very nearly proportional to the rainfall.

Table 2.—Change in level of Lake Victoria and rainfall over Lake Plateau.

Year.		Change of level from Jan. to Jan. (inches)		Rainfall above or below normal. (inches)
1904	...	− 9	...	− 2
1905	...	+ 7	...	+11
1906	...	+ 5	...	+ 7
1907	...	−14	...	− 9
1908	...	+ 2	...	+ 2
1909	...	− 7	...	− 9
1910	...	−15	...	− 7
1911	...	− 5	...	− 3
1912	...	+ 8	...	+ 6
1913	...	+ 5	...	− 2
1914	...	+ 1	...	+ 9
1915	...	+ 8	...	+ 6
1916	...	+12	...	+14
1917	...	+21	...	+11
1918	...	−28	...	−20
1919	...	− 5	...	+ 1
1920	...	−10	...	− 2
1921	...	−12	...	−11
1922	...	− 7	...	− 5

We can now make the following table to account for the rainfall falling over the lake and its basin:

Rainfall over lake basin (excluding the lake itself) ...		60 cubic miles
Loss by evaporation before reaching lake ...	(about)	35 cubic miles
Amount reaching lake	(about)	25 cubic miles
Rainfall on surface of lake	(about)	16 cubic miles
Total water reaching lake	...	41 cubic miles
Run-off	...	5 cubic miles
Loss by evaporation from lake surface ...	...	36 cubic miles

The latter amount, 36 cubic miles, is sequivalent to the removal each year of a layer of water 63 inches deep over the whole lake.

How do sunspots come into this balance-sheet? Since the level of the lake shows so close an agreement with the number of sunspots, the latter must have a dominating influence on one or both of the prime factors which influence the lake-level, namely rainfall and evaporation. The average rainfall over the lake plateau according to Mr. Phillips is set out again in table 3 as a difference from normal. The second column shows the sunspot numbers; it is seen that the rainfall is generally high when sunspots are rising and low when sunspots are falling. The third column shows the change in the average sunspot number from one period of twelve months (July to June) to the succeeding twelve months, and this column shows good agreement with the rainfall amounts. This agreement is expressed numerically by what is known as a "correlation coefficient." A correlation coefficient of +1 indicates complete harmony between the variations of the two elements which are being compared, a co-efficient of −1 indicates complete opposition between them, and a coefficient of 0.0 indicates complete independence.

TABLE 3.—RELATION OF RAINFALL TO SUNSPOTS.

Year.	Plateau Rainfall.	Sunspot number.	Change in sunspot number.
	inches.		
1904	− 2	42	+17
1905	+11	63	+10
1906	+ 7	54	− 3
1907	− 9	62	− 8
1908	+ 2	49	− 2
1909	− 9	44	−17
1910	− 7	19	−20
1911	− 3	6	− 9
1912	+ 6	4	0
1913	− 2	1	+ 1
1914	+ 9	10	+23
1915	+ 6	47	+32
1916	+14	57	+12
1917	+11	105	+25
1918	−20	81	−16
1919	+ 1	64	−32
1920	− 2	38	−18
1921	−11	25	− 9
1922	− 5	15	−14

Now the correlation coefficient between plateau rainfall and the change of sunspots from year to year is +0.64, which indicates good but by no means remarkable agreement. The correlation coefficient between plateau rainfall and the change in the level of Lake Victoria (table 2) is +0.91, indicating a very close agreement. Since the level of the lake depends on the rainfall and the rainfall depends on the sunspots, it is evident that the level of the lake would show agreement with sunspots even if there were no other factor. To measure this agreement between lake level and sunspots through rainfall, we multiply together the two correlation coefficients given above, *i.e.*, 0.64 × 0.91 = +0.58, and this would be the correlation coefficient between lake level and sunspots if no other factor than rainfall had to be taken into account.

But the connection between lake level and sunspots is much closer than this; it gives a correlation coefficient of +0.87 (table 1). Therefore some other factor in the lake level besides rainfall must be closely connected with sunspots, and from what has previously been said it will readily be seen that this factor must be evaporation. Evaporation must be much less in the years immediately preceding sunspot maxima than in those immediately preceding sunspot minima.

This conclusion is quite unquestionable, and throws interesting light on a well-known meteorological paradox. It is known that the sun is hottest at sunspot maxima and coolest at sunspot minima, but W. Köppen and others have shown that temperature in the tropics is on the average about a degree (Fahrenheit) lower near sunspot maximum than it is near sunspot minimum. That is, the hotter the sun the cooler the earth. This unexpected result has been attributed to greater evaporation from the oceans at sunspot maximum causing greater cloudiness and therefore a lower temperature. But we see that over Lake Victoria which is a very large sheet of water, evaporation is least, not greatest, at sunspot maximum; there seems no reason why this conclusion should not be extended to the oceans also. Hence the low temperature at sunspot maxima cannot be due to increased evaporation at those times but must find some other explanation.

It may be of interest to refer briefly to two other periodical variations shown by the level of Lake Victoria, namely the annual and diurnal changes. Superposed on the marked eleven year periodicity is a distinct annual wave with a range of ten inches. This annual wave is sufficiently distinct to be seen as a series of peaks and valleys diversifying the great sweeps of the eleven-year periodicity in figure 1. Over the twenty-six years 1896, 1899 to 1903 the average level in each month was as follows (inches above zero):

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.
5	5	5	8	13	13	10	7	5	3	3	5

The lake is normally lowest in October and November, rises very slowly until the end of March, and rapidly during April and May, remains steady during June and then falls moderately rapidly until September.

The other periodic variation is completed in the space of twenty-four hours. For the past few years the lake gauge at Kisumu has been read twice daily, in the morning and evening. These readings show that the level during the evening is persistently higher by a few inches than that during the morning. During the five years 1917 to 1921 the average difference was 4 inches; it was greatest in February (5 inches) and least in July and October (3 inches). This diurnal variation is probably due to the influence of land and lake-breezes, which owing to the great area of Lake Victoria are well developed. During the night and early morning the land breezes tend to blow the water away from the shores on all sides, accumulating it in the open part of the lake. During the day, on the other hand, the lake breeze tends to drive the water before it, and it collects against the shore, raising the level there at the expense of the centre of the lake. Such an effect would be well developed in an inlet like Kavirondo Gulf. The months when the effect is best shown—December to April—are in general those with least rain on the shores of the lake, and also mainly those in which the diurnal range of temperature is greatest; hence in these months the land and lake-breezes would be expected to be most vigorous.

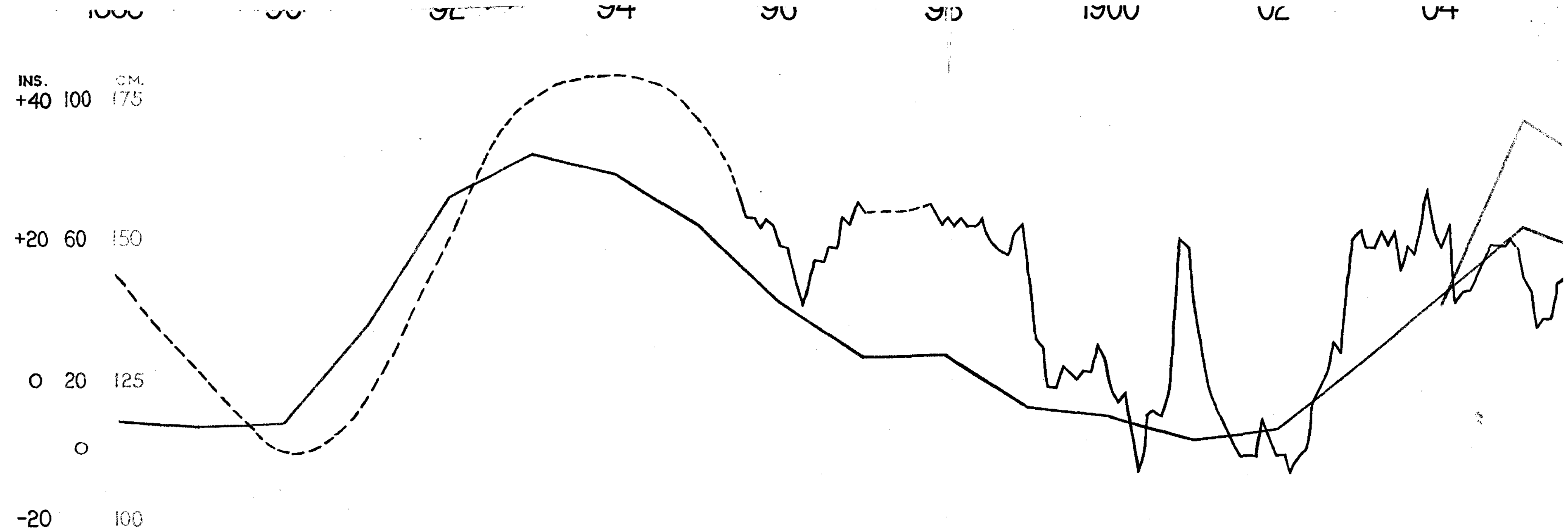
Another lake-gauge from which the records have been studied is that at Butiaba in Lake Albert. This gives similar results to those obtained from the gauge at Kisumu, showing that the eleven-year cycle is developed in Lake Albert as well as in Lake Victoria. Owing perhaps to its smaller area the fluctuations are in fact more than twice as great in Lake Albert, the absolute range being from 6 inches below zero in July, 1908 to 156 inches above zero in November, 1917, a difference of nearly fourteen feet. The annual means are as follows (inches above zero):

1904	29	...	1910	—	...	1916	48
1905	18	...	1911	9	...	1917	110
1906	26	...	1912	21	...	1918	115
1907	22	...	1913	24	...	1919	53
1908	1	...	1914	26	...	1920	33
1909	9	...	1915	37	...	1921	10

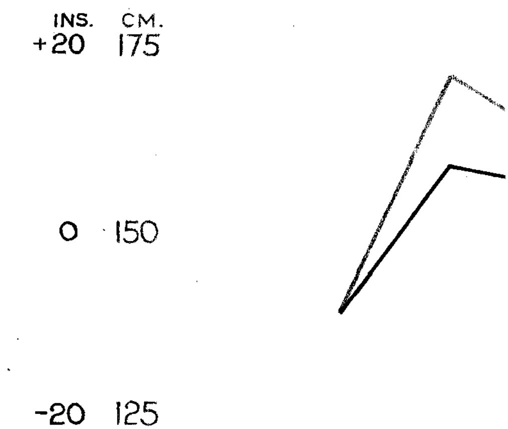
TABLE 4.—VARIATIONS IN THE LEVEL OF LAKE ALBERT.

In the latter part of the record the agreement with sunspot numbers is remarkably close.

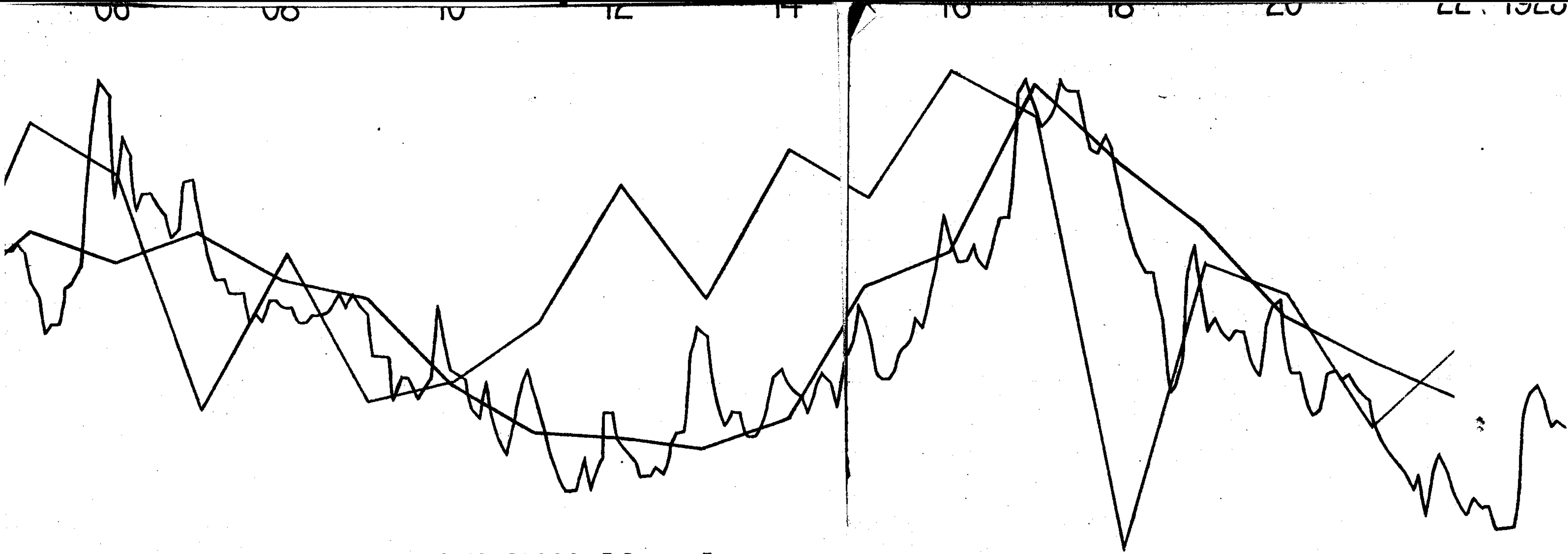
Thus the Central African Lakes Victoria and Albert present us with one of the most remarkable known associations of cosmical and terrestrial phenomena. The agreement between the sunspot curve and the lake-levels in the past thirty years has been so close that one can have little hesitation is prophesying that it will be maintained in the future, and that having reached their lowest level for the time being in 1922 the lakes will rise again, slowly at first, and then more rapidly, to another maximum about 1927 or 1928.



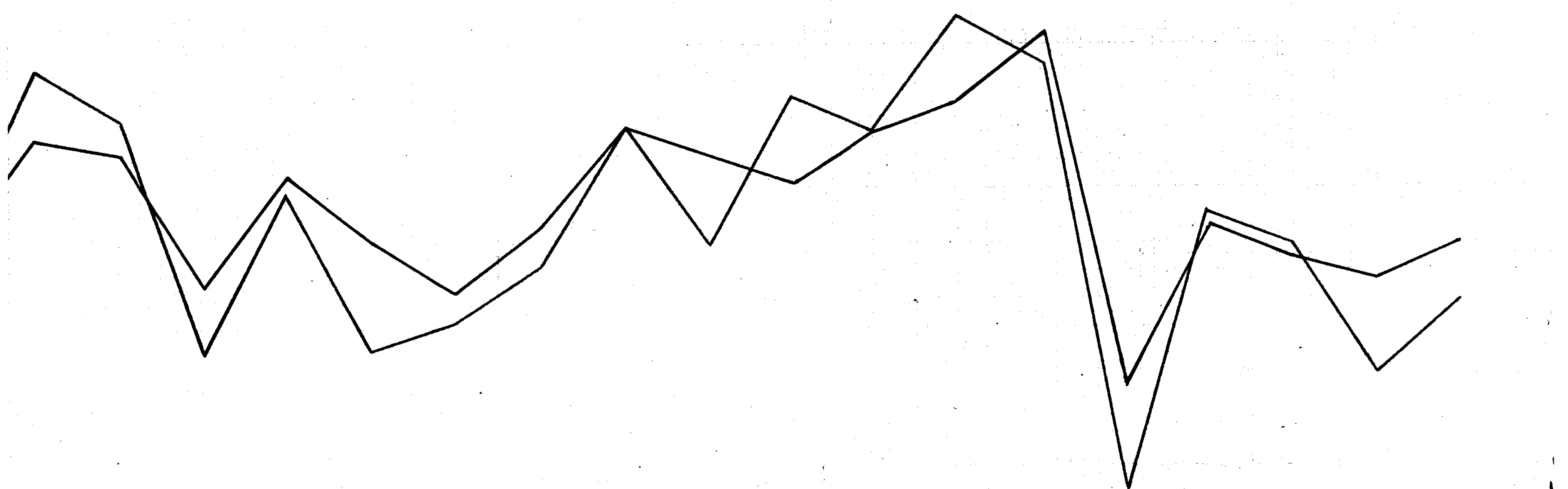
LEVEL OF LAKE VICTORIA [Black] SUNSPOT NUMBERS [Red] RAI



LAKE VICTORIA - CHANGE



RAINFALL OVER LAKE PLATEAU [Green]



ANGE OF LEVEL FROM YEAR TO YEAR [Purple] RAINFALL OVER LAKE PLATEAU [Green]