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NILE RUNOFF AT ASWAN AND LAKE VICTORIA: A CASE OF DISCONTINUOUS CLIMATE TIME SERIES

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With 2 figures

ABSTRACT

The water budget of Lake Victoria is decisively influenced by the convergence of the nocturnal land-breeze, which is associated with lake surface temperatures about 3.5° C higher than air temperature and produces a marked rainfall maximum centered at the Lake itself. Model computations suggest that about half of the annual precipitation is due to this circulation.

A possible mechanism for the rapid increase in lake level, and thus in the White Nile runoff, which occurred after the anomalous rainy season 1961/62, is discussed.

Runoff data for the Nile at Aswan (1899—1928) indicate that the low values during spring (February—May) are significantly correlated, at the 1 percent level, with the fluctuations of Lake Victoria 6 months before. This allows a tentative reconstruction of lake levels since 1870 to be made. Nile runoff values are also correlated with the Ethiopian summer rainfall 8 months before.

DER NILABFLUSS IN ASSUAN UND DER VIKTORIASEE: EINE DISKONTINUIERLICHE KLIMAREIHE

ZUSAMMENFASSUNG

Der Wasserhaushalt des Viktoriasees wird entscheidend von der Konvergenz der nächtlichen Landbrise beeinflußt, die bei Seeoberflächentemperaturen von 3,5° C über der Lufttemperatur eintritt und zu einem markanten Niederschlagsmaximum über der Seemitte führt. Modellrechnungen zeigen, daß etwa die Hälfte des Jahresniederschlags damit erklärt wird.

Ein rascher Anstieg des Seespiegels und damit des Abflusses vom Weißen Nil folgte auf die anomale Regenzeit 1961/62, mögliche Ursachen werden diskutiert.

Abflußdaten des Nils in Assuan, 1899—1928, zeigen, daß das Niedrigwasser vom Februar bis Mai signifikant mit den Schwankungen des Viktoriasees 6 Monate früher korreliert, wodurch eine Rekonstruktion des Seespiegels seit 1870 ermöglicht wird. Eine weitere Korrelation besteht zum äthiopischen Sommerregen 8 Monate früher.

1. THE WATER BUDGET OF LAKE VICTORIA

One of the tasks of a WMO Hydrometeorological Survey of the Catchment of Lake Victoria, Kyoga and Mobutu Sese Seko (WMO 1974), was a revision of the water budget of Lake Victoria, where the available data misleadingly indicated a negative balance, i. e. $[P_{Lake}(\text{precipitation}) + I(\text{inflow})] < [E(\text{evaporation}) + O(\text{outflow})]$.

Rainfall over the lake surface (ca. 67,000 km^2) is essentially controlled, as satellite cloud pictures clearly show, by the convergence of the nocturnal land-breeze. This regularly produces a giant Cb-cluster lasting until 10—11^h local time (Flohn and Fraedrich 1966), centered during its mature phase over the central and western part of the lake, due to the prevailing easterly winds at the 300—700 mb layer. During the afternoon, the daytime lake-breeze diverges, and the clouds disappear from the lake surface. Since the radiational heat stored by this equatorial lake cannot be exported, as in equatorial oceans, its average surface temperature (25.4° C) is about 3.5° C higher than the average air temperature at the coastal stations. Based on pilot-balloon data, Fraedrich (1968, 1971, 1972) constructed a circular convective model, which yielded an area-averaged rainfall rate of 0.81 mm/h, rising in the central region at the peak hour to 14 mm/h. Assuming, on the basis of climatological data (Flohn 1983), a frequency of 175 days per year and a duration of only 6 hours, this circulation produces an annual rainfall of 850 mm averaged over the lake surface. A further 800 mm precipitation would be expected annually (fig. 1) in addition to this local, lake-induced circulation at a hypothetical, dry basin.

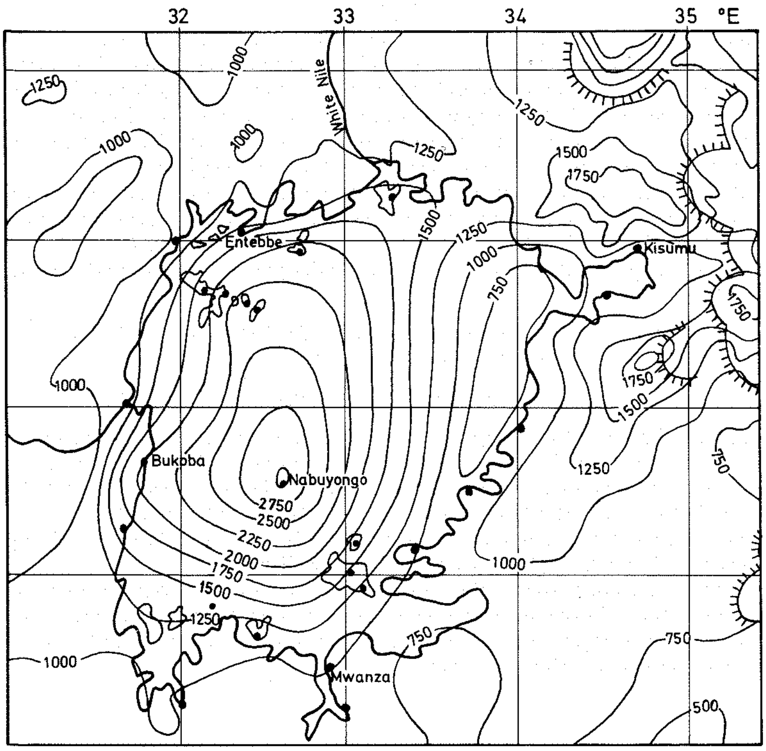

Fig. 1: Rainfall at Lake Victoria, as (nearly) compatible with the water budget (see text)

The increase of the rainfall above the lake itself was already documented from several island stations, especially the Sesse Islands (2000—2250 mm/a) (cf. Flohn and Fraedrich 1966). Six months data from an automatic station on the tiny central island of Nabuyonge had been available. The rainfall here is 30 % higher than at any other coastal or island station. A new, rather unorthodox, rainfall map has been constructed, on the assumption that this short point record and Fraedrich's model (1972) are both representative. Its evaluation leads to a revised area-average of 1690 mm/a; together with the revised estimate of evaporation of 1470 mm/a, the water budget now becomes more satisfactory (WMO 1974). It is essential to note that inflow contributes only 280 mm/a. The real "source of the Nile", the magic goal of so many 19th century explorers, is indeed the nocturnal Cb-cluster above the lake. Since the original map is no longer available, a new map was constructed independently (by T. Burkhardt); its isohyets were less elongated (fig. 1) than the original. Its evaluation yielded 1660 mm, and only 1630 mm/a by the polygon method. The unavoidable error (for P as well as for E) is estimated to be of the order of 50 mm/a.

2. THE RISE IN LAKE LEVEL 1961—64

The most challenging observation was the abrupt increase in lake level and in the discharge of the Nile, which is definitely not affected (Kite 1981) by the dam just above Owens Falls in Jinja, between late 1961 and early 1964 (fig. 2). The lake level rose by about 2.5 m, and remained at a slightly lower, but still high level until at least 1978 (Kite 1981). The average discharge during the period of the WMO survey (1946—70: 35.5 km^3/a equivalent to 500 mm/a) obviously represents neither the period 1900—1961 (average 20.8 km^3/a) nor the period 1962—1978 (average 41.2 km^3/a); the standard deviations are 4.6 and 4.7 km^3/a respectively. Kite's data (1981) indicate a similar increase in water level at other Central African lakes. Compared to the

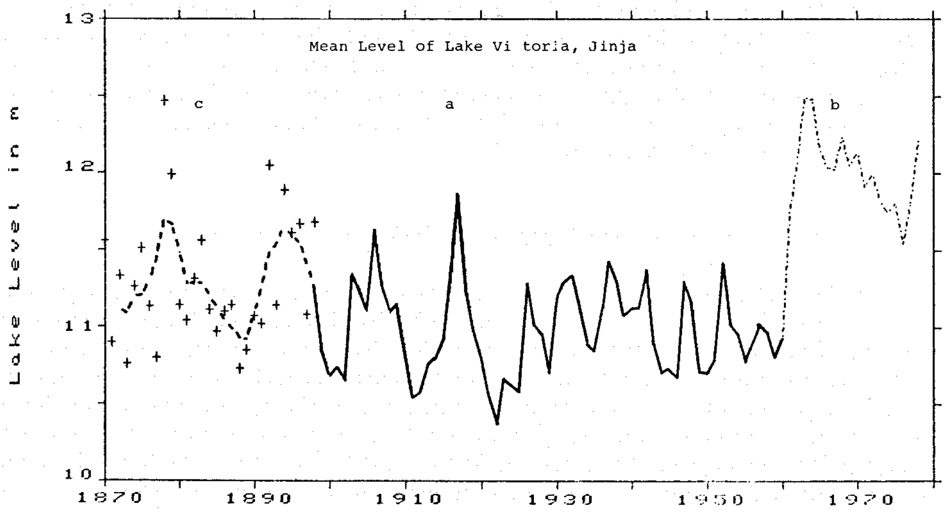

Fig. 2: Fluctuations of the level of Lake Victoria: a) actual measurements, b) reconstructed from lake level at first of January, c) + reconstructed from discharge data, --- polynomial fit. (WMO 1974, Kite 1981)

period between 1950—1961, water levels during 1962—1978 were higher by 1.43 m at Lake Victoria, 1.70 m at Mobutu and 1.56 m at Lake Tanganyika. Even Lake Malawi, which has an outlet near 15° S was 0.83 m higher at this time. The endorheic Lake Turkana rose about 5 m (Butzer 1971) and remained high until at least 1970.

The rainy season 1961/62 produced more rainfall than any other season during this century all over eastern Africa. In Kenya, Tanzania and Uganda, large areas received during five months, 300 to 500 % of the average precipitation. In the deserts of northern Kenya, the rainfall during this season amounted to up to 900 % of the average (cf. Thompson and Mörth 1965). This explains the unique rise in lake levels, if we neglect our ignorance of the mechanism of such an enormously extended and prolonged deluge, but why do these high levels persist for at least 15 years?

A working hypothesis, based on heat budget considerations, has been proposed recently (Flohn 1983). The turbidity of the lake has probably been slightly increased during the deluge of 1961/62 because of the input of very fine soil particles. This pollution would tend to increase the absorption of solar radiation in the uppermost layers of the lake, causing a slight warming and increasing evaporation. This is compatible with a sensitivity test using Fraedrich's model (1972). Assuming an average air (water) temperature T_a (T_W) of 21.5° C (25.0° C), a relative humidity of 75 % and an average wind speed of 3.5 m/s (in agreement with the data given in WMO 1974), an evaporation of 0.4 mm/d or 1.46 m/a is obtained, which is in good agreement with the water budget. If T_w were to be raised by +0.5° C, and the other parameters remain unchanged, the flux of sensible heat rises by 14 %, and that of evaporation by 5 %. This would lead to an intensification of the nocturnal circulation, which is very sensitive to small changes of $T_W—T_a$ and the speed of converging winds, and consequently to a quasi-equilibrium at a higher level.

3. THE NILE DISCHARGE AT ASWAN

A similar (but inverse) discontinuity has been observed in the Nile discharge data at Aswan in 1899 (Kraus 1955). Riehl et al. (1979) and Hassan (1981) have compiled a sequence of periods with alternatively high or low Nile floods since, and occasionally before, the installment of the famous Roda Nilometer at Cairo (715 AD). Using the seasonal amplitude of the Nile level as an index of the relative contribution of Ethiopian rainfall (representing the peak) and equatorial rains (representing the minimum in spring), Hassan suggests that these "episodic" variations in the Nile flood discharge are caused by relative increases in the contribution of the White Nile. This is not confirmed, however, by the two most recent cases. In 1899 no change in amplitude is observed. Comparing the Aswan discharge of the Nile for 1870—98 and 1899—1928, the ratio between both is 1.34 for the spring season (February—May), 1.28 for the peak (August—October) and 1.33 for the whole year. A diminution of the seasonal amplitude occurs only after 1928, as a result of the use of water for irrigation in Egypt. During the period 1929—53 the standard deviation for monthly runoff values drops to less than 40 % from December until April. After Riehl's data only a short rise occurred in 1964, which cannot be compared to the high floods around 1878 and 1894. Before 1825 the reliability of the Roda data seems to be somewhat uncertain (Riehl et al. 1979).

The problem of the observed discontinuities in 1899 and 1962 remains open, since our own suggestion of enhanced local circulation due to increased silt load is not applicable to Lake Turkana or Lake Tanganyika, which also remained high for 8 and

16 years respectively after the 1961 event. Furthermore, the occurrence of very widespread coherent rainfall anomalies in the Tropics, outside of the El Niño-region of the Pacific and Indian Ocean, remains an enigma. As an example, there are high correlations between the Nile runoff late in the year (July—December) and those of the Chari (feeding Lake Chad) and Senegal rivers, with values between 0.44 and 0.74 in 40—70 years series. Flohn and Nicholson (1980) have given further evidence for Africa.

The contribution of the White Nile, during spring, to the total discharge of the Nile at Aswan (A) can be used, however, for a tentative reconstruction of the level of Lake Victoria (V) during the period 1870—98. This is based on an analysis of correlation coefficients (r) between monthly and seasonal values of A and V. The degree to which the Ethiopian summer rainfall, represented by A (August—October) is reflected in the groundwater runoff contributed by the Blue Nile, Sobat and Atbara rivers can be estimated by comparing A (August—October) with A (February—June) of the following year, as shown in table 1.

Table 1: Correlation of total Nile discharge at Aswan, A (August—October) with A (February—June) of the following year

1870—1898 (undisturbed)	$r = 0.69$ $r^2 = 0.48$	significant at 0.1 % level
1899—1928 (slightly disturbed)	$r = 0.66$ $r^2 = 0.44$	
1929—1953 (disturbed)	$r = 0.33$	period not usable

Correlation of the Level of Lake Victoria (September—December) with A (February—June) of the following year

1899—1928	$r = 0.66$ $r^2 = 0.44$	significant at 1 % level

These correlations indicate that the low season discharge at Aswan is indeed controlled by both sources: equatorial rains (with a lag of about 6 months) and groundwater runoff from Ethiopia (depending on seasonal rainfall with a lag of about 8 months).

After some statistical experiments, the simple regression

$$V(9-12) = 10.0 + 0.0047\,A(2-5)$$

was then used to reconstruct V(9—12), which is highly correlated ($r = 0.94$) with V (annual), for the period 1870—1898 (fig. 2: crosses). Early explorer's reports (Lamb 1966) indicate that high stands of Lake Victoria occurred in 1878/79 and again between 1892 and 1895. A few early records after 1896 (Ravenstein 1901) also agree with this reconstruction. The high stand 1878/79 coincides with the Southern Oscillation Index peak 1877/78 and the worst drought in India. Further investigations (cf. Flohn 1983) of such teleconnections have now been started.

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