Reports

Discharge of the Nile River: A Barometer of Short-Period Climate Variation

Abstract. *Eight events of climate variation with durations of the order of 100 years have been found in the history of annual Nile River discharge dating from the year 622. They cease during the "little climatic optimum" in the North Atlantic and then reappear and intensify; this behavior suggests that control is from the belt of the polar westerlies.*

As the period over which climate records at numerous locations have been kept has increased to well over 100 years, the records have revealed that significant variations in climate do occur on time scales intermediate between very short and very long durations, say, 100 years as compared to 10 or 1000 years or more. Discharge measurements on the Nile River were begun in 1870 at Aswan (24°N, 33°E). For the period 1870 through 1941, it was found that a series of years with high discharge (1870 to 1900) was followed abruptly by a series of years with low discharge, almost suggestive of a discontinuity (*1*). Pictorial presentation was made clear and vivid by the use of the technique of determining the cumulative deviations from the mean for the period (*2*). Variations on the order of 10 years are seen as low-amplitude waves superimposed on the general envelope.

Table 1. Summary of episodes.

Period	Duration (years)	Maximum deviation ($\Sigma V'/\bar{V}$)	Percent volume change between high and low flow	Severity (mean slope)	Impact [percent volume change ×duration (×10^2)]
645 to 694	50	1.2	13	1:17	7
714 to 803	90	2.1	10	1:21	9
804 to 853	50	1.4	12	1:17	6
897 to 956	60	1.5	12	1:17	7
1210 to 1285	75	−1.1	6	1:23	5
1286 to 1467	180	−4.8	12	1:17	22
1725 to 1844	120	5.8	24	1:12	29
1845 to present	130 to present	7.0	22; steep part, 30	1:10	(29)

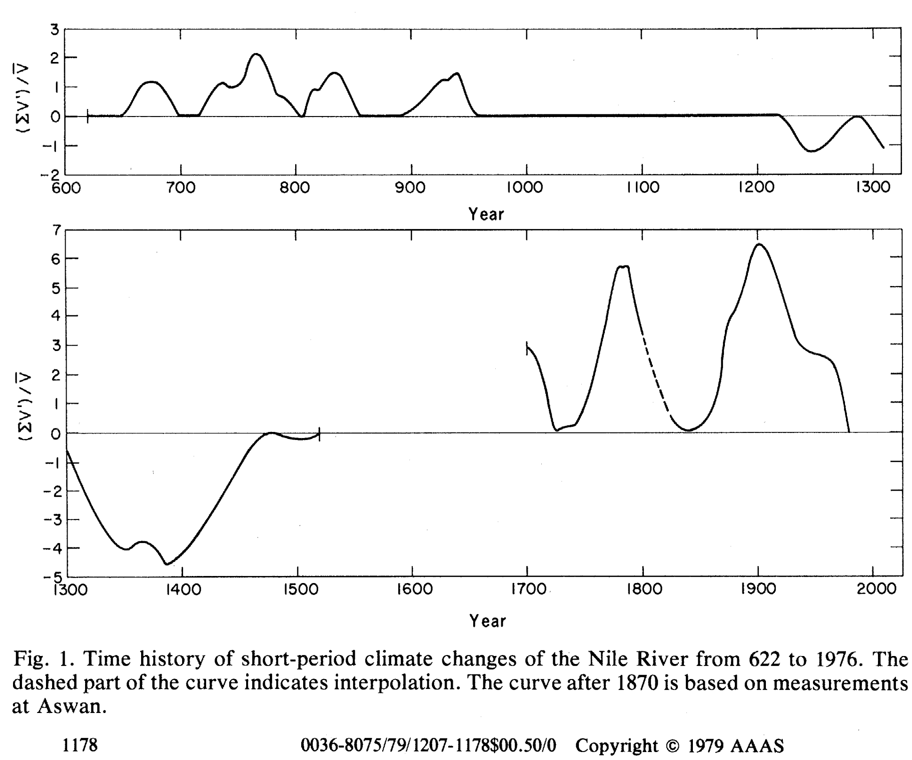

Fig. 1. Time history of short-period climate changes of the Nile River from 622 to 1976. The dashed part of the curve indicates interpolation. The curve after 1870 is based on measurements at Aswan.

If the record is updated to 1976, it is clear that the low-flow regime has continued to the present time (*3*). It would be of much interest if the whole Nile discharge record could be treated just as the record for the period 1870 to 1976. River stage has been measured at several "nilometers"; the longest record is that measured at Roda Island at Cairo. This record starts in A.D. 622, the year in which the Mohammedan calendar begins. There was an interruption after 1520 when political control passed to the Turks. Only broken parts of a record exist for the period 1520 through 1700. Another unfortunate break of 25 years occurred after the short-lived Napoleonic occupation (1800 to 1825) of Egypt. Even with these interruptions, one gains an overview of well over 1300 years. Although shortcomings of the Nile record have been widely discussed in the literature (*4, 5*), there is no indication that these difficulties vitiate analysis of short-period climate change.

We are interested not in the river stage but in discharge variations, such as the decrease of 30 percent near 1900—a large reduction. The highest annual river stage at Roda occurs in September after the flow from the summer rains in the Ethiopian mountains has passed northward, mainly through the Blue Nile and the Atbara River. From the annual discharge data at the first Aswan Dam after 1870 and from coincident measurements of maximum river stage at Roda, Riehl *et al.* (*3*) developed the following regression equation [the equation was also determined by Jarvis (*4*)]:

$$V_{\text{year}} = -308 + 20.8\,H \qquad (1)$$

Where V_{year} is the annual discharge (in cubic kilometers) and H is the maximum height of the Roda gauge (in meters). The correlation coefficient is .77; probably it would be still higher if a mean height value over, say, a month was available instead of the maximum stage and if all height values were fully reliable which, according to the investigators, is not the case.

We compared the variability of the Roda nilometer for the period after 1870 with that for prior centuries; we found

0036-8075/79/1207-1178$00.50/0

that variability was not affected by flow regulation through the first dam. Thus we assumed that the slope constant in Eq. 1 also holds for the earlier record. Then, deviations of the annual maximum river height (H') may be converted to annual volume discharge deviations (V') by setting

$$V' = 20.8\,H' \qquad (2)$$

If V' is normalized through division by some reference value $\overline{V}$, the significance of variations is brought out. We have chosen $\overline{V} = 91$ km^3, the average discharge for the last century. Even if this value varied somewhat over the centuries, the record becomes readily comparable to that of rivers such as the Colorado (V = 18 km^3/year), the Columbia, and other rivers with widely varying mean flow. However, according to Jarvis (*4*, p. 1022), "... one can conclude that the flood levels about 3000 B.C. (which are recorded on the Palermo stone) and the later data concerning Nile floods given by the Greek and Roman authors agree well with those of today."

A major problem is to find values of $\overline{H}$ over the centuries from which the deviations H' are to be computed. The river bed has risen at an average rate of 10 to 15 cm per century as a result of sedimentation. A first attempt to remove this trend linearly fails. The rise of the river bed was not nearly linear; there were only small rises and even reductions during the early centuries of data and then rapid increases thereafter. Therefore, factors other than sedimentation affect the 1300-year trend. We considered that the best procedure would be to plot the "mass curve" showing the changes of slope by 5-year means (*4*), 10- and 100-year means (*6*), and 25-year means. From these changes, the onset and termination of short-period climate fluctuations were determined; only such cases where the duration of an "episode" was at least 50 years and where the accumulation $\Sigma V'/\overline{V}$ exceeded $\pm$ 1 at the extreme value were considered. Altogether, eight such episodes were found (Fig. 1 and Table 1); another maximum has been hypothesized to have occurred near 1600 (*6*). Most remarkable is the fact that, after several small early episodes, fluctuations on the 100-year scale died out completely for over 250 years; this period is coincident with the well-known minimum of storminess of the "little climatic optimum" in the North Atlantic (*6*). At the end of this quiescent period the Nile fluctuations resumed, at first weakly and then strongly after 1300, presumably coupled with strengthening and expansion of the belt of upper west winds (*6*). Herewith interaction between extratropical and tropical regions, well known on very short time bases, is clearly suggested as a major control of the 100-year episodes. Butzer *et al.* (*7*) have found evidence of discharge variations on the time scale of centuries during earlier historical periods.

A second point of interest is that the episodes consist of a combination of high-flow and low-flow (or vice versa) years. One could think of a long-term constant basic flow upon which an occasional period of high-flow or of low-flow years is superimposed. In that case the mass curve would make a single jog and then return to its previous slope. But this pattern was not found. There are always two jogs, so that we are confronted with wavelike oscillations in time, some of them solitary events and some a sequence of events.

Table 1 shows characteristic numbers for all eight episodes. Their duration could be eliminated by the introduction of nondimensional time. There is, however, no obvious way to reduce the other variables so that a single episode model would emerge. Rather, an irregular spectrum of episode properties is brought out. The change in the available water supply across the episode peak (column 4) lies predominantly in the range 10 to 15 percent. However, in the last two events nearly double that change occurred; hence the significance for water supply is much larger. The mean slope of the curves in Fig. 1 may be a measure of the episode severity (column 5); it is well correlated with the preceding column, since the cases were all fairly symmetrical during growth and decay stages. The last column is an attempt to define an impact measure. We calculated these values by multiplying percent volume change by the duration. On the basis of this index, only the last three episodes can be rated as having had major impact on the economy.

HERBERT RIEHL
JOSÉ MEITÍN
Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder 80309

References and Notes

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Recent Crustal Uplift in Yellowstone National Park

Abstract. *Comparison of precise leveling measurements made in 1923 with those made in 1975, 1976, and 1977 reveals that the 600,000-year-old Yellowstone caldera is being uplifted relative to its surroundings. Maximum relative uplift since 1923 is in excess of 700 millimeters—about 14 millimeters vertically per year. The most likely cause of this rapid and unusually large surface deformation is a recent influx of molten or partially molten material to a location within the crust beneath Yellowstone National Park.*

Yellowstone National Park is an important area of Pleistocene intracontinental volcanism; three similar cycles of intense silicic volcanism have occurred there in the past 2 million years (*1*, *2*). The latest cycle began about 1.2 million years ago with the generation of two adjacent ring-fracture zones in central Yellowstone above two magma chambers that were probably connected at deeper levels with a larger magma body. Growth of the ring-fracture zones and minor rhyolitic volcanism eventually led to an explosive eruption of rhyolitic pumice and ash (1000 km^3) 600,000 years ago. Immediately after this eruption the roofs overlying the two magma chambers collapsed to form the elliptical Yellowstone caldera. A resurgent dome in the northeastern part of the caldera developed shortly after formation of the caldera; another resurgent dome in the southwestern part, near Old Faithful, appears to be the result of renewed magmatic activity beginning 150,000 years ago. Rhyolite flows as young as 70,000 years are associated with this recent activity.

In this report we present evidence for recent uplift of the Yellowstone caldera in excess of 700 mm (about 14 mm/year). This rapid and unusually large vertical movement is of considerable interest because geophysical studies indicate that a hot upper crustal body, which may be at least partially molten, still underlies the

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