On the 11-year Solar Cycle and River Flow

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JOHANNESBURG, 2001]

Abstract

The time series of seven river flows, and inflow into three dams possess peaks near the solar cycle in their spectra. The 10 time series have been filtered, using a band pass filter, to remove all fluctuations other than the 10 year one. The filtered series were compared with the series of sun-spot numbers. Although the series covered the length of South Africa, no simple relationship between flow fluctuation and the solar cycle became evident. In some cases, rivers and solar cycle were in phase, in other cases they were in anti-phase, whilst in others there were periods of in-phase followed by an abrupt discontinuity which led to anti-phases. The results suggested that further work was justified since an hypothesis of no relationship between river flow and the solar cycle could not be accepted.

Introduction

In a recent study (Dyer, 1978) dealing with the inflow into a dam at Gaberones it was shown, among other things, that an oscillation of wavelength equal to approximately 10 years was present. This fact applied also to the temporal variation in rainfall adjacent to the same area. It was pointed out that to assume that this oscillation was in sympathy with the sunspot cycle would be foolhardy without first carrying out further research. The present paper reports on an exploratory study of the behaviour of the 10 year oscillation in a selection of river flows and inflow to dams.

In an attempt to study the variation that this oscillation might suffer with changing latitude, a total of ten time series were taken for this work. The names of the rivers and dams considered are presented in Table 1, together with their geographical locations.

Theory

All the variance spectra of the series considered have a peak in the region of 10 years. However, they give no information regarding the phases of these 10 year waves. One way by which these waveforms may be investigated is to isolate them from the composite time series. This can be accomplished with the aid of a suitable band pass filter. As the term suggests, its application to a time series will remove, or severely attenuate, all frequencies other than the one that is of interest. This can be done in the following manner, which shows how the suitable design of the response function of the filter is made. Let f represent frequency in the range $0 \leqslant f \leqslant ½$, R(f) the frequency response of the filter. Then consider the following,

$$\begin{aligned} R(f) &= 0 && 0 \leqslant f < 1/20 \\ R(f) &= 0.5 + 0.5 \cos 20\pi f && 1/20 \leqslant f < 1/10 \\ R(f) &= 0.5 - 0.5 \cos 10\pi f && 1/10 \leqslant f < 2/10 \\ R(f) &= 0 && 2/10 \leqslant f \leqslant 1/2 \end{aligned} \qquad (1)$$

In the neighbourhood of a period of 10 years, this filter will have a response close to unity. Therefore it will not dampen, to any extent, oscillations with wavelengths close to 10 years. The response function falls to zero as one moves both to the left and right of this wavelength. When f is in the range 0 to 1/20

TABLE 1
THE NAMES OF RIVERS AND DAMS STUDIED, TOGETHER WITH THEIR LATITUDES AND LONGITUDES

Name	Latitude	Longitude
Zambezi	17° 29'	24° 18'
Okavango	18° 04'	21° 26'
Gaberone Dam	24° 40'	25° 50'
Marico-Bosveld Dam	25° 28'	26° 23'
Hartbeespoort Dam	25° 44'	27° 52'
Komati	26° 02'	30° 59'
Pongola	27° 21'	31° 55'
Mooi	29° 02'	30° 22'
Mzimkulu	30° 16'	29° 57'
Steenbras	34° 11'	18° 51'

and 2/10 to 1/2, its response is virtually zero (Mitchell, 1966; Koopmans, 1974).

To obtain the necessary filter weights the following is used

$$w(k) = \frac{1}{2l}\left[R(0) + 2\sum_{f=0}^{0.5} R(f)\cos(2\pi fk)\right] \qquad (2)$$

The values of f are taken as 0, 1/2 *l*, 2/2 *l*, ,, *l*/2 *l*, and *l* is a constant of arbitrary length. The value of *l* giving satisfactory results is two or three times the value of the longest wavelength for which R(f) is non-zero. In the present case then, *l* has been taken as 60, i.e. (3 x 20). This filter is a symmetrical one, so but for w(0) it is only necessary to obtain the weights w(1), w(2), ,,w(k). The others, w(− 1), w(− 2), ,, w(− k), follow immediately from these. How many weights to generate is decided upon by having a cut-off value w(k) which is very much less than the central weight w(0). Also, since the weights oscillate from positive to negative values, with peaks occurring at approximately values of k that are multiples of its optimum frequency, it follows that w(k) should be at one of these multiples. Figure 1 shows the frequency response of the particular band pass filter, and it can be seen that it has a value of unity at a period of 10 years. Ideally, one would have liked a filter with a sharper cut-off to zero. There are a number of reasons why this cannot be so, one of which is because the oscillations under study are likely to vary in wavelength. Therefore, if one severely attenuates all wavelengths other than 10 years, a slight change to, say, 9 or 11 years would be lost from the frequency study.

The weights are lined up with the time series so that initially w(− k) is opposite term one in the series and w(k) will be opposite from (2k + 1). The adjacent weights and series terms are then multiplied together and the (2k + 1) products are summed to give the first term of the filtered series. This term is placed in time opposite the original term (k + 1).

The weights are then displaced one term and the process repeated. This operation is continued until w(k) is opposite the last term in the original series. It will be seen that k terms are lost at both the beginning and end of the series. This situation is unfortunate especially on short time series but it is unavoidable.

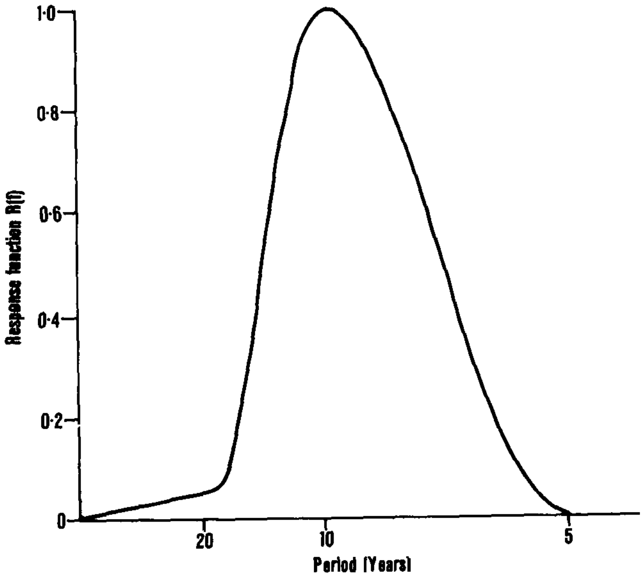


Figure 1
The frequency response function of the band pass filter used on the river and dam data

Some results

Figures 2a and b show a plot of the filtered series for the localities given in Table 1. Some of the filtered series are rather short, but they still serve a useful purpose over the period which they cover. In this diagram the values allotted to the superimposed sunspot curve are arbitrary. In many instances, where several cycles have been completed in the filtered series, the waveforms are remarkably regular. The individual curves appear to fall into roughly three groups. Firstly, there are series such as that for the Zambezi, which appears to have a 10 year oscillation that keeps in step fairly well with the sunspot one; Then there are those, for example Steenbras, which appear to be moving in anti-phase with the solar cycle. While thirdly, there are those that suffer a sudden jump in phase, and probably the best example is the case of the Komati. See how well it is initially in phase with the solar cycle then at about 1953 it changes to being in anti-phase with it. Within these groups there are various sets of different behavioural patterns. Take for example, the Marico which takes its minima at a fixed lag after the solar maxima. The Komati provides an example of a shifting phase, where early on the peaks are in phase, drift away and then appear to be going back in phase again.

It is very difficult to accept any relationship between the phase of the 10 year oscillations with the sun spot cycle, and latitude of the stations. This has been suggested by King (1976), the idea being that standing waves of influence exist and that at some latitudes the 10 year oscillation disappears altogether. An excellent review of recent work covering solar influences and a number of physical variables is to be found in a paper by King (1975). In the present paper the author has in fact shown that the 10 year oscillation appears to be present over all the latitudes considered from about 17°S to 34°S. Of course, the latitudinal grid may be too coarse. By chance, the gaps may enclose or possess completely different behavioural patterns. From a forecasting point of view, one very worrying point merges from this work. This is that whilst a time series may be in either phase, or anti-phase with the solar cycle a sudden discontinuity can arise, take for example the Komati. A forecast of a peak based on knowledge prior to about 1945 for the future based on a relationship with the solar cycle would have been quite unacceptable. But in other cases a strong apparent relationship has existed for many years e.g. Zambezi, Gaberones, Hartbeespoort. What information is presently available for the Okavango shows a very tight anti-phase relationship.

Concluding remarks

Some interesting temporal 10 year patterns in some rivers and dams stretching from 17°S to 34°S over South Africa have been exhibited. Whilst this study has not shown any simple relationships to exist between river flow and the solar cycle, it has shown that there is the need for a further and more comprehensive investigation into these phenomena. It is felt that this should be carried out in conjunction with research dealing with rainfall, river flow, and the general circulation of the atmosphere.

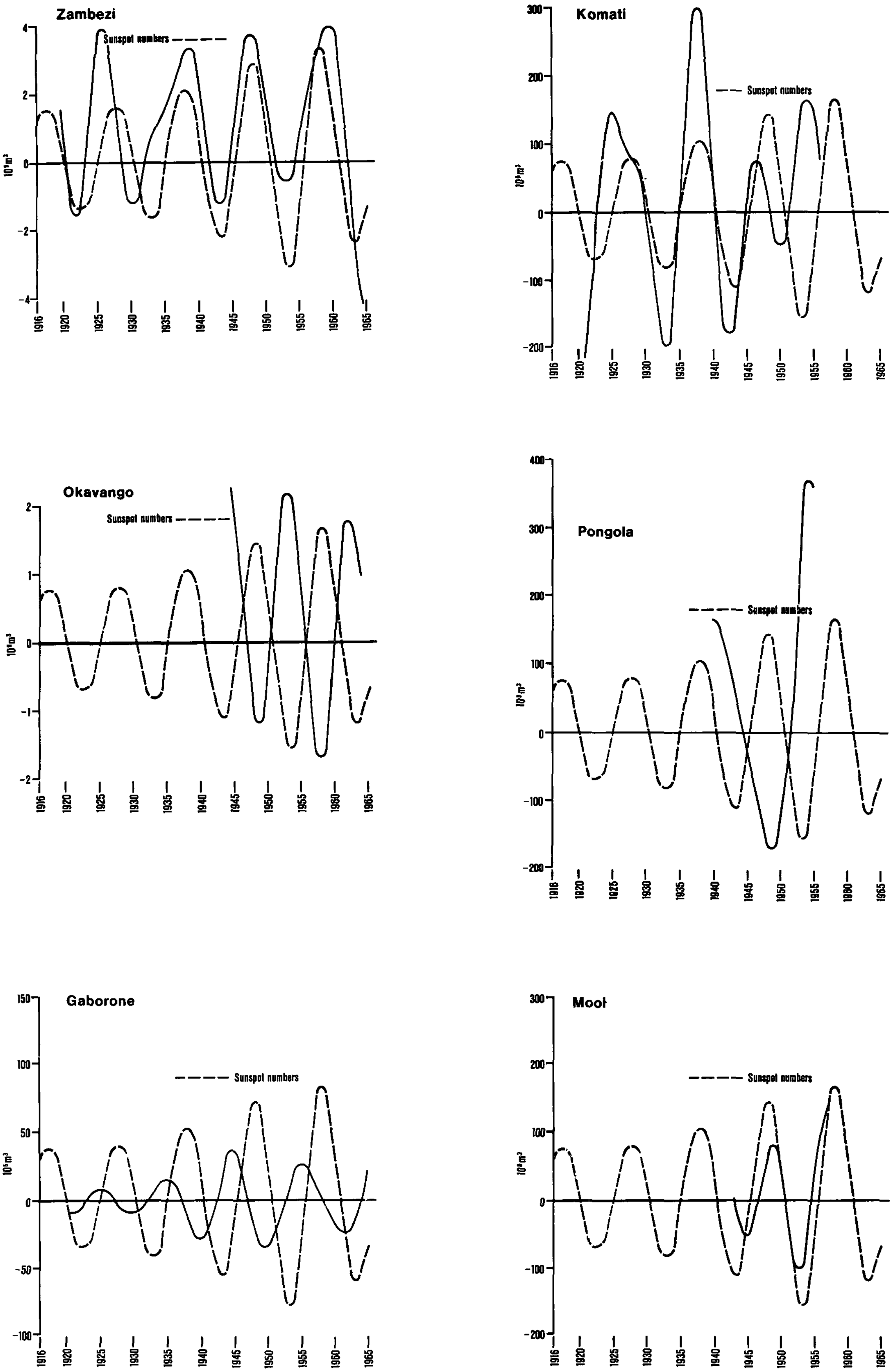
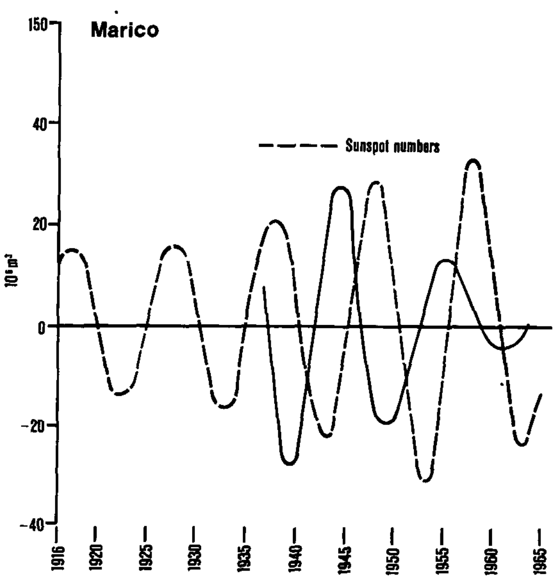
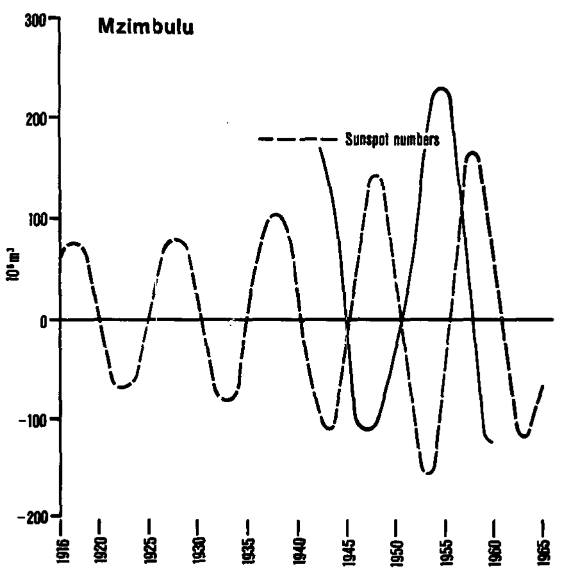
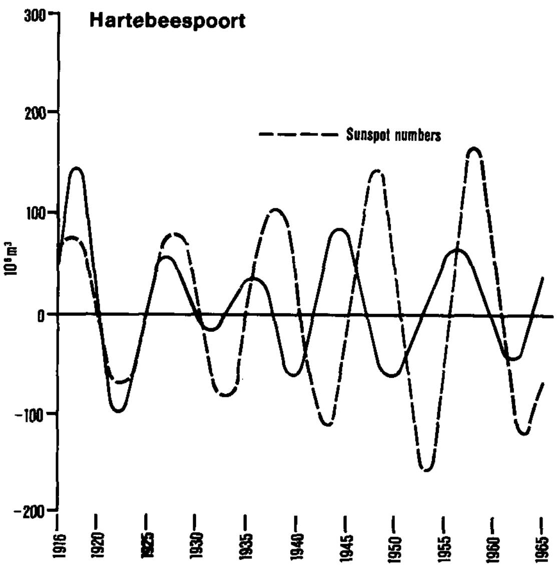
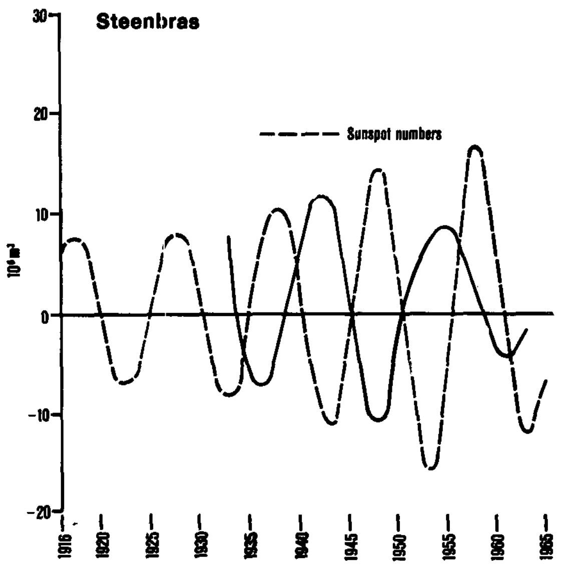


Figure 2a and b (overleaf)
Extent to which river flow, and dam inflow vary over time with the solar cycle. The pecked curve represents the solar cycle in all cases, and its scale is arbitrary









Acknowledgements

The author offers his sincere thanks to Mr BGA Lund, without whose continual pressure and useful discussion this paper may not have been undertaken. Dr King of the Appleton Laboratory, Slough, UK has kept the sunspot data updated, and has provided valuable discussion from time to time. The author is also grateful to the Water Research Commission for financing his visit to the UK in connection with this work.

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month was allowed for analysis of the samples and submission of the results.

Each laboratory was allocated a code number, known only to that laboratory and the originator of the study.

Data Evaluation

Summaries of the results received, together with a statistical analysis of these results, are given in Tables 1 and 2.

All of the results received were first reviewed for outliers, using the ASTM procedure (ASTM, 1975), before analysing for mean, mean error, relative mean error, standard deviation, and coefficient of variation. As in the previous study, the results were then assessed (Table 3) according to the method of Greenberg *et al.*, (1969), *viz*:

1. Results falling between the mean and ± 1 standard deviation are acceptable.
2. Results falling between ± 1 and ± 2 standard deviations are acceptable but questionable.
3. Results outside the limits of ± 2 standard deviations are unacceptable.

Of the results received, 74% were found to be acceptable, 18% were acceptable but questionable, while 8% proved unacceptable.

Finally; the results were evaluated by a graphical technique devised by Youden (1960). To allow for the implementation of this technique, each laboratory must carry out one determination on each requested constituent of two samples containing the same constituents in relatively similar concentrations. A graph is then prepared of the results for each constituent, results from one sample being plotted on the x-axis and those from the other sample being plotted on the y-axis. Thus for each laboratory's pair of results, one point is produced, which is indicated by the code number of that laboratory. A horizontal line is then drawn through the average of the values reported for the first sample and a vertical line drawn through the average of the values reported for the second sample. These two lines divide the graph into four quadrants.

Graphical representation of the data in this manner allows for considerable interpretation as to the overall performance of a laboratory, as well as the types of error which may account for a poor performance by a particular laboratory. For example, points lying close to the intersection of the horizontal and vertical lines represent a high degree of accuracy, whereas distant points represent poor accuracy. Points lying close to one line but far from the other demonstrate inconsistent performance. In addition, information on a participating laboratory's precision may be obtained from the graph. If all participants had perfect precision (i.e. no indeterminate error) then all the paired points would fall on a 45° line passing through the origin. Therefore, the distance of each laboratory's point from this 45° line is indicative of the measure of that laboratory's precision. Still further interpretation is possible for points lying far from the intersection of the two lines. In theory, due to random or chance factors affecting the results, an equal number of

TABLE 1
SUMMARY OF RESULTS FROM ANALYSIS OF SAMPLE 1

Parameter	Units	Laboratory Number																	True value (mg l^{-1})	Mean value (mg l^{-1})	Mean error (mg l^{-1})	Relative mean error (%)	Standard deviation (mg l^{-1})	Coefficient of variation (%)
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17						
Kjeldahl nitrogen		26,0	25,5	—	27,9	—	28,3	24,3	—	23,6	26,2	28,0	29,7	26,2	25,7	31,7	—	—	28,0	26,9	1,1	3,8	2,3	8,5
Ammonia nitrogen	mg l^{-1} N	16,3	16,0	—	15,1	—	16,8	15,3	14,9	12,0	15,1	16,0	16,5	15,0	15,4	16,8	—	18,9	16,0	15,7	0,3	1,7	1,5	9,6
Nitrate nitrogen		12,1	14,5	—	9,8	12,0	15,2	12,4	12,2	12,5	12,0	12,4	13,8	10,8	12,6	12,1	12,9	10,5	12,8	12,4	0,4	3,4	1,4	11,0
Nitrite nitrogen		2,1	2,2	—	2,0	2,2	2,0	2,2	1,8	2,0	1,5	1,7	2,1	2,1	1,6	2,0	1,8	1,5	2,0	1,9	0,1	5,0	0,2	12,6
Total phosphate	mg l^{-1} P	9,5	12,2	—	9,6	—	9,8	9,1	—	8,7	—	—	—	9,7	8,0	—	—	—	9,6	9,6	0	0	1,2	12,8
Ortho-phosphate		8,4	12,2*	—	8,0	8,4	8,5	8,7	7,8	7,7	—	8,7	6,9	7,9	8,2	7,6	4,2*	7,0	8,0	8,0	0	0	0,8	7,3

*Outlier