# Linkages between solar activity, climate predictability and water resource development

**W J R Alexander, F Bailey, D B Bredenkamp, A van der Merwe and N Willemse**

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# Linkages between solar activity, climate predictability and water resource development*

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This study is based on the numerical analysis of the properties of routinely observed hydrometeorological data which in South Africa alone is collected at a rate of more than half a million station days per year, with some records approaching 100 continuous years in length. The analysis of this data demonstrates an unequivocal synchronous linkage between these processes in South Africa and elsewhere, and solar activity. This confirms observations and reports by others in many countries during the past 150 years.

It is also shown with a high degree of assurance that there is a synchronous linkage between the statistically significant, 21-year periodicity in these processes and the acceleration and deceleration of the sun as it moves through galactic space. Despite a diligent search, no evidence could be found of trends in the data that could be attributed to human activities.

It is essential that this information be accommodated in water resource development and operation procedures in the years ahead.

WILL ALEXANDER is Professor Emeritus of the Department of Civil and Biosystems Engineering of the University of Pretoria, and Honorary Fellow of the South African Institution of Civil Engineering. He spent the last 35 years of his career actively involved in the development of water resource and flood analysis methods as well as in natural disaster mitigation and climate change studies. He has written more than 200 papers, presentations and books on these subjects. He has also presented short courses to some two thousand practitioners during this period.

*Contact details:*
Postnet Suite #303, Private Bag X20 009, Garsfontein 0042, South Africa
alexwjr@iafrica.com

FREDERICK (FRED) BAILEY is a retired higher professional technical officer in the Ministry of Defence, UK. Being a naval architect required an advanced understanding of the four-dimensional behaviour of masses on the move through rough seas under the influence of gravity and the elements. This in turn led to his hobby of many years when he achieved an advanced understanding of the behaviour of the solar system as it moved through galactic space under gravitational influences. His findings of the synchronous relationship between the acceleration and deceleration of the sun, sunspot formation, and together with the other authors, the connection with hydrometeorological processes is unique.

*Contact details:*
fredbailey@webaplomb.com
For e-mails greater than 1 MB, please use fredbailey@sky.com

DAVID BREDENKAMP is a hydrogeologist who specialises in groundwater resource assessment. He holds an MSc degree in chemistry and a PhD degree in geohydrology from the University of the Free State. He has written 40 reports and publications on this subject, as well as a handbook on groundwater recharge and aquifer storativity.

*Contact details:*
dbredenkamp@icon.co.za

ALWYN VAN DER MERWE has been working for Eskom for the past 14 years, the last nine years with a variety of water management issues. He has a degree in chemical engineering as well as a postgraduate degree in water resources engineering, both obtained from the University of Pretoria. His interest is in the development of computer programs for the numerical characterisation of regional rainfall and river flow. His participation in this study was in his private capacity.

*Contact details:*
alwyn.vdmerwe@gmail.com

NICO WILLEMSE graduated with a BS Eng from the University of Pretoria in 1979 and obtained an MBL from the University of South Africa in 1986. He spent his first years as engineer with the Transvaal Roads Department and Van Wyk and Louw Consulting Engineers. He later joined Fluor Engineers and Sulzer. After a short spell with management consultants, he returned to the consulting engineering industry where he was a partner in consulting engineering practices. He is currently in Ireland where he is involved in the management and implementation of various water and sewerage schemes. He is a member of the South African Institution of Civil Engineering (SAICE).

*Contact details:*
nwillemse@eircom.net

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## BRIEF HISTORICAL BACKGROUND

### Rippl diagram 1883

The Rippl diagram is a graph of the accumulated values of a hydrologic quantity, generally as ordinate values, plotted against time or date as abscissa. It was first proposed by Rippl (1883) as a basis for determining the volume of storage required to sustain a given demand from a river. A modification of the method is to divide all the sequential values by the record mean value, then accumulate and plot the sums one at a time. The graph will start and end with zero values.

If straight lines are drawn parallel to the mean value such that they pass through the maximum positive and negative deviations from the mean value, the vertical distance apart is the range *R*. This is the required storage capacity, ignoring all evaporation and other losses, that would have been required to sustain a yield equal to the mean value during the period of record.

Assuming a record length of *n* years and a standard deviation of the time series of *S*, then

$$R_n/S_n \sim n^H$$

Theoretically, *H* should have a value of 0,5 for normally distributed sequences of independent random values.

An interpretation of the graph provides an insight into the long term behaviour of the time series. It is also a valuable tool when used in conjunction with statistical serial correlation analyses to identify synchronous characteristics between multiple site and multiple processes, including linkages with solar activity should they be present.

### Hutchins 1889

In 1889 colleagues of D E Hutchins (1889), conservator of forests in Knysna, persuaded him to publish a compilation of his lectures in a book with the title *Cycles of drought and good seasons in South Africa* in which he demonstrated a remarkable insight into global climatic processes.

Hutchins was one of a generation of scientists and civil engineers who served in the British Colonial Office in India and then migrated to South Africa. He was stationed in Mysore, India, when, in 1876, 1,5 million people out of a population of 5 million in the state starved to death during a severe drought. It had been noted previously that there were linkages between sunspot numbers and famines dating back to 1810. Many scientists at that time, including Hutchins, were involved in the search for predictable linkages between droughts and sunspot numbers. Hutchins details their efforts in

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* This paper is a compilation of separate studies by the authors using different methods, different data sets, different time frames and different regions of the globe. For this reason there may be some differences in the analytical methods and presentations. This in no way negates the overall conclusion that an unequivocal synchronous linkage exists between the hydrometeorological processes in South Africa and elsewhere, and solar activity.

**Table 1 Presence of 21-year concurrent periodicity in hydrometeorological data**

| Process | Number of sites | Record years | Periodicity | | | |
|---|---|---|---|---|---|---|
| | | | 95 % | Present | None | Not determinable |
| Evaporation | 20 | 1 180 | 0 | 0 | 20 | 0 |
| Rainfall | 93 | 7 141 | 18 | 67 | 8 | 0 |
| River flow | 28 | 1 877 | 7 | 12 | 5 | 4 |
| Flood peak maxima | 17 | 1 235 | 4 | 7 | 2 | 4 |

his book. His perceptive observations are discussed again later.

## Kokot 1948

In the late 1940s D F Kokot, a civil engineer in the South African Department of Irrigation (now Water Affairs and Forestry), undertook a comprehensive study to determine whether or not there had been recent climatic changes that could have had an effect on rainfall and river flow. The results of his study were published in an Irrigation Department memoir entitled *An investigation into evidence bearing on recent climatic changes over southern Africa* (Kokot 1948). It included many reports by early travellers and missionaries.

Kokot concluded that there was no evidence of any changes in rainfall and river flow that could be ascribed to climate change or any other causes.

## Hurst 1950s

In 641 AD – more than a thousand years ago – a water level gauging structure was built on Rodda Island in the Nile River at Cairo. The record from the Rodda Nilometer is the longest available hydrological record in the world. In 1950 the civil engineer H E Hurst (1951, 1954) analysed 1 080 years of data from the Rodda Nilometer recorded during the period 641–1946 which he used to determine the required storage capacity of the proposed new Aswan High Dam.

Hurst applied the Rippl method to successive segments of equal length, that is, $n$ = 10, 20 etc, and found an unexplained anomaly in the data. The value of the coefficient $H$ for the Nile River was approximately 0,75. He then analysed other long geophysical records, where he found the same anomaly. These were lake deposits (2 000 years, $H$ = 0,69), tree rings (900 years, 0,80), temperature (175 years, 0,70), rainfall (121 years, 0,70), sunspots (0,70) and wheat prices (0,69). This anomaly became known as the Hurst phenomenon, or Hurst's Ghost. It is important to note that the same multiyear anomalies that were present in the flow records of the Nile River are also present in the proxy data used by today's climate change scientists.

For more than two decades these anomalies were studied by hydrologists and mathematicians.

There are many examples of studies by mathematicians, hydrologists and civil engineers at that time (Rodrigues-Iturbe & Yevjevich 1968; Mandelbrot & Wallis 1968; Yevjevich 1968; Wallis & Matalas 1971; Yevjevich 1972; Wallis & O'Connell 1973). Klemes (1974) commented that ever since Hurst published his famous plots for some geophysical time series, the classical Hurst phenomenon continued to haunt statisticians and hydrologists, and that attempts to derive theoretical explanations from the classical theory of stationary stochastic processes have failed.

The studies included the effects of serial correlation. When this could not be identified in the data, the assumption had to be made that no meaningful serial correlation existed. However, once the records become long enough to identify the presence of 21-year serial correlation and its synchronous linkage with sunspot activity, then everything fell into place.

The accumulated departure method and serial correlation analyses are fundamental to time series analyses in situations where non-stationary processes are involved. It was only when records became long enough to detect the 21-year periodicity in the hydrological data that Hurst's Ghost was eventually laid to rest.

## Commission of Enquiry into Water Matters, 1970

The Commission of Enquiry into Water Matters was appointed by the State President (*Government Gazette* 1966). Its terms of reference included the instruction to inquire into, report upon and submit recommendations on all aspects of water provision and utilisation within South Africa. The following extract from the report is directly relevant to this paper:

> The drought phenomenon remains one of the country's most vexing problems and it is in drought prediction that long-term forecasting can probably be of the greatest value. On the other hand, it must be admitted that meteorologists have not yet succeeded in discovering the fundamental causative factors either of drought or of excessive precipitation. The classical attitude, viz that drought is purely a chance occurrence in the climatic history of the country, does not appear to be correct.
>
> In an objective approach the possible influence exerted by fluctuations in the sun's radiant energy on the incidence of drought is stressed. Some of South Africa's most severe and prolonged droughts of the nineteenth and twentieth centuries have without doubt coincided with troughs of minimum sunspot activity. The sun thus appears to be either directly or indirectly responsible for abnormal weather. As the exact mechanism is not yet clear, research in this field should evidently receive earnest attention (Commission of Enquiry into Water Matters 1970:92).

This report provided the impetus for Alexander's studies from the 1970s through to the present day.

## ANALYSES (ALEXANDER 1978–2007)

The following material is from reports and published papers prepared by Alexander during the past 30 years. It illustrates the development of analytical methods used to quantify the multiyear periodicity in the hydrometeorological data and the development of climate prediction and water resource development models based on this periodicity. The analytical procedures used in the analyses are simple. They can be readily replicated by anyone with experience in observation theory and time series analyses. The data used in the analyses are from published records of the responsible authorities.

The starting point was the incontestable, statistically significant (95 %), 21-year periodicity in the South African rainfall, river flow and other hydrometeorological data. Table 1 shows the presence of 21-year concurrent periodicity in South African hydrometeorological data. The degree of statistical significance is dependent on the length of the record as well as the magnitude and nature of the variability about the mean. The periodicity is almost certainly present in all hydrometeorological data series, other than open water surface evaporation, but has not yet reached a high level of statistical significance at some of the sites.

The commencements of the periods are readily identified and predictable. They are characterised by sudden reversals from sequences of years with low rainfall (droughts) to sequences of years with widespread rainfall and floods.

While the reversals are a characteristic of the start of the periods, the periodicity refers to the whole spectrum of values. For example, a significant correlation exists between all the fifth values after the commencement of the periods, all the $n$-th values, and so on. This relationship is stronger than the relationship between successive values in the hydrometeorological data where no statistically significant serial correlation exists.

*Table 2 Vaal River – annual flow record 1923/24 to 1995/96 (expressed as percentages of the mean, showing the mid-period and full period sudden reversals from drought sequences to flood sequences)*

| Year | Inflow | Year | Inflow | Year | Inflow | Year | Inflow |
|---|---|---|---|---|---|---|---|
| 23/24 | 39 | 43/44 | 353 | 63/64 | 58 | 83/84 | 79 |
| 24/25 | 246 | 44/45 | 87 | 64/65 | 149 | 84/85 | 30 |
| 25/26 | 42 | 45/46 | 66 | 65/66 | 27 | 85/86 | 36 |
| 26/27 | 66 | 46/47 | 58 | 66/67 | 175 | 86/87 | 46 |
| 27/28 | 44 | 47/48 | 57 | 67/68 | 31 | 87/88 | 208 |
| 28/29 | 83 | 48/49 | 33 | 68/69 | 35 | 88/89 | 165 |
| 29/30 | 142 | 49/50 | 100 | 69/70 | 60 | 89/90 | 65 |
| 30/31 | 40 | 50/51 | 33 | 70/71 | 52 | 90/91 | 59 |
| 31/32 | 36 | 51/52 | 60 | 71/72 | 102 | 91/92 | 13 |
| 32/33 | 24 | 52/53 | 100 | 72/73 | 23 | 92/93 | 26 |
| 33/34 | 170 | 53/54 | 45 | 73/74 | 112 | 93/94 | 92 |
| 34/35 | 131 | 54/55 | 181 | 74/75 | 295 | 94/95 | 17 |
| 35/36 | 87 | 55/56 | 80 | 75/76 | 247 | 95/96 | 464 |
| 36/37 | 225 | 56/57 | 277 | 76/77 | 123 | 96/97 | N/A |
| 37/38 | 59 | 57/58 | 188 | 77/78 | 122 | 97/98 | N/A |
| 38/39 | 202 | 58/59 | 69 | 78/79 | 31 | 98/99 | N/A |
| 39/40 | 112 | 59/60 | 75 | 79/80 | 63 | | |
| 40/41 | 131 | 60/61 | 105 | 80/81 | 62 | | |
| 41/42 | 54 | 61/62 | 50 | 81/82 | 19 | | |
| 42/43 | 185 | 62/63 | 68 | 82/83 | 12 | | |

It is interesting to note the absence of 21-year periodicity in the evaporation data in table 1. Another observation is that the magnitudes of the periodic changes relative to the long-term mean values, increase from evaporation (absent) to rainfall, to river flow, to flood peak maxima. Together, these characteristics indicate that the periodicity is amplified by the processes involved in the poleward redistribution of solar energy.

Neither the lengths of the periods nor the synchronous occurrences are precise in the mathematical sense, but their presence is beyond all doubt.

## Sunspot database

Conventional sunspot cycles were used as indicators of solar activity. The following data are from website information distributed by the World Data Centre for the Sunspot Index (2005).

There were eight complete cycles during the past century. These commenced with the sunspot minimum that occurred in June 1913 and ended with the sunspot minimum in March 1996. The lengths of the cycles were 10, 10, 11, 10, 10, 12, 10 and 10 years, with a mean of 10,4 years. These values are within a narrow range of between 10 (minimum) and 12 (maximum) years. A corresponding increase in solar activity during the past century is reflected in the increase in the numbers of sunspots per cycle, commencing with the cycle that started in 1913. Alternating cycles are identified by negative values. The sunspot numbers per cycle were +442, -410, +605, -757, +950, -705, +829 and –785. The maximum was more than twice that of the minimum that occurred only three cycles earlier.

The lengths of the corresponding double sunspot cycles were 20, 21, 22 and 20 years with a mean of 20,8 years, a minimum of 20 years and a maximum of 22 years. The average number of sunspots in the alternate cycles that make up the double cycles were +706 and –664, demonstrating a meaningful difference in sunspot activity in the alternating cycles. As will be seen, the alternating sunspot cycles have appreciably different effects on the hydrometeorological processes.

It will later be demonstrated that it is not the annual sunspot numbers that are important in identifying the relationship, but the rate of change in the numbers. This is not apparent in the conventional graphs of the sunspot cycles where all numbers have positive values. The sunspot numbers in the alternating sunspot cycles were therefore given negative values, and an arbitrary graph origin of -200 was used for convenience in order to present all values as positive numbers. This is a requirement for statistical analyses where logarithms are employed (Alexander 2002b). These are graphical datum changes and do not affect the interpretations.

## Methodology

The emphasis was on simple arithmetical and graphical interpretations rather than mathematical interpretations. The reasons were that mathematical analyses such as harmonic and spectral analysis methods suppress the important, sudden changes that are present in hydrometeorological time series, and may also introduce oscillatory behaviour that is not present in the data.

Standard serial correlation analyses were sufficient to identify statistically significant serial dependence and/or cyclical behaviour should they be present. This procedure followed the standard time series analysis methods that require that the processes be identified graphically in the first instance, and only subsequently be described mathematically (Chatfield 1982). Additional information on the methodology developed for hydrological time series analyses, is detailed in Alexander (1994, 1995a, 1997).

## Trend analyses

Annual rainfalls recorded in the Weather Bureau's (now South African Weather Service) district rainfall database were studied (Weather Bureau 1972, updated annually). Conventional statistical trend analyses could not be performed in the presence of the large periodic variations in the data. However, simple arithmetical and graphical analyses demonstrated increases in rainfall in 75 of the 81 rainfall districts with complete records, totalling 9 % for South Africa as a whole for the 78-year period 1921 to 1999. Forty-two districts had increases of 10 % or more, 12 districts had increases of more than 20 %, and four districts had increases of more than 40 %. There was also an increase in the numbers of widespread, heavy rainfall events during the latter half of the past century (Alexander & Van Heerden 1991).

There were also increases in open water surface evaporation observed in 14 of the 19 accepted data sets studied. No trends were discernible in any of the other processes studied. If present, they were overwhelmed by the natural variability of these processes.

## Numerical comparison

The next aspect studied is illustrated in table 2, which lists the annual flows in the Vaal River at Vaal Dam as percentages of the mean annual runoff at the site. Vaal Dam is the major source of water for South Africa's largest metropolitan, industrial and mining region. This is the most analysed hydrological record in South Africa. The full period reversals (heavy horizontal lines) refer to the years when the sudden reversals from low flow sequences to high flow sequences occurred. These identified the commencement of the 21-year periods. Note that these are not exactly 21 years apart. The light horizontal lines identify the commencement of the mid-period reversals.

The reversals in the flows in the Vaal River from drought sequences to flood

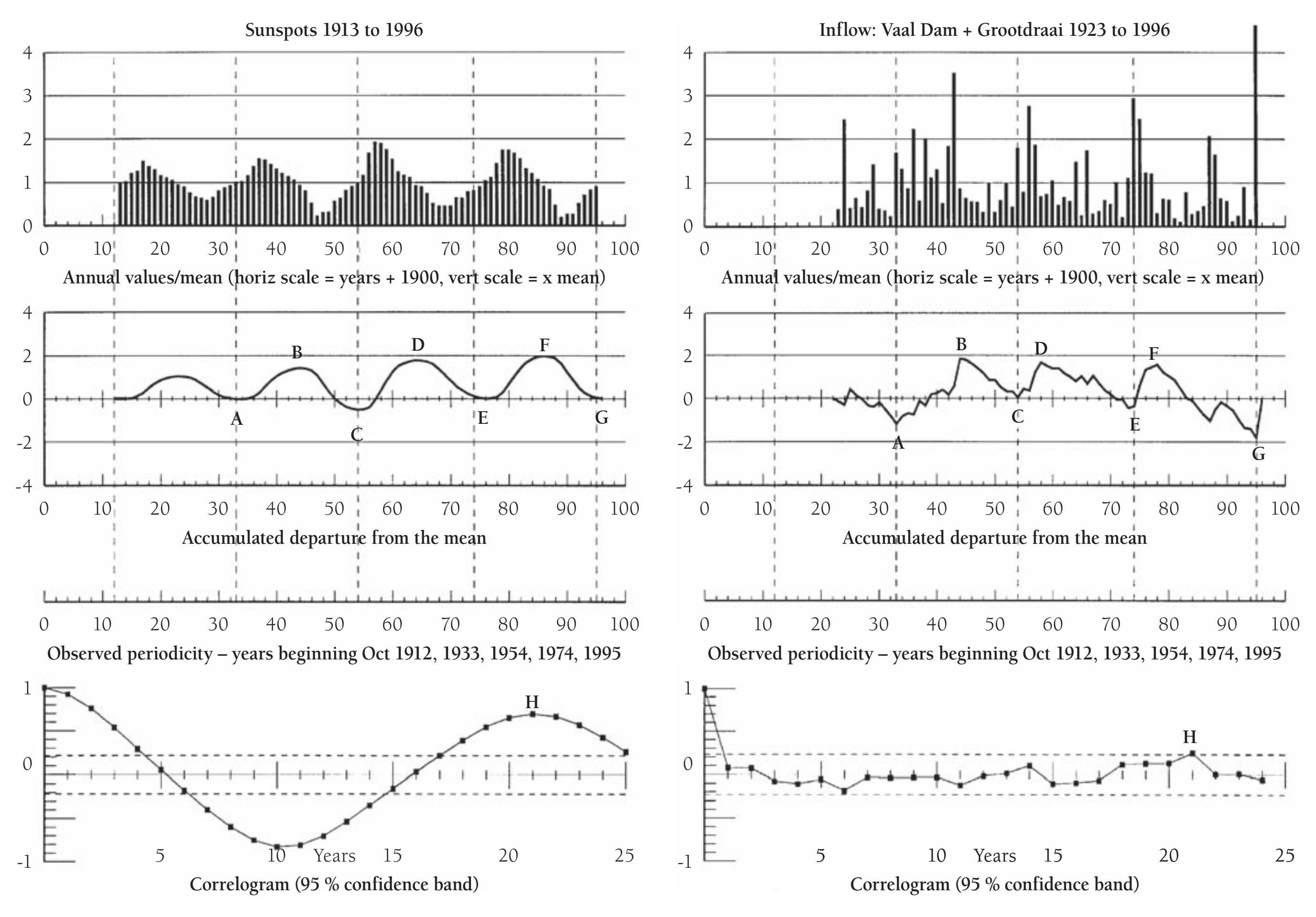


*Figure 1 Comparison of the characteristics of annual sunspot numbers with corresponding characteristics of the annual flows in the Vaal River*

*Table 3 Comparison of sudden changes in the annual flows in the Vaal River with corresponding sudden changes in sunspot numbers*

| Three-year totals of flows in Vaal River (% of record mean) | | | Three-year totals associated with the corresponding sunspot minimum | | |
|---|---|---|---|---|---|
| Minimum year | Three previous years | Three subsequent years | Sunspot minimum | Three lowest years | Three subsequent years |
| 1932/33 | 100 | 388 | 1933 | 25 | 250 |
| 1941/42 | 297 | 625 | 1944 | 56 | 277 |
| 1953/54 | 205 | 538 | 1954 | 50 | 370 |
| 1965/66 | 234 | 241 | 1964 | 53 | 247 |
| 1972/73 | 177 | 654 | 1975 | 73 | 275 |
| 1986/87 | 112 | 438 | 1986 | 60 | 400 |
| 1994/95 | 135 | 464+ | 1996 | 48 | 277 |
| Average | 180 | 478 | Average | 52 | 300 |

sequences evident in table 2 correspond closely with similar reversals in sunspot numbers. This is evident in table 3. In all but one sequence (Vaal River 1965/66, data not available), the three-year totals after the minima of both river flow and sunspot numbers, are substantially greater than the three-year totals before the minima. This information demonstrates the close association between major variations in river flow and corresponding variations in sunspot activity, with a high degree of confidence.

There are several interesting features in this table. There is an almost three-fold, sudden increase in the annual flows in the Vaal River from the three previous years to the three subsequent years. This is directly associated with a six-fold increase in sunspot numbers. The second important point is the consistency in the range of sunspot numbers before and after the reversal. The totals for the three prior years varied between 25 and 60, and the totals of the three immediately subsequent years varied between 250 and 400. It is very clear that these are systematic changes associated with the sunspot minima, and are not random events.

## Graphical comparison

The next issue is the nature of the solar-induced periodicity of the hydrometeorological processes. Figure 1 shows graphical comparisons of the properties of the double sunspot cycle with those of the Vaal River. This follows the method developed by Alexander (1978) and successfully used to predict the climate reversals from drought to flood sequences that occurred in 1995 and again in 2006 (Alexander 1995b, 2005c).

A reference datum value of –200 was used in the sunspot data in order to accommodate the negative values assigned to the alternate sequences. This has no effect on the interpretations as it only affects the position of the datum line but not the variability about that line. The top panels are the conventional dimensionless histograms, where all values are expressed as multiples of the record mean values. While the cyclicity is apparent in the sunspot panel, it is not recognisable in the river flow. The river flow histogram shows the high degree of asymmetry about the mean value with many more values less than the mean value than above it. This is typical of river flow data in dry climates.

The most informative graphs are those in the second panels, which show the accumulated departures from the record mean values. These are obtained by subtracting the mean values (1,0) from each of the values in the histogram. Some of the values

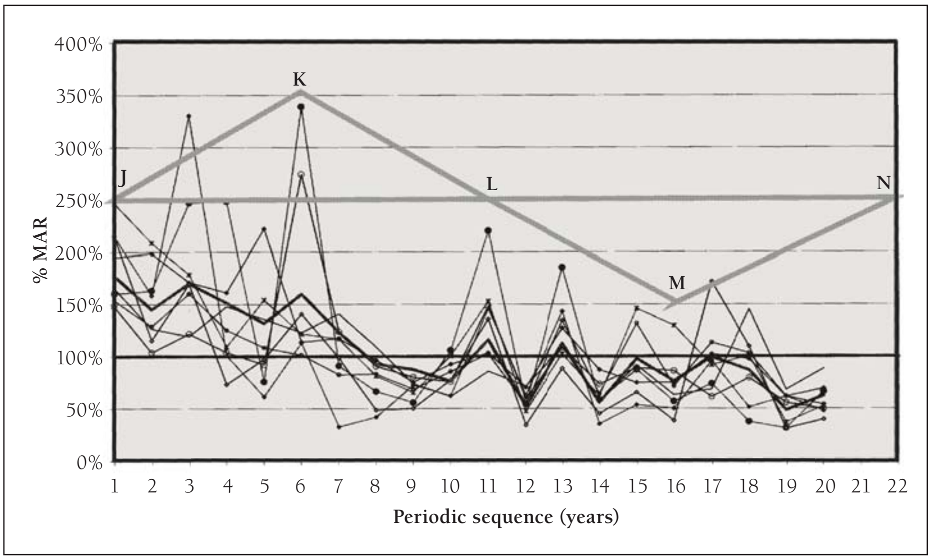


*Figure 2 Characteristics of the periodic sequences of river flow at representative dam sites. The double sunspot cycle is diagrammatically superimposed*

will be negative. These are accumulated one at a time and the sum plotted.

An increase in the accumulated departures of the sunspot numbers during the period of record is immediately apparent. The maximum negative departures occurred at the start of the 21-year periods, identified as A, C, E and G.

The comparison with that of the flow in the Vaal River is very instructive. The reversals at points A, C, E and G are virtually identical with the corresponding reversals in the sunspot data. They occurred during the hydrological years beginning October 1933, 1954, 1974 and 1995. The rising limbs A-B, C-D and E-F are sequences of years where the inflows were greater than the mean value. The falling limbs B-C, D-E, and F-G are sequences where the inflows were less than the mean value. These alternating sequences were reported in the early hydrological literature where they were referred to as the Joseph effect, after Joseph's biblical prophecy (Mandelbrot & Wallis 1968).

The third panels are the correlograms. This is a standard calculation procedure in time series analyses. The statistically significant cyclicity in the sunspot data is clearly apparent. The 95 % confidence limits are ± 0,22. The minimum and maximum (*H*) autocorrelation coefficients occur respectively at 10 (–0,83) and 21 (+0,70) years, which are well in excess of the 95 % confidence limits.

The statistically significant cyclicity in the sunspot data is no longer present in the correlogram of the annual flows in the Vaal River, where the residual coefficients indicate random noise. The only, but very important, residual serial correlation, is the statistically significant 21-year periodicity. This is identified at (*H*) in the bottom panel of the figure.

This relationship exists despite the long and complex energy path starting at the sun and ending in the river flow that enters Vaal Dam. The only residual energy is the potential energy, which is a function of the elevation of the water mass above sea-level. This residual energy has its origin in solar activity; followed by the arrival on the earth's atmosphere, continents and oceans; followed by the poleward movement of the energy through complex atmospheric and oceanic processes; followed by the systems that produce the rainfall; and finally by the complex rainfall-runoff processes. The survival of the periodic signals on its own demonstrates a strong and unequivocal relationship between variation in solar activity and the corresponding variation in climatic responses.

Note also the increase in sunspot activity during the last century, with some indication of a decrease E-F-G at the end of the century.

## Time interval of interest

In 1889 D E Hutchins (1889) published his book *Cycles of droughts and good seasons in South Africa*. It was based on records of three processes – rainfall, river flow and air temperature – and their linkage with sunspot activity. He described the sudden changes from drought to flood conditions.

Note how his study referred to a combination of eight conditions. These were global and multiyear, alternating, multi-process, sunspot linkage, abrupt changes, and the two hydrological extremes.

The key time unit of interest is not twelve months, but a sequence of 21 years. Furthermore, each of these sequences has two components, a good year sequence component followed by a drought sequence component. Together they constitute the time unit of interest. It is the numerical properties of the time unit of interest that have to be determined. Hutchins appreciated this more than 100 years ago.

## Predictability

Figure 2 is from Alexander 2005a. Without going into detail, it shows the properties of the time unit of interest and its association with the double sunspot cycle. It illustrates the nature of the periodicity in river flow at a number of representative sites in South Africa. The procedure used for each site was to extract the data in the first 20 years of each sequence starting in October of the following years: 1912, 1933, 1954, 1974 and 1995. Then the average values for each year of the sequence divided by the record mean annual runoff (MAR), were determined and plotted. The reference period used for calculating the MAR was that from 1954 to 1974 as it was the only period that was common to all data sets. The selection of a reference period does not affect the results. This procedure was repeated for the other sites. The rainfall and flood peaks exhibited similar characteristics, although the rainfall amplitudes were less and the flood peak amplitudes were greater than those of river flow. The diagrammatic double sunspot cycle J-K-L-M-N is included in the figure for ease of comparison.

While there is a large scatter in the plotted results, the general trend is clear and several conclusions can be drawn from it. Major flood events are associated with the first half of the first sunspot cycle (J-K). This is the sub-period when the rate of increase in sunspot numbers is greatest, and is associated with global atmospheric and oceanic turbulence at this time. This in turn generates the processes that produce heavy, widespread rainfall events that generate river flow.

The characteristics of the second of the two sunspot cycles (L-M-N) are very different from those of the first cycle (J-K-L). Fewer heavy rainfall events occur. Droughts become increasingly prevalent during this cycle. It is postulated that this is the consequence of the differences in solar activity between the two cycles as well as the lesser sunspot numbers.

There is also a clear, diminishing, annual oscillatory pattern during the beginning of the second sunspot cycle (L-M) that is not present in the greater scatter during the first cycle. No possible causes can be offered.

The first ten years of the sequence are associated with the first sunspot cycle J-K-L. These are Hutchins' good years and the last ten years L-M-N are his drought years.

## Characteristics of the periodicity

The regular grouping of alternate sequences of wet and dry years and its linkage with the 21-year (approximately) periodicity is beyond all doubt. The best description of the periodic behaviour is that provided by Hutchins (1889:25): 'The yellow line rising steeply to a maximum and then falling away gradually to a minimum is the sunspot curve – a curve which ought to be graven on the mind of every man and woman in South Africa.' There is no evidence of the sinusoidal oscillatory behaviour in the data.

An important characteristic is that the most extreme conditions occur at the beginning of the periods (floods) and at the end of the periods (droughts) with sudden revers-

***Table 4 Comparison of ranked maximum values with sunspot minima***

| Rank | South African rainfall | | Sunspot minima | |
|---|---|---|---|---|
| | Month | mm | Year | Lag (years) |
| 1 | Mar 1925 | 211 | 1923 | +2 |
| 2 | Jan 1974 | 149 | 1976 | -2 |
| 3 | Feb 1939 | 148 | 1933 | +6 |
| 4 | Feb 1988 | 145 | 1986 | +2 |
| 5 | Jan 1923 | 138 | 1923 | 0 |
| 6 | Jan 1976 | 136 | 1976 | 0 |
| 7 | Feb 1955 | 132 | 1954 | +1 |
| 8 | Jan 1958 | 130 | 1954 | +4 |

***Ranked flood peak maxima in the Mkomazi River***

| Rank | Flood maxima | | Sunspot minima | |
|---|---|---|---|---|
| | Year | $m^3/s$ | Year | Lag (years) |
| 1 | Mar 1856 | 7 000 | 1856 | 0 |
| 2 | Mar 1925 | 6 260 | 1923 | +2 |
| 3 | May 1959 | 6 200 | 1954 | +5 |
| 4 | ? 1868 | 6 130 | 1867 | +1 |
| 5 | Mar 1976 | 2 140 | 1974 | +2 |

***Table 5 Wet and dry sequences***

| Years | Wet/dry | Periodic sequence number | Length of sequence | | Reversals (Alexander) |
|---|---|---|---|---|---|
| | | | Wet | Dry | |
| Bredenkamp: Mzimgazi + St Lucia + Uitenhage + Wondergat | | | | | |
| 1919–1924 | Wet | 08 to 13 | 5 | | |
| 1925–1929 | Dry | 14 to 18 | | 4 | 1933 |
| 1930–1939 | Wet | –03 to 07 | 9 | | |
| 1941–1953 | Dry | 09 to 21 | | 12 | 1954 |
| 1955–1962 | Wet | 02 to 09 | 7 | | |
| 1965–1971 | Dry | 12 to 18 | | 6 | 1973 |
| 1972–1978 | Wet | –01 to 06 | 6 | | |
| 1980–1983 | Dry | 08 to 11 | | 3 | |
| 1984–1990 | Wet | 12 to 18 | 6 | | 1995 |
| Tyson: South African rainfall | | | | | |
| 1905–1915 | Dry | 14 to 04 | | 10 | 1912 |
| 1916–1924 | Wet | 05 to 13 | 8 | | |
| 1925–1932 | Dry | 14 to 21 | | 7 | 1933 |
| 1933–1943 | Wet | 01 to 11 | 10 | | |
| 1944–1952 | Dry | 12 to 20 | | 8 | 1954 |
| 1953–1961 | Wet | –01 to 08 | 8 | | |
| 1962–1970 | Dry | 09 to 17 | | 8 | 1973 |
| 1971–1980 | Wet | –02 to 08 | 9 | | |

als from droughts to floods that identify the beginning of the periods. Note that this information on the characteristics of the hydrometeorological data has been known for more than 100 years.

Analyses showed that the rainfall and river flow during the first half-period (first sunspot cycle) are appreciably higher than the second half-period. For example, for the first ten years of the period, the average of the maximum annual river flow values for all sites analysed was 675 % of the record mean values compared with the average of the following ten years of only 380 % of the record mean values. This is probably associated with the sign of the sun's magnetic polarity. Other analyses not reported here showed that the high values in the first half-period are the result of widespread, heavy rainfall events, while the low values in the second half-period are the consequence of the absence of these events.

Compare the lengths of the sequences of wet and dry years with the biblical seven years of plenty followed by seven years of famine. The ancient Egyptians were well aware of these alternating sequences in the annual flows of the life-giving Nile River.

This periodicity is very important for all those who maintain that global warming will result in increased variability in the hydrological process – specifically floods, droughts and water supplies. If they are to provide convincing arguments they will have to demonstrate (not postulate) how global warming will change the alternating wet and dry sequences; the associated periodic properties; and the drought and flood severities.

## Further confirmation

Further confirmation of the linkage between the rate of increase in sunspot numbers and rainfall over South Africa as a whole is shown in table 4, which shows the relationship between the months during which the maximum rainfall occurred and the corresponding years in which the sunspot minima occurred. The lag is the difference in years when the sunspot minima are used to predict the rainfall maxima. The lower panel is a repeat of the upper panel, using the flood peak maxima observed in the Mkomazi River, south of Durban.

The 1856 peak was concurrent with the flood peak in the Mgeni River, where floodwaters flowed across Durban and into Durban harbour. These floods occurred in March 1856. The maximum recorded flood engraved on the buttress of the Georges V Bridge built in 1760 across the Loire River in Orléans, France, occurred in June 1856. The sunspot minimum occurred in December 1855 (World Data Centre for the Sunspot Index 2005). This correspondence in time (months) and space (hemispheres apart) is far too great to be coincidental.

Six of the eight rainfall events and four of the five flood peak maxima occurred within two years of the sunspot minima. This confirms that these extreme events are sensibly synchronous with the reversals in sunspot numbers associated with the sunspot minima, as shown in table 3.

It is also important to note that these maxima were recorded 80 years ago (rainfall) and 149 years ago (Mkomazi floods) and that there is no evidence of an increase in time that could be associated with global warming. Historical observations in several other rivers confirm that the floods in the mid-1800s remain the highest on record.

## Alternating wet and dry sequences – Tyson and Bredenkamp

Table 5 shows the alternating wet and dry sequences in South African hydrom-

***Table 6 Sequence numbers of 40 world maximum floods***

| Sequence number | Number of floods | Sequence number | Number of floods |
|---|---|---|---|
| 1 | 4 | 11 | 2 |
| 2 | 2 | 12 | - |
| 3 | 1 | 13 | 1 |
| 4 | - | 14 | 2 |
| 5 | 3 | 15 | 3 |
| 6 | 6 | 16 | - |
| 7 | 2 | 17 | 1 |
| 8 | 1 | 18 | 1 |
| 9 | 2 | 19 | - |
| 10 | 3 | 20 | 4 |
|  |  | 21 | 2 |
| Total | 24 | Total | 16 |

eteorological data. The following conclusions can be drawn from the independent observations by Tyson and Bredenkamp. Each author used different data and different analytical methodologies. Bredenkamp analysed lake and groundwater levels while Tyson studied areal rainfall over South Africa.

Tyson (1987) provided evidence supporting the presence of alternating sequences of years with high and low rainfall over large regions of South Africa. He noted the oscillatory nature of the data, although he was unable to trace its cause. He concluded that its physical reality was considerable in South Africa and in other countries. He noted that the 11-year solar cycle was mentioned in the literature but did not discuss it further.

Bredenkamp (2000) studied groundwater resources. He used the cumulative departure method as his principal tool, for which he developed a mathematical relationship. He demonstrated the presence of wet and dry sequences from 1919 through to 1992 based on water level observations at Lake Mzingazi; discharge from the Uitenhage springs corrected for abstractions; water levels at Lake St Lucia; and groundwater levels at the Wondergat sinkhole in a large dolomitic formation. These all have high storage/input ratios that smooth out the short-term fluctuations.

Begin with the right-hand column of the table. This shows the years in which the 21-year reversals occurred based on studies by Alexander. The fourth and fifth columns show the alternating wet and dry sequences. Note how the periods between the reversals each consist of a wet sequence followed by a dry sequence. This confirms the pattern observed in other hydrometeorological data.

There is also a good correspondence between the dates in the first column of the two panels, as well as between the first and last columns in both panels, considering the different data sets and methodologies used by the two authors. These are well within the range of achievable accuracy in most hydrometeorological estimates.

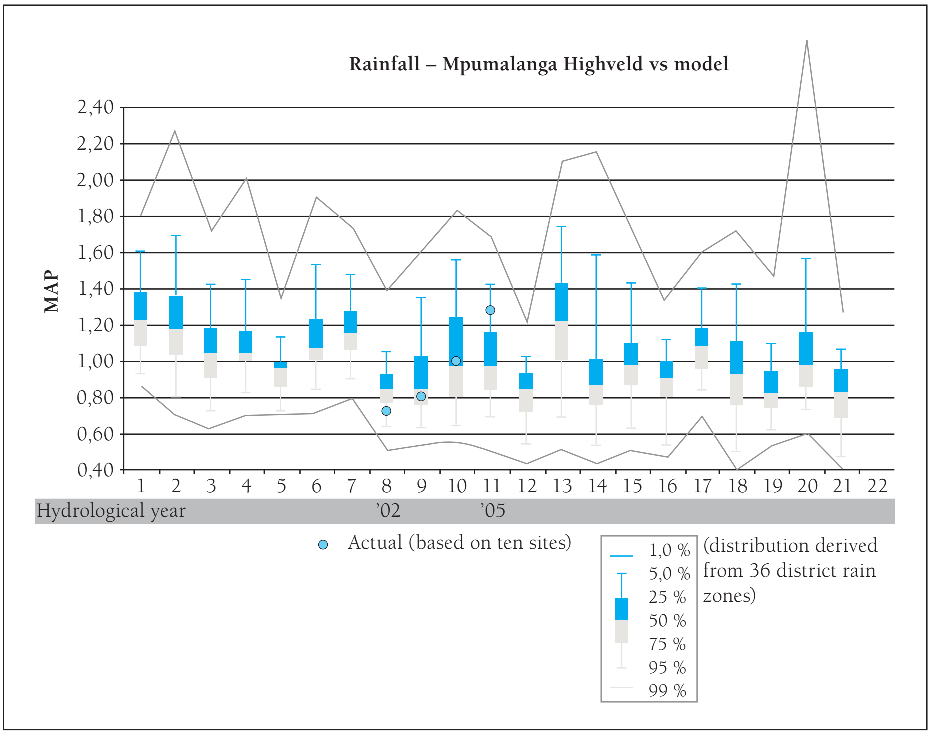


***Figure 3 Validation of the Alexander climate prediction model based on regional rainfall in the Highveld region***

## Flood alerts

In November 2005, during the then drought, Alexander (2005c) issued the first of four flood alerts based on the model. They included details of action that local authorities should take to limit the potential loss of life in informal settlements.

Three months later large regions of the African subcontinent were wetter and greener than at any time in human memory. Floods occurred in many rivers from Angola in the north through to the coastal rivers of the southern Cape. Dams filled over most of the region. The loss of life was minimal thanks to the emergency services in the areas. These observations are further confirmation of the validity of the prediction model.

## World maximum floods

In 1984 the International Association of Hydrological Sciences (IAHS) published a *World Catalogue of Maximum Observed Floods* (Rodier & Roche 1984) as a contribution to the International Hydrological Programme of UNESCO (the United Nations Educational, Scientific and Cultural Organisation). The 40 largest recorded floods in the world between 1900 and 1982 from the catalogue were listed on this basis. Twenty-four of them occurred during the first of the two sunspot cycles that made up the double sunspot cycle, while 16 occurred during the second cycle. This analysis of world maxima supports the hypothesis that the linkage with the double sunspot cycle is a global phenomenon.

Table 6 shows the sequence numbers during the time units of interest of the world's 40 maximum floods. Compare this with the information in figure 2 where the sequence numbers are identified.

There is a wealth of information worldwide on these alternating sequences and their linkage with the double sunspot cycle.

## Mathematical modelling

The final stage was the development of a mathematical simulation model for water resource development and management applications that accommodates the characteristics described in this report. The mathematical simulations were based on the readily quantifiable periodicity of the hydrological data. There was no need to invoke linkages with solar activity. Nor was it necessary to include the postulated adverse consequences of global warming, such as increases in floods and droughts and threats to water supplies. The methodology is described in Alexander 1994 and 1997.

## Development of the climate prediction model

> Very great advantages in the management and practical utilisation of our water resources would follow if a measure of reliability could be achieved in the long-term forecasting of climatological conditions … The Commission regards it as essential that research and attempts to acquire the necessary data to make long-term weather forecasting possible be actively supported (Commission of Enquiry into Water Matters 1970:7).

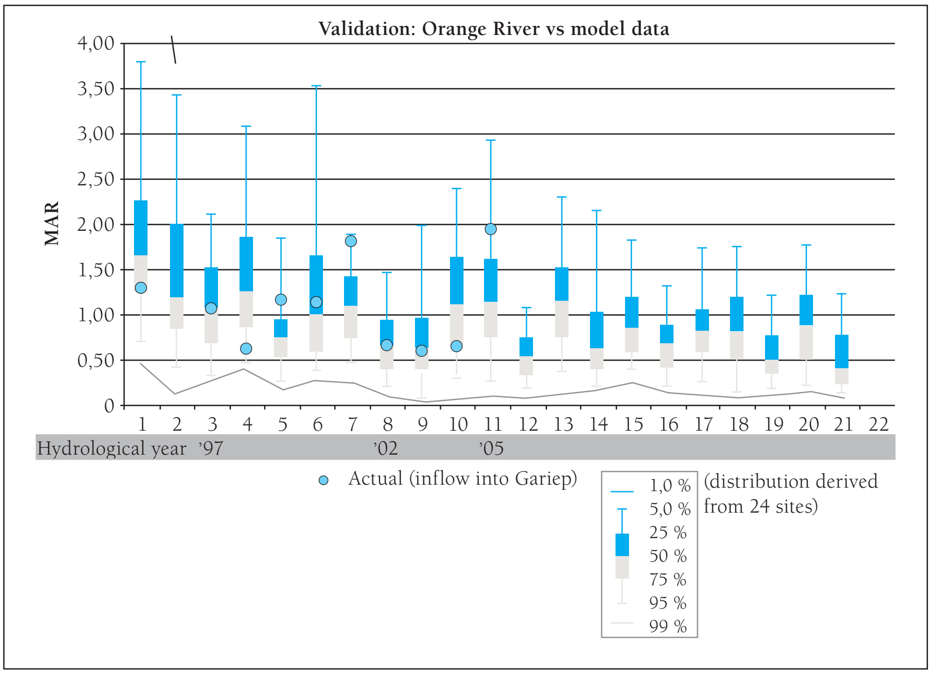


*Figure 4 Validation of the Alexander climate prediction model based on Orange River flow data*

The prediction model is based on the statistically significant (and therefore predictable) 21-year periodicity in South African hydrometeorological data. Verification is an essential process in any prediction model. The model has to pass this test before it can be used with confidence. Alexander's climate prediction model was published in *Water SA* in April 2005 (Alexander 2005a). It has now been tested and verified and can be applied in practice for multiyear regional rainfall and river flow analyses and predictions. In particular it can be used with greater assurance than current methods for multiyear simulations required for water resource development and management.

## VERIFICATION OF THE CLIMATE PREDICTION MODEL (VAN DER MERWE)

An Excel program was developed to implement the model and tested on a number of occasions. The following is an example of the verification of the model following the first complete hydrological year after its publication.

Figure 3 is the annual rainfall for the Highveld region where the interest is in the availability of water for cooling at the coal-fired power stations. Figure 4 is the annual river flow in the Orange River where the interest was in hydropower generation at the Gariep and Van der Kloof dams. These are both important practical applications on an issue of national importance.

The figures shows box and whisker probability plots derived directly from recorded data within the regions of interest. The outer thin lines show the observed maximum and minimum values. Current simulation models used for water resource analyses assume that all the boxes are in the same vertical position, that is, there is no year-to-year variability in the probability distributions.

The model is based on the observed 21-year periodicity in the data. Although not included in the model, the synchronous linkage with sunspot activity is beyond all doubt. Note also the increase in rainfall relative to the mean values during the past four years 8 to 11 in the figures. Similar increases occurred in the river flows in the Western Cape. Note further that the observed annual rainfall and river flows during the past years were nowhere near the historical maxima and minima.

Most importantly, refer to figures 2, 3 and 4 and note that with the exception of year 13 (rainfall and river flow) and year 17 (rainfall only) the mean values of the predictions for the next ten years are all less than the long-term mean annual runoff (MAR). The predictions for the present hydrological year (2006/07) are below average rainfall and river flow. The next climate reversal from drought to flood conditions based on the analysis of historical data is only expected to occur in 2016. This confirms the linkage with the double sunspot cycle.

The next ten years will be critical for water resource development and operation. This has nothing whatsoever to do with global warming.

## LAKE VICTORIA AND A RENEWED SOLAR CORRECTION (MASON)

The level of Lake Victoria has been carefully monitored by international survey teams since 1896, as have its outflows into the Nile river system. In the 1950s the relationship between the lake level and the Nile discharges, controlled by the Ripon falls, was established in the form of an 'agreed curve'. After the commissioning of the Owen Falls dam and power station in 1954, at Jinja on the mouth of the Main Nile, flows through the power station were maintained on a ten-day rolling basis so as to match the flows which would have occurred, had the Ripon Falls still been the control. Thus, in effect, the natural Nile outflows were maintained in an unbroken form up until June 2000. This requirement was enshrined in the Nile Waters Agreement. In June 2000 the new Kiira power station was commissioned in parallel to the original station and subsequent extractions then exceeded the 'natural' ones.

The massive Lake Victoria is situated on the equator. Kite (1982) established that 80 % of the lake's water balance comprised rainfall and evaporation with only 20 % due to tributary inflows and Nile outflows. In the period up to the 1960s the lake level oscillated about a Jinja gauge level of approximately +11 m. The 'agreed curve' flows corresponding to this were used to size the original power station and its installed capacity of 150 MW. However, in the early 1960s a dramatic rainfall increase over central and east Africa raised the lake to unprecedented levels. To meet 'agreement' requirements from the 1960s onwards, the sluice gates at the dam had to discharge excess water, beyond those which could be used for generation. The rainfall event and the climate anomaly it produced have been thoroughly reported by Lamb (1966). Since the 1960s the lake would appear to have been dropping with an overall mean trend of 29 mm/yr.

In the 1920s it was noted that the level of Lake Victoria seemed to respond to patterns of solar variation in the form of the sunspot number index. The correlation disappeared after the 1920s and when the matter was later reviewed by Hurst (1952), he found no statistical correlation for the complete record and concluded that the apparent correlation up until the 1920s had been a coincidence.

The issue was re-examined by the present writer (Mason 1993, 1998, 2006). When the falling trend of 29 mm/yr is removed, it would appear that the solar index correlation has been re-established since 1968 (see figures 5a and 5b). Coupled with the earlier period to 1928, this implies that the correlation covers two-thirds of the gauged record. The two periods of correlation also correspond to periods of high volcanic dust (Lamb 1970, 1977, 1983).

The reasons for a possible volcanic dust link are not clear, although there has been speculation in recent years on the way in which radiation may affect dust, aerosols and water vapour in the atmosphere to affect climate (Lockwood *et al* 1999). A discussion of such linkages is beyond the scope of this paper, however, it is hoped that the apparent Lake Victoria example may provide useful data for those working in that field.

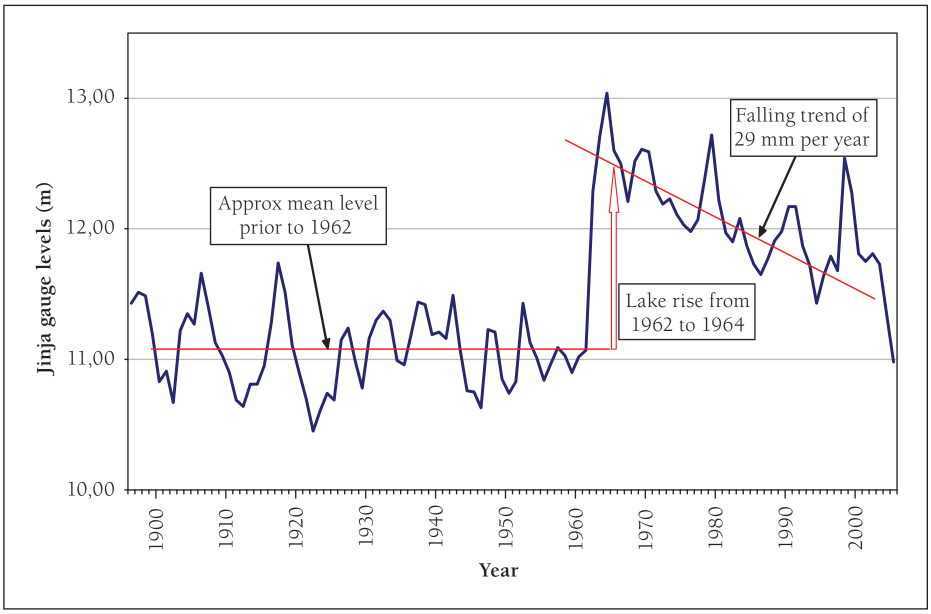


*Figure 5a Levels of Lake Victoria from 1896 to 2005*

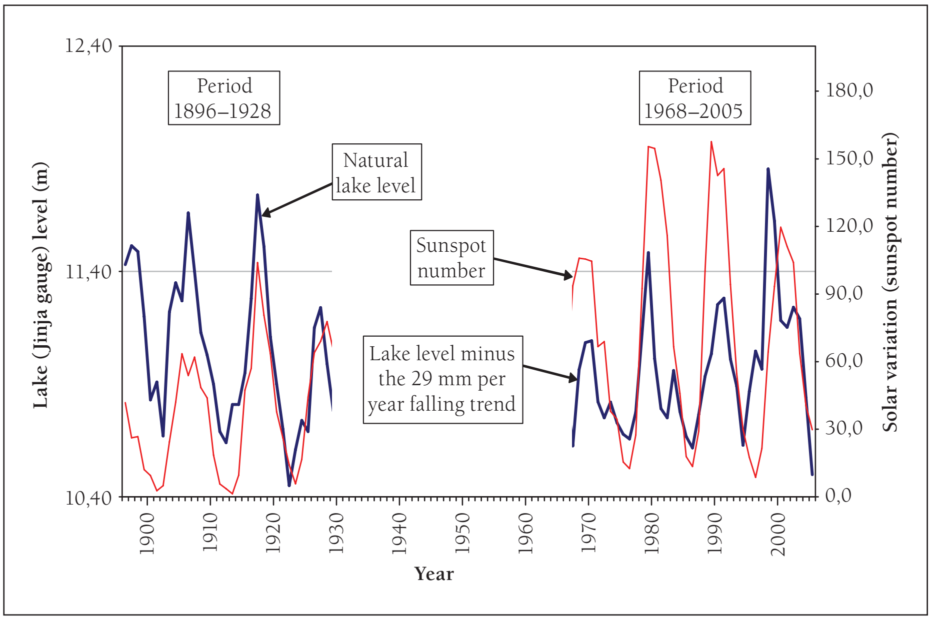


*Figure 5b Levels of Lake Victoria from 1896 to 1928 and from 1968 to 2005 compared to solar variation in the form of sunspot number indices, but with the 29 mm per year falling trend in lake level eliminated from the 1968 to 2005 data*

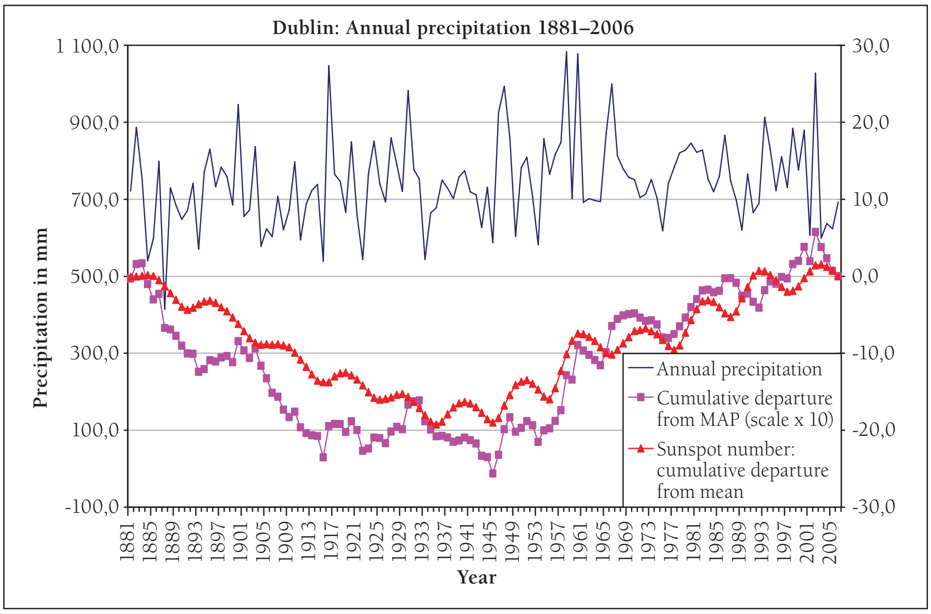


*Figure 6 Comparison between annual rainfall recorded in Dublin, Republic of Ireland, and annual sunspot numbers*

In particular it would seem useful to explore whether or not the correlations with the sunspot index could be improved still further using other variable solar parameters.

If past trends continue, some respite may occur after 2006, until the next low is reached on or around 2016. It remains unclear if the present correlation will continue. However, the present writer believes the matter warrants a wider awareness and further investigation. Even if the assumption of continued correlation is used as just one possible planning scenario, the potential benefits for planned lake usage and for assessing future aid and famine relief requirements in areas affected by the Nile system would seem clear.

## IRELAND (WILLEMSE)

Willemse studied the relationship between annual rainfall and sunspot numbers for several meteorological stations in the Republic of Ireland. These included Dublin, Malin Head (most northern point of the island), Valentia (south-west coast) and Birr (midlands). The data for Dublin date back to 1881 (more than 46 000 data sets), but the other data sets were a lot shorter.

Figure 6 is the comparison for Dublin. Other analyses not reported here included the wet and dry seasonal rainfall periods separately in an attempt to identify any difference in the wet/dry cycle.

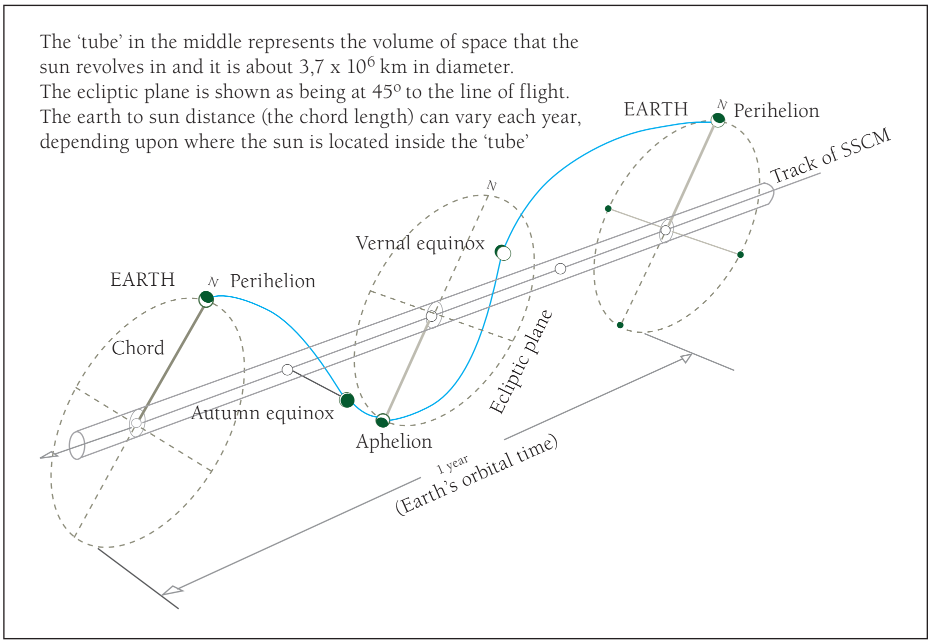
The cusp shape of the cumulative departure plots indicates that both the accumulated totals of sunspot numbers and annual rainfall were increasing synchronously with time. It is particularly interesting to note the close correlation between the sunspot numbers and rainfall from about 1940 onwards. This corresponds with an increase in sunspot activity during the latter half of the last century (see figure 1).

## CAUSES OF PERIODICITY IN SOLAR ACTIVITY (BAILEY)

The synchronous linkages between sunspot activity and the hydrometeorological processes are demonstrated earlier in this paper. Bailey identified the processes within the solar system that are responsible for sunspot activity. His studies require the visualisation of four-dimensional, time-space acceleration and deceleration of the sun, and consequent changes in the distance between the earth and the sun, as they move in an oblique plane through galactic space.

### The earth's spiral path

Conventional illustrations show the earth orbiting around a static sun. This is misleading. First, the sun wobbles through a tube of space and not along a smooth path at a constant velocity. Second, the earth orbits



The 'tube' in the middle represents the volume of space that the sun revolves in and it is about 3,7 x $10^6$ km in diameter.
The ecliptic plane is shown as being at 45° to the line of flight.
The earth to sun distance (the chord length) can vary each year, depending upon where the sun is located inside the 'tube'

*Figure 7 Earth's orbital path through the galaxy*

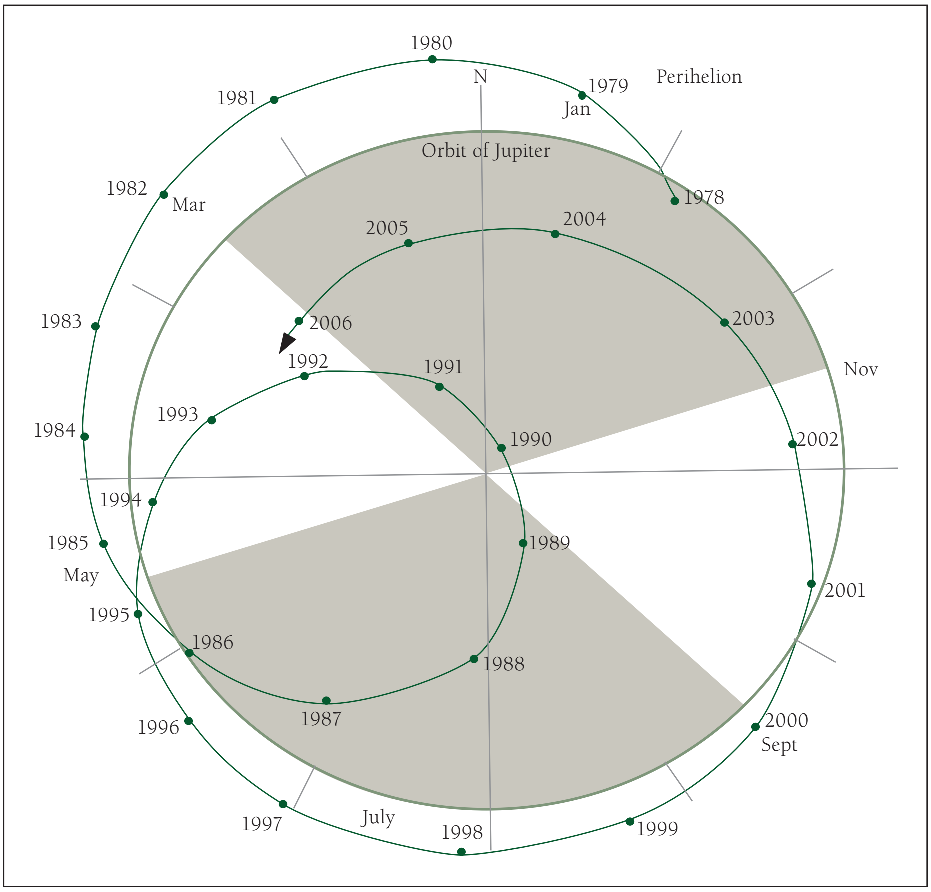


*Figure 8 The orbit of the centre of mass of the four major planets about the SSCM from 1978 to 2006. The movement is towards the viewer*

the solar system's centre of mass (SSCM) and not the sun's centre of mass. The earth therefore follows a spiral path as it moves through space. This is illustrated in figure 7. (It is important to note that the scales in the figures are highly compressed so that they can fit.)

The tube in the middle represents the volume of space that the sun revolves in and is about $3,7\ 10^6$ km in diameter. The ecliptic plane is at a 45° angle to the line of movement. The earth to sun distance (the chord length) varies, depending on where the sun is located in the tube. While the paths of the sun and the earth are closely linked as they move through space, the changing relative positions result in corresponding changes in the distance between them.

## Influence of the planets

Figure 8 shows the path of the combined centre of mass of the four major planets, Jupiter, Saturn, Uranus and Neptune, relative to the SSCM for the period 1978–2006. Visualise the three-dimensional view of this figure with the orbit path spiralling towards the viewer.

Starting in 1978, the orbit maintains a nearly constant distance from the SSCM. In 1985 the orbit starts moving closer to the central point occupied by the SSCM. It swings around the SSCM, reaching its closest position in 1990. It then spirals away from the SSCM until 1994. From 1995 through to 2000 there is little change in the displacement from the SSCM. From 2001 through to 2006 it makes another approach to the SSCM.

The sun follows a weighted reciprocal path but its centre of mass is much closer to the SSCM. It also accelerates and decelerates synchronously but moves in the opposite direction in order to maintain the system in equilibrium.

The sunspot minima occurred in 1986, 1996 and 2006. The compass points on the figure are for reference purposes only. Note that the sunspot minima of 1986 and 1996 both occurred in the SW quadrant of the figure, and that of 2006 in the NW quadrant when viewed from a position ahead of the approaching solar system. This is in an anticlockwise direction relative to the forward clockwise movement of the spiral paths about the SSCM followed by the orbiting components of the solar system. The angular distance followed by the orbit from 1986 to 1996 was 360° when it returned to the same quadrant. It was only 270° from 1996 to 2006 when it did not complete a full 360° rotation around the SSCM. The angles are approximate but are amenable to calculation.

Table 7 shows the positions of the planetary system's centre of mass (PCM) at the time of the sunspot minima during the period 1902–2006.

The information in this table provides the first positive linkage between solar activity and the hydrometeorological time series. Alexander's analyses showed a statistically significant linkage with the double sunspot cycle. He found no statistically significant linkage with the single, 11-year cycle. His analyses showed that these alternating cycles are associated with different hydrometeorological characteristics.

The periodic behaviour of the solar system has a duration of 21 years (actually 20,8 years during the past century), not 11 years. (Note the sums of the pairs in the last column of table 6.) This explains why scientists have been unable to find a linkage with the 11-year cycle, from which they erroneously concluded that there is no linkage with solar activity. While the relative positions of the planets are closely grouped in space at 21-year intervals, they are not precise in either time or space. This is the reason for longer period cyclicity including 178 years and longer cycles.

*Table 7 Angular shift in the position of the planetary centre of mass at the time of sunspot minima for the period 1902–2006*

| Cycle number | Cycle period | PCM quadrant | Rotation angle (approx) | Cycle length (years) |
|---|---|---|---|---|
| 14 | 1902–1913 | SW | 360 | 11 |
| 15 | 1913–1923 | SW | 270 | 10 |
| 16 | 1923–1934 | NW | 360 | 11 |
| 17 | 1934–1944 | NW | 270 | 10 |
| 18 | 1944–1954 | NE | 360 | 10 |
| 19 | 1954–1965 | NE | 270 | 11 |
| 20 | 1965–1975 | SE | 360 | 10 |
| 21 | 1975–1986 | SE | 270 | 11 |
| 22 | 1986–1996 | SW | 360 | 10 |
| 23 | 1996–2006 | SW | 270 | 10 |

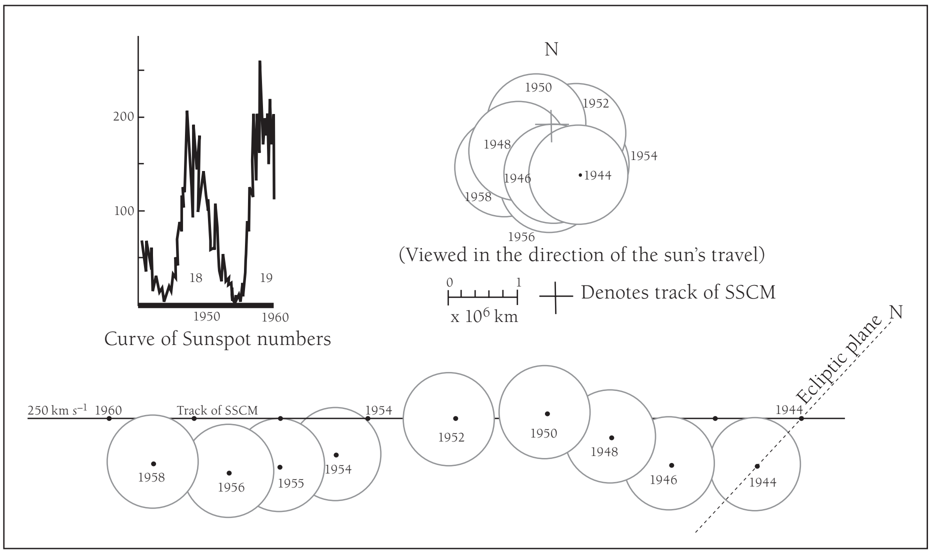


*Figure 9 The location of the sun's centre of mass relative to that of the SSCM from 1944 to 1958*

## Sunspot production

The plane of the path of the orbiting planets and the sun must be at 45° to the line of motion of the solar system. This is in order to balance the gravitational forces of a three-dimensionally balanced group of objects travelling at constant forward speed relative to that of the SSCM. Each body in the solar system will follow a three-dimensional spiral track around the SSCM thus maintaining the group's constant forward speed. This path will also be influenced by the changing positions of the major planets relative to one another and the sun's reciprocal movement.

All bodies of the solar system therefore have a combination of two velocities. The dominant velocity component is the constant galactic velocity that is followed by the SSCM. The orbital velocities of the individual bodies around the SSCM are superimposed on the galactic velocity. As they orbit the SSCM their net forward velocity will be the galactic velocity plus the orbital velocity (corrected for the 45° slope of the solar orbits) as they move forward in their orbits around the SSCM, and the galactic velocity minus the orbital velocity as they move backwards in their orbits around the SSCM.

The net result is that the galactic velocities equal that of the SSCM when the bodies directly trail or lie directly ahead of the SSCM. The galactic velocities increase as they move forward around the SSCM, and they decrease as they move backwards about the SSCM. The galactic velocity of each body in the solar system, including the sun, therefore alternately accelerates and decelerates within the galactic plane as it orbits the SSCM. This is the crux of the issue. Once it is appreciated that the reference system is the galactic plane and not the plane of the solar system, then everything else falls into place.

Sunspot production is a direct function of the sun's galactic acceleration and deceleration, with sunspot minima occurring when the sun is directly ahead or trailing the SSCM. There can be no doubt that it is the influence of the changing relative positions of the major planets that is the direct cause of sunspot activity. The actual mechanism for sunspot production as a result of galactic velocity changes has yet to be determined, although several theories exist.

Alexander's studies of the hydrometeorological data indicate the presence of an instability phenomenon associated with the predictable, sudden climatic reversals from drought to widespread rainfall conditions. These are closely synchronous with the sunspot minima. It is not yet clear whether this instability is associated with solar processes or with the responding climatic processes.

## VARIATIONS IN SOLAR IRRADIANCE

### The sun's wobble

The distance of the sun from the SSCM is the weighted reciprocal of the distance of the combined centre of mass of the orbiting planets. Consequently, both the sun's distance from the SSCM and its galactic velocity are continually changing. This creates a wobble in its path through space. This can be calculated given the knowledge of the masses and orbits of the four major planets.

Astronomers make use of the wobbles in the trajectories of distant stars to determine whether or not they are accompanied by orbiting objects. Figure 9 shows the sun's wobble as it moved through galactic space during the period 1944 to 1958. During most of this time its orbit was below that of the SSCM in this view. While the SSCM lies within the body of the sun most of the time, there are occasions when the sun wobbles outside the SSCM. This figure provides an indication of the extent of its wobble as the sun moves through space.

### Earth to sun chord distance

As a result of the sun's wobble, the chord length between the earth and the sun and the amount of energy received by the earth will change accordingly. The next exercise is therefore to determine the corresponding changes in the distance between the earth and the sun and thereby the changes in the rate of solar energy reaching the earth. This is amenable to precise calculation.

The calculation of the chord length between the earth and the sun at any particular time has two components. The first is the position of the sun relative to the SSCM at that time. The second is the elliptical path of the earth about the SSCM.

The sun's displacement from the SSCM changes relatively slowly but the ecliptic direction of the earth about the sun changes with the seasons. Figure 10 shows the displacement of the position of the sun from the SSCM during 1993 and its effect on variations in solar energy received on earth during that year.

The Intergovernmental Panel on Climate Change (IPCC) (2001) dismisses the view that solar activity has a meaningful influence on global climate. The basis for this view is that variations in the receipt of solar

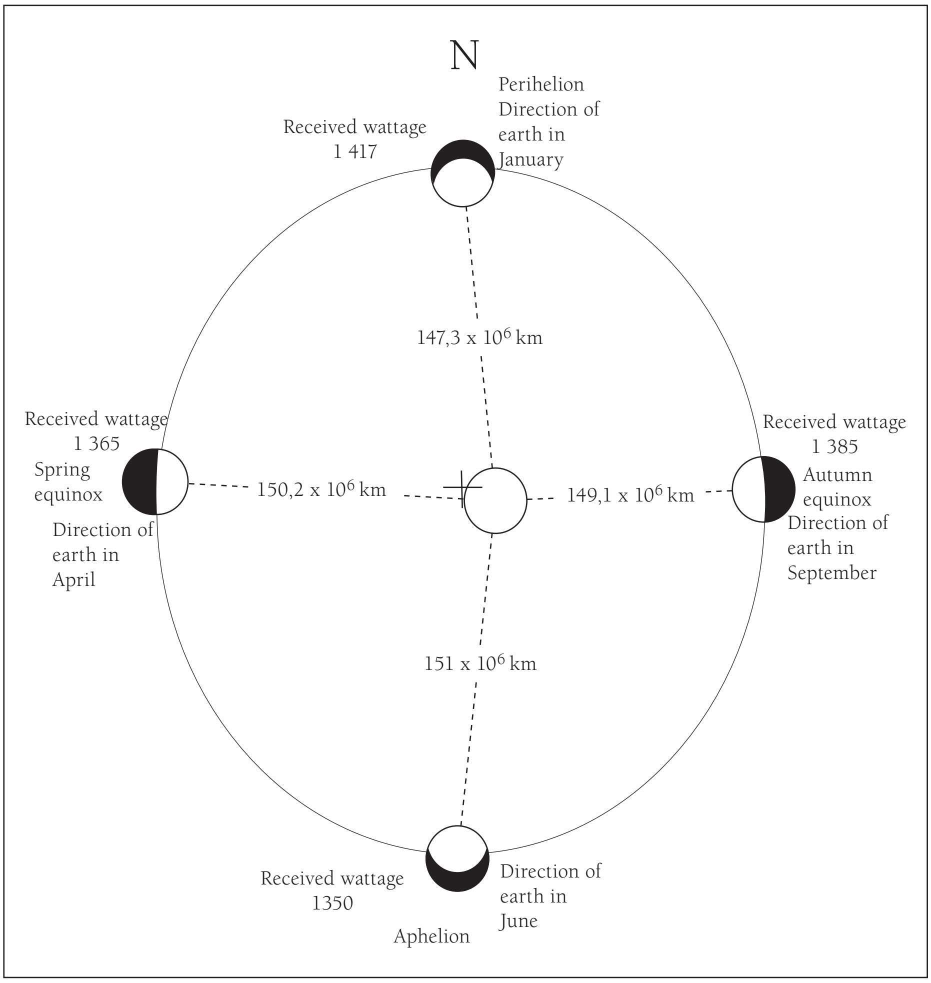


***Figure 10 Received wattages per square metre for the year 1993, based on the calculated 0,63 $10^6$ km solar displacement from the SSCM***

activity are too small to account for variations in the climatic responses. These variations were determined from satellite and other observations. What the IPCC scientists failed to appreciate is that changes in the level of solar radiation received on earth are amenable to precise calculation. The variations are well in excess of the IPCC value of $+0{,}3\ \mathrm{Wm}^{-2}$ quoted earlier.

Although the chord length is of paramount importance on a month-by-month or year-by-year basis, whereby the actual wattage received by the earth can be determined, it does not compare with the accumulative effect of high or low wattages in a given direction on the ecliptic plane, which determines the type of weather that certain parts of the globe will experience for a given 21-year period.

The cold periods that were experienced by the northern hemisphere in the 1400s, 1600s and 1800s would have been counterbalanced by opposing hot spells in the southern hemisphere. This is because of the reciprocal effect of the changes in chord length.

Probably the most important shortcoming in current climate change science is the failure to appreciate that variations in received solar energy are amenable to precise calculations, instead of attempting to derive these changes from observations from orbiting satellites and other sources that are incomplete in both space and time. Furthermore, the calculated wattage changes are appreciably greater than those derived from the sources quoted in the literature.

As can be seen in figure 8, these changes are not regular in time. They were relatively unchanged from 1979 to 1985, and again from 1995 to 2000. They changed rapidly from 1986 through to 1994, when they closely orbited the SSCM.

## CONCLUSIONS

### Transparency and reproducibility

This paper is a brief summary of the results of our studies. Alexander's studies are described in his comprehensive, 474-page technical report entitled *Climate change and its consequences – an African perspective* (Alexander 2006). It includes 51 tables, 33 figures and 218 references. The data used in the report were obtained from readily available records published by the responsible national authorities. The report is available on CD.

Bailey's studies are detailed in his 88-page book *The sunspot mystery – who is listening?* (Bailey 2006). It includes 23 detailed figures. His calculations are based on well-established theoretical physics and mathematical analyses. The other authors have also undertaken extensive studies on this subject.

We believe that our combined studies have made a major contribution to the advancement of international science in this field. Our findings are reproducible by anybody with sufficient knowledge in these fields.

### Uncertainties

A study of the literature shows that there are still large uncertainties in three related issues. These are the following:

- The physical causes of the regular sunspot activity
- Reasons for the different climatic responses to the alternating sunspot cycles
- The mechanisms that link changes in sunspot activity with corresponding changes in climate

We believe that we have thrown light on answers to the first two questions and that he outstanding uncertainties relating to causal linkages do not invalidate the results of the fundamental studies described in this paper.

### Recommendations

It is extremely important that all those involved with water resource studies should appreciate that there are fundamental flaws in current global climate models used for climate change applications. These models fail to accommodate the statistically significant, multiyear periodicity in the rainfall and river flow data observed and reported by South African scientists and engineers for more than the past 100 years. They also failed to predict the recent climate reversals based on Alexander's model (Alexander 1995b, 2005a). The global climate model outputs can therefore not be used for adaptation studies.

All those who have a genuine interest in the prosperity of our country and the welfare of its peoples are urged to assist in the development of joint strategies to optimise future water resource development and management.

Those who have expressed concerns regarding the environmental consequences associated with water resource development should appreciate that the provision of water to meet rising demands is essential for the prosperity of any nation. South Africa does not have the luxury of abundant water supplies. The provision of water and conservation of the water environment are non-commensurate objectives in that one cannot be met without sacrificing the other. Reasoned compromises will have to be made. This can only happen if all parties have a sound knowledge of the multiyear properties of rainfall and river flow. It is hoped that the information in this paper will go a long way towards meeting this requirement.

## REFERENCES

Alexander, W J R1978. *Long range prediction of river flow – a preliminary assessment*. Technical Report TR80. Pretoria: Department of Water Affairs.

Alexander, W J R and Van Heerden, J 1991. *Determination of the risk of widespread interruption of communications due to floods*. Report of the Department of Transport Research, Project No RDAC 90/16.

Alexander, W J R 1994. Alexander, Anomalies in the stochastic properties of river flow and their effect on reservoir yield. In Jan-Tai Kuo and Ko-Fei Liu (eds), *Proceedings* of the Republic of China – South Africa Bilateral Symposium on Water Resources, Taipei.

Alexander, W J R 1995a. Detection of climate change. In *Proceedings* of the IGBP Conference on Global Environmental Change – Implications for Southern Africa. Pretoria.

Alexander, W J R 1995b. Floods, droughts and climate change. *South African Journal of Science,* 91:403-408.

Alexander, W J R 1997. Predictability of widespread, severe droughts, and their effect on water resource management. In *Proceedings* of the 5th International Conference on Southern Hemisphere Meteorology and Oceanography. Pretoria. (Invited guest presentation.)

Alexander, W J R 2002a. Climate change – the missing links. *Science in Africa*, September 2002.

Alexander, W J R 2002b. Statistical analysis of extreme floods. *Journal of the South African Institution of Civil Engineering,* 44(1):20–25.

Alexander, W J R 2004. Climate change – there is no need for concern. *Science in Africa*, April. Available at http://www.scienceinafrica.co.za/2004/april/climate.htm.

Alexander, W J R 2005a. Development of a multi-year climate prediction model. *Water SA*, 31(2). Available at http://www.wrc.org.za/downloads/watersa/205/Apr-05/1788.pdf.

Alexander, W J R 2005b. Linkages between solar activity and climatic responses. *Energy & Environment*, 16(2).

Alexander, W J R 2005c. Flood alert. Issued in November 2005.

Alexander, W J R 2006. *Climate change and its consequences – an African perspective*. Technical report (available on CD).

Bailey, F 2006. *The sunspot mystery – who is listening?* Plymouth, Devon: Frederick Bailey (ISBN 978-0-9551202-1-3).

Bredenkamp, D B 2000. *Groundwater monitoring: a critical evaluation of groundwater monitoring in water resources evaluation and management*. Water Research Commission Report No 838/1/00.

Chatfield, C 1982. *The analysis of time series.* London/New York: Chapman and Hall.

Commission of Enquiry into Water Matters 1970. RP 34/1970. Pretoria: Government Printer.

*Government Gazette* 1966. No 1480 of 1 July. Pretoria: Government Printer.

Hurst, H E 1951. Long-term storage capacity of reservoirs. *Transactions of the American Society of Civil Engineers*, Paper 2447.

Hurst, H E 1952. *The Nile*. London: Constable.

Hurst, H E 1954. Measurement and utilisation of the water resources of the Nile Basin. *Proceedings of the Institution of Civil Engineers*, volume 3, part III, pp 1–26, April 1954: discussions pp 26–30, correspondence pp 580–594.

Hutchins, D E 1889. *Cycles of drought and good seasons in South Africa.* Wynberg Times Steam Printing Office.

Intergovernmental Panel on Climate Change 2001. Summary for policymakers.

Intergovernmental Panel on Climate Change 2007. Summary for policymakers.

Kite, G W 1982. Analysis of Lake Victoria levels. *Hydrological Sciences Journal*, 27(2):99–110.

Klemes, V 1974. The Hurst Phenomenon: a puzzle? *Water Resources Research*, 4.

Kokot, D F 1948. *An investigation into the evidence bearing on recent climatic changes over southern Africa.* Irrigation Department Memoir. Pretoria: Government Printer.

Kruger, A C and Shongwe, S 2004. Temperature trends in South Africa: 1960–2003. *International Journal of Climatology*, 24:1929–1945.

Lamb, H H 1966, Climate in the 1960s. *The Geographical Journal*, 132(2):183–212.

Lamb, H H 1970, Volcanic dust in the atmosphere; with a chronology and assessment of its meteorological significance. *Transactions of the Royal Society London*, A, 266 (1178):425–533.

Lamb, H H 1977. Volcanic activity and climate. *Climate Monitor*, 6:54–67.

Lamb, H H 1983 Update of the chronology of assessments of the volcanic dust veil index. *Climate Monitor*, 12:79–90.

Lockwood, M, Stamper, R, Wild, M N, Balogh, A and Jones, G 1999. Our changing sun. *Astronomy & Geophysics*, 40(4).

Mandelbrot, B B and Wallis, J R 1968. Noah, Joseph, and operational hydrology. *Water Resources Research,*4(5):909–918.

Mason, P J 1993. Hydrology or climate change, a case study. *Dams and Reservoirs* (Journal of the British Dam Society), 3(2).

Mason, P J 1998. Sunshine over Lake Victoria. *The Chemical Engineer*, 6 August 1998.

Mason, P J 2006. Lake Victoria: a predictably fluctuating resource. *Hydropower & Dams*, 13(3).

Rippl, W 1883. The capacity of storage reservoirs for water supply. *Proceedings of the Institution of Civil Engineers,* 71:270–278.

Rodier, J A and Roche, M 1984.*World catalogue of maximum observed floods.* International Association of Hydrological Sciences Publication No 143.

Rodrigues-Iturbe, I and Yevjevich, Y 1968. *The investigation of relationships between hydrologic time series and sunspot numbers.* Colorado University Hydrology Paper No 26. Fort Collins.

Tyson, P D 1987. *Climatic change and variability in Southern Africa.* Cape Town: Oxford University Press.

Wallis, J R and Matalas, NC 1971. Correlogram analysis revisited. *Water Resources Research*, 7(6).

Wallis, J R and O'Connell, P E 1973. *Firm reservoir yield. How reliable are historic hydrologic records?* IBM Research RC 4298.

Weather Bureau (now South African Weather Service) 1972. *Climate of South Africa: Part 10, District rainfall and the annual march of rainfall over Southern Africa.* WB 35, Pretoria: Weather Bureau.

World Data Centre for the Sunspot Index 2005. *Yearly sunspot numbers from 1750 to 2004.* Available at http://sidc.oma.be.

Yevjevich, Y 1968. Misconceptions in hydrology and their consequences. Water Resources Research, 4(2).

Yevjevich, Y 1972. *Stochastic processes in hydrology.* Water Resources Publications, Fort Collins, USA.