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# Late Cainozoic Palaeoclimates of the Southern Hemisphere

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# An analytical climate model: Application to the Southern Hemisphere Quaternary period

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ABSTRACT. By considering various time-series data over a range of time scales from 3000 million to 1 million years a quantitative analytical climatic model is evolved in the form of a sine series of long period components. This is then extrapolated to higher frequencies and compared successfully with observed climatic time series for the Quaternary of the Southern Hemisphere.

## INTRODUCTION

Over recent decades the realization has been growing that climate changes both regionally and globally on a time scale from as little as a year to over the tens of thousands of years of a glacial epoch and the millions of years of the geological time scale. Examples of concern are to be seen in the many national (Lamb 1972; Bryson 1977) and international (Bach et al. 1980; WMO 1975) research programmes that attempt to elucidate the problem, for a problem it is. For example, Faure and Gac (1981) report that in the short term hundreds of thousands of people die in semi-regularly recurring droughts in the Sahel; the production of corn in the American Midwest is said by Silcock (1981) to be sensitive to a global change of 1 °C to the tune of about 11%, and that in Kazakhstan to about 20% (Bach 1978); while the Interdepartmental Group of Climatology (1980) notes that the UK Department of Energy recognizes an annual budgetary implication of about £200 million for the same change.

It is the object of this paper to illustrate that the long-term climatic changes are equally well represented by the analytical model for the Southern and the Northern Hemisphere.

The literature abounds with time series describing the variation of a multitude of climatic indices on every conceivable time scale. Most writers conclude that climatic change has taken place and many of them such as Hayes et al. (1976) and Gray (1975) attempt to deduce by means of computers the periodicities of the changes through spectral analysis. Until recently no one, not even Milankovitch (1938), had succeeded in establishing the elusive relationship which would enable climatic change on all time scales to be embraced by one single model. If this were possible, so that the model could match time-series data on a scale of billions of years as well as millions, thousands, and a few years, it would represent not only an interesting step towards the culmination of so much effort in unravelling the past but also a soundly based predictive method for the future. Recently Denness (in press) introduced such a model in relation to the Quaternary of south-east Asia, using primarily Northern Hemisphere data for a range of time scales covering climatic variation over periods from about one million years down to a few decades.

## A CLIMATIC MODEL: GENERATING THE MODEL

Several hundred examples of climate related time-series data were examined in an attempt to approach such a model. Though the tangled path through this information to the construction of the model described below was in itself an exciting detective story (Denness 1981), it is sufficient here to take the complete model and show its ability to match, in hindcast, measured time-series at appropriate time scales. This is done graphically by superimposing selected time-series data onto computer drawn, moving-average plots from the "fundamental" equation:

$$G(t) = \sum_{n = N(T)}^{\alpha} A(T)a^{n} \cdot \sin b^{n-1}\pi\left(\frac{t}{T}\right), \text{ zero registered at time } T_0$$

Where G(t) = a time-based climate index,
A(T) = the amplitude of a reference periodicity T,
N(T) = the reference integer for periodicity T,
a,b = absolute constants, here taken as 0.84 and 0.50 respectively,
n = an integer, i.e. the reference number of a particular sine component,
and t = time in years.

We are thus seeing the variation of the sum of a series of sine curves, each successively smaller component being 0.84 times the amplitude of its more fundamental neighbour and of half the period. Over the range of time scales required to establish the climate model during the Phanerozoic, more than 12 components are needed to secure variation with a period as gross as a few billion years and as sensitive as a million years. This analytical model is here seen to represent global temperature variation with consequent regional implications for other climate-related data.

## TESTING THE MODEL OVER THE GEOLOGICAL TIME SCALE

In the subsequent figures a moving average technique has been applied to G(t) before plotting the derived $G_{ma}(t)$ to remove the higher frequencies from each plot. This was done in an attempt to secure compatibility of sensitivity between the climate model and the measured data. To achieve this, the time interval for each diagram was divided into 600 portions for each of which G(t) was calculated and then subjected to a moving average analysis over successive groups of 100 points, resulting in the following plots which consequently use 500 data points each. In order that each moving-average plot should commence at the present time (zero BP) it was necessary to use the predictive quality of the equation to project 50 data points into the future for each time scale. Consequently the degree of success in matching the latest (nearest zero BP) 10% of the plots to the observed data could be seen as a preliminary assessment of these predictive capabilities.

The technique generally used to overlay the observed time-series data, all of which have been culled from the literature, was to photograph the figure and place the negative in an enlarger so that its image could be superimposed at the appropriate time scale onto the $G_{ma}(t)$ graph which had been previously prepared by x-y plotter. Apart from errors involved in tracing the image by hand, this preserves the accuracy of the measured data and renders it readily recognizable from the original source. The advantage of preserved integrity is offset to some degree by the consequent inconsistencies of ordinate scale. However, no serious attempt is made here to describe absolute temperature (or other) amplitudes but merely to demonstrate the consistent compilation of a regular sine series with ordered periodicities. In addition some data required processing to be compatible with the common presentation; this is noted where appropriate.

The reader is referred to the original publications for additonal information concerning the reasons for supposing that the variables are climatically related. Equally, the original publications are the best sources of reference on dating accuracy which the writer here notes to be somewhat irregular between the various records. The first two figures use essentially global data while the others are more local, as indicated.

## 3000 m.y. BP to the present

Figure 1 describes the progress of three variables over the period 3000 m.y. BP to the present. These are estimates of global temperature and precipitation by Frakes (1979) and oxygen isotope ratios measured on chert by Knauth and Epstein (1976). These data have been treated brutally by comparing maxima and minima at every point possible for the isotope data and every point possible up to about 600 m.y. BP (80% of the record) for the temperature and precipitation data. For the more recent period the sensitivity of the data exceeds that of the intended interpretation on this time-scale and have also been reduced photographically from the original pseudo-logarithmic time scale used by Frakes so that not even relative amplitudes could be preserved later than that time.

There appears to be a near-coincidence of maxima and minima from each of the measured time series with those (arrowed) in the $G_{ma}(t)$ plot. This applies equally to the long period variation between 3000 m.y. to 600 m.y. BP and to the shorter period variation since 600 m.y. BP for the isotope data. The curves show that it is merely the record of the data that has become more frequent in the more recent period; this does not necessarily imply more rapid variation of the variables. Nevertheless, accepting all the isotope data and all the low frequency temperature and precipitation data (and, indeed, higher frequency temperature data to some extent), the near coincidence of four maxima and four minima is evident between the observed time series and the model. Both the long period of variation of about $1.125 \times 10^9$ years and the shorter of about $5.623 \times 10^8$ years are available for comparison.

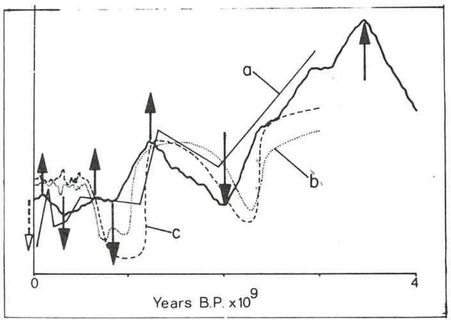

Figure 1. Timescale 0-3000 m.y. BP.
a) Oxygen isotope ratio for cherts
b) Estimated global temperature
c) Estimated global precipitation

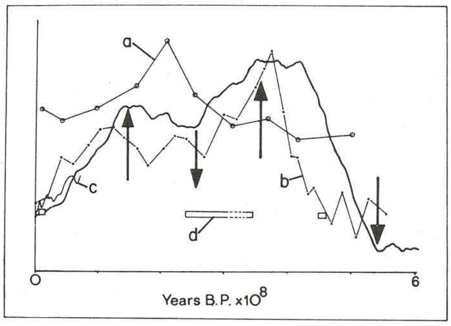

Figure 2. Timescale 0-600 m.y. BP.
a) Area of continental platforms covered by evaporites
b) Solar radiation absorption at Earth's surface
c) Arctic surface water temp and
d) Glacial epochs

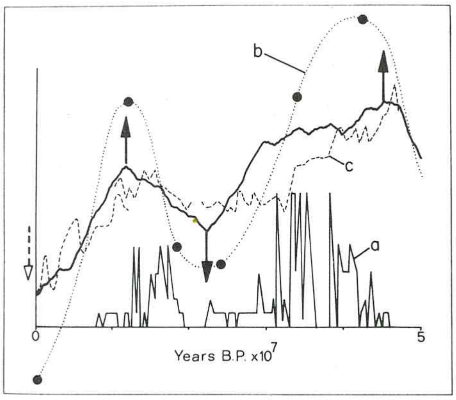

Figure 1-5. Comparison of climatic indices and model on different timescales.
The thick line on each figure is the model prediction.
Note the coincidence of maxima and minima of the observed time series with those of the model (arrowed).

Figure 3. Timescale 0-50m.y. BP.
a) Fish debris in sand fraction off South Africa
b) Carbonate compensation depth in South Atlantic
c) Oxygen isotope ratio for foramenifera in southern oceans

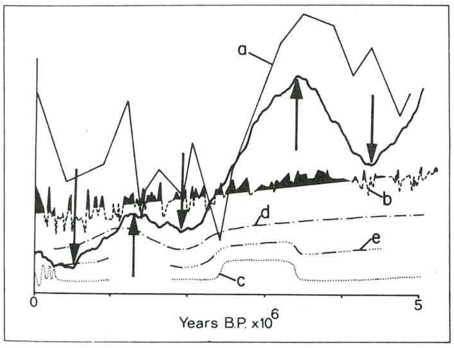

Figure 4. Timescale 0-5 m.y. BP.
a) Foramenifera (N.Pachyderma) abundance for sub. Antarctic
b) Oxygen isotope ratio for N.Atlantic
c) Sediment temp. for Weddell Sea
d) Faunal index for New Zealand
e) Estimated mean for c & d

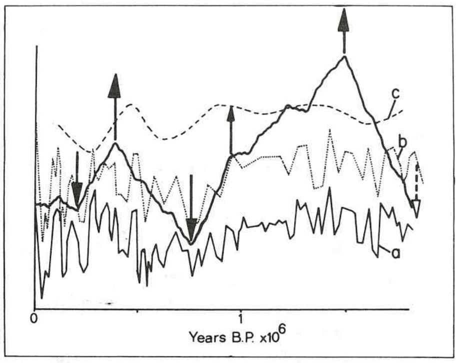

Figure 5. Timescale 0-1.8 m.y. BP.
a) Oxygen isotope ratio for Tropical Atlantic
b) Volume of glacial ice
c) Oxygen isotope ratio for the Challenger Plateau

## 600 m.y. BP to the present

This leads to the consideration of Fig. 2 which again illustrates three types of primary, climate-related variables but now over the time scale from 600 m.y. BP to the present, essentially the Phanerozoic. The figure shows the secular change of global evaporite volume according to Gordon (1975), the variation of solar radiation absorption deduced by Burnett (1982), and the occasion of major glacial epochs noted by Whyte (1977) and comparable, relatively recent, high latitude marine water temperatures described by Savin et al. (1975). These exhibit three minima and two maxima which are reasonably consistent with those of the major period seen on the $G_{ma}(t)$ plot (large arrows). That the depiction of glacial conditions and water temperature trend is broadly in agreement with the minima of the $G_{ma}(t)$ curve, needs no further comment. The approximate correspondence of increasing occurrence of evaporite with maxima on the model is also to be expected. The solar radiation absorption takes account of differing albedo anticipated from the drifting of crustal plates known from palaeomagnetic studies. It is, therefore, an indirect measure of heat absorption from which global temperature is inferred and seen to be in approximate agreement with the $G_{ma}(t)$ plot.

## 50 m.y. BP to the present

With definite observation of a period of variation of about $2.812 \times 10^8$ yrs and the tentative observation of shorter period variations of the order of $1.406 \times 10^8$ yrs and $7.029 \times 10^7$ yrs, it is appropriate to move to Fig. 3 which shows the variation of three more climate-related variables over the period $5 \times 10^7$ yrs to the present. In addition to the continuing higher frequency variation of $G_{ma}(t)$, this diagram also shows the observed secular variation of carbonate compensation depth (CCD) in the South Atlantic described by Le Pichon et al. (1978), the oxygen isotope ratio in planktonic foraminifera in the southern oceans presented by Sclater (1978) and the proportion of fish debris in the sand fraction off South Africa determined by Melguen and Thiede (1974). The general association of the next shorter period (arrowed) in the $G_{ma}(t)$ series at $3.515 \times 10^7$ yrs with the variation of all the observed variables is seen clearly.

## 5 m.y. BP to the present

Time-series describing the observed variation of climatic indices over the anticipated periods $1.757 \times 10^7$ and $8.787 \times 10^6$ years could not be traced in the available literature. However, Fig. 4 restores the correlation of the $G_{ma}(t)$ series with foraminiferal abundance from the sub-Antarctic, determined by Kennett and Vella (1975), a further oxygen isotope record from North Atlantic sediment prepared by Shackleton and Cita (1979), and the variation of Weddell Sea Sediment temperature described by Anderson (1972) and of New Zealand fauna noted by Hornibrook (1971) from $5 \times 10^6$ yrs to the present. Collectively these records draw attention to minima (arrowed) at about $4.3 \times 10^6$, $1.9 \times 10^6$ and $0.5 \times 10^6$ yrs with interposed maxima (arrowed), all superimposed on a generally falling trend with the passage of time. This is consistent with the behaviour of $G_{ma}(t)$ and draws attention to a periodicity of 2.197 x $10^6$ yrs (especially in the general trend available from simultaneous consideration of the sediment temperature and fauna variation curves), while hinting at the longer period of 4.393 x $10^6$ yrs through the isotope records (maxima emphasized in solid form above a falling mean) and foraminiferal abundance.

## APPLYING THE MODEL TO THE QUATERNARY OF THE EQUATORIAL REGION AND THE SOUTHERN HEMISPHERE

The model has already been shown to comprise a series of components with periods down to 2.197 x $10^6$ yrs. A continuation of the series should lead, therefore, to the inclusion of the next two shorter period components with variations of period 1.098 x $10^6$ and 5.492 x $10^5$ yrs respectively. If the model is general both over different time scales and in different regions, these should be evident in observed Quaternary climatic time series for any part of the Southern Hemisphere.

Figure 5 depicts the progress of two separate records of oxygen isotope ratio, one from the Challenger Plateau off New Zealand, as reported by Shackleton and Kennett (1975) and the other from the tropical Atlantic recorded by Van Donk (1976). In addition the volume of glacial ice, which would have a Southern Hemisphere component, a fact also noted by Van Donk, is also presented superimposed with the others on the $G_{ma}(t)$ plot from 1.8 x $10^6$ yrs to the present. The more sensitive isotope ratio plot and that for ice volume clearly indicate two primary maxima (arrowed) corresponding approximately to those of the $G_{ma}(t)$ plot at about 0.4 x $10^6$ and 1.5 x $10^6$ yrs with intermediate and neighbouring minima (arrowed) offset in the saw-toothed pattern typical of the $G_{ma}(t)$ plot at all time scales. This could suggest support for a variation with period of about 1.098 x $10^6$ yrs as does the less sensitive isotope ratio curve, which also indicates a further maximum (arrowed) at about 0.95 x $10^6$ yrs and neighbouring minima representing the observation of a higher frequency variation with a period 5.492 x $10^5$ yrs. This degree of sensitivity is sufficient to demonstrate that the extrapolation of the model to higher frequencies is able to compare with gross climatic variation of the Southern Hemisphere and the equatorial region during the Quaternary.

## DISCUSSION

Seventeen observational time-series have thus been used in the figures to illustrate the compatibility of the sine series model with measured climate-related indices. These are less than a third of the time-series used to test the validity of the model in hindcast over this range of geological time scales. It should also be noted that three of the sine series (the 3000 million year general temperature record, the 50 million year CCD record and the 5 million year North Atlantic oxygen isotope ratio record) were among those used to derive the sine series; the rest were not, and are thus genuine tests of the model.

Through the figures periodicities of climatic indices have been demonstrated from a "fundamental" of 1.125 x $10^9$ yrs with the superposition of higher frequency variations at periods ever halving, and amplitudes reducing by about 0.84 for each successive component. Consideration of both period and amplitude is necessary to retain compatibility across time scales, i.e. between each figure. The inclusion of longer period variation of G(t) was necessary in the preparation of Fig. 1 in order to provide the correct trend of $G_{ma}(t)$ to match the observed time-series. However, the observed data are not sufficiently extensive to permit a matching of these periods. Their mention here is to invite consideration of the degree of fundamentality of the 1.125 x $10^9$ year period.

With the illustration of observed data which are consistent with 10 of 12 essential components of the model used in the preparation of the figures it is to be hoped that the palaeoclimatic literature for the geological time scale will soon provide evidence in support of those two periods not substantiated here. However, the use of Fourier analysis to approach these periods is questionable since, if this model is indeed appropriate, there is no linear datum axis about which the series is based nor can the whole of the influential components be contained in the sampling interval.

## CONCLUSION

Observational evidence supports the establishment of an analytical climatic model that applies equally to gross climate variations in both the Northern and Southern Hemispheres. Climate variations over billions of years and also less than a million years can be described by the model.

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## Late Cainozoic palaeoclimates of the Southern Hemisphere

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In order to be able to reconstruct what climatic changes took place in the past, knowledge of the palaeoclimates of the Southern Hemisphere is of the utmost importance. The Antarctica and the surrounding oceans play the major role in regulating atmospheric circulation patterns; even across the equator. In addition, evidence from deep sea cores has recently indicated that climatic change in the south actually preceded that in the northern regions by some 3000 years.

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**Palaeoclimatology.** Climatic evolution in the Southern Hemisphere and the equatorial region during the Late Cenozoic (H.Flohn, Univ. Bonn); A climatic model of the Last Glacial/Interglacial transition based on palaeotemperature and palaeohydrological evidence (S.P. Harrison, S.E.Metcalfe & F.A.Street-Perrott, School Geogr., Oxford, A.B. Pittock, CSIRO, Mordialloc, Australia, C.N.Roberts, Loughborough Univ. Technol. & M.J.Salinger, Univ.East Anglia, UK); etc.
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